Effect of seaweed-containing diets on visceral organ sizes, carcass characteristics, and meat quality and stability of Boschveld indigenous hens

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ABSTRACT Seaweeds are functional feed ingredients that have antioxidant, antimicrobial, and growth-boosting properties that can improve poultry product quality. This study, therefore, investigated the effect of graded levels of green seaweed meal (*Ulva* spp.) (**SWM**) on visceral organ sizes, carcass characteristics, and meat quality and stability of Boschveld indigenous hens. A total of 275, four-week-old female chicks (202.4 ± 6.65 g of live weight) were reared on 5 isocaloric and isonitrogenous diets formulated by adding SWM at a concentration of 0 (**SW0**), 2 (**SW20**), 2.5 (**SW25**), 3 (**SW30**), and 3.5% (**SW35**). Birds were humanely slaughtered at 14 wk of age. Cecum weight linearly increased (R^2 = 0.366, P = 0.002), whereas proventriculus (R^2 = 0.205, P = 0.025) and duodenum (R^2 = 0.242, P = 0.010) weights linearly decreased with SWM levels. Neither linear nor quadratic trends ($P > 0.05$) were observed for carcass traits, meat quality parameters, and shelf life indicators in response to dietary SWM levels. Repeated-measures analysis showed a significant time × diet interaction effect on meat redness (a^*). After 24 h of storage, meat from hens fed with SW35 (2.47) diet had a higher a^* value than meat from hens fed with SW30 diet (0.48). However, the inclusion of SWM promoted similar ($P > 0.05$) shelf life indicators as the control diet for the rest of the 7-d storage period at room temperature. In conclusion, dietary inclusion of SWM had no adverse effect on visceral organ size, carcass and meat quality traits, and meat stability of Boschveld indigenous hens.

Key words: carcass trait, indigenous chicken, meat quality, seaweed, visceral organ

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INTRODUCTION

Compared with red meats, poultry meat is a more affordable and healthier option (Qi et al., 2018). Consequently, the demand for poultry meat has continued to rise (Chivandi et al., 2020) in tandem with human population growth. Traditionally, the poultry industry has mostly focused on efficient production of improved exotic commercial birds at the expense of indigenous chicken strains. This could be because indigenous chickens are slow growing with low feed utilization efficiency, reach sexual maturity at advanced ages, and attain market weight much later compared with improved birds (Atela et al., 2019). As a result, the feeding cost is too high for commercial production of indigenous chickens as alternative sources of animal protein. To ensure sustainable commercial production of indigenous chicken strains, it is important to use locally available feedstuffs with potential to not only boost feed utilization efficiency but also enhance the quality of poultry products for human health. There is growing consumer demand for healthier animal products with functional properties (Granato et al., 2020).

Seaweeds (*Ulva* spp.), commonly known as marine algae, are known to be functional feed ingredients with potential to enhance feed utilization efficiency and meat quality. They contain compounds such as protein, polyunsaturated fatty acids, polysaccharides, minerals, carotenoids, and vitamins (Wong and Cheung, 2001; Kendel et al., 2015; Sharma et al., 2018). In addition, seaweeds are known to be rich in phenolic compounds (phenolic

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acids, tannins, flavonoids, catechins, and phlorotannins) with antioxidant, anti-inflammatory, antiproliferative, and antimicrobial activities (Gullón et al., 2020), which can be exploited to improve growth performance and meat quality in poultry. Seaweeds also contain high levels of amino acids especially sulfur amino acids such as methionine, lysine, and threonine, which have beneficial effects on carcass characteristics, breast meat yield, and dressing percentage (Wong and Cheung, 2001). The inclusion of seaweeds as additives in indigenous chicken diets is an ingenious strategy to produce meat products with higher content of bioactive agents with health benefits for consumers. Despite seaweeds being ubiquitous in most coastal parts of South Africa, their potential as a feed additive for indigenous chicken strains remains unknown. Thus, the utility of seaweeds in chicken diets is likely to be limited by their high levels of fiber (Kraan, 2012), which may negatively affect nutrient digestion and absorption in chickens. Indeed, Gullón et al. (2020) report that seaweeds possess high levels of nonstarch polysaccharides (xylan, laminarin, fucoidan, hemicellulose, and cellulose) that may reduce energy utilization in birds and thus affect muscular fat deposition and meat tenderness. Therefore, it is important to establish the tolerance level of indigenous chickens to dietary seaweed. To this end, we investigated the effect of graded levels of dietary seaweed on visceral organ sizes, carcass characteristics, meat quality traits, and meat shelf life indicators in Boschveld indigenous hens. Given the presence of beneficial bioactive compounds with antioxidant, anti-inflammatory, antiproliferative, and antimicrobial properties in seaweed, we tested the hypothesis that including green seaweed meal (**SWM**) in Boschveld indigenous chicken diets would improve carcass characteristics and meat quality traits.

MATERIALS AND METHODS

Study Site and Ingredient Sources

The study was carried out in summer at Molelwane Research Farm (25°86′00″S, 25°64′32″E) of the North-West University, South Africa. During this time, ambient temperatures ranged from 22°C to 33°C. The green seaweed (Chlorophyceae; *U.* spp.) was harvested by hand from Aqunion abalone farm in Gansbaai (34°34′58″S 19°21′8″E), South Africa. The seaweed was allowed to drain water in an oyster net overnight, sun-dried, and transported to Molelwane Research Farm, where it was oven-dried (60°C) until constant weight and ground to pass through a 2-mm sieve (Polymix PX-MFC 90 D, Kinematica AG, Luzern, Switzerland) before blending with other feed ingredients. In brief, the chemical composition of green SWM was as follows: 856.5 g/kg of DM, 375.2 g/kg of DM ash, 175.9 g/kg of DM CP, 339.3 g/kg of DM crude fat, 322.5 g/kg of DM neutral detergent fiber, and 171.1 g/kg of DM acid detergent fiber (Nhlane et al., 2020). All other ingredients used for dietary formulation were bought from Nutroteq (Centurion, Gauteng, South Africa).

Diet Formulation

Five isocaloric and isonitrogenous experimental diets in a mash form were formulated to meet the NRC requirements (NRC, 1994). The diets were formulated by diluting a standard chicken grower diet with graded levels of SWM using a nutritional software program as follows: 1) SW0 = commercial grower diet without SWM, 2) SW20 = commercial grower diet with 20 g/kg of SWM, 3) SW25 = commercial grower diet with 25 g/kg of SWM, 4) SW30 = commercial grower diet with 30 g/kg of SWM, and 5) SW35 = commercial grower diet with 35 g/kg of SWM, as shown in Table 1. The inclusion levels evaluated in this study were selected based on evidence (Angell et al., 2016) that seaweed levels higher than 50 g/kg depress feed utilization and growth performance in several poultry species.

Chemical Analyses

Samples of the experimental diets (SW0, SW20, SW25, SW30, and SW35) were oven-dried (60°C) until constant weight was achieved and then milled (2-mm; Polymix PX-MFC 90 D) in preparation for chemical analyses (Table 2). The samples were then analyzed for DM, organic matter, CP, crude fiber, and crude fat using the Association of Official Analytical Chemists international methods (AOAC, 2005). Minerals were analyzed as per Agri-Laboratory Association of Southern Africa (AgriLASA, 1998). ME contents of the diets were predicted using models of near-infrared reflectance spectroscopy (SpectraStar XL; Unity Scientific, Brookfield) as described by Mnisi and Mlambo (2017).

Table 1. Ingredient composition (g/kg as-fed basis, unless stated otherwise) of experimental diets.

	[1]Experimental diets				
	SW0	SW20	SW25	SW30	SW35
Seaweed meal	0.0	20.0	25.0	30.0	35.0
Yellow maize, 8%	630.3	643.7	647.3	648.1	648.8
Extruded full-fat soya	120.0	81.1	61.5	46.6	31.9
Soya oil cake, 47%	176.6	192.8	203.0	207.5	211.9
Sunflower oil cake, 36%	30.0	30.0	31.6	36.6	41.5
Limestone	11.9	9.7	9.1	8.5	7.9
Monocalcium phosphate	7.8	8.1	8.1	8.2	8.3
Fine salt	2.6	0.6	0.1	0.0	0.0
Sodium bicarbonate	1.5	1.5	1.5	1.5	1.5
DL-Methionine	2.8	2.9	2.9	2.9	2.9
L-Threonine	0.7	0.8	0.9	0.9	1.0
Lysine HCL	2.7	3.0	3.1	3.3	3.4
Crude soya oil mixer	7.2	0.0	0.0	0.0	0.0
Lignobond	2.5	2.5	2.5	2.5	2.5
BSGF	2.5	2.5	2.5	2.5	2.5
AxtraPhy10000	0.1	0.1	0.1	0.1	0.1
Salinomycin, 12%	0.5	0.5	0.5	0.5	0.5
Zinc bacitracin	0.3	0.3	0.3	0.3	0.3

[1]Experimental diets: SW0 = commercial grower diet without seaweed meal; SW20 = commercial grower diet with seaweed meal at a rate of 20 g/kg; SW25 = commercial grower diet with seaweed meal at a rate of 25 g/kg; SW30 = commercial grower diet with seaweed meal at a rate of 30 g/kg; SW35 = commercial grower diet with seaweed meal at a rate of 35 g/kg.

Table 2. Chemical composition (g/kg as-fed basis, unless stated otherwise) of seaweed meal–containing diets.

	[1]Experimental diets				
	SW0	SW20	SW25	SW30	SW35
DM	884.8	882.5	882.1	881.8	881.6
Organic matter	859.1	851.6	849.7	847.9	846.2
ME (MJ/kg)	12.9	12.9	12.9	12.9	12.9
Crude protein	192.2	192.2	192.2	192.2	192.2
Crude fat	56.2	43.4	40.2	37.9	35.5
Crude fiber	35.5	44.0	46.2	49.1	51.9
Calcium	8.4	8.4	8.4	8.4	8.4
Chloride	2.4	2.7	2.8	3.2	3.5
Sodium	1.8	1.8	1.8	2.0	2.2
Total phosphorus	5.5	5.5	5.5	5.5	5.5
Available phosphorus	4.2	4.2	4.2	4.2	4.2
AP Lysine	10.7	10.7	10.7	10.7	10.7
AP Methionine	5.6	5.6	5.6	5.6	5.6
AP Threonine	6.9	6.9	6.9	6.9	6.9

[1]Experimental diets: SW0 = commercial grower diet without seaweed meal; SW20 = commercial grower diet with seaweed meal at a rate of 20 g/kg; SW25 = commercial grower diet with seaweed meal at a rate of 25 g/kg; SW30 = commercial grower diet with seaweed meal at a rate of 30 g/kg; SW35 = commercial grower diet with seaweed meal at a rate of 35 g/kg.

Experimental Design and Animal Management

Experimental protocols used during rearing and slaughtering of the hens were approved by the North-West University Animal Production Sciences Research Ethics Committee (approval no. NWU-00357-19-A5). All procedures conformed to the guidelines for care and use of research animals. Two hundred seventy-five, 3-wk-old Boschveld female chicks (Boschveld Ranching (PTY) LTD., Bela-Bela, Limpopo, South Africa) were randomly and evenly allocated to 25 replicate pens (3.5-m length × 1.0-m breadth × 1.85-m height), with each pen (experimental unit) carrying 11 birds. The five experimental diets were then randomly allocated to the 25 pens, and the birds were adapted to their diets for 1 wk. The birds were reared until 14 wk of age and slaughtered to measure the size of visceral organs, carcass characteristics, and meat quality parameters. The average temperature (30°C) and humidity (40%) of the poultry house was regularly monitored using a multimeter device (HTC-1, Xuzhou Sanhe Automatic Control Equipment Co., Ltd., Jiangsu, China). All experimental pens were monitored daily for sicknesses and mortalities. No mortalities were recorded during the study period, thus giving a 100% survival rate. Experimental diets and clean water were offered to birds *ad libitum*, and rearing was conducted under natural lighting (12 h of daylight).

Slaughter Procedure, Carcass Characteristics, and Sizes of Visceral Organs

At 14 wk of age, the hens were weighed to obtain the slaughter weight before being fasted for 12 h. The birds were then taken to a local poultry abattoir, where they were electrically stunned and slaughtered by cutting the jugular vein using a sharp knife. After bleeding, the birds were defeathered and eviscerated. Hot carcass weight (**HCW**) was determined immediately after slaughter. After chilling (16°C) for 24 h in a cold room, the carcasses were reweighed to determine cold carcass weight. Dressing percentage was calculated as the proportion of HCW to slaughter weight. Weights of carcass parts (breast, drumstick, wing, and thigh) and visceral organs (liver, gizzard, spleen, proventriculus, small intestine, duodenum, ileum, jejunum, large intestine, and cecum) were determined using a digital weighing scale (Explorer EX224, OHAUS Corp., NJ) and also expressed as a proportion of HCW.

Meat Quality Parameters

Meat pH and temperature were recorded 1 h after slaughter on the breast muscle (central area of the breast) using a Corning Model 4 pH-temperature meter (Corning Glass Works, Medfield, MA) fitted with an Ingold spear-type electrode (Ingold Messtechnik AG, Udorf, Switzerland). After every 10 measurements, the pH meter was calibrated using pH 4, pH 7 and pH 10 standard solutions meant for this purpose. Breast meat color coordinates (L^* = lightness, a^* = redness, and b^* = yellowness) were determined 1 h postmortem using a Minolta color-guide (BYK-Gardener GmbH, Geretsried, Germany) following the guidelines by the Commission International De I′ Eclairage (CIE, 1976). Color meter was calibrated before measurements and after every 10 measurements using the zero and white standard calibration set as prescribed by the manufacturer. Hue angle and chroma were calculated using the coordinates $a^*$and b^* as described by Priolo et al. (2002).

Cooking losses were determined following the modified method described by Honikel (1998), wherein breast meat samples were oven cooked at 180°C for 30 min. The cooked breast samples were further mounted on a Texture Analyzer (TA XT plus; Stable Micro Systems, Surrey, UK) and sheared using a Meullenet-Owens Razor Shear Blade (A/MORS) to determine average Warner-Bratzler shear force in newtons. For drip loss measurement, pieces of the breast muscle (W1; ∼2 g) were hooked and suspended using wire steel in a plastic bottle and stored in a cold room (4°C) for 72 h following the method by Zhang et al. (2010). The breast samples were reweighed to obtain weight after drip (W2), and the difference in weight of each sample before and after drip was conveyed as percentage drip loss and calculated as follows:

$$\text{Drip loss } (\%) = \frac{W1 - W2}{W1} \times 100$$

The water holding capacity (**WHC**) of breast meat samples was determined by expressing water from the meat held under pressure (60-kg pressure) using the filter paper press method invented by Grau and Hamm (1957). The water from the fresh meat was absorbed

using a preweighed filter paper. The WHC of the meat was then calculated using the following formula:

$$\text{WHC (\%)} = 100 - \left[\frac{\text{initial meat weight} - \text{meat weight after pressing}}{\text{initial meat weight}} \times 100\right]$$

Meat Stability

Two randomly selected breast meat fillet samples from each replicate pen were used for the determination of shelf life indicators and meat stability at room temperature. The breast meat samples were placed in labeled foil trays and kept at room temperature for 7 d where meat pH and color (L^*, a^* and b^*) were recorded daily as already described previously.

Statistical Analysis

Polynomial contrasts were used to evaluate carcass characteristics, visceral organ sizes, and meat quality and stability data for linear and quadratic effects of SWM. A response surface regression analysis (SAS, 2010) was applied to estimate the optimum SWM inclusion level, as per the following quadratic model: $y = ax^2 + bx + c$, where y is the response variable, a and b are the coefficients of the quadratic equation, c is the intercept, x is the seaweed level (%), and $-b/2a$ is the x value for optimal response.

Meat stability data were analyzed using the repeated-measures procedure of SAS (2010) to determine the interaction effect of storage time and diets. In a completely randomized design, a one-way ANOVA was used to account for dietary effects on visceral organs, carcass characteristics, and meat quality and stability using the general linear model procedure of SAS (2010). For all statistical tests, significance was declared at $P < 0.05$. Least square means were compared using the probability of difference option in the least square means statement of SAS.

RESULTS

Visceral Organ Sizes and Carcass Traits

Each Boschveld chicken consumed a total of 4112.6–4632.4 g of the experimental diets in the 10-wk feeding period while gaining between 1027.0 and 1085.9 g body mass. This growth performance translated into a feed conversion efficiency range of 0.233–0.252. Table 2 shows that the inclusion of SWM tended to increase the crude fiber content in the diets, despite nutrient density being the same across diets. There were neither linear nor quadratic trends ($P > 0.05$) for visceral organ sizes except for proventriculus, duodenum, and cecum weights (Table 3). Cecum weight linearly increased [$y = 1.0$ (± 0.048) $+ 0.007$ (± 0.0062) x; $R^2 = 0.366$, $P = 0.002$], whereas proventriculus [$y = 0.78$ (± 0.028)–0.007 (± 0.0036) x; $R^2 = 0.205$, $P = 0.025$] and duodenum [$y = 1.38$ (± 0.027)–0.010 (± 0.004) x; $R^2 = 0.242$, $P = 0.010$] weights linearly decreased in response to graded levels of SWM. Dietary effects ($P > 0.05$) were only observed in duodenum and cecum weights. Hens fed with the control diet SW0 (1.37 g/100 g of HCW) had heavier duodenum weights than those fed with SW25 diet (1.22 g/100 g of HCW), but the weights were similar ($P > 0.05$) to those of hens fed with other diets. Heavier cecum weights were recorded in hens fed with SW35 diet (1.23 g/100 g of HCW) than in those fed with the control diet SW0 (1.00 g/100 g of HCW). Nonetheless, the hens fed with the control diet had the same ($P > 0.05$) cecum weights as those fed with SW20, SW25, and SW30 diets. There were no linear and quadratic trends ($P > 0.05$) for all carcass traits in response to dietary SWM levels (Table 4). There were also no significant dietary effects on all carcass characteristics.

Meat Quality and Stability

There were no linear or quadratic effects ($P > 0.05$) for breast meat pH, temperature, and color measured 1 h after slaughter (Table 5). Similarly, no significant dietary effects were observed on these parameters. Table 6 shows that neither linear nor quadratic trends ($P > 0.05$) were observed for WHC, drip loss, cooking loss, and shear force in response to dietary SWM levels. There were dietary effects ($P < 0.05$) only on drip loss. Meat from hens fed with SW25 diet (7.91%) had lower drip loss than meat from hens fed with SW35 diet (10.82%). The control diet promoted similar ($P > 0.05$) drip loss as the SWM-containing diets.

The effect of graded levels of SWM on stability of breast meat pH and color, as shelf life indicators, upon storage at room temperature was measured for 7 d. No significant linear and quadratic effects were observed for pH (5.72–6.36), L^* (35.9–64.5), a^* (0.48–2.67), and b^* (9.97–16.8). Repeated-measures analysis showed no significant storage time × diet interaction effect on breast meat pH, L^*, and b^*, but a significant interaction effect was observed on a^*. After 24 h of storage, meat from hens fed with SW35 diet (2.47) had a higher a^* value than meat from hens fed with SW30 diet (0.48). The inclusion of SWM promoted the same pH and color as the control diet for the storage period of 7 d at room temperature.

Table 3. Sizes of visceral organs (g/100 g of HCW) of 14-wk-old Boschveld indigenous hens fed with seaweed meal–containing diets.

	[1]Experimental diets						*P* value	
	SW0	SW20	SW25	SW30	SW35	SEM	Linear	Quadratic
Liver	2.72	2.75	2.72	2.76	2.82	0.071	0.306	0.384
Gizzard	3.34	2.90	3.18	3.17	3.12	0.168	0.532	0.169
Spleen	0.43	0.33	0.34	0.34	0.37	0.038	0.137	0.090
Proventriculus	0.78	0.69	0.68	0.71	0.68	0.028	0.025	0.213
Small intestine	4.62	4.65	4.48	4.63	5.72	0.512	0.291	0.131
Duodenum	1.37[b]	1.29[a,b]	1.22[a]	1.27[a,b]	1.28[a,b]	0.028	0.010	0.056
Ileum	1.41	1.39	1.47	1.40	1.49	0.069	0.514	0.575
Jejunum	1.86	1.83	1.76	1.75	1.78	0.062	0.272	0.908
Large intestine	0.31	0.24	0.25	0.28	0.26	0.024	0.197	0.159
Cecum	1.00[a]	1.14[a,b]	1.17[a,b]	1.17[a,b]	1.23[b]	0.049	0.002	0.965

[a,b]In the same row, means with different superscripts significantly differ at $P < 0.05$.

Abbreviation: HCW, hot carcass weight.

[1]Experimental diets: SW0 = commercial grower diet without seaweed meal; SW20 = commercial grower diet with seaweed meal at a rate of 20 g/kg; SW25 = commercial grower diet with seaweed meal at a rate of 25 g/kg; SW30 = commercial grower diet with seaweed meal at a rate of 30 g/kg; SW35 = commercial grower diet with seaweed meal at a rate of 35 g/kg`.

DISCUSSION

Visceral Organ Sizes

To the best of our knowledge, there are no reports on the effect of SWM supplementation on visceral organ sizes, carcass characteristics, and meat quality traits, as well as shelf life indicators, of Boschveld indigenous chickens. Thus, this study represents the first ever attempt to use green SWM in the diets of indigenous chickens. We found that cecum weights linearly increased with graded levels of SWM, and this was not surprising because the inclusion of SWM increased the fiber content of the experimental diets. This enlarged cecum is an anatomical adaptation by birds in response to higher dietary fiber content. The cecum is part of the large intestines that carry a more diverse, rich, and stable microbial community that is responsible for the fermentation of extra dietary fiber. Thus, the inclusion of seaweed, which is a rich source of structural polysaccharides such as cellulose (Gullón et al., 2020), would have prolonged hindgut microbial fermentation, resulting in a highly developed cecum (Videnska et al., 2013). These results are consistent with the findings of Kulshreshtha et al. (2014) who reported an increase in cecum weights of laying hens fed with seaweed-containing diets. Proventriculus weight linearly decreased in response to graded levels of SWM; however, no dietary influences were recorded for this parameter. The proventriculus is the glandular stomach where digestion primarily begins; thus, the lack of dietary effect could indicate a higher outflow rate. Duodenum weights linearly decreased with increasing levels of dietary SWM, and this was in agreement with the findings of Sklan et al. (2003) who reported that high-fiber diets reduced duodenum length of broilers as compared with low-fiber diets. The duodenum receives chyme for further chemical digestion in preparation for absorption. It is, therefore, not clear why hens fed with SW25 diet had heavier duodenum weights that those fed with the control diet. This could have been a measurement error, given that hens fed with the control diet had similar duodenum weights as those fed with SW20, SW30, and SW35 diets. Furthermore, no dietary effects were observed on the sizes of the liver, gizzard, spleen, ileum,

Table 4. Carcass characteristics (g/100 g of HCW, unless stated otherwise) of 14-wk-old Boschveld indigenous hens fed with seaweed meal–containing diets.

	[1]Experimental diets						*P* value	
	SW0	SW20	SW25	SW30	SW35	SEM	Linear	Quadratic
Dressing, %	72.25	71.63	71.81	74.34	72.40	1.153	0.593	0.582
Slaughter weight (g)	1232.5	1251.8	1289.3	1227.4	1286.0	18.173	0.193	0.932
HCW (g)	890.5	897.0	926.1	910.8	930.9	16.243	0.106	0.688
CCW (g)	861.4	872.4	891.3	881.3	902.3	16.110	0.106	0.680
Breast	14.15	15.96	13.73	15.64	14.70	0.713	0.608	0.358
Drumstick	6.71	6.60	6.26	5.51	6.59	0.472	0.324	0.874
Wing	5.34	6.20	6.09	6.05	6.00	0.357	0.109	0.326
Thigh	6.94	6.90	7.18	7.13	7.24	0.142	0.098	0.293

Abbreviations: CCW, cold carcass weight; HCW, hot carcass weight.

[1]Experimental diets: SW0 = commercial grower diet without seaweed meal; SW20 = commercial grower diet with seaweed meal at a rate of 20 g/kg; SW25 = commercial grower diet with seaweed meal at a rate of 25 g/kg; SW30 = commercial grower diet with seaweed meal at a rate of 30 g/kg; SW35 = commercial grower diet with seaweed meal at a rate of 35 g/kg.

Table 5. Meat pH, temperature, and color measured 1 h after slaughter in Boschveld indigenous hens fed with seaweed meal–containing diets.

	[1]Experimental diets						*P* value	
	SW0	SW20	SW25	SW30	SW35	SEM	Linear	Quadratic
pH	6.00	5.91	5.80	5.67	5.61	0.202	0.099	0.349
Temperature	22.04	20.13	21.30	19.38	18.98	1.215	0.114	0.545
Lightness (L^*)	56.93	58.45	60.59	56.71	61.87	2.274	0.210	0.590
Redness (a^*)	4.32	3.93	3.29	3.70	4.71	0.642	0.936	0.103
Yellowness (b^*)	9.36	9.18	10.58	10.42	11.67	1.084	0.256	0.538
Hue angle	1.15	1.17	1.25	1.21	1.19	0.054	0.419	0.565
Chroma	10.41	10.04	11.13	11.10	12.68	1.096	0.316	0.353

[1]Experimental diets: SW0 = commercial grower diet without seaweed meal; SW20 = commercial grower diet with seaweed meal at a rate of 20 g/kg; SW25 = commercial grower diet with seaweed meal at a rate of 25 g/kg; SW30 = commercial grower diet with seaweed meal at a rate of 30 g/kg; SW35 = commercial grower diet with seaweed meal at a rate of 35 g/kg.

jejunum, and small and large intestines, which shows that the inclusion of seaweed did not induce any anatomical changes to these organs. Similar liver sizes across dietary treatments suggest that feeding seaweeds does not cause toxicities. In addition, the sizes of the gizzards did not change in response to dietary SWM levels, indicating normal mechanical digestion (Al-Dabbagh et al., 1987; Choi et al., 2014).

Carcass Characteristics and Meat Quality and Stability

Understanding factors that affect chicken meat quality and carcass characteristics is essential in a poultry enterprise. Unfortunately, knowledge on such factors is scanty, particularly in resource-limited poultry production systems. The success of poultry meat production depends on the higher breast-to-abdominal fat ratio (Musa et al., 2006). In this study, the inclusion of SWM did not improve carcass characteristics of the hens. These results were consistent to those of El-Deek and Mervat Brikaa (2009), who tested the effect of different levels (0, 5, 10, and 15%) of red seaweed in starter and finisher diets on carcass quality of ducks. They found that the dressing and thigh weight as well as breast meat length and width were not influenced by inclusion of dietary SWM in the finisher phase. However, in a study conducted by Abudabos et al. (2013), inclusion of green seaweed up to a concentration of 30 g/kg improved breast yield and dressing percentage of broiler chickens. The inconsistencies of these reports are not surprising because seaweeds have a highly variable composition, which depends on the species, time of collection, habitat, water temperature, light intensity, and nutrient concentration in water (Makkar et al., 2016).

Meat quality is largely influenced by the rate of pH decline in muscles after slaughter and by ultimate pH (Muchenje et al., 2009). In this study, breast meat pH measured 1 h after slaughter did not change with dietary SWM levels, which implies that the inclusion of seaweed in poultry diets does not affect glycogen levels during postmortem aging (Muchenje et al., 2009). Indeed, the inclusion of seaweed did not negatively affect meat quality parameters. These results agreed with earlier studies on ducks (El-Deek et al., 1987) and broilers (Maurice et al., 1984), wherein SWM had no effects on meat quality attributes. It is not clear why meat from hens fed with SW25 diet had lower drip loss than meat from hens fed with SW35 diet, given that both diets promoted the same drip loss as the control diet. Upon storage at room temperature for 7 d, the inclusion of SWM promoted the same shelf life indicators as the control diet. This shows that dietary seaweeds did not improve the keeping quality of meat in Boschveld chickens. Repeated-measures analysis showed a significant storage time × diet interaction effect on breast meat a^*, which indicates that the pigmentation of meat depended on storage time. Meat color depends on the presence of muscle pigments (myoglobin and hemoglobin). After 24 h of storage, meat from hens fed with SW35 diet had a higher a^* value than meat from hens fed with SW30 diet, suggesting that meat from birds

Table 6. Meat quality parameters (%, unless stated otherwise) of 14-wk-old Boschveld indigenous hens fed with seaweed meal–containing diets.

	[1]Experimental diets						Significance	
	SW0	SW20	SW25	SW30	SW35	SEM	Linear	Quadratic
WHC	83.48	85.46	85.40	83.05	85.99	1.437	0.439	0.775
Drip loss	8.80^{a,b}	9.25^{a,b}	7.91^{a}	10.42^{a,b}	10.82^{b}	0.674	0.146	0.142
Cooking loss	18.15	16.22	17.36	14.95	15.42	1.287	0.107	0.824
Shear force (N)	1.64	1.63	1.60	1.70	1.59	0.041	0.745	0.767

[a,b]In a row, means with different superscripts differ significantly at $P < 0.05$.

Abbreviation: WHC: water holding capacity.

[1]Experimental diets: SW0 = commercial grower diet without seaweed meal; SW20 = commercial grower diet with seaweed meal at a rate of 20 g/kg; SW25 = commercial grower diet with seaweed meal at a rate of 25 g/kg; SW30 = commercial grower diet with seaweed meal at a rate of 30 g/kg; SW35 = commercial grower diet with seaweed meal at a rate of 35 g/kg.

fed with SWM at a concentration of 3.5% had higher conversion of deoxymyoglobin to oxymyoglobin, which gives a cherry red color associated with fresh meat (Chikwanha et al., 2019). According to Wang et al. (2017), pale meat color is often associated with lower pH, but the meat pH (5.72–6.36) from this study fell within the normal range (5.5–6.5) for chicken meat, as reported by Ao et al. (2008) and Glamoclija et al. (2015). This could also explain why there was a lack of dietary effects on WHC of meat (Dransfield and Sosnicki, 1999). However, other shelf life indicators such as thiobarbituric acid reactive substances or malondialdehyde were not determined owing to limited analytical capacity in our laboratory.

CONCLUSIONS

We concluded that the inclusion of SWM up to a concentration of 35 g/kg had no adverse effect on visceral organ size, carcass characteristics, and meat quality traits as well as meat stability of Boschveld indigenous hens. Seaweed meal promoted similar shelf life indicators as the control diet, which indicates that green seaweeds have no potential to delay both oxidation reactions in poultry meat. However, shelf life measures such as thiobarbituric acid and microbial load should also be determined in future studies for a better insight into the effect of SWM in Boschveld hens. In addition, sensory meat evaluation should be carried out as there is a possibility the final product will taste different. Because seaweeds are a locally available and low-cost feed ingredient, their dietary inclusion has the potential to reduce total feed costs in indigenous Boschveld chickens without compromising carcass traits and meat quality parameters.

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DISCLOSURES

The authors report no conflict of interest.

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