Performance, carcass and digesta characteristics of broilers fed broiler finisher diet supplemented with different levels of *Moringa oleifera* leaf meal, acorn meal and crushed maize

B. Moyo[1], P. Nakalebe[1] and K.E. Ravhuhali[2*]

[1]*Department of Agriculture, Fort Cox College of Agriculture and Forestry, South Africa*
[2]*Department of Animal Science, School of Agricultural Sciences, Faculty of Natural and Agricultural Sciences, North West University, South Africa*

**Corresponding author email*: ravhuhalike@gmail.com

A possible cost-effective way of meeting the demand of poultry products is through reduction of cost of production by introducing affordable unconventional sources of protein, particularly from plant products such as seeds and leaves. The objective of this study was to determine the feed intake, performance, carcass and digesta characteristics of broilers fed broiler finisher diet supplemented with *Moringa oleifera* leaf meal (MOLM), oak nuts (acorn meal) and crushed maize. The best growth performance, feed intake and tenderer and yellower meat were observed in birds fed 20% inclusion of crushed maize. Various inclusion levels of acorn, MOLM and crushed maize had no significant (P > 0.05) influence on feed conversion ratio. Feed intake was reduced by 20% inclusion of acorn meal. Dressing percentage, liver weight and abdominal fat were not significantly (P > 0.05) affected by dietary treatment. However, there was a significant (P ≤ 0.05) increase in gizzard weight with 20% inclusion of crushed maize. The breast muscle from birds fed 20% acorn had lowest ultimate pH and were less yellow. Low dry matter of digesta in the small intestine and caeca were observed with 20% inclusion of crushed maize and 20% inclusion of acorn, while 15% inclusion of crushed maize, together with 5% MOLM increased the dry matter of digesta and lowered pH in the caeca. It was concluded that 20% of crushed maize can be included in the first and the last finisher phases without negatively influencing performance. Furthermore, the significant positive synergistic effect of 15% acorn and MOLM on performance was prominent at the post-finisher phase (day 45 – 56), suggesting that the birds had adapted to the diet.

Keywords**:** Acorn, broiler performance, carcass, colour, *Moringa oleifera*

A prospective way of increasing the supply of poultry products at cheaper prices would be by reducing the cost of production through the use of cheaper, unconventional sources of protein, particularly from plant products such as seeds and leaves replacing costly soybean and cotton seed meals. Some of these unconventional sources of protein and carbohydrates have chemicals which improve the keeping and eating quality of meat (Cui et al. 2018; Sebola et al. 2018). The meat quality characteristics such as colour, pH and tenderness have important effects on the characteristics of the fresh chicken at the point of sale (Mothershaw et al. 2009; Glitsch, 2000; Sebola et al. 2015). In addition, these ingredients also have varied influence on digestibility of the feed due to their composition in terms of non-starch polysaccharides, anti-nutritional factors (Ng`ambi et al. 2009) and type and amount of fibre (Mabelebele et al. 2015; Mulaudzi et al. 2022).

There is, therefore, a need to continually seek and assess affordable alternative sources of energy and protein that are not competitively sought by both human and livestock such as maize and conventional plant protein sources such as soybean, cotton seed and rapeseed meal. Oak kernels (acorn) and *Moringa oleifera* leaf meal (MOLM), may fit into this class. There has been significant utilisation of leaf meals as plant protein sources in poultry diets (Sebola et al. 2015; Mahfuz and Piao 2019; Nduku et al. 2020). Plant leaves are cheap protein sources since leaves can be harvested and dried before mealing. *M. oleifera* is a multipurpose tree with both leaves and flowers edible; it is utilised by humans for medicinal purposes and also as a vegetable (Abdull Razis et al. 2014; Ebert and Palada 2015; Leone et al. 2016) and the leaves and pods are used as a livestock feed (Mahfuz and Piao 2019; Moreno-Mendoza et

0041–3216/2022/020131–145

al. 2021; Meel et al. 2021). Nutritionally, *M. oleifera* dry matter contains 27.05% non-structural carbohydrates (Sanchez-Machado 2010), 38.7 g/kg DM dietary fiber (Sebola et al. 2019), 29 – 40% crude protein (Mahfuz and Piao 2019; Rweyemamu 2006), 14.6% ash and 4.96% lipid (Sanchez-Machado 2010). A comparison of chemical composition of edible parts of *M. oleifera* revealed that leaves had the highest protein, ash and lipid concentration compared to the flowers and immature pods (Sanchez-Machado 2010). A high content of tocopherol has been found in leaves, ranging from 5.7 μg/g (adult leaves) to 27.8 μg/g (6 month-old leaves) of dry mass (Machado et al. 2005). In addition, leaves have significant amount of vitamins A, B and C, plus Ca^{2+} and Fe (Abbas et al. 2018), β-carotene (Dachana et al. 2010) and low quantity of tannins (12 k/kg dry matter), phytates (21g/kg) and absence of trypsin and amylase inhibitors, lectins, cyanogenic glucosides and glucosinolates (Makkar and Becker 1997). Kakengi et al. (2003) found higher pepsin and total soluble protein in *M. oleifera* leaves than in other parts of the plant. The high pepsin and total soluble protein make *M. oleifera* suitable to monogastric animals such as poultry.

Oak fruit (acorn) contains 5.6% tannin and 6.4% phenolic compounds (Bekri and Torki 2021) and considerable amounts of fat (4.8%) (Kilic et al. 2010). Kekos and Kaukios (1985) reported 47 – 60% starch and 7 – 14% lipids, while Ofcarcik and Burns (1971) indicated that the unsaturated fatty acids and oils are almost similar to that of olive oil. The major fatty acids are oleic (48 – 63%), linoleic (16.5 – 17%), palmitic (12.1 – 13%), stearic (3 – 6%) and linolenic (1 – 5%), the other fatty acids are less than 0.5% (Dodd et al 1993; Cantos et al. 2003; Lopes and Bernardo-Gil 2005). Acorns also contain bioactive anti-nutritive factors (Moujahed et al. 2005) such as tannins (Bekri and Torki 2021) which possess antioxidant activity (Rakić et al. 2007) and are rich in α– and γ–tocopherol (Rakić et al. 2006). Antioxidant properties of acorns were shown in meat and dry-cured meat products of the Iberian pig under free-range feeding on the natural feed resources such as acorns (Cava et al. 2000). Effects of acorn on performance of various avian species have been investigated (Houshmand et al. 2015; Rezaie and Semnaninejad 2016; Ghaedi et al. 2018). Abarghoui (2001) showed that supplementing broiler diet with up to 3% acorn improves performance and suggested that it might be influencing the microbial content of the gastrointestinal tract. Negative effects on broiler productivity and tibia characteristics were obtained when dietary acorn level was increased to 15% (Houshmand et al. 2015). Acorn use as an energy source was also investigated in Turkey on Japanese quail, and it was concluded that up to 20% shelled acorn seed could be included as an energy source in quail diets (Midilli et al. 2008). In addition, Saffarzadeh et al. (1999) reported that up to 20% acorn seed could replace maize in the diet of laying hens with no serious adverse effects on performance.

Proximate analysis alone does not indicate the palatability or precise nutritive value of feedstuffs but only gives a quantitative estimate of the nutrients in the ingredient. Hence, the amount of feed consumed by animals is very important as it affects total nutrient intake, digestibility and therefore performance of the animal. Mnisi and Mlambo (2018) showed that apart from affecting growth and intake parameters, nutrition exerts several influences on the development of carcass traits, organs and certain muscles in poultry. Therefore, the objective of this study was to determine the feed intake, performance, carcass and digesta characteristics of broilers fed broiler finisher diet supplemented with MOLM, acorn meal and crushed maize.

Materials and methods

Study area

The study was conducted at the Poultry Unit of Fort Cox College farm (32° 47' S, 27° 01' E; 547 m altitude), located 38 km west of King William's Town, in the Eastern Cape province of South Africa. The area receives rains in summer, and the annual rainfall ranges from

400 – 600 mm. The mean temperature ranges from 10˚C in winter to 26˚C in summer.

Experimental diets, preparation of MOLM and oak nuts (acorn)

There were six experimental treatment diets (Table 1). Treatments 1, 2, 3, 4, and 5 had 80% broiler finisher and varying percentages of crushed maize, ground oak nuts (acorns) and *M. oleifera* leaf meal; Treatment 6 (control) was only composed of broiler finisher with no supplementation. The percentage composition of the broiler finisher is shown in Table 2. Fresh leaves of *M. oleifera* were manually harvested from mature trees at Sedikong sa Lerato in Tooseng village Ga-Mphahlele (24˚ 27´ S, 29˚ 34´ E), Limpopo Province, South Africa. The mean annual rainfall of the area was approximately 300 mm, and the mean annual temperature was 15°C. The leaves were air-dried under shade by spreading on clean plastic sheets and turned several times. The sun-dried leaves were later milled using a commercial feed milling machine. Oak nut seeds were collected at Hogsbag farm (32º 35´ 'S 26º 56´ E) in the Eastern Cape, the seed coat layer was removed, and they were dried at 80ºC for 24 hours before milling in a hammer mill to produce a seed meal.

Table 1: Percentage composition of broiler finisher diets supplemented with acorns, *Moringa oliefera* leaf meal and crushed maize

	Percent composition				
Treatment	**Broiler finisher**	**Acorn meal**	***M. oliefera***	**Crushed maize**	**Total**
1	80	20	0	0	100
2	80	7.5	5	7.5	100
3	80	0	0	20	100
4	80	0	5	15	100
5	80	15	5	0	100
6	100	0	0	0	100

Table 2: Composition (%) and calculated chemical composition (%) of the control diet (broiler finisher)

Ingredients	**% inclusion**
White maize	70.6
Soyabean meal	17.4
Sunflower cake	6.3
Full-fat soya	2.7
Limestone	1.78
Methionine	0.06
Lysine	0.11
Mono calcium phosphate	0.65
Salt	0.15
Premix*	0.25
Total	100
Calculated chemical composition	
Crude protein (%)	16.2
Calcium (%)	1.1
Phosphate (non-phytate) (%)	0.46
Metabolisable energy (kcal/kg)	3100

*Vitamin/trace mineral premix/kg diet: vitamin A - 12 000 IU; vitamin D3 - 1 500 IU; vitamin E - 50 mg; vitamin K3 - 5 mg; vitamin B1 - 3 mg; vitamin B2 - 6 mg; vitamin B6 - 5 mg; vitamin B12 - 0.03 mg; niacin - 25 mg; Ca-D-pantothenate – 12 mg; folic acid - 1 mg; D-biotin - 0.05 mg; apo-carotenoic acid ester - 2.5 mg; choline chloride - 400 mg ; Mn - 80 mg; Fe - 60 mg; Zn - 60 mg; Cu - 5 mg; Co - 0.20 mg; I - 1 mg; Se - 0.15 mg

Experimental birds and their management

A total of 48, 4 week – sexed, white leghorn broilers were used for the experiment. The day-old broilers were brooded using infra-red brooders and electric bulbs as a source of light in a deep-litter house. The house had half walls, and both sides were open and covered with wire gauze. The birds were randomly allotted to the six treatment diets after brooding for 4 weeks. The experimental diets were fed for 28 days (from day 28 to day 56). There were eight birds in each treatment and four broilers per pen. Feed and water were provided *ad libitum*. Health management practices included the administration of Newcastle and infectious bronchitis vaccine at day-old, infectious bursa disease (Gumboro) vaccine at days 7 and 21, Newcastle disease vaccine (Lasota) at day 14 day. Cocciodiostats were administered to broilers at 2^{nd} week. Birds were cared for according to guidelines of the institution and of the Federation of Animal Science Societies for the care and use of animals for teaching and research purposes (FASS 2010).

Data collection

The broilers were weighed at the beginning of the experiment and subsequently weighed every 3 days after. Subtracting initial live weight from final live weight gave weight gain. Feed offered were weighed daily and leftover feed (feed not consumed) were also weighed. Feed intake was determined by subtracting leftover feed from feed offered to the birds. Weighing of birds took place in the morning (07.00 – 08.00 local time) once weekly. Feed conversion ratio was determined by dividing feed intake by weight gain.

Carcass measurements

After 56 days the birds were slaughtered to determine the weight of the carcass and internal organs such as the liver, spleen, heart, gizzard, proventriculus, pancreas and abdominal fat. The birds were fasted overnight, with only access to water to clear the gut of digesta. Live weights were measured the following morning and later the birds were slaughtered by decapitating the heads. The birds were thoroughly bled and the carcass defeathered, cleaned with water and properly drained. The eviscerated weight was measured to calculate the dressing percentage as the percent of dressed carcass weight to live weight of the bird.

pH and colour

The breast muscle was used in the determination of pH and colour. Intramuscular pH measurements were acquired using a glass tipped pH Star-Probe (Crison) calibrated in pH 4.60 and 7.00 buffer solutions. A portable Minolta surface spectro colorimeter was used to determine colour, expressed as L* (lightness), a* (redness) and b* (yellowness) values, on the surface of the intact skinless breast muscles. The measurements were done at 45 minutes, 4 hours and 24 hours (ultimate pH) after slaughter.

Intestinal, caeca and vent digesta collection

Digesta from the small intestine, caeca and vent were collected immediately after slaughter. Digesta were evacuated, mixed and pH was measured. Samples were dried at 65^{o}C for 48 hours for analysis of dry matter and pH.

Warmer – Bratzler shear force determination

At 96 h post-mortem, the 48 chicken breasts were weighed, placed in individual bags and cooked by immersion at 85^{o}C for 30 minutes until an internal temperature of 77°C was obtained (Schilling et al. 2003). The breasts were then cooled to room temperature and weighed. Six adjacent 1 cm (width) by 2 cm (length) strips were cut from the frontal area of the cooked breast parallel to the muscle fibres and then trimmed to a thickness of 1 cm. Each strip was sheared once and the mean was calculated for each breast. Samples were sheared perpendicular to the muscle fibre using a Warmer-Bratzler shear attachment mounted on an Instron (Model 1011, Instron Corp, Canton, MA) with a 50 kg load transducer and a crosshead speed of 200 mm/min.

Data analysis

A one-way analysis of variance in SAS (SAS 2010) was used to test for dietary effects on broiler performance, feed intake, digesta and carcass characteristics. The significance of difference between pairs of treatment means within any overall treatment effects, found significant by analysis of variance, was tested by Duncan's Multiple Range Test. The following model was used:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij}$$

Where: Y_{ij} = single observation on the broiler characteristics; μ = overall mean; T_i = effect of treatment diet and ε_{ij} = experimental error.

Results

Broiler performance

There was a significant difference ($P \leq 0.001$) in broiler performance among the six treatments in the live weight changes, carcass weight, dressing percentage, liver, heart, gizzard and pancreas (Table 3). Birds with the broiler finisher diet mixed with 20% and 15% crushed maize were much heavier than other birds. There was a significant difference ($P \leq 0.001$) in broiler performance among the six treatments in the growth periods day 30 – 44 and day 45 – 56 (Table 4). Birds with the broiler finisher diet mixed with 15% crushed maize and 15% acorn meal had the similar weights to the all treatments including control group in day 30 – 44 growth period (Table 4). Birds with the broiler finisher diet mixed with 20% crushed maize and 15% acorn meal had the highest weights when compared to the all treatments in day 45 – 56 growth period.

Weight at slaughter was also significantly different ($P \leq 0.05$) among treatment diets, with birds fed 20% inclusion rate of crushed maize (Treatment 3) having the higher weight when compared to Treatments 1, 2, 4 and 6 (those fed diets containing 0, 20 and 7.5% acorn meal, 15% crushed maize and the control group). There was a significant difference ($P \leq 0.001$) in feed intake among broilers in the six treatments during the day 30 – 44 and 45 –56 growth period (Table 4). In both growing periods, the highest intake was observed for broilers fed broiler finisher with 20% inclusion of crushed maize, and the lowest was those chickens fed 20% acorn meal. There was a significant difference ($P \leq 0.05$) in the feed conversion ratio (FCR) among broilers in the six treatments for the two growth periods. In day 30 – 44 growing period, the highest FCR was observed for broilers fed broiler finisher with 15 and 20% inclusion of crushed maize and the lowest was those chickens fed 20% acorn meal. In day 45 – 56 growing period, the highest FCR was observed for broilers fed 20% acorn meal.

Carcass traits and meat parameters

The carcass and internal organ parameters are shown in Table 3. Inclusion of 20% crushed maize significantly ($P \leq 0.05$) increased the weight of the carcass, heart and pancreas and the dressing percentage.

The influence of diets on pH, colour and shear force on meat of broilers are reported in Tables 5 and 6. Meat pH after 45 minutes ($P \leq 0.001$), 4 hours ($P \leq 0.05$) and 24 hours ($P \leq 0.001$) significantly varied among broilers fed the various diets. At 45 minutes post-mortem meat from birds fed broiler finisher had the highest pH (suggesting a not so rapid lowering of pH), while the lowest pH was observed in the diet with 20% inclusion of acorn (Table 5). Though no significant differences were observed from Treatments 2 to 6, a trend of decline in pH after 4 hours was observed in all treatments.

In this study, diet had a significant impact on the lightness (L*), redness (a*) and yellowness (b*) (P ≤ 0.001) colorimetric indices after 45 minutes (Table 6). Broiler birds fed diet containing 20% crushed maize had the highest (P ≤ 0.05) lightness value, whereas, broiler birds fed diet containing the combination of 5% moringa and 15% crushed maize had the highest (P ≤ 0.05) redness. The control group had the highest yellowness value.

After 4 hours post-slaughter there was a significant (P ≤ 0.05) difference in lightness or redness of the meat from the six treatments. Broiler birds fed the diet containing 20% crushed maize and 15% acorn meal had highest (P ≤ 0.05) lightness values, whereas, broiler birds fed diet containing combination of 5% moringa and 7.5% acorn meal and control group had highest (P ≤ 0.05) meat tenderness values. The broiler birds fed the diet containing combination of 5% moringa and 15% crushed maize had the highest (P ≤ 0.05) yellowness value.

After 24 hours, broiler birds fed the diet containing combination of 5% moringa and 15% acorn meal had highest (P ≤ 0.05) lightness value. The chickens on the control group diet had the highest (P ≤ 0.05) meat tenderness value. Broilers fed the diet containing 20% acorn meal had highest yellowness value. However, all treatments were very tender on average, far much below the < 45 N acceptable level of tender meat.

Table 3: Body, carcass and internal organ weights (kg) of broilers fed broiler finisher with different levels of *Moringa oleifera* leaf meal, acorn meal and crushed maize

	Treatment							
	1	**2**	**3**	**4**	**5**	**6**	**SE**	**P value**
Live weight	3.6^{c}	3.9^{b}	4.7^{a}	4.1^{b}	4.4^{a}	4.1^{b}	0.092	0.001
Carcass weight	2.8^{b}	2.8^{b}	3.5^{a}	2.8^{b}	3.0^{b}	3.0^{b}	0.081	0..001
Dressing percentage	71.7^{d}	72.6^{c}	74.0^{a}	69.6^{e}	68.0^{f}	73.7^{b}	0.053	0.001
Liver	0.8^{a}	0.08^{c}	0.10^{c}	0.09^{c}	0.3^{b}	0.06^{c}	0.041	0.001
Spleen	0.005^{a}	0.005^{a}	0.005^{a}	0.005^{a}	0.005^{a}	0.005^{a}	0.0001	0.9958
Heart	0.02^{b}	0.02^{b}	0.06^{a}	0.02^{b}	0.02^{b}	0.02^{b}	0.005	0.001
Gizzard	0.04^{b}	0.04^{b}	0.13^{b}	0.04^{b}	0.05^{b}	0.3^{a}	0.041	0.004
Proventriculus	0.01^{a}	0.02^{a}	0.02^{a}	0.02^{a}	0.02^{a}	0.02^{a}	0.005	0.602
Pancreas	0.006^{b}	0.008^{b}	0.02^{a}	0.006^{b}	0.02^{a}	0.005^{b}	0.003	0.015
Abdomen fat	0.09^{a}	0.1^{a}	0.9^{a}	0.1^{a}	0.09^{a}	0.09^{a}	0.006	0.571

In row: different superscripts represent differences among treatments (P ≤ 0.05)

Table 4: Body weight, feed intake and feed conversion ratio of broilers from 30 – 44 and 45 – 56 days of age fed broiler finisher with different levels of *Moringa oleifera* leaf meal, acorn meal and crushed maize

	Treatment							
Weight changes	**1**	**2**	**3**	**4**	**5**	**6**	**SE**	**P value**
Day 30 – 44 weight (kg)	2.5^{a}	2.3^{b}	2.6^{a}	2.4^{ab}	2.4^{ab}	2.5^{a}	0.064	0.044
Day 45 – 56 weight (kg)	3.3^{c}	3.4^{bc}	3.9^{a}	3.5^{bc}	3.9^{a}	3.6^{b}	0.058	0.001
Slaughter weight (kg)	4.0^{bc}	3.9^{c}	4.7^{a}	4.1^{bc}	4.4^{ab}	4.1^{bc}	0.138	0.013
Feed intake (g/bird)								
Day 30 – 44	158.3^{f}	176.7^{e}	214.1^{a}	190.6^{c}	184.8^{d}	203.0^{b}	0.058	0.001
Day 45 – 56	176.8^{f}	181.2^{e}	209.7^{a}	207.1^{b}	195.1^{d}	204.5^{c}	0.058	0.001
Feed conversion ratio								
Day 30 – 44	1.7^{c}	1.4^{d}	2.4^{a}	2.4^{a}	1.7^{c}	2.0^{b}	0.053	0.001
Day 45 – 56	2.0^{a}	1.1^{d}	1.7^{c}	1.8^{bc}	0.9^{e}	1.9^{ab}	0.058	0.001

In row: different superscripts represent differences among treatments (P ≤ 0.05)

Table 5: Mean values of pH of breast muscle of broilers fed on broiler finisher diet with different levels of *Moringa oleifera* leaf meal, acorn meal and crushed maize at different times

	Treatment							
Period	**1**	**2**	**3**	**4**	**5**	**6**	**SE**	**P value**
45 minutes	6.3^{c}	6.6^{b}	6.6^{b}	6.6^{b}	6.8^{ab}	6.9^{a}	0.053	0.001
4 hours	6.0^{b}	6.2^{ab}	6.3^{a}	6.1^{ab}	6.3^{a}	6.3^{a}	0.058	0012
24 hours	5.7^{b}	6.0^{a}	5.7^{b}	5.9^{ab}	5.7^{b}	5.8^{ab}	0.059	0.019

In row: different superscripts represent differences among treatments (P ≤ 0.05)

Table 6: Colour and shear force of broiler meat from various dietary treatments

	Time									Shear force (N)
Treatment	45 mins			4 hours			24 hours			
	L*	a*	b*	L*	a*	b*	L*	a*	b*	
1	41.2^{d}	1.7^{c}	13.9^{d}	47.4^{b}	3.5^{b}	15.7^{c}	48.8^{c}	4.0^{b}	18.4^{a}	16.3^{a}
2	43.7^{b}	1.8^{c}	14.6^{c}	45.6^{e}	3.8^{a}	12.6^{e}	45.8^{f}	4.0^{b}	16.1^{f}	16.4^{a}
3	44.5^{a}	2.4^{b}	14.6^{c}	48.9^{a}	2.5^{d}	15.3^{d}	48.5^{d}	4.0^{b}	17.6^{d}	11.7^{d}
4	41.1^{d}	3.1^{a}	14.9^{b}	47.0^{c}	3.0^{c}	17.0 ^{a}	46.3^{e}	3.8^{c}	17.9^{c}	15.0^{c}
5	41.4^{c}	2.3^{b}	11.1^{e}	48.9^{a}	2.6^{d}	11.4^{f}	51.6^{a}	4.0^{b}	17.1^{e}	15.7^{b}
6	41.5^{c}	2.5^{b}	15.1^{a}	46.0^{d}	3.7^{a}	16.7^{b}	50^{b}	4.3^{a}	18.2^{b}	14.9^{c}
SE	0.058	0.058	0.053	0.053	0.058	0.062	0.053	0.058	0.058	0.058
P value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0019	0.0001	0.0001

L* (Lightness), a* (redness), b* (yellowness). In column: different superscripts represent differences among treatments (P ≤ 0.05)

Digesta pH and dry matter

There was a significant (P ≤ 0.05) dietary effect on the dry matter of the small intestine and caecum digesta. Diet also significantly (P ≤ 0.05) affected the pH of digesta in the vent and small intestine (Table 7). Broiler birds fed the diet containing the combination of 7.5% crushed maize, 5% moringa and 7.5% crushed maize had the highest (P ≤ 0.05) small intestine dry matter digesta value. Broiler birds fed diet 20% crushed maize had the highest (P ≤ 0.05) vent and caeca dry matter values.

The diet with combination of 15% acorn meal and 5% moringa had the highest small intestine pH, while 15% crushed maize plus 5% MOLM resulted in the lowest small intestine and pH values. The highest pH values in the vent were obtained from chicken exposed to diet containing 20% acorn meal and also to diets containing the combination of 7.5% acorn meal, 5% moringa and 7.5% crushed maize. The diet with 20% inclusion of acorn meal resulted in highest caeca pH value.

Table 7: Dry matter and pH of digesta in the small intestine, vent and caeca

	% Dry matter			pH		
Treatment	Small Intestine	Vent	Caeca	Small Intestine	Vent	Caeca
1	44.1[d]	49.6[c]	35.9[f]	6.4[b]	6.9[a]	7.3[a]
2	64.2[a]	45.8[d]	40.8[c]	6.4[b]	7.0[a]	7.1[b]
3	32.4[f]	50.2[b]	43.3[b]	6.3[b]	6.5[b]	7.1[b]
4	35.9[e]	52.0[a]	51.5[a]	5.3[d]	5.3[d]	6.4[c]
5	41.2[c]	45.3[e]	40.1[d]	5.7[c]	5.7[c]	7.0[b]
6	42.6[b]	45.3[e]	39.7[e]	7.0[a]	6.4[b]	7.0[b]
SE	0.058	0.058	0.058	0.067	0.053	0.058
P value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

In column: different superscripts represent differences among treatments ($P \leq 0.05$)

Discussion

The superior growth associated with diets supplemented with crushed maize is primarily attributed to the observed high feed intake. The poor performance in the diet with similar quantities of acorn and crushed maize (7.5%), plus 5% MOLM and broiler diet supplemented with 20% acorns (Treatments 1 and 2) is also associated with low feed intake which might have been due to the combined anti-nutritional factor effects of acorns and MOLM (Sebola et al. 2019; He et al. 2020). Dietary inclusion of tanniferous leaf meals of *L. Leucocephala*, *G. Sepium*, *R. Pseudoacacia*, *C. Cajan*, *S. Sesban* and *S. Grandiflora* depressed growth rates and feed intake of chicks at levels ranging from 75 – 100g kg^{-1} (D'Mello et al. 1987; Raharjo et al. 1988; Udedibie and Igwe 1989; Ash et al. 1992). Less intake was also observed on diet supplemented with 15% acorns and 5% *M. oliefera* (Treatment 5) (185 g at days 33 – 44). A negative effect on growth performance of high MOLM inclusion level was also observed in fish (Richter et al. 2003), and broilers (Olugbemi et al. 2010), while Nkukwana et al. (2014) did not find any variation in growth performance on broilers under different MOLM level at age 35 days. The negative effects of MOLM might be the results of high fibre content (Dachana et al. 2010; Stevens et al. 2015; Mulaudzi et al. 2022) and anti-nutritional factors (Teixeira et al. 2014; Mulaudzi et al. (2022). Inclusion of acorns also decreased performance and intake as observed by Bouderoua et al. (2009). Acorns have high tannin content (Luo et al. 2019), which might have decreased the availability of amino acids. The high amount of coarse material from crushed maize in Treatment 3 (diet with supplemented with 20% crushed maize) might have stimulated the activity of the gizzard (Gonzalez-Alvarado et al. 2008) and hence its increase in size (0.13 g), which resulted in efficient utilisation of the feed. It has been found that feeding of coarsely ground feed or of whole grains increases gizzard weight (Xu et al. 2015). The lower feed intake of Treatments 1 and 2 during the 30 – 44 and 45 – 56 day growth periods could be related to decrease in palatability which might be related to the reported high levels of tannins in acorn in Treatment 1 and high fibre in Treatment 2. Feed intake can be improved by including enzymes when formulating diets with ingredients high in anti-nutritional factors and non-starch polysaccharides (Laudadio and Tufarelli 2010; Woyengo et al. 2019).

Compared to Treatments 1, 2, 4 and 5, inclusion of 20% crushed maize (Treatment 3) significantly increased the weight of the heart by 0.06 g and the gizzard by 0.13 g. The size of gizzard is determined by the amount of work required by the muscular walls of the organ to grind feed particles (Obun et al. 2008). The amount of dietary fibre (Owusu-Asiedu et al.

2006) and non-starch polysaccharides (NSP) affect gizzard weight (Banfield et al. 2002). The amount and type of fibre and NSP affect the development of organs in various ways.

The rate of decrease in pH early post-mortem and the final pH of the meat are key factors of chicken meat quality (Le Bihan-Duval et al. 2008). A rapid pH decline indicates increased protein denaturation (Sams 1999). However, the ultimate pH for all treatments was between 5.7 – 6.0 within the normal range for broiler breast meat (Lopez et al. 2011; Nkukwana et al. 2015).

Meat colour is an important parameter of meat quality and is one of the critical meat characteristics observed by customers (Mortimer et al. 2014) since consumers are often willing to pay more for poultry products having appetising colour. Meat colour is affected by pH, myoglobin concentration and nitrites (Matshogo et al. 2018). Carotenoids, such as xanthophylls, are compounds responsible for the yellow skin colour in broilers (Langi et al. 2018). Yellow coloration of the diets with inclusion of MOLM was mainly attributed to the presence of xanthophylls and carotenoid pigments in *M. oleifera* as in other tree and shrub leaf meals (Austic and Neisheim 1990). *M. oleifera* leaves have high β-carotene content (Dachana et al. 2010), hence the high yellowness values observed. Yellowing of the colour of shank, beak and skin of the broilers on diets with MOLM was also observed by Olugbemi et al. (2010). Low yellowness in the diet of 15% acorn plus 5% MOLM inclusion (Treatment 5) after 45 minutes might have been related to pH. Allen et al. (1997) reported that lower yellowness values were correlated to higher pH values of the broiler breast meat. In addition, acorn has lower amounts of carotene compared to maize, hence a combination of MOLM and crushed maize (Treatment 4) had the highest yellowness value after 4 hours.

Tenderness has been shown to be the most important factor in consumer perception of quality meat products (Samant and Seo 2016). Meat tenderness is highly dependent on post-mortem pH as well as the ultimate pH attained by the carcass (Simela et al. 2004). Though there was variation in tenderness of meat, in this study the ultimate pH for birds in all treatments was between 5.7 – 6.0 and this might explain the tenderness observed in meat from all these groups of birds. In addition, colour has been associated with tenderness, with Wulf et al. (1997) reporting that dark-cutting beef was less tender. In this study meat from birds fed similar amounts of crushed maize and acorns with 5% inclusion of MOLM had the less tender meat (after 45 minutes) and the lowest lightness value after 4 hours and 24 hours.

Low dry matter in the small intestine with a sole inclusion of crushed maize might have been due to increased viscosity due to the added grain. Sole inclusion of acorn meal resulted in low dry matter in the caeca, perhaps because of its viscosity. Reduced digesta dry matter with diets of high NSPs has been reported in the literature (Refstie et al. 1999; Leenhouwers et al. 2007).

The combination of crushed maize plus MOLM without acorn meal (Treatment 4) resulted in lower pH of the digesta in the small intestine, caeca and vent. The lower pH observed suggests that the fibre fraction of MOLM might have stimulated bile salts and bicarbonate secretions (Hetland et al. 2003). The importance of the type of fibre in determining the pH in the gastrointestinal tract was shown by Jimenez-Moreno et al. (2009) who found that the pH of the digesta in the small intestine increased with sugar beet pulp and decreased with cellulose inclusion in broiler diets. The cellulose in MOLM might have adsorbed and retained the bile salts in the surface.

Conclusion

The sole inclusion of acorn meal had a performance comparable to that of broiler finisher diet with however, a reduced intake and lower digesta of dry matter in the caecum. The pH value for the meat ranged from 5.7 – 6.0 which is a good indicator of improved meat quality. However, acorn meal had a detrimental effect on the colour of the meat, with less yellower meat being observed as opposed to more yellower meat with inclusion of crushed maize. The sole inclusion of crushed maize resulted in high feed intake, which was associated with high carcass, heart and gizzard weights. Lowering the combination of acorn meal plus crushed maize (7.5%) in the diet resulted in lower weights due to a probable lower feed intake which might be implicated to the rising effects of MOLM.

Acknowledgement

Authors fully acknowledge the financial support of Department of Agriculture, Fort Cox College of Agriculture and Forestry, Eastern Cape South Africa.

Conflicts of Interest

The authors declare no conflict of interest.

References

Abarghoui, A.H. 2001. "Acorn Substitution for Corn in Broilers Diet and its Effect on Broilers Performance." DVM Thesis. Azad University of Shahre-kord, Shahre-kord, Iran.

Abbas, R.K., F.S. Elsharbasy, and A.A. Fadlelmula. 2018. "Nutritional Values of *Moringa oleifera*, Total Protein, Amino Acid, Vitamins, Minerals, Carbohydrates, Total Fat and Crude Fiber, under the Semi-Arid Conditions of Sudan." *Journal of Microbial and Biochemical Technology* **10**:56–58.

Abdull Razis, A.F., M.D. Ibrahim, and S.B. Kntayya. 2014. ''Health Benefits of *Moringa oleifera*." *Asian Pacific Journal of Cancer Prevention* **15** (20): 8571–8576.

Allen, C.D., S.M. Russell, and D.L. Fletcher. 1997. "The Relationship of Broiler Breast Meat Color and pH to Shelf-Life and Odor Development." *Poultry Science* **76**: 1042–1046.

Ash, A.J., L.Petaia, and H. Ako. 1992. "Nutritional Value of *S.grandiflora* Leaves for Monogastrics and Ruminants." *Tropical Agriculture* **69**: 223–228.

Austic, R.E., and M.C. Neishem. 1990. "Poultry Production." Lea and Febiger, Philadelphia. 260–275p.

Banfield, M.J., P.P. Kwakkel, and J.M. Forbrs. 2002. "Effects of Wheat Structure and Viscosity on Coccidiosis in Broiler Chickens." *Animal Feed Science and Technology* **98**: 37–48.

Bekri, F., and M. Torki. 2021. "Egg Quality Traits, Blood Biochemical Parameters and Performance of Laying Hens Fed Diet Included Processed Oak Fruit." *Veterinary Medicine and Science* **7 (2)**: 483–490.

Bouderoua, K., J. Mourot, and G. Selselet-Attou. 2009. "The Effect of Green Oak Acorn (*Quercus ilex*) Based Diet on Growth Performance and Meat Fatty Acid Composition of Broilers." *Asian-Australasian Journal of Animal Sciences* **22**: 843–848.

Cantos, E., J. Espin, C. Carlos-Lopez-Bote, L. De La Hoz, J.A. Ordonez, and F.A. Tomas-Barberan. 2003. "Phenolic Compounds and Fatty Acids from Acorns (Quercus spp.), the Main Dietary Contituent of Free Ranged Iberian Pigs." *Journal of Agricultural and Food Chemistry* **51**: 6248–6255.

Cava, R., J. Ventanas, J.F. Tejeda, J. Ruiz, and T. Antequera. 2000. "Effect of Free-Range Rearing and α-tocopherol and Copper Supplementation on Fatty Acid Profiles and Susceptibility to Lipid Oxidation of Fresh Meat from Iberian Pigs." *Food Chemistry* **68**: 51–59.

Cui, Y., J. Wang, W. Lu, H. Zhang, S. Wu, and G. Qi. 2018. "Effect of Dietary Supplementation with *Moringa oleifera* Leaf on Performance, Meat Quality, and Oxidative Stability of Meat in Broilers." *Poultry Science* **97 (8)**: 2836–2844.

D'Mello, J.P.F., T. Acamovic, and A.G. Walker. 1987. "Evaluation of *leucaena* Leaf Meal for Broiler Growth and

Pigmentation." *Tropical Agriculture* **5**: 45–50.

Dachana, K.B., J. Rajiv, D. Indrani, and J. Prakash. 2010. "Effect of Dried Moringa (*Moringa Oleifera* Lam) Leaves on Rheological, Microstructural, Nutritional, Textural and Organoleptic Characteristics of Cookies." *Journal of Food Quality* **33**: 660–677.

Dodd, R.S., Z.A .Rafii, and E. Zavarin. 1993. "Chemosystematic Variation in Acorn Fatty Acids of Californian Live Oaks (Quercus agrifolia and Q. wislizenii)." *Biochemical Systematics and Ecology* **21**: 279–285.

Ebert, A.W., and M.C. Palada. 2015. "Moringa-A Vegetable Tree for Improved Nutrition, Health and Income of Smallholder Farmers." *In I International Symposium on Moringa* **1158**. 309–316.

FASS (Federation of Animal Science Societies). 2010. "Guide for the Care and Use of Agricultural Animals in Research and Teaching." 3rd ed. Federation of Animal Sciences Societies, Illinois, USA.

Ghaedi, L., M. Houshmand, and S. Parsaei. 2018. "Performance and Tibia Characteristics of Broilers Fed Diets Containing Raw or Treated Oak Acorn (*Quercus brantii* lindl)." *Journal of Animal and Plant Sciences* **28(1)**: 38–45.

Glitsch, K. 2000. "Consumers Perceptions of Fresh Meat Quality: Cross-National Comparison." *British Food Journal* **102 (3)**: 177–194.

González-Alvarado, J.M., E. Jiménez-Moreno, D.G. Valencia, R. Lázaro, and G.G. Mateos. 2008. "Effects of Fiber Source and Heat Processing of the Cereal on the Development and pH of the Gastrointestinal Tract of Broilers Fed Diets Based on Corn or Rice." *Poultry Science* **87**: 1779–1795.

He, L., H. Lv, N. Chen, C. Wang, W. Zhou, X. Chen, and Q. Zhang. 2020. "Improving Fermentation, Protein Preservation and Antioxidant Activity of *Moringa oleifera* Leaves Silage with Gallic Acid and Tannin Acid." *Bioresource Technology* **297**: 122390.

Hetland, H., B. Svihus, and A. Krogdalhl. 2003. "Effects of Oat Hulls and Wood Shaving on Digestion in Broilers and Layers Fed Diets Based on Whole or Ground Wheat." *British Poultry Science* **44**: 275–282.

Houshmand, M., F. Hojati, and S. Parsaie. 2015. "Dietary Nutrient Manipulation to Improve the Performance and Tibia Characteristics of Broilers Fed Oak Acorn (*Quercus brantii* Lindl)." *Brazilian Journal of Poultry Science* **17(1)**: 17–24.

Jiménez-Moreno, E., J.M. González-Alvarado, A. de Coca-Sinova, R. Lázaro, and G.G. Mateos. 2009. "Effects of Source of Fibre on the Development and pH of the Gastrointestinal Tract of Broilers." *Animal Feed Science and Technology* **154**: 93–101.

Kakengi, A.M.V., M.N. Shem, S.V. Sarwatt, and T. Fujihara. 2003. "Can *Moringa oleifera* be used as a Protein Supplement to Ruminants?" *Asian-Australasian Journal of Animal Sciences* **18**:1:42–47.

Kekos, D., and E.G. Kaukios. 1985. "Acid Hydrolysate of Acorn Polysacharide as Substrates of Candida utilisis Growth." *Biotech. Letters* **7**: 345–348.

Kilic, U., M. Boga, and I. Guven. 2010. "Chemical Composition and Nutritive Value of Oak (Quercus robur) Nut and Leaves." *Journal of Applied Animal Research* **38(1)**: 101–104.

Langi, P., S. Kiokias, T. Varzakas, and C. Proestos. 2018. "Carotenoids: From Plants to Food and Feed Industries." In *Microbial Carotenoids: Methods in Molecular Biology*, edited by Carlos Barreiro and José-Luia Barredo. Vol 1852:57-71. New York, NY: Humana Press.

Laudadio, V., and V. Tufarelli. 2010. "Growth Performance and Carcass and Meat Quality of Broiler Chickens Fed Diets Containing Micronized-Dehulled Peas (*Pisum sativum* cv. Spirale) as a Substitute of Soybean Meal." *Poultry Science* **89**: 1537–1543.

Le Bihan-Duval, E., M. Debut, C.M. Berri, N. Sellier, V. Santé-Lhoutellier, Y. Jégo, and C. Beaumont. 2008. "Chicken Meat Quality: Genetic Variability and Relationship with Growth and Muscle Characteristics." *BMC Genetics* **9**: 53.

Leenhouwers, J.I., R.C. Ortega, J.A.J. Verreth, and J.W. Schrama. 2007. "Digesta Characteristics in Relation to Nutrient Digestibility and Mineral Absorption in Nile Tilapia (*Oreochromis niloticus* L.) Fed Cereal Grains of Increasing Viscosity." *Aquaculture* **273**: 556–565.

Leone, A., A. Spada., A. Battezzati., A. Schiraldi., J. Aristil, and S. Bertoli. 2016. ''*Moringa oleifera* Seeds and Oil: Characteristics and Uses for Human Health." *International Journal of Molecular Sciences* **17**(12), p.2141.

Lopes, I., and M.G. Bernardo-Gil. 2005. "Characterisation of Acorn Oils Extracted by Hexane and by Supercritical Carbon Dioxide." *European Journal of Lipid Science Technology* **107**: 12–19.

Lopez, K.P., M.W. Schilling, and A. Corzo. 2011. "Broiler Genetic Strain and Sex Effects on Meat Characteristics." *Poultry Science* **90(5)**:1105–1111.

Luo, X., R. Bai, D. Zhen, Z. Yang, D. Huang, H. Mao, X. Li, H. Zou, Y. Xiang, K. Liu, and Z. Wen. 2019. "Response Surface Optimization of the Enzyme-Based Ultrasound-Assisted Extraction of Acorn Tannins and their Corrosion Inhibition Properties." *Industrial Crops and Products* **129**: 405–413.

Mabelebele, M., M. Siwela., R.M. Gous, and P.A. Iji. 2015. "Chemical Composition and Nutritive Value of South African Sorghum Varieties as Feed for Broiler Chickens." *South African Journal of Animal Science* **45 (2):** 206–213.

Machado, D.I.S., J.L. Cervantes, and N.J.R. Vazquez. 2005. "High Performance Liquid Chromatography Method to Measure α, γ-tocopherol in Leaves, Flowers and Fresh Beans from *Moringa oleifera*." *Journal of Chromatography* **1105**: 111–114.

Mahfuz, S., and X.S. Piao. 2019. "Application of Moringa (*Moringa oleifera*) as Natural Feed Supplement in Poultry Diets." *Animals* **9 (7)**: 431.

Makkar, H.P.S., and K. Becker. 1997. "Nutrients and Antiquality Factors in Different Morphological Parts of the *Moringa oleifera* Tree." *Journal of Agricultural Science* **128**: 311–322.

Matshogo, T.B., V. Mlambo, U. Marume, and N. Sebola. 2018. "Growth Performance, Blood Parameters, Carcass Characteristics and Meat Quality Traits in Potchefstroom Koekoek Chickens Fed *Lippia javanica* Leaf Meal." *Tropical Animal Health and Production* **50(8)**: 1787–1795.

Meel, M.S., T. Sharma, M. Joshi, M.L. Gurjar, S.K. Sharma, and M. Kumari. 2021. "Effect of Feeding *Moringa oleifera* Leaf Meal with Multi-enzyme on Performance, Carcass Characteristics and Economics of Production of Broiler Chicks." *Asian Journal of Dairy and Food Research* **40(1)**: 118–122.

Midilli, M., Ö.H. Muglal, L. Altıntas, H. Erol, and S. Cakır. 2008. "Shelled Acorn Seed (*Quercus cerris*) as a Diet Ingredient on the Performance of Growing Japanese Quail." *South African Journal of Animal Science* **38**: 38–42.

Mnisi, C.M., and V. Mlambo. 2018. "Growth Performance, Haematology, Serum Biochemistry and Meat Quality Characteristics of Japanese Quail (*Coturnix japonica*) Fed Canola Meal-Based Diets." *Animal Nutrition* **4(1)**: 37–43.

Moreno-Mendoza, Y., K.D. López-Villarreal, C.A. Hernández-Martínez, L.E. Rodríguez-Tovar, A.C. Hernández-Coronado, A. Soto-Domínguez, M.E. Hume, and G. Méndez-Zamora. 2021. "Effect of Moringa Leaf Powder and agave inulin on performance, intestinal morphology, and meat yield of broiler chickens." *Poultry Science* **100(2)**: 738–745.

Mothershaw, A.S., T. Gaffer, I. Kadim, N. Guizani, I. Al-Amri, O. Mahgoub, and S. Al-Bahry. 2009. "Quality Characteristics of Broiler Chicken Meat on Salt at Different Temperatures." *International Journal of Food Properties* **12(3)** 681–690.

Mortimer, S.I., J.H.J. Van der Werf, R.H. Jacob, D.L. Hopkins, L. Pannier, K.L. Pearce, G.E.Gardner, R.D. Warner, G.H. Geesink, J.H. Edwards, and E.N. Ponnampalam. 2014. "Genetic Parameters for Meat Quality Traits of Australian Lamb Meat." *Meat Science* **96(2)**: 1016–1024.

Moujahed, N., C.B. Mustapha, and C. Kayouli. 2005. "Effect of Maturity Stage on Chemical Composition, in Sacco Degradation and In Vitro Fermentation of Acorns (Quercus coccifera L.)." *Sustainable Grazing, Nutritional Utilization and Quality of Sheep and Goat Products* Zaragoza: CIHEAM. 413–417p.

Mulaudzi A., C.M. Mnisi, and V. Mlambo. 2022. "Enhancing the Utility of Dietary *Moringa oleifera* Leaf Meal for Sustainable Jumbo Quail (*Coturnix* sp.) Production." *Sustainability*. **14(9)**: 5067.

Nduku, X.P., S.P. Mabusela, and T.T. Nkukwana. 2020. "Growth and Meat Quality of Broiler Chickens Fed *Moringa oleifera* Leaf Meal, a Probiotic and an Organic Acid." *South African Journal of Animal Science* **50(5):** 710–718.

Ng`ambi, J.W., P.M. Nakalebe, D. Norris, M.S, Malatje, and C.A. Mbajiorgu. 2009. "Effects of Dietary Energy Level and Tanniferous Acacia Karroo Leaf Meal Level of Supplementation at Finisher Stage on Performance and Carcass Characteristics of Ross 308 Broiler Chickens in South Africa." *International Journal of Poultry Science* **8(1)**: 40–46.

Nkukwana, T.T., V. Muchenje, P.J. Masika, E. Pieterse, L.C. Hoffman, and K. Dzama. 2015. "Proximate Composition and Variation in Colour, Drip Loss and pH of Breast Meat from Broilers Supplemented with *Moringa oleifera* Leaf Meal Over Time." *Animal Production Science* **56(7)**: 1208–1216.

Nkukwana, T.T., V. Muchenje, E. Pieterse, P.J. Masika, T.P. Mabusela, L.C. Hoffman, and K. Dzama. 2014. "Effect of *Moringa oleifera* Leaf Meal on Growth Performance, Apparent Digestibility, Digestive Organ Size and Carcass Yield in Broiler Chickens." *Livestock Science* **161**:139–146.

Obun, C.O., A.O. Olafadehan, B.A. Ayanwale, and M. Inuwa. 2008. "Growth, Carcass and Organ Weights of Finisher Broilers Fed Differently Processed *Detarium microcarpum* (Guill and Sperr) Seed Meal." *Livestock Research for Rural Development* 20(8).

Ofcarcik, R.P., and E. Burns. 1971. "Chemical and Physical Properties of Selected Acorns." *Journal of Food Science* **36**: 576–578.

Olugbemi, T.S., S.K. Mutayoba, and F.P. Lekule. 2010. "Effect of Moringa (*Moringa oleifera*) Inclusion in Cassava Based Diets Fed to Broiler Chickens." *International Journal of Poultry Science* **9**: 363–367.

Owusu-Asiedu, A., J.F. Patience, B. Laarveld, A.G. Van Kessel, P.H. Simmins, and R.T. Zijlstra. 2006. "Effects of Guar Gum and Cellulose on Digesta Passage Rate, Ileal Microbial Populations, Energy and Protein Digestibility, and Performance of Grower Pigs." *Journal of Animal Science* **84**: 843–852.

Raharjo, Y.C., P.R. Cheeke, and N.M. Patton. 1988. "Evaluation of Tropical Forage and Rice By-Products as Rabbit Feeds." *Journal of Applied Rabbit Research* **11**: 201–211.

Rakić, S., D. Povrenović, V. Tešević, M. Simić, and R. Maletić. 2006. "Oak Acorn, Polyphenols and Antioxidant Activity in Functional Food." *Journal of Food Engineering* **74**: 416–423.

Rakić, S., S. Petrović, J. Kukić, M. Jadranin, V. Tesevic, D. Povrenović, and S. Siler-

Marinkovic. 2007. "Influence of Thermal Treatment on Phenolic Compounds and Antioxidant Properties of Oak Acorns from Serbia." *Food Chemistry* **104**: 830–834.

Refstie, S., B. Svihus, K.D. Shearer, and T. Storebakken. 1999. "Nutrient Digestibility in Atlantic Salmon and Broiler Chickens Related to Viscosity and Non-Starch Polysaccharide Content in Different Soyabean Products." *Animal Feed Science and Technology* **79**: 331–345.

Rezaie, M., and H. Semnaninejad. 2016. "Effects of Different Levels of Raw and Processed Oak Acorn (*Quercus castaneifolia*) on Performance, Small Intestine Morphology, Ileal Digestibility of Nutrients, Carcass Characteristics and Some Blood Parameters in Broiler Chickens." *Poultry Science Journal* **4(2):** 127–138.

Richter, N., P. Siddhuraju, and K. Becker. 2003. "Evaluation of Nutritional Quality of Moringa (*Moringa oleifera* Lam.) Leaves as an Alternative Protein Source for Nile tilapia (*Oreochromis niloticus* L.)." *Aquaculture* **217**: 599–611.

Rweyemamu, L.M.P. 2006. "Challenges in the Development of Micronutrient-Rich Food Ingredients from Soya Beans and *Moringa oleifera* Leaves." *Proceedings of the Workshop on Moringa and Other Highly Nutritious Plant Resources*: *Strategies, Standards and Markets for a Better Impact on Nutrition in Africa*. Accra, Ghana, November 16–18, 2006.

Saffarzadeh, L., L. Vincze, and J. Csapo. 1999. "The Effect of Different Levels of Acorn Seeds on Laying Hens Performance in First Phase of Egg Production." *Acta Agraria Kaposvariensis* **3**: 369–377.

Samant, S.S., and H.S. Seo. 2016. "Quality Perception and Acceptability of Chicken Breast Meat Labeled with Sustainability Claims Vary as a Function of Consumers' Label-Understanding Level." Food Quality and Preference **49**: 151–160.

Sams, A. 1999. "Looking for Solutions: Pale Meat, Poor Yield." *Broiler Industry* **62**: 26–30.

Sánchez-Machado, D., J. Núñez-Gastélum, C. Reyes-Moreno, B. Ramírez-Wong, and J. López-Cervantes. 2010. "Nutritional Quality of Edible Parts of *Moringa oleifera*." *Food Analytical Methods* **3**: 175–180.

SAS (Statistical Analysis System). 2010. "Statistical Analysis System." SAS/STAT Users Guide; Statistic Version 9.4. SAS Institute Inc. Cary, North Carolina.

Schilling, M.W., J.K. Schilling, J.R. Claus, N.G. Marriott, S.E. Duncan, and H. Wang. 2003. "Instrumental Texture Assessment and Consumer Acceptability of Cooked Broiler Breasts Evaluated Using a Geometrically Uniform-Shaped Sample." *Journal of Muscle Foods* **14:** 11–23.

Sebola, N.A., V. Mlambo, H.K. Mokoboki, and V. Muchenje. 2015. "Growth Performance and Carcass Characteristics of Three Chicken Strains in Response to Incremental Levels of Dietary *Moringa oleifera* Leaf Meal." *Livestock Science* **178**: 202–208.

Sebola, N.A., V. Mlambo., H.K. Mokoboki., A. Hugo, and V. Muchenje. 2018. "Comparison of Meat Quality Parameters in Three Chicken Strains Fed *Moringa oleifera* Leaf Meal-Based Diets." *Journal of Applied Poultry Research* **27**(3): 332–340.

Sebola, N.A., V. Mlambo, and H.K. Mokoboki. 2019. "Chemical Characterisation of *Moringa oleifera* (MO) Leaves and the Apparent Digestibility of MO Leaf Meal-Based Diets Offered to Three Chicken Strains." *Agroforestry Systems* **93(1):**149–160.

Simela, L., E.C. Webb, and L. Frylinck. 2004. "Effect of Sex, Age, and Pre-Slaughter Conditioning on pH, Temperature, Tenderness and Colour of Indigenous South African Goats." *South African Journal Animal Science* **34**: 208–221.

Stevens, C.G., F.D. Ugese, G.T. Otitoju, and K.P. Baiyeri. 2015. "Proximate and Anti-Nutritional Composition of Leaves and Seeds of *Moringa oleifera* in Nigeria: A Comparative Study." *Agro-Science* **14(2):** 9–17.

Teixeira, E.M.B., M.R.B. Carvalho, V.A. Neves, M.A Silva, and L. Arantes-Pereira. 2014. "Chemical Characteristics and Fractionation of Proteins from *Moringa oleifera* Lam. Leaves." *Food Chemistry* **147**: 51–54.

Udedibie, A.B.I., and F.O. Igwe. 1989. "Dry Matter Yield and Chemical Composition of Pigeon Pea (*Cajanus cajan*) Leaf Meal and the Nutritive Value of Pigeon Pea Leaf Meal and grain Meal for Laying Hens."S *Animal Feed Science Technology* **24**: 111–119.

Woyengo, T.A., K.J. Bogota, S.L. Noll, and J. Wilson. 2019. "Enhancing Nutrient Utilization of Broiler Chickens through Supplemental Enzymes." *Poultry Science* **98(3)**: 1302–1309.

Wulf, D.M., S.F. O`Connor, J.D. Tatum, and G.C. Smith. 1997. "Using Objective Measures of Muscle Colour to Predict Beef Longissimus Tenderness." *Journal of Animal Science* **75**: 684–692.

Xu, Y., C.R. Stark, P.R. Ferket, C.M. Williams, and J. Brake. 2015. "Effects of Feed Form and Dietary Coarse Ground Corn on Broiler Live Performance, Body Weight Uniformity, Relative Gizzard Weight, Excreta Nitrogen, and Particle Size Preference Behaviors." *Poultry Science* **94(7)**: 1549–1556.