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The effect of dietary Marula nut meal on the physical properties, proximate and fatty acid content of Japanese quail meat

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ABSTRACT

Soyabean meal (SBM) is the major dietary protein source for the poultry industry in sub-Saharan Africa. Due to inadequate local soyabean production, alternative protein sources are required. Two hundred 9-day old Japanese quail chicks were randomly allocated to grower diets wherein Marula nut meal (MNM) substituted SBM on a crude protein (CP) basis at 0%, 25%, 50%, 75% and 100% and fed for 4 weeks, followed by being fed on similarly formulated finisher diets for 2 weeks, and thereafter they were humanely slaughtered and dressed. Initial pH (pH_i) and ultimate (pH_u), colour, thawing loss (TL), cooking loss (CL), tenderness, proximate and fatty acid (FA) composition of the breast and thigh meat were determined. The results showed that pH_i and pH_u of meat from carcasses of quail fed diet 1 was lower, but had lighter and less red meat than that from counterparts fed diet 5 ($P < 0.01$). Dietary MNM had no effect ($P > 0.05$) on TL, CL and tenderness of the meat. The ash content of the meat increased with an increase in dietary MNM, but its CP and fat decreased ($P < 0.05$). In addition, the total saturated FA content of meat from birds fed diet 4 was lower ($P < 0.05$) than other counterparts. Meat from birds fed diets 1 and 2 had a lower oleic acid (OA) content in comparison to meat from birds fed diets 3, 4 and 5. MNM can potentially be utilised in quail feeds without compromising the physical and proximate properties of the meat. Also, it can be used to produce lean but OA-rich meat with possible potential health benefits to consumers.

1. Introduction

In sub-Saharan Africa (SSA), the per capita consumption of meat is projected to increase by 2.5 kg from the year 2015 to 2030 (Bruinsma, 2017), representing a 22.94% increase in consumption. The surge in demand is driven by population growth, urbanization, and increasing incomes (Augustin et al., 2016; Thornton, 2010). Poultry meat, particularly broiler chicken, is one of the most popular and widely consumed meat in SSA due to its wide acceptance (Wahyono & Utami, 2018), cooking ease (Petracci et al., 2015) and is relatively cheaper when compared to other meats (Delport et al., 2017). Its high protein and low fat content make it a healthy product (Qi et al., 2018). In resource-limited rural communities, where animal-derived dietary protein for human consumption is most limited, the production of improved chicken breeds is limited by the high cost associated with their housing, feed and veterinary requirements (Etal, 2014; Moreki, 2010). There is a need to introduce and produce less costly but complementary poultry species such as Japanese quail.

Quail have a short generation interval, mature early, and require less feed and space in comparison to improved chicken breeds (Oguz & Minvielle, 2001; Sakamoto et al., 2018). Their meat provides the human body with essential amino acids (Genchev et al., 2008; Nasr, Ali, & Hussein, 2017), essential fatty acids, vitamins and antioxidants (Cavani, et al., 2009). These essential amino acids and essential fatty acids are vital for normal growth and development of the human brain (Bourre, 2004). When compared to other meats, quail meat is low in calories but has higher protein content (Ribarski & Genchev, 2013).

Therefore, in a bid to reduce the sub-Saharan African poultry industry's dependence on costly imported soyabean meal (Chivandi et al., 2018), we recently established that defatted Marula nut meal (MNM) can be used to replace SBM as a dietary protein source in Japanese quail grower and finisher diets, without compromising growth performance and feed utilisation efficiency (Mazizi et al., 2019). However, its effects on the physico-chemical properties of broiler quail meat have not been determined. It is an established fact that feed ingredients (Kralik et al., 2018) and diet composition influence meat quality (Kannan et al., 2006). The feed ingredient- and or diet-induced effects on meat quality play a significant role in the acceptability of the meat by consumers as well as its (meat) physical properties and chemical nutrient composition. Thus, the aim of this study was to evaluate the effect of

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substituting SBM with MNM as a dietary protein source in broiler Japanese quail starter and finisher diets on the meat's physico-chemical properties.

2. Materials and methods

2.1. Study site

The study was carried out at the Central Animal Service (CAS) unit of the University of the Witwatersrand (Wits) and the Wits School of Physiology Laboratories (Coordinates: -26.176259, 28.046167).

2.2. Feed ingredients: sources and processing

Most of the ingredients used in the formulation of diets (soyabean meal, yellow maize, limestone and wheat bran) were bought from Obaro, Pretoria, South Africa. Trouw Nutrition (Isando, Johannesburg, South Africa) supplied the vitamin-mineral premix.

Partially defatted MNM was obtained from Home of Phadima Marula Oil, Phalaborwa, Limpopo, South Africa. Prior to use in diet formulation, it was further defatted using hexane as a solvent as described by Mazizi et al. (2019). Briefly, 40 kg of the meal in a cotton bag was steeped for 48 h in 400 L of hexane in a stainless steel 800-litre tank following which the oil-laden hexane was drained and the extracted meal was then air-dried for 24 h. The amino acid, fatty acid, fibre, mineral (calcium and phosphorus) and proximate composition of the hexane-extracted MNM were determined prior to diet formulation.

2.2.1. Determination of the amino acid content

The amino acid concentration content of MNM was determined as described by Einarsson et al., (1983). Briefly, the seed meal was hydrolysed in an acid (6 M HCl) at a temperature of 110 °C for 24 h followed by pre-column fluorescence derivatisation of amino acids with 9-flourenylmethyl chloroformate. The amino acids were then extracted with pentane and separated by gradient elution on a chromatograph. The chromatograph consisted of a SpectraSystem P4000 Quaternary high-performance liquid chromatography system (Thermo Fisher Scientific Inc., Waltham, MA, USA) equipped with a SpectraSystem FL3000 fluorescence detector (Thermo Fisher Scientific Inc.) and a Rheodyne 7125 valve (IDEX Corp., Rohnert Park, CA, USA) with a 20-µL injection loop. The amino acids were separated using an OmniSper 5 C18 150 × 4.6 analytical column and guard-column (Varian Australia Pty Ltd, Perth, Australia). The identification of the amino acids was done at an excitation wavelength of 264 nm and an emission wavelength of 340 nm. A PC equipped with TSP software was used for quantification.

2.2.2. Determination of the fatty acid content

An automated Soxhlet apparatus (Soctec Avanti 2055, Foss, Sweden) was used to extract the fat from MNM as described by the Association of Official Analytical Chemists (AOAC, 2006, method number 920.39). The methyl ethers were analyzed using gas chromatography as described by Christopherson and Glass, (1969). Briefly, the fat extracts were trans-methylated with 2 M methanol-sodium hydroxide. Heptane was used to extract the fatty acid methyl esters which were then filtered and dried under nitrogen. The fatty acids were separated by a temperature gradient over 45 min on gas chromatography with nitrogen as carrier gas on a DB-23 capillary column (90 cm × 250 μm × 0.25 μm) (Supelco, Sigma-Aldrich). The chromatograph consisted of an HP6890 gas chromatograph (Hewlett Packard, Bristol, United Kingdom) with a flame ionization detector (FID). Both the detector and injector temperatures were set at 300 °C. A PC equipped with Chemstation software was used for quantification. Nonadecanoic acid (C19:0) was used as an internal standard.

2.2.3. Determination of the fibre content

The neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) components of MNM were determined as described by Van Soest et al. (1991). Briefly, the NDF of the meal was determined by adding 0.5 g of the meal sample in 100 ml of a neutral detergent solution (sodium lauryl sulphate and ethylenediamine-tetra-acetic acid) which contained heat-stable alpha-amylase (20 350 IU ml-1) and refluxed at 100 °C for 1 h. Thereafter the mixture was filtered and the residue dried and then weighed. To determine the ADF of each meal, 0.5 g of the meal sample was refluxed in the acid detergent (20 g cetyl-trimethyl ammonium bromide dissolved in 1L N H_2SO_4) solution for 1 hour. Immediately thereafter, the mixture was filtered and the residue was dried and then weighed. The ADL was determined using a similar procedure to that of the determination of NDF except that after rinsing each sample residue, 72% of concentrated sulphuric acid was added to the residue and boiled at 700 °C for 3 h. After boiling, the sulphuric acid was washed off with hot water and the residue was dried in an oven at 100 °C for 12 h, cooled and then weighed.

2.2.4. Determination of the calcium and phosphorus content

The calcium and phosphorus content of MNM was determined as described by Zasoski & Burau, (1977). Briefly, 0.5 g of seed meal sample was digested in mixture of 25 ml of 65% nitric acid and 5ml of perchloric acid at 200 °C. The digest solution was then used to determine the mineral content of the seed meal spectrophotometrically, using inductively coupled plasma-optical emission spectrometry (ICP-OES) on a Varian Liberty 200 spectrometer (Varian, Perth, Australia) as described by Huang & Schulte (1985).

2.2.5. Determination of the proximate content

The dry matter (DM), crude protein (CP), ash and ether extract (EE) of MNM were determined as described by the Association of Official Analytical Chemists (AOAC, 2006: method numbers 934.01, 942.05, 954.01, and 920.39, respectively). The organic matter (OM) of the samples was computed using the equation: OM = DM-ash

2.3. Diet formulation and dietary treatments

Iso-caloric and iso-nitrogenous diets that met the nutritional requirements of growing and finishing quail were formulated based on the National Research Council (1994) recommendations. The diets were formulated such that MNM replaced SBM, on a CP basis, at 0%, 25%, 50%, 75% and 100% (diets 1, 2, 3, 4 and 5, respectively), for both the grower and finisher diets. Tables 1 and 2, show the ingredient and nutrient composition of the brooding/grower and finisher diets, respectively.

2.4. Bird management, housing and feeding

Two hundred 7-day old Japanese quail chicks used in the study were sourced from SA Quail Breeders, East London, South Africa. The chicks were habituated for two days before commencement of the trial. During this period (habituation), they were dewormed with piperazine (Kyron Laboratories Pvt Ltd, Johannesburg, South Africa). The piperazine was added to their drinking water at 90 mg/L. A deep litter system (pen dimensions: 1.7 × 1.1 × 1.3 m) was used to house the chicks. Feeders and drinkers were provided. Feed and clean drinking water were provided *ad libitum*. Since the study was done indoors, lights were switched on at 07h00 and off at 19h00. Infra-red lights were used to provide supplementary heat. Bedding, made from clean dry wheat straw was changed twice a week. The quail were fed the brooder/grower diets for 4 weeks and then transferred onto corresponding finisher diets for 2 weeks.

Table 1
Ingredient and chemical composition of brooding/grower dietary treatment diets

Ingredients (g/kg)	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
Maize meal	422.00	402.00	417.00	423.00	379.00
Soyabean meal	406.00	318.00	212.00	108.00	0.00
Marula nut meal	0.00 (0%)	74.00 (25%)	149.00 (50%)	228.00 (75%)	315.00 (100%)
Wheat bran	135.00	140.00	141.00	144.00	180.00
Limestone	9.00	9.00	9.00	10.00	10.00
Vegetable oil	0.00	33.00	47.00	63.00	90.00
Dl-methionine,99%	2.00	2.00	2.00	2.00	2.00
L-lysine HCL, 98.5%	1.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	17.00	12.00	12.00	13.00	13.00
Salt (NaCl)	3.00	2.00	2.00	2.00	3.00
*Vit/mineral premix	5.00	5.00	5.00	5.00	5.00
Total	**1000**	**1000**	**1000**	**1000**	**1000**
Calculated chemical composition					
DM (% DM)	89.95	88.36	87.82	87.30	87.43
Crude protein (% DM)	24.05	24.05	24.05	24.03	24.04
Crude fibre (% DM)	3.76	3.64	3.62	3.57	3.65
Ash (% DM)	3.69	3.71	3.63	3.55	3.62
Fat (% DM)	2.46	5.92	7.72	9.48	12.04
Neutral detergent fibre (% DM)	14.37	13.53	13.10	12.56	12.58
Acid detergent fibre (% DM)	4.75	4.17	3.69	3.19	2.86
Calcium (%DM)	0.90	0.89	0.91	0.90	0.91
Phosphorus (%DM)	0.54	0.56	0.57	0.57	0.57
Sodium (%DM)	0.16	0.16	0.16	0.16	0.16
Chloride (%DM)	0.27	0.17	0.17	0.27	0.27
Methionine (%DM)	0.54	0.52	0.54	0.52	0.54
Lysine (%DM)	1.37	1.37	1.37	1.37	1.37
Metabolizable energy (MJ/kg DM)	16.27	16.62	16.88	16.97	17.03

* Vit A: 20000000.000 IU, Vit B1 (Thiamine): 003.000 g, Vit D3 (500 000): 3000000.000 IU, Vit E (500 iu):40000.000 IU, Vit K3 (43%): 003.000 g, Vit B2 (80%): 010.000 g, Vit B6 98% (Pyrod): 005.000 g, Vit B12 1g/kg (m):100.000 mg, Niacine 99.5%: 060.000 g, Choline (Chloride 60): 606.060 g, Biotine 2%: 200.000 mg, Manganese (Mn 31%):160.000 g, Copper (Cu 25.2%): 005.000 g, Cobalt (Co 20%): 100.000 mg, Selenium (Se 4.5%): 400:000 mg, Calcium pantothenate: 020.000 g, Folic acid (96% pure): 001.000 g, Anty-ox Vit Dry: 100.000 g, Zinc (Zn 35%): 090.000 g, Iodide (KI 76.45%): 001.000 g, Ferrous (Fe 30%): 035.000 g, Limestone powder: 2647.133 g; DL-Methionine with purity of 99%, L-Lysine HCL with purity of 98,5%; Diet 1 – 0% MNM meal CP substitution of SBM CP contribution, Diet 2 – 25% MNM meal CP substitution of SBM CP contribution, Diet 3 – 50% MNM meal CP substitution of SBM CP contribution, Diet 4 – 75% MNM meal CP substitution of SBM CP contribution, Diet 5 – 100% MNM meal CP substitution of SBM CP contribution.

Table 2
Ingredient and chemical composition of finisher dietary treatments

Ingredients (g/kg)	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
Maize meal	560.60	554.80	566.00	606.20	607.80
Soyabean meal	327.00	246.50	165.00	82.90	0.00
Marula nut meal	0.00 (0%)	57.80 (25%)	115.00 (50%)	173.80 (75%)	233.00 (100%)
Wheat bran	79.40	103.60	113.10	94.70	114.00
Limestone	18.70	20.30	20.30	20.8	20.90
Dl-methionine,99%	2.10	2.80	3.00	3.50	4.00
L-lysine HCL 98.5%	2.00	4.70	6.00	9.5	11.70
Dicalcium phosphate	1.90	9.00	9.00	0.00	0.00
Salt (NaCl)	3.60	3.80	3.80	3.80	3.80
*Vit/mineral premix	4.70	4.80	4.80	4.80	4.80
Total	**1000**	**1000**	**1000**	**1000**	**1000**
Calculated chemical composition					
Dry matter (% DM)	88.27	87.61	87.50	87.28	87.09
Crude protein(% DM)	20.04	20.57	21.02	21.25	21.79
Crude fibre(% DM)	3.15	3.30	3.38	3.26	3.39
Ash (% DM)	3.33	3.31	3.30	3.19	3.22
Fat (% DM)	2.59	2.94	3.33	3.71	4.09
Neutral detergent fibre (% DM)	12.20	12.59	12.66	11.89	12.22
Acid detergent fibre(% DM)	3.93	3.78	3.53	3.03	2.86
Calcium (%DM)	0.81	0.83	0.82	0.80	0.80
Phosphorus (%DM)	0.38	0.41	0.45	0.48	0.52
Sodium (%DM)	0.14	0.14	0.14	0.14	0.14
Chloride (%DM)	0.25	0.26	0.26	0.25	0.25
Methionine (%DM)	0.52	0.53	0.50	0.50	0.50
Lysine (%DM)	1.28	1.32	1.30	1.32	1.30
Metabolisable energy (MJ/kg DM)	15.67	15.62	15.66	15.68	15.72

* Vit A: 20000000.000 IU, Vit B1 (Thiamine): 003.000 g, Vit D3 (500 000): 3000000.000 IU, Vit E (500 iu):40000.000 IU, Vit K3 (43%): 003.000 g, Vit B2 (80%): 010.000 g, Vit B6 98% (Pyrod): 005.000 g, Vit B12 1g/kg (m):100.000 mg, Niacine 99.5%: 060.000 g, Choline (Chloride 60): 606.060 g, Biotine 2%: 200.000 mg, Manganese (Mn 31%):160.000 g, Copper (Cu 25.2%): 005.000 g, Cobalt (Co 20%): 100.000 mg, Selenium (Se 4.5): 400:000 mg, Calcium pantothenate: 020.000 g, Folic acid (96% pure): 001.000 g, Anty-ox Vit Dry: 100.000 g, Zinc (Zn 35%): 090.000 g, Iodide (KI 76.45%): 001.000 g, Ferrous (Fe 30%): 035.000 g, Limestone powder: 2647.133 g; DL-Methionine with purity of 99%, L-Lysine HCL with purity of 98,5%; Diet 1 – 0% MNM meal CP substitution of SBM CP contribution, Diet 2 – 25% MNM meal CP substitution of SBM CP contribution, Diet 3 – 50% MNM meal CP substitution of SBM CP contribution, Diet 4 – 75% MNM meal CP substitution of SBM CP contribution, Diet 5 – 100% MNM meal CP substitution of SBM CP contribution.

2.5. Study design

The two hundred 9-day old Japanese quail chicks were randomly allocated to and fed brooder/grower diets wherein MNM replaced SBM on a CP basis for four weeks as follows: diet 1 - 0% MNM + 100% SBM, diet 2 - 25% MNM + 75% SBM, diet 3 - 50% MNM + 50% SBM, diet 4 - 75% MNM + 25% SBM and diet 5 - 100% MNM + 0% SBM. Immediately thereafter they were transferred to corresponding finisher diets and fed for two weeks. The birds were randomly allocated such that each dietary treatment has 4 replicate pens of 10 chicks.

2.6. Slaughter and carcass processing

At the end of the six-week feeding trial, the birds were fasted by removing feed only from the pen for 4 h before slaughter in order to reduce the risk of carcass contamination by gut contents (Genchev & Mihaylov, 2008). Twenty-four birds (n = 12 males and n = 12 females) were randomly selected from each dietary treatment group and then were humanely slaughtered by decapitation using a small animal guillotine (Harvard Apparatus, Holliston, Massachusetts, United States) (Genchev & Mihaylov, 2008). Feathers were hand plucked followed by evisceration to obtain the carcass. The meat colour and pH were determined while the breast and thigh were still part of the carcass. However, for the determination of the CL, TL and tenderness, the breast meat was first carefully dissected out using a scalpel blade (Genchev & Mihaylov, 2008).

2.7. Determination of the physical attributes of the meat

The meat colour and pH were determined from the breast (*Pectoralis major*) and thigh (*Iliotibialis* and *Femerotibialis*), while the TL, CL and tenderness were determined from the breast meat only of the carcasses from each treatment group. Samples were randomly taken from carcasses of 12 male and 12 female birds per dietary treatment.

2.7.1. Determination of colour and pH

Thirty mins post-slaughter, meat colour [lightness (L*), redness (a*), yellowness (b*), chroma (C) and hue angle (H)] was determined using a Lovibond Colour Meter (LC 100 Spectrophotometer, Lasec, SA, China) as recommended by the Commission International De I' Eclairage, (1976). The initial pH (pH_i) of the meat was also measured

30 min post-slaughter on the breast and thigh muscles of each carcass using a digital pH meter (following a two-point calibration at pH 4.0 and pH 7.0) with a piercing electrode set at 24 °C (Crison pH25, CRISON instruments, SA, Spain) as per the manufacturer's instructions. Following storage at 4 °C for 24 h the ultimate meat pH (pH_u) and meat colour were determined as described above. The meat samples were put into ziplock plastic bags and stored at -18 °C until the determination of CL and TL.

2.7.2. Determination of thawing and cooking loss

A total of twenty-four breast meat samples were randomly selected per dietary treatment group to determine the TL and CL as described by De Marchi et al. (2011). Briefly, the whole breast stored samples (-18 °C) were weighed, defrosted at room temperature for approximately 15 h then blotted dry and weighed again using an electronic balance. The TL was computed using the equation:

$$TL = \frac{\text{Weight of frozen meat sample (g)} - \text{Weight of thawed meat samples (g)}}{\text{Weight of frozen meat sample (g)}} \times 100$$

Thereafter the thawed meat samples were cooked in self-seal plastic bags in a water bath (Julabo PURA a30, Gerhard–Juchheim-Strasse, Seelbach, Germany) until an internal temperature of 75 °C for 60 min. While, the CL was determined using the equation:

$$CL = \frac{\text{Weight of thawed meat sample (g)} - \text{Weight of cooked meat sample (g)}}{\text{Weight of thawed meat sample (g)}} \times 100$$

2.7.3. Determination of tenderness

After determining the CL, the samples were used to determine tenderness after they had been cooled to room temperature (23–25 °C). The fillet cuts obtained from the cooked breast muscles were sheared once in the centre. Shearing was done by using a Warner–Bratzler shear force (WBSF) machine with a Warner–Bratzler Shear mounted on a Universal Instron Machine (Model 4301, Instron Corporation, Massachusetts, United States). The shear force was determined at a cross speed of 200 mm/min with a 1 kN load cell as recommended by the Stock and Board, (1995). The results of shear force were captured by a personal computer linked to the Universal Instron machine.

2.8. Determination of the proximate chemical composition of the meat

The proximate components; crude protein, ash and ether extract of the meat and fatty acid profile of the breast meat (only) were determined on a dry matter basis. The chemical assays were determined from twenty-four breast meat samples from twenty-four carcasses randomly selected from each dietary treatment group.

2.8.1. Determination of the proximate composition

The proximate content of the breast muscle were determined as described by the Association of Official Analytical Chemists (AOAC), (2006) method numbers: 942.05, 988.05 and 920.39, respectively. Each assay was done in triplicate.

2.8.2. Determination of the fatty acid profile

The Soxhlet Apparatus was used to extract the oil from the breast muscle sample as described by the Association of Analytical Chemists (AOAC, 2006; method number: 920.39). The fatty acid profiles of the oil extracted from the meat were determined as described by Christopherson & Glass, (1969). Briefly, the oil extracts were transmethylated with 2 mol/L methanol sodium hydroxide. The resulting fatty acid methyl esters were extracted in heptane, filtered (Nylon syringe filters, pore size: 0.45 μm, diameter: 13 mm with a glass fibre prefilter, Membrane Solutions) and dried under nitrogen after which they were separated by a temperature gradient over 45 min on a gas chromatograph with nitrogen as carrier gas on a DB-23 capillary column (90 cm × 250 μm × 0.25 μm; Supelco, Sigma-Aldrich). The gas chromatograph consisted of an HP6890 GC (Hewlett Packard, Bristol, UK) with a flame ionisation detector. Both the detector and injector temperatures were set at 300 °C. A personal computer equipped with Chemstation software (Agilent Technologies Inc., Santa Clara, CA, USA) was used for quantification. Nonadecanoic acid (C19:0) was used as an internal standard.

3. Statistical analyses

The data were expressed as mean ± SD and analysed using GraphPad Prism 5 software (GraphPad Software, San Diego, California, USA). Data on pH, colour, moisture characteristics, tenderness, proximate content and fatty acid profile of meat were analysed using a one-way ANOVA. Treatment means were compared using Tukey's *post hoc* test. Significance was set at $P < 0.05$. The linear statistical model employed was as follows:

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

where: Y_{ij} = dependent variable of interest (pH, colour, TL, CL, tenderness, ash, crude protein, ether extract and fatty acid profile)

μ = population mean

T_i = effect of diets *(1,2….,5)*E_{ij} = random error

4. Results

4.1. Physical characteristics of meat

The breast muscles (meat) pH_i from the carcasses of female quail fed diet 1 was lower ($P < 0.05$; Table 3) than that from carcasses of quail fed diets 2 through to 5. The breast meat from the female birds fed diet 1 was significantly lighter in comparison to carcasses of birds fed other diets. Furthermore, the breast meat from carcasses of female quail fed 5 was more red (4.16 ± 0.89) in comparison to the carcasses of female quail fed diet 1 (1.58 ± 0.44) and diet 3 (1.63 ± 0.34) at 30 min post-slaughter ($P < 0.05$). The hue angle of breast from female birds fed diet 5 (84.68 ± 5.90) was higher ($P < 0.05$) in comparison to those fed diet 1 (68.37 ± 3.68). The pH_i and colour of breast meat from the carcasses of male quail was similar across dietary treatments ($P > 0.05$). Also the hue angle of the breat from female birds fed diet 5 was higher (P$P < 0.05$) in comparison to the breast of those fed diet 1. After aging (24 h at 4 °C), the pH_u of the meat (breast) from the carcasses of female quail fed diet 1 was lower ($P < 0.05$) pH_u but the meat was lighter ($P < 0.05$), in comparison to the carcasses of female quail fed diets 2 through to 5. Twenty-four hours post-slaughter, the pH_u of breast meat from carcasses of male quail was similar ($P > 0.05$) across dietary treatments although the breast meat from the carcasses of male quail fed diet 1 was lighter (47.72 ± 1.50 vs 44.77 ± 1.00) in comparison to counterparts fed diet 5 ($P < 0.05$).

The results from Table 4 showed that, the pH_i of the meat from the thighs of female quail fed diet 2 was higher (6.92 ± 0.0 vs 6.69 ± 0.06; $P < 0.05$) than female quail fed diet 3 but the colour of the meat from the thighs was similar ($P > 0.05$) across dietary treatment at 30-min and 24-hours post-slaughter. The pH_u and pH decline of the meat derived from the thighs of carcasses of females were similar across dietary treatments ($P > 0.05$). The pH_i of meat from the thighs from male quail fed diet 1 was higher compared to that from derived from counterparts fed diet 3 (7.03 ± 0.06 vs 6.88 ± 0.03; $P < 0.01$). The decline in pH of the thigh meat from the carcasses of male birds fed diet 1 was higher ($P < 0.0001$) than the other treatments. However, the colour of the meat derived from thighs of carcasses of male quails was similar ($P > 0.05$) at 30 min post-slaughter across dietary treatments. The L* and a* values of the thigh meat from carcasses of male birds were similar ($P > 0.05$) across dietary treatment groups but the thigh from the carcasses of the birds fed diet 2 (13.37 ± 1.21) and 5 (10.84 ± 0.88)

Table 3
Effect of graded dietary substitution of soyabean meal with Marula nut meal on the colour and pH of breast muscle from female and male broiler Japanese quail

	Parameter	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Significance level
Female	pH_i	5.36 ± 0.11^{a}	6.37 ± 0.05^{b}	6.29 ± 0.08^{b}	6.37 ± 0.06^{b}	6.33 ± 0.08^{b}	*
30-min post-slaughter	L*	49.99 ± 0.68^{a}	44.24 ± 0.75^{b}	46.09 ± 0.90^{b}	44.13 ± 1.53^{b}	44.20 ± 0.60^{b}	**
	a*	1.58 ± 0.44^{a}	3.78 ± 0.80^{b}	1.63 ± 0.34^{a}	2.14 ± 0.42^{ab}	4.16 ± 0.89^{b}	*
	b*	9.76 ± 0.37^{a}	9.71 ± 0.31^{a}	8.93 ± 0.53^{a}	9.331 ± 0.73^{a}	9.84 ± 0.51^{a}	ns
	C*	10.66 ± 0.78^{a}	10.76 ± 0.49^{a}	9.20 ± 0.56^{a}	11.31 ± 1.53^{a}	11.03 ± 0.75^{a}	ns
	H*	68.37 ± 3.68^{a}	69.18 ± 3.75^{ab}	82.95 ± 3.16^{ab}	76.64 ± 3.03^{ab}	84.68 ± 5.90^{b}	*
24-hours post-slaughter	pH_u	5.14 ± 0.04^{a}	6.31 ± 0.06^{b}	6.28 ± 0.18^{b}	6.26 ± 0.04^{b}	6.22 ± 0.08^{b}	*
	pH decline	0.22 ± 0.46^{a}	0.06 ± 0.31^{a}	0.00 ± 0.73^{a}	0.11 ± 0.21^{a}	0.11 ± 0.28^{a}	ns
	L*	48.57 ± 0.93^{a}	46.20 ± 1.12^{b}	46.05 ± 1.29^{b}	46.14 ± 1.12^{b}	46.29 ± 0.80^{b}	*
	a*	2.92 ± 0.41^{a}	4.75 ± 0.68^{b}	2.52 ± 0.45^{a}	3.60 ± 0.54^{a}	6.06 ± 0.84^{b}	*
	b*	12.05 ± 0.81^{a}	12.73 ± 0.58^{a}	12.20 ± 0.59^{a}	12.04 ± 0.96^{a}	14.30 ± 0.76^{a}	ns
	C*	13.21 ± 0.90^{a}	18.66 ± 4.71^{a}	12.60 ± 0.55^{a}	13.83 ± 0.56^{a}	15.71 ± 0.93^{a}	ns
	H*	93.50 ± 17.28^{a}	72.53 ± 4.08^{a}	78.01 ± 2.21^{a}	68.65 ± 5.95^{a}	67.38 ± 2.29^{a}	ns
Male	pH_i	6.47 ± 0.13^{a}	6.50 ± 0.07^{a}	6.26 ± 0.09^{a}	6.37 ± 0.09^{a}	6.40 ± 0.07^{a}	ns
30-min post-slaughter	L*	42.67 ± 1.40^{a}	42.41 ± 0.73^{a}	43.20 ± 0.77^{a}	43.72 ± 0.36^{a}	42.04 ± 0.53^{a}	ns
	a*	4.14 ± 0.93^{a}	5.00 ± 0.72^{a}	4.38 ± 0.39^{a}	5.45 ± 0.33^{a}	5.82 ± 0.74^{a}	ns
	b*	8.76 ± 1.14^{a}	10.11 ± 0.69^{a}	10.11 ± 0.54^{a}	9.63 ± 0.65^{a}	10.00 ± 0.66^{a}	ns
	C*	14.27 ± 2.55^{a}	11.54 ± 0.75^{a}	11.13 ± 0.59^{a}	11.57 ± 0.60^{a}	12.10 ± 0.67^{a}	ns
	H*	70.50 ± 8.81^{a}	65.97 ± 3.28^{a}	66.49 ± 1.67^{a}	59.83 ± 1.76^{a}	59.40 ± 3.75^{a}	ns
24-hours post-slaughter	pH_u	6.27 ± 0.08^{a}	6.14 ± 0.19^{a}	6.52 ± 0.08^{a}	6.23 ± 0.07^{a}	6.16 ± 0.10^{a}	ns
	pH decline	0.21 ± 0.43^{ab}	0.37 ± 0.72^{a}	-0.27 ± 0.45^{b}	0.14 ± 0.42^{ab}	0.24 ± 0.28^{ab}	*
	L*	47.72 ± 1.50^{a}	48.67 ± 4.56^{ab}	45.72 ± 1.49^{ab}	49.17 ± 4.53^{ab}	44.77 ± 1.00^{b}	*
	a*	4.00 ± 0.93^{a}	4.74 ± 1.13^{ab}	4.94 ± 0.59^{ab}	6.10 ± 0.78^{ab}	8.11 ± 1.16^{b}	*
	b*	12.38 ± 1.34^{a}	10.37 ± 1.18^{a}	8.81 ± 0.92^{a}	9.22 ± 0.58^{a}	10.80 ± 0.87^{a}	ns
	C*	12.35 ± 1.11^{a}	13.83 ± 1.39^{a}	12.81 ± 0.91^{a}	13.49 ± 1.36^{a}	16.41 ± 1.05^{a}	ns
	H*	72.25 ± 3.94^{a}	73.96 ± 5.26^{a}	68.11 ± 2.62^{a}	66.96 ± 5.25^{a}	62.86 ± 2.14^{a}	ns

ns = not significant, $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, L*-lightness, a*- redness, b*-yellowness, C*-chroma, H*-Hue angle, pH_u-ultimate pH, pH_i-initial pH, ^{ab} Within row means with different superscripts are significantly different at $P < 0.05$. Diet 1 – 0% inclusion of MNM (control), Diet 2 – 25% MNM inclusion on crude protein basis, Diet 3 – 50% MNM inclusion on crude protein basis, Diet 4 – 75% MNM inclusion on crude protein basis, Diet 5-100% MNM inclusion on crude protein basis; values expressed as mean ± SD; $n = 24$ birds ($n = 12$ males and $n = 12$ females).

had yellower meat than those fed diet 3 (7.07 ± 0.9) ($P < 0.0001$) at 24 h post-slaughter. In addition, the TL, CL and tenderness from the breast meat were similar across dietary treatments (Table 5).

4.2. Chemical composition of the meat

The CP content of the breast meat from the carcasses of the quails decreased ($P < 0.05$) with an increase in dietary MNM (Table 6). The

Table 4
Effect of graded dietary substitution of soyabean meal with Marula nut meal on the colour and pH of thigh muscles from female and male broiler Japanese quail

	Parameter	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Significance level
Female	pH_i	6.86 ± 0.07^{ab}	6.92 ± 0.06^{a}	6.69 ± 0.06^{b}	6.83 ± 0.04^{ab}	6.81 ± 0.03^{ab}	*
30-min post-slaughter	L*	46.57 ± 0.94^{a}	46.20 ± 1.12^{a}	49.05 ± 1.29^{a}	49.44 ± 0.93^{a}	47.88 ± 0.98^{a}	ns
	a*	0.64 ± 0.31^{a}	2.63 ± 0.67^{a}	0.89 ± 0.76^{a}	2.18 ± 0.62^{a}	3.00 ± 0.79^{a}	ns
	b*	8.83 ± 0.64^{a}	10.33 ± 1.29^{a}	8.63 ± 0.69^{a}	10.88 ± 0.89^{a}	11.44 ± 1.16^{a}	ns
	C*	9.06 ± 0.63^{a}	11.01 ± 1.35^{a}	8.98 ± 0.78^{a}	11.36 ± 0.92^{a}	12.09 ± 1.28^{a}	ns
	H*	90.17 ± 3.23^{a}	80.99 ± 3.48^{a}	84.42 ± 4.08^{a}	78.36 ± 3.91^{a}	78.39 ± 3.49^{a}	ns
24-hours post-slaughter	pH_u	6.88 ± 0.04^{a}	6.94 ± 0.09^{a}	6.84 ± 0.09^{a}	6.67 ± 0.13$^{a\#}$	6.82 ± 0.06^{a}	ns
	pH decline	0.35 ± 1.47^{a}	-0.01 ± 0.30^{a}	-0.14 ± 0.31^{a}	0.15 ± 0.47^{a}	-0.00 ± 0.24^{a}	ns
	L*	46.20 ± 0.91^{a}	44.65 ± 1.64^{a}	43.72 ± 1.85^{a}	42.81 ± 3.55^{a}	47.15 ± 1.02^{a}	ns
	a*	4.06 ± 0.62^{a}	5.00 ± 0.53^{a}	3.05 ± 0.95^{a}	3.87 ± 0.64^{a}	3.19 ± 0.43^{a}	ns
	b*	11.36 ± 0.96^{a}	13.00 ± 0.64^{a}	10.68 ± 1.09^{a}	11.06 ± 0.97^{a}	11.32 ± 1.15^{a}	ns
	C*	12.09 ± 1.02^{a}	14.49 ± 0.77^{a}	11.41 ± 1.11^{a}	11.80 ± 1.11^{a}	11.98 ± 1.19^{a}	ns
	H*	73.03 ± 1.81^{a}	72.24 ± 4.05^{a}	74.17 ± 4.34^{a}	80.96 ± 8.05^{a}	74.80 ± 2.08^{a}	ns
Male	pH_i	7.03 ± 0.06^{a}	6.86 ± 0.08^{ab}	6.88 ± 0.03^{b}	6.81 ± 0.07^{ab}	6.88 ± 0.08^{ab}	**
30-min post-slaughter	L*	48.16 ± 0.99^{a}	45.55 ± 1.42^{a}	47.30 ± 0.80^{a}	45.69 ± 1.13^{a}	46.49 ± 1.21^{a}	ns
	a*	3.83 ± 0.79^{a}	4.58 ± 1.09^{a}	2.61 ± 0.50^{a}	3.26 ± 0.80^{a}	3.43 ± 0.45^{a}	ns
	b*	12.38 ± 1.34^{a}	10.37 ± 1.17^{a}	8.81 ± 0.92^{a}	10.26 ± 0.87^{a}	11.33 ± 0.73^{a}	ns
	C*	12.27 ± 0.91^{a}	11.74 ± 1.54^{a}	9.47 ± 0.99^{a}	11.15 ± 1.03^{a}	12.12 ± 0.80^{a}	ns
	H*	73.30 ± 4.36^{a}	69.02 ± 3.45^{a}	71.13 ± 3.43^{a}	73.10 ± 3.40^{a}	75.82 ± 3.89^{a}	ns
24-hours post-slaughter	pH_u	6.84 ± 0.10^{a}	6.77 ± 0.10^{a}	6.63 ± 0.09^{a}	6.55 ± 0.16^{a}	6.65 ± 0.08^{a}	ns
	pH decline	0.93 ± 0.68^{a}	0.09 ± 0.31^{b}	-0.25 ± 0.38^{c}	0.26 ± 0.71^{b}	0.23 ± 0.41^{b}	***
	L*	44.50 ± 1.37^{a}	47.81 ± 1.70^{a}	42.70 ± 1.17^{a}	45.69 ± 1.13^{a}	44.34 ± 1.21^{a}	ns
	a*	5.55 ± 0.83^{a}	5.77 ± 0.79^{a}	4.15 ± 0.66^{a}	6.84 ± 1.00^{a}	6.69 ± 1.37^{a}	ns
	b*	11.07 ± 0.92^{a}	13.37 ± 1.21^{a}	7.07 ± 0.90^{b}	10.83 ± 1.25^{a}	10.84 ± 0.88^{a}	***
	C*	14.36 ± 2.17^{a}	15.13 ± 1.38^{a}	11.17 ± 2.44^{a}	13.36 ± 1.31^{a}	12.88 ± 0.95^{a}	ns
	H*	62.80 ± 3.56^{a}	68.80 ± 2.46^{a}	69.09 ± 6.31^{a}	62.80 ± 6.28^{a}	64.35 ± 4.17^{a}	ns

ns = not significant, $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.0001$, ^{ab} Within row means with different superscripts are significantly different at $P < 0.05$. L*-lightness, a*-redness, b*-yellowness, C*-chroma, H*-Hue angle, pH_u-ultimate pH, pH_i-initial pH. Diet 1 – 0% inclusion of MNM (control), Diet 2 – 25% MNM inclusion on crude protein basis, Diet 3 – 50% MNM inclusion on crude protein basis, Diet 4 – 75% MNM inclusion on crude protein basis, Diet 5-100% MNM inclusion on crude protein basis; values expressed as mean ± SD; $n = 24$ birds ($n = 12$ males and $n = 12$ females).

Table 5
Effect of graded dietary substitution of soyabean meal with Marula nut meal on thawing loss, cooking loss and tenderness of Japanese quail breast muscles

Parameter	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Significance level
Thawing loss (%)	3.83 ± 4.71	2.23 ± 2.32	2.59 ± 4.13	3.66 ± 6.12	3.79 ± 6.06	ns
Cooking loss (%)	16.25 ± 6.31	17.59 ± 4.79	16.48 ± 5.71	16.46 ± 4.91	15.70 ± 9.76	ns
Tenderness (N)	8.03 ± 2.08	7.51 ± 1.75	7.28 ± 1.91	7.60 ± 1.57	7.39 ± 2.16	ns

ns = not significant, $P > 0.05$. Diet 1 – 0% inclusion of MNM (control), Diet 2–25% MNM inclusion on crude protein basis, Diet 3–50% MNM inclusion on crude protein basis, Diet 4–75% MNM inclusion on crude protein basis, Diet 5-100% MNM inclusion on crude protein basis; Data presented as mean ± SD; $n = 24$ birds ($n = 12$ males and $n = 12$ females).

Table 6
Effect of graded dietary substitution of soyabean meal with Marula nut meal on the proximate composition of Japanese quail breast muscles

Proximate (% DM)	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Significance level
Crude protein	84.79 ± 0.37^{a}	83.38 ± 0.35^{c}	83.87 ± 0.24^{ac}	83.86 ± 0.32^{ac}	78.91 ± 0.72^{b}	***
Ash	6.96 ± 0.42^{a}	7.27 ± 0.42^{ab}	7.25 ± 0.71^{ab}	7.92 ± 0.18^{ab}	8.29 ± 0.27^{b}	***
Ether extract	13.84 ± 0.14^{a}	9.38 ± 0.01^{b}	8.77 ± 0.31^{cd}	8.71 ± 0.18^{d}	7.54 ± 0.21^{e}	***

ns = not significant, $P > 0.05$, *** $P < 0.0001$; $^{a\text{-}e}$ Within row means with different superscripts are significantly different at $P < 0.05$. Diet 1 – 0% inclusion of MNM (control), Diet 2 – 25% MNM inclusion on crude protein basis, Diet 3 – 50% MNM inclusion on crude protein basis, Diet 4–75% MNM inclusion on crude protein basis, Diet 5-100% MNM inclusion on crude protein basis; Data presented as mean ± SD; $n = 24$ birds ($n = 12$ males and $n = 12$ females).

breast meat from the carcasses of quails fed diet 1 had the highest CP while that from the carcasses of quail fed diet 5 had the lowest ($P < 0.0001$). The ash content of the breast meat from carcasses of the quails fed diets 1 through to 4 was similar ($P > 0.05$) but higher ($P < 0.0001$) than the breast meat from the carcasses of quails fed diet 5. The ether extract (lipid) content of the breast meat from the carcasses of the quail decreased with an increase in dietary MNM ($P < 0.05$). The breast meat from the carcasses of quail fed diet 1 had the highest ($P < 0.05$) lipid content while that from quail fed diet 5 had the least ($P < 0.0001$). The TSFA of the breast meat from the carcasses of quail fed diets 1, 2 and 5 at 22.77 ± 0.25%, 29.16 ± 0.61% and 27.91 ± 0.43%, respectively, was higher ($P < 0.01$) compared to TSFA content of breast meat from the carcasses of counterparts fed diet 4 (Table 7). The TMUFA content of the breast meat from carcasses of quails fed diets 1 and 2 at 54.52 ± 0.01 and 53.88 ± 0.52, respectively, was lower compared to that from carcasses of quails fed diet 3 (57.35 ± 0.26). However, the breast meat from the carcasses of quails fed diets 4 and 5 at 59.52 ± 0.56 and 60.27 ± 0.07, respectively, had the highest ($P < 0.05$) TMUFA content. The oleic acid (OA) of the breast meat from the carcasses of quails fed diet 1 and diet 2 at 46.50 ± 0.51 and 46.76 ± 0.21, respectively, was lower compared to those from the carcasses of quails fed diet 3, 4 and 5 at 50.54 ± 0.78, 52.32 ± 3.39 and 53.68 ± 0.81, respectively. The TPUFA content of the quail breast meat was similar across dietary treatments ($P > 0.05$). The omega-3 content of the breast meat from quail fed diet 4 was higher than that from the carcasses of counterparts fed other diets. The omega-6 content of the breast meat from the carcasses of quails fed diet 2 was higher (18.90 ± 0.09 vs 17.88 ± 0.06; $P < 0.0001$) compared to that from the carcasses of quail fed diet 1. However, the omega-6 content of the breast meat from carcasses of quail fed diets 3, 4 and 5 at 16.71 ± 0.13, 16.88 ± 0.14 and 16.19 ± 0.33, respectively, was lower compared to that from the carcasses of quail fed diets 1 and 2 at 17.88 ± 0.06 and 18.90 ± 0.09, respectively. The omega-9 content of the breast meat from the carcasses of quail fed diets 1 and 2 at 46.58 ± 0.62 and 46.90 ± 0.22 respectively were lower compared to those from carcasses of quail fed diet 5 (53.81 ± 0.82; $P < 0.05$).

5. Discussion

The pH_u of the breast meat from both male and female Japanese quail has been reported to range from 5.4 to 6.62 (Boni et al., 2010; Genchev et al., 2008; Gevrekçi et al., 2009; Mnisi & Mlambo, 2018; Narinc et al., 2013; Nasr, Ali & Hussein, 2017; Ribarski & Genchev, 2013). In the current study, the pH_u of the breast meat from the carcasses of male and female quail which ranged from 6.14 to 6.52 fell within the reported range from previous studies but that of meat from the thighs, which ranged from 6.55 to 6.94, was higher. While dietary MNM significantly impacted the pH_u of the breast meat from carcasses of the Japanese quail, the observed values fall within the range reported in previous studies suggesting that dietary MNM neither altered nor negatively impacted the biochemical processes that occur when breast muscle is converted to meat.

In the process of converting muscle to meat, muscle glycogen content is a critical determinant of the ultimate pH (Mir et al., 2017) as it impacts the production of lactic acid (Webb & Casey, 2010). Pre-slaughter stress has been shown to deplete muscle glycogen reserves leading to reduced lactic acid production (Matarneh et al., 2017). While all efforts were put in place to keep stress to a minimum during the feeding trial by having enough space and environmental enrichment in the pens for the birds and, during the pre-slaughter period by keeping the birds in the pens separate from the slaughter room, with minimal noise and correct restraint and handling, the higher than previously reported pH_u of meat derived from the thighs reported in the current study may still be related to stress from other factors. The housing conditions during the feeding trial and pre-slaughter meant the quail mostly used their leg muscles when compared to breast muscle (flight muscles). Although the pens were big enough for the birds to walk around, they could not fly around in the cages. This might have led to lower glycogen reserves in the thigh muscles (due to more use) hence the observed higher than normal pH_u values which may potentially have an effect on meat colour.

Consumers tend to be concerned about the colour of the meat as they consider it as an indicator of freshness (Çelen et al., 2016; Fletcher, 2002; Kralik et al., 2018; Ribarski & Genchev, 2013). Despite the decreasing lightness values with increasing MNM, at 24 h post-slaughter, the L* values from both male and female breast meat reported in this study ranged from 45.72 ± 1.49 to 49.17 ± 4.53, respectively. Gevrekçi et al., 2009; Mnisi & Mlambo, 2018; Ribarski & Genchev, 2013 reported L* values ranging from 47.92 to 54.87 in the breast meat of quail. However, Narinc et al., (2013); Genchev et al., (2008) reported average L* values of 43.09 and 40.81, respectively, in Japanese breast meat. While the L* values of the quail breast meat of the current study are within the range reported by other researchers (Mnisi & Mlambo, 2018; Ribarski & Gencheve, 2013; Gevrekçi et al., 2009), they are higher compared to those reported by Narinc et al. (2013); Genchev et al. (2008). In comparison to the findings by Mnisi & Mlambo, 2018; Ribarski &

Table 7
Effect of graded dietary substitution of soyabean meal with Marula nut meal on the fatty acid profile of Japanese quail breast muscles

Fatty acid (%)	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Significance level
Saturated						
C10:0 (capric acid)	0.06 ± 0.01^{a}	0.06 ± 0.00^{a}	0.05 ± 0.02^{a}	nd	0.03 ± 0.04^{a}	ns
C12:0 (lauric acid)	0.07 ± 0.00^{a}	0.07 ± 0.01^{a}	0.05 ± 0.01^{a}	nd	0.03 ± 0.04^{a}	ns
C14:0 (myristic acid)	0.57 ± 0.07^{a}	0.51 ± 0.02^{a}	0.49 ± 0.10^{a}	0.38 ± 0.07^{a}	0.39 ± 0.01^{a}	ns
C15:0 (pentadecanoic acid)	0.03 ± 0.04^{a}	0.61 ± 0.03^{b}	0.32 ± 0.03^{c}	nd	nd	**
C16:0 (palmitic acid)	19.77 ± 0.18^{a}	19.74 ± 0.03^{a}	18.39 ± 0.57^{a}	15.88 ± 0.84^{b}	19.53 ± 0.67^{a}	ns
C17:0 (margaric acid)	0.14 ± 0.01^{a}	0.17 ± 0.01^{a}	0.18 ± 0.04^{a}	0.16 ± 0.06^{a}	0.14 ± 0.05	ns
C18:0 (stearic acid)	6.73 ± 0.01^{ab}	7.31 ± 0.05^{a}	6.24 ± 0.02^{b}	7.75 ± 0.45^{c}	7.50 ± 0.19^{ac}	**
C20:0 (arachidic acid)	0.14 ± 0.03^{a}	0.27 ± 0.23^{a}	0.23 ± 0.08^{a}	0.70 ± 0.36^{a}	0.08 ± 0.12^{a}	ns
C20:2 (eicosadienoic acid)	0.03 ± 0.04^{a}	nd	nd	0.25 ± 0.35^{a}	nd	ns
C21:0 (henicosanoic acid)	0.09 ± 0.06^{a}	0.23 ± 0.33^{b}	nd	nd	nd	*
C22:0 (behenic acid)	0.01 ± 0.01	nd	nd	nd	nd	-
C24:0 (lignoceric acid)	0.18 ± 0.07^{a}	0.43 ± 0.35^{a}	0.10 ± 0.08^{a}	0.87 ± 0.86^{a}	0.19 ± 0.24^{a}	ns
TSFA	27.77 ± 0.25^{a}	29.16 ± 0.61^{a}	26.16 ± 0.33^{ab}	25.03 ± 0.51^{b}	27.91 ± 0.43^{a}	**
Monounsaturated						
C18:1n9c (oleic acid)	46.50 ± 0.51^{a}	46.76 ± 0.21^{a}	50.54 ± 0.78^{ab}	52.32 ± 3.39^{ab}	53.68 ± 0.81^{b}	*
C18:1n9t (elaidic acid)	0.06 ± 0.09^{a}	0.15 ± 0.02^{a}	0.07 ± 0.02^{a}	0.22 ± 0.30^{a}	nd	ns
C14:1(myristoleic acid)	0.13 ± 0.00^{a}	0.17 ± 0.04^{a}	0.12 ± 0.05^{a}	0.14 ± 0.20^{a}	0.05 ± 0.08^{a}	ns
C16:1(palmitoleic acid)	7.54 ± 0.26^{a}	6.46 ± 0.02^{ab}	5.90 ± 0.44^{b}	4.78 ± 0.83^{b}	5.38 ± 0.42^{b}	*
C17:1(cis-10-Heptadecanoic acid)	0.08 ± 0.03^{a}	0.18 ± 0.07^{a}	0.12 ± 0.04^{a}	nd	0.12 ± 0.04^{a}	ns
C20:1 (eicosenoic acid)	0.25 ± 0.27^{a}	0.32 ± 0.20^{a}	0.35 ± 0.02^{a}	0.16 ± 0.22^{a}	3.98 ± 5.12^{a}	ns
C15:1 (pentadecenoic acid)	nd	nd	0.31 ± 0.03^{a}	2.06 ± 2.52^{a}	0.34 ± 0.16^{a}	ns
TMUFA	54.52 ± 0.01^{a}	53.88 ± 0.52^{a}	57.35 ± 0.26^{c}	59.52 ± 0.56^{b}	60.27 ± 0.07^{b}	***
Polyunsaturated						
C18:2n6t(linolelaidic acid)	0.04 ± 0.05^{a}	nd	0.05 ± 0.01^{a}	0.29 ± 0.24^{a}	0.30 ± 0.34^{a}	ns
C18:2n6c (linoleic acid)	17.64 ± 0.08^{a}	nd	16.55 ± 0.16^{ab}	16.59 ± 0.38^{ab}	15.89 ± 0.67^{b}	*
C18:3n3 (α-linolenic acid)	1.14 ± 0.02^{a}	0.96 ± 0.06^{b}	1.44 ± 0.02^{a}	1.41 ± 0.09^{a}	0.93 ± 0.09^{b}	**
C18:3n6 (γ-linolenic acid)	0.09 ± 0.03	nd	nd	nd	nd	-
C20:3n3 (eicosatrienoic acid)	2.22 ± 0.09^{a}	2.34 ± 0.05^{a}	1.53 ± 0.01^{c}	3.27 ± 0.55^{b}	1.97 ± 0.11^{c}	**
C20:3n6 (eicosatrienoic acid)	0.12 ± 0.05^{a}	nd	0.09 ± 0.03^{a}	nd	nd	ns
C22:6n3 (docosahexaenoic acid)	0.21 ± 0.01^{a}	0.11 ± 0.15^{a}	0.14 ± 0.08^{a}	nd	nd	ns
TPUFA	21.45 ± 0.09^{a}	22.30 ± 0.08^{a}	19.77 ± 0.09^{a}	41.06 ± 28.11^{a}	18.99 ± 0.79^{a}	ns
Trans fatty acids	0.10 ± 0.14^{a}	0.15 ± 0.02^{a}	0.13 ± 0.03^{a}	0.50 ± 0.53^{a}	0.35 ± 0.28^{a}	ns
Cis fatty acids	64.14 ± 0.42^{a}	65.65 ± 0.13^{a}	67.08 ± 0.92^{a}	68.92 ± 3.77^{a}	69.57 ± 1.48^{a}	ns
Omega-3	3.58 ± 0.05^{a}	3.40 ± 0.18^{a}	3.10 ± 0.04^{a}	4.67 ± 0.45^{b}	3.10 ± 0.11^{a}	**
Omega-6	17.88 ± 0.06^{a}	18.90 ± 0.09^{b}	16.71 ± 0.13^{c}	16.88 ± 0.14^{c}	16.19 ± 0.33^{c}	***
Omega-9	46.58 ± 0.62^{a}	46.90 ± 0.22^{a}	50.63 ± 0.79^{ab}	52.54 ± 3.09^{ab}	53.81 ± 0.82^{b}	*
DHA (Docosahexaenoic acid)	0.21 ± 0.01^{a}	0.11 ± 0.15^{a}	0.14 ± 0.08^{a}	nd	0.06 ± 0.09^{a}	ns

ns = not significant, $P > 0.05$,* $P < 0.05$ ** $P < 0.01$, *** $P < 0.0001$; ^{a,b,c} Within row means with different superscripts are significantly different at $P < 0.05$. TSFA= total saturated fatty acids, TMUFA= total mono-unsaturated fatty acids, TPUFA= total poly-unsaturated fatty acids, nd= not detected. Diet 1 – 0% inclusion of MNM (control), Diet 2 – 25% MNM inclusion on crude protein basis, Diet 3 – 50% MNM inclusion on crude protein basis, Diet 4 – 75% MNM inclusion on crude protein basis, Diet 5-100% MNM inclusion on crude protein basis; Data presented as mean ± SD; n = 24 birds (n=12 males and n=12 females).

Gencheve, 2013; Gevrekçi et al., 2009, results from the current study show that dietary MNM did not negatively affect the pH and colour of both breast and thigh meat. However, when compared to the findings of Narinc et al. (2013); Genchev et al. (2008) it would appear that dietary MNM resulted in “whiter” quail breast meat.

Redness of the meat is a major determinant of acceptability of meat by consumers (Mir et al., 2017). The content of myoglobin in muscle is the major factor impacting redness (a*) of the meat (Çelen et al., 2016). Higher muscle myoglobin content is associated with increased redness and increased acceptability (Neethling et al., 2017). In the current study at 24 h post-slaughter following storage at 4 °C, the redness (a*) the breast meat increased with increasing dietary MNM with a range of 2.52 ± 0.45 to 8.11 ± 1.16. The high protein content of MNM could have contributed to myoglobin production thus increasing breast meat redness. Gevrekçi et al. (2009); Mnisi & Mlambo (2018) reported a* values of 3.23 and 3.09 to 6.79, respectively. These reports show that generally, the redness of the quail breast was within the range (considering the variance) reported by other researchers (Gevrekçi et al., 2009; Mnisi & Mlambo, 2018). The composition of the finisher diet has been shown greatly impact yellowness (b*) of meat (Ribarski & Genchev, 2013). In the current study only the yellowness of the thigh meat from the male quail was influenced by dietary MNM with quail fed diet 3 having the least yellow meat (Table 4). The birds fed diet 3 may not have been able to metabolise the carotenoid pigments in the diet efficiently in comparison to those fed diets 1, 2, 4 and 5 thus the lower b* values. Although, the thigh meat from birds fed diet 3 had the lowest b* value, the range (7.07 ± 0.90 to 14.30 ± 0.76) of the b* values of the meat from the thigh muscles from the carcasses of male quail in the current study was within the range (7.74 to 12.72) reported by Ribarski & Genchev (2013); Genchev et al. (2008); Narinc et al. (2013). The meat colour and pH may be good indicators of other meat properties such as water holding ability and tenderness (Abril et al., 2001; Hughes et al., 2014).

A low pH of meat during post mortem affects water retention, juiciness and tenderness (Barbut, 1997; Fletcher, 2002). Despite the discernible decline in pH of the breast meat 24 h post-slaughter, its pH_u was within the range of that reported by other researchers. The meat's within previously reported range pH_u potentially accounts for the lack of effect on TL, CL and tenderness; thus, it can be inferred that MNM can be used as a dietary protein source without compromising the meat's water holding capacity and tenderness as well as its acceptability (based on colour) by consumers.

It has been documented that approximately 202 million tonnes of dietary protein is needed globally to sustain 7.3 billion inhabitants of the world (Henchion et al., 2017). Nutrient content in foodstuffs and feedstuffs are better compared on a dry matter basis (Hall et al., 2005). Therefore, for the purposes of comparing findings on components of the proximate composition of meat from the current study, results from comparative studies reported in literature have been converted to a dry matter basis. Findings on the determined proximate components of the

meat in the current study show that across dietary treatments, the breast meat from the quail carcasses, on a dry matter basis, had a CP, EE and ash content which ranged from 78.90 ± 0.72 to 83.86 ± 0.32%, 7.54 ± 0.21 to 9.38 ± 0.01% and 7.27 ± 0.42 to 8.29 ± 0.27%, respectively. Breast meat from Japanese quail is reported to contain 80.81 to 96.14% CP, 2.85 to 13.91% EE and 2.60 to 6.21% ash (Fakolade, 2015; Gecgel et al., 2015; Genchev et al., 2008; Lukanov et al., 2018; Raji et al., 2015). With regards to CP, EE and ash content of the breast meat of Japanese quail from current study, it is evident that these fall within the ranges reported in literature. It can therefore be inferred that MNM can be used a dietary protein source in Japanese quail grower and finisher diets without the risk of altering its (meat's) CP, EE and ash content suggesting that dietary MNM does not compromise the nutrient (CP, EE and ash) content of the meat. Importantly, dietary fat, particularly the consumption of diets rich saturated fatty is associated with increased risk of developing obesity (Lai et al., 2018) leading to a host of metabolic derangements and diseases (Yan et al., 2015). The within previously reported range of EE content of the meat suggests that MNM can potentially be used as a dietary protein source in quail without the risk of producing fat-laden meat which would otherwise increase the risk of developing obesity and its associated metabolic disease in consumers.

The World Health Organisation recommended a fat intake of less than 35% of the daily energy needed, in which saturated fatty acids (SFA) and polyunsaturated fatty acids (PUFA) should not exceed 10% and 11%, respectively (World Health Organisation, 2008). The SFA content plays an important role in the meat quality as it improves juiciness, flavour and tenderness (De Smet et al., 2004). The extent of fatty acid content of the meat has been associated with the composition of the diet (Raes et al., 2004). Partially defatted MNM contains high content oleic acid (76.08 to 77.81%), palmitic acid (12.36 to 14.16%) and linoleic acid (7.15 to 7.20%) (Malebana et al., 2018) and the hexane-extracted MNM used in the current study contained 65.93% oleic acid, 14.16% palmitic acid and 6.68% linoleic acid. The breast meat from Japanese quail is reported to contain 34.13 to 34.65% total saturated fatty acids (TSFA), 40.70 to 49.70% total monounsaturated fatty acids (TMUFA) and 13.81 to 24.98% total polyunsaturated fatty acids (TPUFA) (Gecgel et al., 2015; Genchev et al., 2008). However, Boni et al. (2010) reported 25.84 to 29.07% TSFA, 41.90 to 42.76% TMUFA and 28.40 to 32.59% TPUFA in young and spent Japanese quail, respectively. Findings from the current study showed that quail breast meat had a TSFA, TMUFA and TPUFA content ranging from 25.03 ± 0.51 to 29.16 ± 0.61%, 53.88 ± 0.52 to 60.27 ± 0.07% and 41.06 ± 28.11 to 22.30 ± 0.08%, respectively. In the breast meat, stearic acid (6.73 ± 0.01 to 7.75 ± 0.45%) was the dominant SFA while oleic acid (46.50 ± 0.51 to 53.68 ± 0.81%) and linoleic acid (15.89 ± 0.67 to 17.64 ± 0.08%) were the dominant MUFA and PUFA, respectively. While the TPUFA content of the quail breast meat was within the range reported by Gecgel et al. (2015); Genchev et al. (2008), its TSFA was lower (Gecgel et al., 2015; Genchev et al., 2008) and its TMUFA content is higher compared to that reported by Boni et al. (2010). The MNM used to formulate the experimental diets had an oleic acid content of 65.93%. Since ingredient and diet composition impact the fatty acid profile of meat, the high oleic acid content in the breast meat from carcasses of quail fed MNM-based diets could be attributed to the high oleic acid content of the MNM. In general, the consumption of high dietary saturated fatty acids induces metabolic derangements and diseases (Dupont, 2003). Findings from the current study point to high but similar concentration of palmitic and stearic acid in the breast meat (Table 7). While high intake of dietary palmitic acid is associated with the development of metabolic diseases (Calle & Kaaks, 2004), the similarity in its concentration in the meat across dietary treatments suggests that MNM can potentially be used as a dietary protein source in quail grower and finisher diets without decreasing and or increasing the palmitic acid content of the meat. Stearic acid (C18:0) has been reported to reduce total and low-density lipoprotein cholesterol (Romero et al., 2013) which makes it an important nutrient in human diets (Covas, 2007). Oleic acid has several health's beneficial activities/properties including among others antioxidant (Hernandez, 2015) and hypocholesterolaemic activities (Kris-Etherton, 1999) thus is vital to mitigating coronary heart disease (Lopez-Huertas, 2010). In the current study, there is a general increase in the meat's stearic acid content with an increase in dietary MNM (Table 7). Similarly there is also an increase in the oleic acid content of the meat with an increase in dietary MNM (Table 7). These findings suggest that dietary MNM positively impacted the fatty acid profile of the meat. It can therefore be speculated that dietary MNM can be used to manipulate the fatty acid profile of poultry meat to increase the desirable and health beneficial stearic and oleic acid. In conclusion, MNM can be used as a dietary protein source in quail grower and finisher diets in place of SBM without compromising the meat's water holding properties (TL and CL) but improving the colour (redness) and its stearic and oleic acid content. Taken together dietary MNM can potentially improve the acceptability and nutritional quality of quail.

Ethical approval

Ethical clearance was approved by the Animal Ethics Screening Committee (AESC) of the University of the Witwatersrand, South Africa (AESC approval number: 2017/08/54B).

Disclosure statement

No potential conflict of interest was reported by the authors.

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