

Influence of production systems and sex on nutritional value and meat quality of native Malawian Muscovy ducks

J. Tanganyika^{1,2#} & E.C. Webb¹

¹Department of Animal and Wildlife Sciences, Faculty of Natural and Agricultural Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

²Animal Science Department, Faculty of Agriculture, Bunda College, Lilongwe University of Agriculture and Natural Resources, P. O. Box 219, Lilongwe, Malawi

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Abstract

This study was conducted to assess effects of production systems and sex on nutritional value and meat quality of native Malawian Muscovy ducks. One hundred twenty ducks were randomly assigned to either an intensive (IS), duck-rice integration (DR) or free-range (FR) production system. A starter ration containing 20% crude protein and a finisher containing 17% crude protein were fed to ducks in IS (1 to 4 weeks), and provided as a supplement to ducks in DR and FR (5 to 10 weeks). Feed and water were offered ad libitum. At 10 weeks of age, 16 ducks per treatment were selected randomly, slaughtered and chilled at 4 °C for 24 hours. Carcass temperature, pH and meat colour were measured at 45 min, and at 3, 6, 12 and 24 hours post mortem. Tenderness, cooking loss, proximate and mineral composition were determined 24 hours post mortem. Production system and sex had no effect on carcass temperature, pH and proximate composition of duck breast meat. However, production system affected tenderness and mineral composition of the meat and sex influenced moisture and tenderness. Males were moister and had less tender meat than females. Carcasses from ducks in the FR system contained more zinc, copper, manganese, and potassium, but less iron while those in IS had the lowest mineral content of the three production systems. Thus, DR can be adopted to improve the current FR system of native Malawian Muscovy duck production with supplementation to produce duck with acceptable mineral composition and better meat quality.

Keywords: cooking loss, meat colour, mineral, proximate composition

[#]Corresponding author: jtanganyika@gmail.com

Introduction

The duck population is increasing in Malawi with about 2 390 304 ducks, which represent about 2.1% of the total poultry population (Department of Animal Health and Livestock Development, 2017). Duck meat is the third most widely produced poultry meat in the world after chicken and turkey (Uhlřřov *et al.*, 2018). Duck meat comprises 2900 tonnes of meat production in Malawi, which represents 0.4% of its total meat production (Department of Animal Health and Livestock Development, 2017). The most common production system of ducks is the traditional free-range system (FAO, 2008; Gondwe, 2004) in which ducks are mostly kept together with indigenous chickens with limited provision of supplementary feed, especially during periods of feed shortage and reduced scavenging (FAO, 2016). It is estimated that the consumption of meat in Malawi was 8.3 kg per person per year in 2013, which is below the 10 kg norm (FAO, 2013). This level of meat consumption is considered insufficient, since such low intake often leads to under-nourishment and malnutrition. Meat from conventional livestock species such as goats, cattle, pigs, sheep and chicken is not sufficient, and ducks could be an alternative since they are hardier and more tolerant of viral diseases than chickens, survive in free-range environments, and contribute significantly to the food security and protein intake of people in rural communities (FAO, 2017).

According to Ramadhan *et al.* (2010), the diets fed to ducks affect their chemical composition. Duck meat has low cholesterol and high unsaturated fatty acid, and is recognised as a healthy alternative source of animal protein, which is gaining popularity (Hong *et al.*, 2014). Nowadays, consumers are health conscious and prefer food and meat products that are low in fat, cholesterol and caloric content (Yang *et al.*,

2007). At the same time, consumers believe that poultry that is raised in confined systems is prone to stress, resulting in negative physiological and behavioural responses and poor performance (Li *et al.*, 2017). Apart from diet, meat quality attributes such as carcass temperature and pH, meat colour, cooking loss, proximate and mineral composition and tenderness are affected by age, genetics, species, sex, slaughter method, and handling methods such as catching, grading, transportation, unloading and shackling of birds.

Consumers of duck meat in Malawi are unaffected by cultural or religious taboos, so duck meat provides a huge opportunity for sustainable food security. However, duck meat production is still low owing to a lack of knowledge of proper management systems, the preference for chicken production by many smallholder farmers (Njunga *et al.*, 2010), and the absence of health and extension services. So far, no studies have been conducted in Malawi to assess the nutritive value and quality of duck meat raised in different production systems, hence, the current study.

Materials and Methods

The study was conducted at Bunda College of Lilongwe University of Agriculture and Natural Resources (LUANAR) in Malawi, with ethics approval by the Animal Ethics Committee of the University of Pretoria (EC 032–17). A total of 120 one-week-old ducklings were raised in three production systems, namely intensive (IS), duck-rice integration (DR) and free-range (FR) in a 3 × 2 (production × sex) factorial experiment in a completely randomised block design. According to NRC (1994), a starter ration (20% CP, 1–4 weeks) and finisher (17% CP, 5–10 weeks) were given as complete feed to ducks in IS, and as a supplement to ducks in the DR and FR systems. The feed ingredients for the ration were maize meal, maize bran, soybean meal, fish meal, salt and mineral/vitamin premixes (Table 1). The main feed ingredients, namely maize meal, maize bran, soybean and fish meal, were subjected to chemical analysis (AOAC International, 2005) and Pearson square was used to formulate the ration (Table 1).

Table 1 Feed ingredients and chemical composition of the ration used in duck feeding systems, 100 kg bag

Ingredient	Starter (kg)	Finisher (kg)
Maize	22.65	25.51
Maize bran	45.30	51.01
Soybeans roast / full fat	19.77	14.05
Fishmeal	9.89	7.03
Salt	0.25	0.25
Vitamin and mineral premix*	0.25	0.25
Mono calcium phosphate (MCP)	1.00	1.00
Agricultural lime	0.80	0.80
DL-Methionine	0.10	0.10
Chemical composition (dry matter)		
Crude protein (g/kg)	199.5	169.6
Digestible energy Mcal/kg)	3.476	3.420
Metabolizable energy (Mcal/kg)	3.0	3.0
Crude fibre (g/kg)	39.0	39.2
Calcium (g/kg)	6.5	6.1
Available phosphorus (g/kg)	8.0	7.6
Methionine (g/kg)	4.0	3.6
Lysine (g/kg)	10.0	8.1

*Each 2.5 kg contains vitamin A: 10 000 000 IU; vitamin D3: 3 000 000 IU; vitamin E: 15 000 IU; vitamin K: 1 000 mg; thiamine (B1): 1 000 mg; riboflavin (B2): 5 000 mg; pyridoxine (B6): 1 000 mg; vitamin B12: 10 000 mcg; niacin: 32 000 mg; pantothenic acid: 16 000 mg; folic acid: 1 000 mg; biotin: 100 mg; choline chloride: 200 000 mg; antioxidant: 6 000 mg; manganese: 80 000 mg; zinc: 70 000 mg; iron: 30 000 mg; copper: 10 000 mg; iodine: 1 000 mg; selenium: 100 mg; cobalt: 500 mg

At the end of the experiment, feed was withdrawn 12 hours before slaughter (Kwon *et al.*, 2014) and 48 ducks (16 from each treatment) were selected randomly, slaughtered and kept in the chiller at 4 °C for 24 hrs for further analysis such as cooking loss, tenderness, and proximate and mineral composition. Duck breasts (*Pectoralis* muscle) were analysed for meat quality attributes since the breast is one of the crucial parts for the culinary value and technological properties of duck meat (Witkiewicz, 2000; Wołoszyn *et al.*, 2002; Galal *et al.*, 2011), the other part being the thigh muscle.

Carcass pH and temperature profiles were measured by a pH meter (Kim *et al.*, 2012) at 45 minutes, 3 hours, 6 hours, 12 hours, and 24 hours post mortem and recorded in triplicate (Ronald *et al.*, 2006). The pH meter, which also measured carcass temperature, was dipped into the *pectoralis* muscle to at least a depth of 2 cm at a similar place in each *pectoralis* muscle.

Meat colour was determined by means of a Konica Minolta CR400 chroma meter (Mussah & Phoya, 2017), whereby 30 x 30 mm samples from the *pectoralis* muscle were prepared, labelled and used to capture colour scores of lightness (L^*), redness (a^*), and yellowness (b^*). Three random readings were taken from each meat sample from different angles.

Meat tenderness was determined by an Instron universal testing machine (TA.XT plus texture analyser). The machine was calibrated to have a crosshead speed of 100 mm/min at the full-scale load of 50 kg (500 N). From each *pectoralis* muscle, a sample of 5 x 40 mm (ca. 2.0 cm²) cross section was cut for shear force measurement (Ali *et al.*, 2007). The meat samples were placed at right angles to a plunger-type blade. Nine samples from each *pectoralis* muscle were tested and readings recorded. Data were collected and analysed based on the shear force values to obtain the maximum force required to shear through each muscle sample.

Cooking loss was determined by cutting and weighing 20 g of the *pectoralis* muscle. The meat samples were put in the plastic tubes and boiled in a water bath to an internal temperature of 90 °C for 30 minutes. After boiling, the samples were surface dried, and weighed. Cooking loss was determined by expressing weight of cooked sample (B) as a percentage of the precooked sample (A):

$$\text{Cooking loss (\%)} = [(A-B)/A] \times 100 \text{ (Khan et al., 2016)}$$

Proximate composition was determined after removing the skin and external fat from the breast (*pectoralis major*) meats according to procedures of the AOAC International (2005). Total fat was determined by the AOCS standard procedure Am 5-04 (Ankom, 2001) in which the Ankom XT10 extraction system was used. Micro-minerals that were analysed in the duck meat were potassium (K), zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn). The analyses of micro-mineral content were conducted at the Agricultural Research and Extension Trust (ARET) Laboratories in Malawi. Five grams of defatted and dry samples, which were ashed at 550 °C for six hours, were solubilized in concentrated nitric acid. Then, five ml of 6 molar hydrochloric acid were added to the samples before they were assayed with a Varian atomic absorption spectrometer (Spectra AA20, Agilent Technologies, Australia). Any silica compounds that were present were removed by filtration. The filtrate was then diluted to the desired volume and aspirated into the air-acetylene flame of the atomic absorption spectrometer. The absorbance of each element was measured by comparison with the absorbance of calibration solutions for the same element. The adjusted wavelengths were copper (Cu): 324.8 nm, iron (Fe): 248.3 nm, manganese (Mn): 279.5 nm, zinc (Zn): 213.8 nm, and potassium (K): 766.5 nm.

Data were analysed using the general linear model of IBM SPSS software version 22 (IBM Inc., Armonk, New York, USA). Multivariate analysis of variance was used to test the effects of production system, sex and the interactions among these factors. Differences between treatment means were tested using Duncan's multiple range test ($P < 0.05$). Each duck was regarded as an experimental unit and the statistical significance was set at P -value < 0.05 . Means and standard errors (SE) are reported.

Results and Discussion

There were no significant differences ($P > 0.05$) in the conversion of duck breast muscle to meat over the 24-hour post-mortem period, although numerically the carcass pH of ducks in IS decreased faster than those in other treatments (Figure 1), but retained similar values after 24 hours. The same trend was observed for carcass temperature (Figure 2). Pooled carcass temperature dropped from 27.45 °C to 5.47 °C and pooled carcass pH dropped from as high as 6.68 to 5.86, with the highest drop at six hours post mortem for both quality factors. Similarly, the study found no significant differences between production systems and sex for the initial (45 minutes) and final (24 hrs) carcass temperatures and pH of Muscovy duck meat (Table 2). Generally, no interactions between production systems and sex were found, except on ultimate pH.

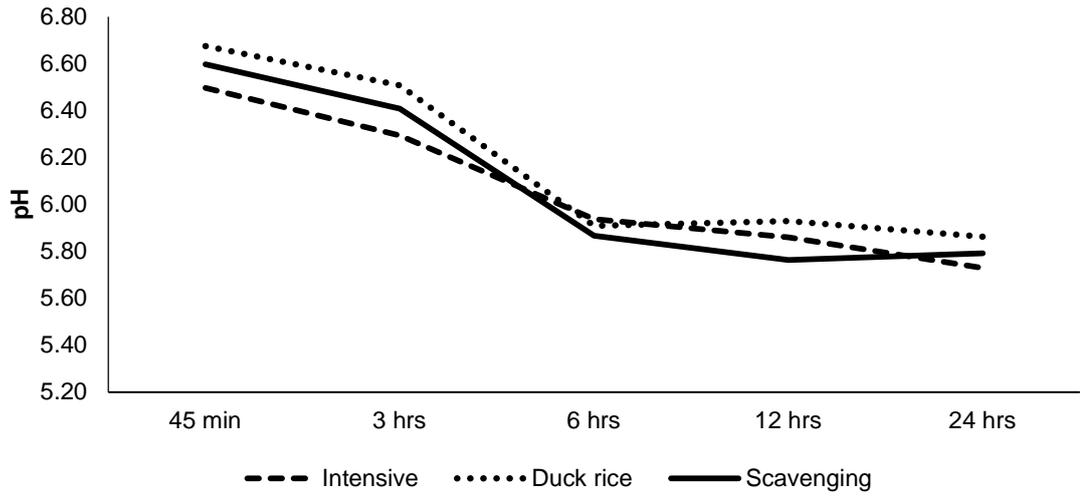


Figure 1 Carcass pH from 45 minutes to 24 hours post slaughter of ducks raised in different production systems

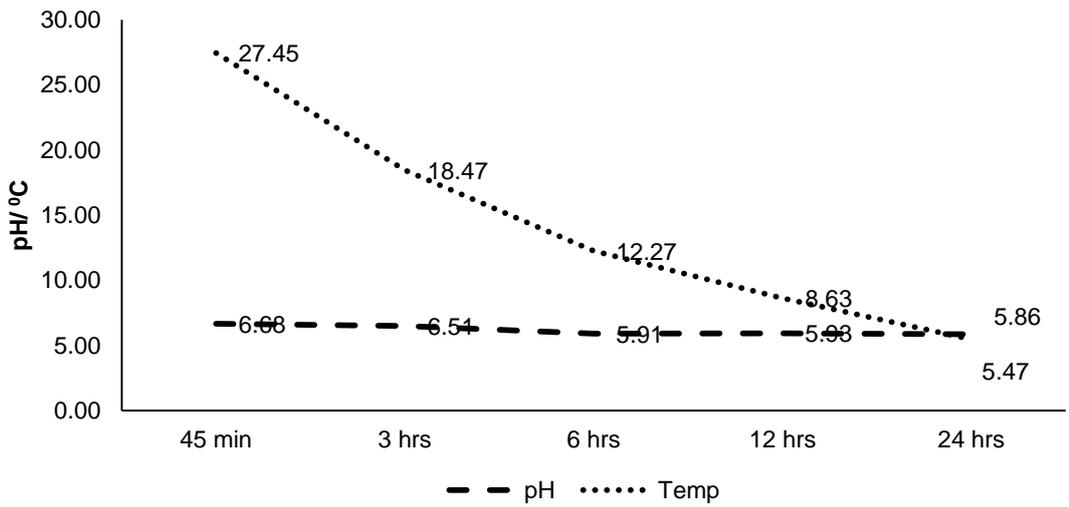


Figure 2 Carcass temperature and pH from 45 minutes to 24 hours post slaughter of ducks raised in different production systems

Table 2 Means (\pm SE) for carcass temperature and pH of breast meat of Muscovy ducks as affected by production system, sex and their interaction

Sex	Production system				Level of significance ¹		
	Intensive	Duck-rice	Free range	Pooled	P	S	P*S
Initial pH (45 min)							
Female	6.42 \pm 0.14	6.57 \pm 0.14	6.80 \pm 0.14	6.60 \pm 0.79			
Male	6.55 \pm 0.14	6.60 \pm 0.14	6.59 \pm 0.14	6.58 \pm 0.79			
Overall	6.49 \pm 0.97	6.59 \pm 0.97	6.70 \pm 0.97	6.59 \pm 0.56	0.34	0.88	0.48
Ultimate pH (24 hr)							
Female	5.80 \pm 0.65	5.66 \pm 0.65	5.78 \pm 0.65	5.74 \pm 0.38			
Male	5.95 \pm 0.65	5.93 \pm 0.65	5.66 \pm 0.65	5.84 \pm 0.38			
Overall	5.87 \pm 0.46	5.79 \pm 0.46	5.72 \pm 0.46	5.79 \pm 0.27	0.10	0.09	0.03
Initial temperature ($^{\circ}$ C) (45 min)							
Female	27.10 \pm 0.62	27.00 \pm 0.62	27.70 \pm 0.62	27.27 \pm 0.36			
Male	27.20 \pm 0.62	26.90 \pm 0.62	26.83 \pm 0.62	26.98 \pm 0.36			
Overall	27.15 \pm 0.44	26.95 \pm 0.44	27.27 \pm 0.44	27.12 \pm 0.25	0.88	0.58	0.72
Final temperature ($^{\circ}$ C) (24 hr)							
Female	5.47 \pm 0.13	5.60 \pm 0.13	5.43 \pm 0.13	5.50 \pm 0.08			
Male	5.50 \pm 0.13	5.57 \pm 0.13	5.40 \pm 0.13	5.49 \pm 0.08			
Overall	5.43 \pm 0.94	5.58 \pm 0.94	5.42 \pm 0.94	5.49 \pm 0.05	0.48	0.92	0.96

¹ P: production system, S: sex, P*S: interaction between production system and sex

Muscle pH is important in the preservation and stability of meat, because high muscle pH results in shorter shelf life, especially as it pertains to microbial growth (Li *et al.*, 2017). [not in refs] Muscle pH depends on the biochemical state of the muscle at the time of slaughter and the development of rigor mortis (Singh & Pathak, 2017). Post-mortem muscle pH decline is important in terms of meat tenderness, colour, and water-holding capacity (WHC) (Aberle *et al.*, 2001). which depends mainly on a decrease in pH and on protein degradation under the action of proteases (Baeza, 2006). It is a direct indication of meat quality in which glycogen reserves in muscles affect the post-mortem pH level. Duck muscle is regarded as red meat because it has 16% white fibres and 84% red fibres, compared with 100% white fibres in chicken breast (Smith *et al.*, 1993), thus differences post mortem are expected (Ali *et al.*, 2007). Generally, the mean ultimate pH value of duck meat is between 5.90 (Fernandez *et al.*, 2003) and 5.65 (Raj *et al.*, 1998). The current results are in agreement with those of Li *et al.* (2017), in which production system had no effect on pH level of breast meat and the lack of interaction between production systems and sex is similar to what Wang *et al.* (2009) and Fanatico *et al.* (2007) reported on ducks in a free-range system versus those in an intensive system. However, the values for ultimate pH in this study were higher than those reported by Erisir *et al.* (2009) and lower than reports by Ismed *et al.* (2009) and Khan *et al.* (2016). On the contrary, Raj *et al.* (1998), Mallia *et al.* (2000), Fernandez *et al.* (2003), and Lacin *et al.* (2008) reported that treatment had an effect on pH values, and found comparable ultimate pH values for ducks in IS environments, which were lower than FR and duck-fish rearing systems. The differences could be due to age of slaughter, which causes glycolytic metabolism in muscle to increase with age, inducing a decrease in ultimate pH value (Baéza *et al.*, 1998) and glycogen levels during slaughter, which can be altered by many factors ante mortem and post mortem (Braden, 2013).

Lack of difference in pH between sexes in this study is similar to the findings of Liao *et al.* (2016) and Uhlřov *et al.* (2018) in Pekin ducks and Geldenhuys *et al.* (2015) in Egyptian geese. However, Kirmizibayrak *et al.* (2011) reported significantly higher ultimate pH of the breast muscles in females than in males. In the current results at 24 hours post mortem, the pH values on breast meat between sex showed female ducks were slightly lower (5.74) than males (5.84). It is reported that lower pH (5.7) at 24 hours post mortem indicates poor meat quality (Van Laack *et al.*, 2000). All the production systems presented overall pH₂₄ values between 5.72 and 5.87, an indication of good meat quality. The higher ultimate pH above 5.7 at 24 hours in this study could be due to the fasting period and exposure to high temperatures before slaughter

(Baéza, 1995). However, the pooled ultimate pH in this study was lower than that reported by Liao *et al.* (2016). Differences in pH values could be attributed to differences in the glycogen reserves at slaughter, responses to pre-slaughter stress and slaughter weight (Uhlířov *et al.*, 2018).

The colour of the pectoralis muscle was affected by production system only in terms of lightness (L^*) at 45 min, and by the sex of the duck on redness (a^*) at 24 hours ($P < 0.5$). Interactions between production systems and sex were observed on lightness (L^*) and yellowness (b^*) at 45 min (Table 3). Generally, the colour of pectoralis muscle at 24 hours post mortem was not affected by production systems.

Table 3 Means (\pm SE) for the colour of duck breast meat as affected by production system, sex and their interaction

Time	Sex	Production system				Level of significance ¹		
		Intensive	Duck rice	Free range	Pooled	P	S	P*S
Lightness (L^*)								
45 min	Female	65.4 \pm 2.12	52.3 \pm 2.12	61.3 \pm 2.12	59.8 \pm 1.22			
	Male	61.3 \pm 2.12	57.0 \pm 2.12	52.4 \pm 2.12	58.8 \pm 1.22			
	Overall	63.3 ^a \pm 1.49	57.8 ^b \pm 1.49	56.8 ^b \pm 1.49	59.3 \pm 0.86	0.02	0.55	0.01
24 hr	Female	32.3 \pm 4.34	31.2 \pm 4.34	38.2 \pm 4.34	34.1 \pm 2.53			
	Male	43.7 \pm 4.34	34.1 \pm 4.34	45.9 \pm 4.34	41.2 \pm 2.53			
	Overall	38.3 \pm 3.10	32.7 \pm 3.10	42.1 \pm 3.10	37.7 \pm 1.79	0.14	0.07	0.67
Redness (a^*)								
45 min	Female	4.83 \pm 1.42	9.65 \pm 1.42	6.61 \pm 1.42	7.03 \pm 0.82			
	Male	8.00 \pm 1.42	5.26 \pm 1.42	11.4 \pm 1.42	8.22 \pm 0.82			
	Overall	6.42 \pm 1.00	7.46 \pm 1.00	9.00 \pm 1.00	7.63 \pm 0.58	0.23	0.33	0.16
24 hr	Female	12.4 ^x \pm 1.35	10.5 ^x \pm 1.35	14.9 ^x \pm 1.35	12.6 ^x \pm 0.78			
	Male	9.12 ^y \pm 1.35	11.0 ^y \pm 1.35	9.77 ^y \pm 1.35	9.99 ^y \pm 0.78			
	Overall	10.8 \pm 0.95	10.8 \pm 0.95	12.3 \pm 0.95	11.3 \pm 0.55	0.43	0.04	0.15
Yellowness (b^*)								
45 min	Female	13.3 \pm 1.26	10.2 \pm 1.26	14.7 \pm 1.26	12.7 \pm 0.73			
	Male	14.5 \pm 1.26	13.1 \pm 1.26	10.1 \pm 1.26	12.5 \pm 0.73			
	Overall	13.9 \pm 0.89	11.6 \pm 0.89	12.4 \pm 0.89	12.6 \pm 0.51	0.23	0.85	0.03
24 hr	Female	12.8 \pm 1.50	9.76 \pm 1.50	14.2 \pm 1.50	12.2 \pm 0.87			
	Male	12.4 \pm 1.50	9.48 \pm 1.50	12.6 \pm 1.50	11.5 \pm 0.87			
	Overall	12.6 \pm 1.06	9.62 \pm 1.06	13.4 \pm 1.06	11.9 \pm 0.61	0.06	0.56	0.90

^{a,b,c} Row means with different superscripts differ significantly at $P < 0.05$

^{x,y} Column means with different superscripts differ significantly at $P < 0.05$

¹ P: production system, S: sex, P*S: interaction between production system and sex

Meat colour is the most important sensory attribute that affects consumer purchasing decisions, and is affected predominantly by myoglobin, which is the primary red pigment in meat (del Puerto *et al.*, 2016) and influences consumer preferences (Pripwai *et al.*, 2014; Pathare & Roskilly, 2016), since it indicates meat freshness and the level of doneness (Chang *et al.*, 2011). Fibre type and myoglobin content have a strong effect on meat colour. Like other eating quality attributes, meat colour is affected by factors such as species, animal genetics, rearing systems, post-mortem changes in muscle (especially the dynamics of pH and carcass temperature decline). Poultry meat colour is also affected by sex, age, processing method, exposure to chemicals; cooking method, irradiation and freezing (Huda *et al.* 2009). Among the various studies on colour values of the raw *pectoralis* muscle of ducks, the current results on overall lightness (L^* :37.7) at 24 hours post mortem are consistent with those of Smith *et al.* (1993) (36.45), Raj *et al.* (1998) (38), Baeza *et al.* (2002) (39.6), and Fernandez *et al.* (2003) (40.5). The current results on overall redness at 24 hours post mortem ($a^* = 11.3$) and yellowness ($b^* = 11.9$) are closer to what was reported by Baeza *et al.* (2002), who

found $a^* = 13.86$ and $b^* = 12.18$. However, ducks from FR and DR integration had brighter *pectoralis* muscle than those from IS. This finding is supported by Ponte *et al.* (2008), who reported that birds from a free-range system were characterized by a brighter colour of meat and a higher contribution of yellow colour in muscles, owing to their diet, which included green forage rich in natural carotenoids. These green forages cause the deposition of melanin and xanthophyll into the skin and give its colour. Ducks on free range and duck-rice integration were more active than those in the intensive system, thus they used more oxygen in their muscles, which requires more myoglobin and a greater supply of oxygen from blood to the muscle cells. Because the iron content of duck meat is high, the meat from free range and duck-rice integration appeared darker than those from the intensive system. In the previous discussion, it was observed that duck meat pH from duck-rice and free range had slightly higher pH and some studies reported a high correlation between ultimate muscle pH and meat colour, especially lightness. Fletcher *et al.* (2000) reported that muscles with a high pH have a darker colour than those with a low pH. In the current study, meat from duck-rice and free-range systems, which had numerically higher pH values, was darker than that from the intensive system. Hence, rearing systems affect the physical parameters of muscles and may significantly affect consumers' choice and preferences (Fanatico *et al.*, 2007). On the other hand, sex had a significant effect on lightness and redness and females had higher values of redness (a^*) than males ($P < 0.05$). No differences between females and males were observed for lightness and yellowness ($P > 0.05$). The results in muscle redness and yellowness at 24 hours from this study between the sexes agree with those of Uhlřřov *et al.* (2018) in geese.

The effects of production system and sex of ducks on tenderness and cooking losses of duck meat are presented in Table 4. The results confirmed that the tenderness of duck breast meat was affected by both production system and sex ($P < 0.05$), while cooking loss was not influenced by either of these factors. As indicated by shear force, ducks kept in IS had more tender breast meat (1.56 kg), followed by ducks in DR integration (1.95 kg), and the least tender meat was from ducks in the FR system (2.28 kg). However, further comparisons showed that tenderness of duck breast for ducks in DR was not different from that of ducks in the FR system. In addition, there was an interaction between production system and sex on tenderness of duck breast meat ($P = 0.009$)

Table 4 Means (\pm SE) for the influence of production system, sex and their interactions on tenderness and cooking loss of breast meat of Muscovy ducks

Sex	Production system				Level of significance ¹		
	Intensive	Duck rice	Free range	Pooled	P	S	P*S
Tenderness (kg force)							
Female	1.47 ^x \pm 0.23	1.67 ^x \pm 0.23	1.40 ^x \pm 0.23	1.51 ^x \pm 0.13			
Male	1.33 ^y \pm 0.23	2.23 ^y \pm 0.23	3.17 ^y \pm 0.23	2.24 ^y \pm 0.13			
Overall	1.87 ^a \pm 0.16	1.95 ^b \pm 0.16	2.28 ^b \pm 0.16	1.88 \pm 0.09	0.01	0.01	0.01
Cooking loss (%)							
Female	31.7 \pm 2.64	31.7 \pm 2.64	26.7 \pm 2.64	30.6 \pm 1.52			
Male	28.3 \pm 2.64	33.3 \pm 2.64	31.7 \pm 2.64	30.6 \pm 1.52			
Overall	30.0 \pm 0.16	32.5 \pm 0.16	29.2 \pm 0.16	30.6 \pm 1.08	0.44	1.00	0.86

^{a,b,c} Row means with different superscripts differ significantly at $P < 0.05$

^{x,y} Column means with different superscripts differ significantly at $P < 0.05$

¹ P: production system, S: sex, P*S: interaction between production system and sex

Meat palatability is the primary sensory trait of consumer acceptance (Choi *et al.*, 2016), and the main attribute of palatability that influences consumer acceptance is tenderness (Mennecke *et al.*, 2007; Piao *et al.*, 2015), especially for consumer decisions on repeat purchases (Grunert *et al.*, 2004). It is dictated by the presence of several factors, including the amount of fat, water-holding capacity (WHC) and the actomyosin complex (Singh & Pathak, 2017) and processing techniques (Adam & Abugroun, 2015). The results from the current study on the effect of production systems on tenderness are in line with those of Michalczuk *et al.* (2014), who reported that meat from chickens on a FR system was characterised by higher shear force, and therefore was tougher than the meat of chickens from IS. In their studies Chen *et al.* (2006) and Farmer *et al.* (1997) reported significant production system effects, with higher shear force values of drumstick and

breast meat of chickens raised organically, which is similar to the FR system in the current study. However, it was not surprising to have duck meat from IS that was more tender than meat from DR and FR systems, since ducks under IS had restricted space allowances in the house, so the muscles were not under heavy exercise as a result of walking longer distances (Mutibvu *et al.*, 2017). However, shear force values in this study were lower than those that Ali *et al.* (2007) reported for Chungdong ori ducks. Numerically, meat from ducks in DR was more tender than that from the FR system, because ducks in the DR had some restricted movement in the rice field, which was fenced, as opposed to ducks in FR, where there was no limitation of movement, resulting in greater muscle activity. The effects of production systems on carcass and meat quality, and in particular meat tenderness have been confirmed in other livestock (Webb & Erasmus, 2013). The results of the effect of sex on meat tenderness in this study are in line with those of Chen *et al.* (2006), who found higher shear force values in males than females in two chicken breeds (Anka and Rugao). However, the results are contrary to the findings by Smith *et al.* (2015), who did not find differences in tenderness between male and female Pekin ducks, and to those of Uhlířov *et al.* (2018) in geese and to Huff-Lonergan *et al.* (1995) in the bovine *longissimus* muscle. The use of Muscovy ducks in the present study may explain the difference between sexes.

Cooking loss is a critical factor in the meat industry because it determines the technological yield of the cooking process (Kondjoyan, 2013) and serves as an indicator of WHC, which affects meat quality. From a nutritional point of view, cooking loss brings about loss of soluble proteins, vitamins and different supplements (Yarmand *et al.*, 2013) and depends on cooking time and cooking temperatures (Adam & Abugroun, 2015). In this study, cooking loss was not affected by production system or sex, which agrees with the findings of other studies (Lopez *et al.*, 2011; Uhlířov *et al.*, 2018). The values in the present study were lower than those reported by Alvarado and Sams (2000) and Ali *et al.* (2007). However, Musundire *et al.* (2017) reported that cooking loss was affected ($P < 0.05$) by sex in chickens and guinea fowl managed under village FR systems. The differences are due to species, age at slaughter, and conditions in the management system.

The nutritional composition of breast muscle from Muscovy ducks is presented in Table 5 and shows that production system had no effect on any of the nutrients that were analysed. However, sex had an effect ($P < 0.05$) on moisture, with males containing a higher percentage of moisture than females. The proximate composition in breast was not affected by interaction between production system and sex.

Table 5 Means (\pm SE) for proximate composition of breast meat of Muscovy ducks as affected by production system, sex and their interaction

Sex	Production system				Level of significance ¹		
	Intensive	Duck rice	Free range	Pooled	P	S	P*S
Moisture (%)							
Female	62.2 \pm 1.92	61.7 \pm 1.92	61.2 \pm 1.92	61.7 \pm 1.11			
Male	66.2 \pm 1.92	64.8 \pm 1.92	65.7 \pm 1.92	65.6 \pm 1.11			
Overall	64.2 \pm 1.35	63.2 \pm 1.35	63.4 \pm 1.35	63.6 \pm 0.78	0.63	0.03	0.94
Protein (%)							
Female	20.3 \pm 1.22	20.9 \pm 1.22	21.4 \pm 1.22	21.1 \pm 0.70			
Male	21.8 \pm 1.22	22.7 \pm 1.22	23.3 \pm 1.22	22.0 \pm 0.70			
Overall	21.2 \pm 0.86	21.8 \pm 0.86	21.8 \pm 0.86	21.6 \pm 0.50	0.55	0.39	0.18
Fat (%)							
Female	3.55 \pm 1.02	6.22 \pm 1.02	5.91 \pm 1.02	5.23 \pm 0.59			
Male	4.82 \pm 1.02	4.53 \pm 1.02	3.65 \pm 1.02	4.33 \pm 0.59			
Overall	4.18 \pm 0.72	5.37 \pm 0.72	4.78 \pm 0.72	4.78 \pm 0.42	0.29	0.30	0.22
Ash (%)							
Female	6.21 \pm 1.33	6.79 \pm 1.33	5.75 \pm 1.33	6.25 \pm 0.77			
Male	6.80 \pm 1.33	6.32 \pm 1.33	6.38 \pm 1.33	6.50 \pm 0.77			
Overall	6.50 \pm 0.94	6.56 \pm 0.94	6.07 \pm 0.94	6.38 \pm 0.54	0.73	0.82	0.90

¹ P: production system, S: sex, P*S: interaction between production system and sex

The nutritional composition of duck meat varies, depending on the breed and strain of duck and diet (Ramadhan *et al.*, 2010). The present results agree with those of Holcman *et al.* (2003) and Michalczuk *et al.* (2014), who found no significant differences in the chemical composition of muscle due to rearing system. In their studies, Holcman *et al.* (2003) and Lorenzo *et al.* (2011) reported that sex did not influence the proximate analysis of breast meat, which may indicate similar skeletal muscle composition between sexes, though not in moisture for this study, which was influenced by sex.

The overall moisture content of duck meat in the current study was lower than that reported by Chartin *et al.* (2006), Ali *et al.* (2007), Lorenzo *et al.* (2011), Galal *et al.* (2011) and Ismed *et al.* (2013) in Muscovy ducks, and Baeza *et al.* (2000) in mule ducks. These differences could be due to age at slaughter, which affects the proximate composition and especially moisture content (Wattanachant, 2008) as it decreases with age. The effect of sex on moisture, whereby males had significantly higher values than females in this study, is comparable with findings by Baeza *et al.* (2000) and Zangh *et al.* (2010).

Levels of protein found here in duck meat are in line with studies by Ali *et al.* (2007), who found 20.1% crude protein (CP), Ensminger *et al.* (1993), who found 21.4% CP, Rahman (2014), who found 20.3% CP, and Cobos *et al.* (2000), who found 20.08% CP. However, the current results are lower than values reported by Lorenzo *et al.* (2011), who recorded a protein level of 24.29% CP. On the other hand, the current protein value is higher than the 18.3% reported by the USDA (2015), and the 17.9% reported by Ismed *et al.* (2013). These differences could be as a result of age at slaughter, breed and management system, since the other authors did not specify the breeds of duck. Age at slaughter also affects the protein content of meat, whereby an increase in age results in a decrease in protein content.

The fat content of meat is affected by breed, feeding and age at slaughter. In free-ranging Guinea fowls and chickens fat has been observed to increase with age and females have more fat than males (Musundire *et al.*, 2017). The pooled fat composition found in this study, ranging from 4.18 to 5.37%, is in agreement with results of Chartin *et al.* (2006), Ismed *et al.* (2013) and USDA (2015), but higher than the results of Mazanowski *et al.* (2003), who reported fat content of 1.7% in specialized sire lines. Though not statistically different numerically, it was observed that ducks kept in free range and duck-rice integration were slightly fatter than those in intensive systems. This may be due to the wide range of feedstuffs that are available to the ducks in the vicinity. Feedstuffs such as grass, insects, frogs and small animals that are eaten by the scavenging ducks could have contributed to their high fat and ash contents, since grass is digested by the ducks in the colon and thereby supplies energy, which is usually stored as fat (Tougan *et al.*, 2003). However, the tendency for birds to deposit fat is genetically driven, indicating that fatness and leanness have to be modified at breeding level for sustainable improvement (Grashorn, 2010). On the other hand, the relationship between fat and moisture in this study, whereby the pooled moisture content for males was slightly higher than for females and affected the fat content negatively, agrees with works of Stankov *et al.* (2002), Chowdhury and Mutalib (2003) and Rahman (2012), who reported that the decrease in moisture content in meat is due to the increase in fat content.

While the ash content of duck breast meat in this study was higher than values reported by Zhou *et al.* (2000) and Baeza *et al.* (2002), the current results on ash content are in line with those of Ali *et al.* (2007), Ismed *et al.* (2013) and USDA (2015). The significantly high ash of the ducks on free range might be attributed to the season of production. The study was conducted at the start of the rainy season in Malawi, when the grasses were young and more nutritious, and had a relatively high mineral value. These grasses are liked by scavenging birds, and contribute to the high mineral level. The season is also characterized by snails, worms, and small insects, which contain high levels of minerals, and might have contributed to this high ash content (Tougan *et al.*, 2003).

The minerals of the duck breast muscle were affected by the production system ($P < 0.05$) except for potassium. No effects of sex or interactions between sex and production systems were observed on the minerals of duck breast muscle (Table 6). The general trend in this study was that free-range ducks had the highest values of all minerals, followed by those in duck-rice integration, and the intensively managed ducks had the lowest minerals. However, differences between production systems were observed for manganese, zinc and copper ($P < 0.05$).

Minerals are present in the animal body in concentrations not greater than 50 mg/kg (0.05 mg/g) (McDonald *et al.*, 2010). Ash is an indication of the total amount of minerals in the muscle and the quantity can vary as a result of species differences, hormones, age, sex, region and diet (Keeton & Eddy, 2004). An increase in mineral levels in the current study was as a result of higher ash values (Table 5), which agrees with what Musundire *et al.* (2017) reported. The high mineral levels of the ducks in the FR and DR systems than ducks in the intensive system are explained by the high values of ash in Table 5, which are attributed to availability of feed resources for scavenging birds, which influence their ash content (Tougan *et al.*, 2013), and consequently the high micro-minerals.

Table 6 Means (\pm SE) for production system, sex and their interaction effects on the mineral composition of breast meat from Muscovy ducks

Sex	Production system				Level of significance ¹		
	Intensive	Duck-rice	Free-range	Overall	P	S	P*S
Zinc mg/100 g							
Female	0.99 \pm 1.52	1.28 \pm 1.52	1.37 \pm 1.52	1.21 \pm 0.09			
Male	0.95 \pm 1.52	1.32 \pm 1.52	1.43 \pm 1.52	1.24 \pm 0.09			
Overall	0.97 ^a \pm 0.11	1.30 ^{ab} \pm 0.11	1.40 ^b \pm 0.11	1.23 \pm 0.06	0.04	0.85	0.93
Iron mg/100 g							
Female	1.05 \pm 0.71	2.19 \pm 0.71	2.91 \pm 0.71	2.50 \pm 0.41			
Male	1.42 \pm 0.71	3.65 \pm 0.71	2.85 \pm 0.71	2.64 \pm 0.41			
Overall	1.24 ^a \pm 0.50	2.92 ^b \pm 0.50	2.88 ^b \pm 0.50	2.35 \pm 0.29	0.06	0.33	0.56
Copper mg/100 g							
Female	0.18 \pm 0.08	0.34 \pm 0.08	0.42 \pm 0.08	0.32 \pm 0.05			
Male	0.19 \pm 0.08	0.46 \pm 0.08	0.48 \pm 0.08	0.38 \pm 0.05			
Overall	0.19 ^a \pm 0.06	0.40 ^b \pm 0.06	0.45 ^b \pm 0.06	0.35 \pm 0.32	0.01	0.35	0.77
Manganese mg/100 g							
Female	0.09 \pm 0.08	0.36 \pm 0.08	0.28 \pm 0.08	0.24 \pm 0.04			
Male	0.23 \pm 0.08	0.43 \pm 0.08	0.33 \pm 0.08	0.33 \pm 0.04			
Overall	0.16 ^a \pm 0.05	0.40 ^b \pm 0.05	0.31 ^{ab} \pm 0.05	0.29 \pm 0.03	0.03	0.18	0.90
Potassium mg/100 g							
Female	91.6 \pm 11.1	88.0 \pm 11.1	98.5 \pm 11.1	92.7 \pm 6.41			
Male	62.4 \pm 11.1	101 \pm 11.1	92.6 \pm 11.1	85.4 \pm 6.41			
Overall	77.0 \pm 7.86	94.6 \pm 7.86	95.5 \pm 7.86	89.0 \pm 4.54	0.21	0.43	0.20

^{a,b,c} Row means with different superscripts differ significantly at $P < 0.05$

¹ P: production system, S: sex, P*S: interaction between production system and sex

Conclusion

The duck-rice integrated system is a new farming system in Malawi, but has proved to be a useful alternative alongside free-range and intensive systems. The results from this study indicate that the use of duck-rice integration improves the nutritive value of duck meat to levels that comparable with free-range systems because of the freedom of birds to scavenge. The use of the duck-rice integration system produced more tender breast meat than from free-range systems, but less so than from intensive systems. The study also concurred with other studies on the effect of sex on meat tenderness, whereby females produced more tender duck breast meat than males. On the other hand, production systems had no effect on the proximate composition of Muscovy duck breast meat, while sex affected only the moisture content, with males containing more moisture than females. Therefore, farmers could adopt the duck-rice integrated system as an alternative to the current free-range system with supplementation to improve the nutritional value and meat quality of native Malawian Muscovy ducks. However, further on-farm studies need to be conducted before implementation on a full scale, since this was an on-station study with most of the factors under control.

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Authors' Contributions

This work was part of the PhD in Animal Science study at the University of Pretoria. JT was the student and in charge of the experimental design, preparation and execution of the project in Malawi. ECW was the supervisor for the PhD research and participated in project planning and implementation and in results, statistics and interpretation of the study. JT as a student wrote the manuscript. ECW edited and corrected the manuscript for submission.

Conflict of Interest Declaration

There is no conflict of interest.

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