Effect of *Imbrasia belina* meal on growth performance, quality characteristics and sensory attributes of broiler chicken meat

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**ABSTRACT**

The study aimed to evaluate the effect of dietary graded levels of *Imbrasia belina* at 0%, 4%, 8% and 12% of broiler diets on meat quality and sensory attributes. A total of 360 one-day-old broiler chicks, were fed graded *I. belina* diets and slaughtered on day 35. Body weight (BW), Average Daily Gain (ADG), Feed Intake (FI) and Feed Conversion Ratio (FCR) were recorded. Breast muscles were evaluated for ultimate pH, meat colour (L\(_*\) (lightness), a\(_*\) (redness), b\(_*\) (yellowness), tenderness, cooking loss. Forty consumer panellists evaluated sensory attributes. On day 28, the ADG in birds fed IB4 (88.06 g) and control (80.09 g) were statistically similar. On day 28 and 35 FI of broiler chickens fed control (147.47 g; 178.45 g) was the highest. The highest values for L\(_*\) were observed in IB1, but not significantly different (p > .05) from IB3 and IB4. For redness, a\(_*\) values were highest in IB3 and lowest in IB1. Lightness, yellowness, pH24 and Hue showed a quadratic response to increasing levels of IB meal. The shear force values were highest in IB1 (11.27), but not significantly different (p > .05) from IB3 (9.97) and IB4 (9.85). However, the tenderness scores were observed to be highest from IB3 (7.00). The highest acceptability scores of the breast meat were from IB2 (7.65). In conclusion, adding graded levels of *I. belina* meal up to 12% into diets of broilers had a positive effect on growth performance, meat quality and sensory attributes.

**HIGHLIGHTS**

- Dietary inclusion levels of *I. belina* meal increased body weight gains in dietary treatment groups.
- The shear force in all dietary treatment groups decreased compared to the control.
- The tenderness of breast meat was found to be significantly influenced by the dietary treatment

**Introduction**

The roles of dietary protein have gained vast attention in impelling growth and body composition of poultry, regulating the expression of essential lipogenic genes and growth of white adipose tissue (Li et al. 2015; Libién-Jiménez et al. 2015). More so, maintaining dietary fatty acids would facilitate the absorption and utilisation of fatty acids and free amino acids and would result in improved muscle and adipose composition (Li et al. 2015). Dietary protein and meat of superior quality can be obtained through feed optimisation and strategy. Meat quality can be utilised as an indicator of anxiety and energy breakdown in poultry (Ozturk et al. 2012; Bahadori et al. 2017). Meat quality encompasses many different attributes, which are crucial as they affect sensory attributes (Yang et al. 2011). The first and most crucial meat quality factor is appearance; several factors involved include meat colour, pH, tenderness, water holding capacity as they affect customers’ choice (Christiansen and Boyle 2013). Meat colour is an essential assessment criterion and is one of the most vital sensory attributes that influence consumers’ acceptance of meat and their products (Adeyemi and Sazili 2014; Barbut 2015; Mir et al. 2017). Various factors such as age, genetics, stress, slaughter methods and diet may affect meat colour (Mir et al. 2017). More so, it depends predominantly on myoglobin content, which is influenced by factors such as bird species, age, muscle type, and pH of meat, which is linked to biochemical
state at slaughter and the advancing rigour motis (Kokoszyński et al. 2016).

The use of redness (a*) to measure chicken meat colour is restricted as myoglobin (the protein that regulates redness of meat) is not readily measurable in chicken meat (Zhuang and Savage 2012; Barbut 2015). It has been acknowledged that in monogastric animals, sensory attributes of the meat are strongly influenced by feed consumed (Teye et al. 2013). Hence, their muscle flavour and odour will be influenced by the fatty acid profile of the muscle, which is influenced by that of the diet (Coetze and Hoffman 2002; Pieterse et al. 2014). Thus, it can be postulated that dietary composition may influence meat quality.

Presently, the international poultry industry is facing challenges of sustaining production costs, particularly with regards to energy and protein sources (Pieterse et al. 2014). This has resulted in the industry revaluing substitute protein sources, and their stability for use in broiler feeds. However, it is not only the production factors that are crucial but also the effect of these dietary sources on meat quality characteristics. A protein source that may be of great potential is *Imbrasia belina* worm meal. The replacement of soybean meal with *I. belina* meal might lower the cost of poultry feed for the smallholder farmers if there is no negative impact on the performance and physical traits of meat.

There is, however, a paucity of information on the utilisation of *I. belina* meal in broiler diets and its influence on the meat characteristics. Very little is known about the effect of *I. belina* worm meal on the meat quality of broilers. In current years, poultry products produced from natural and organic sources have attracted consumer interest (Dhama et al. 2015). A study by Mareko et al. (2010) found that there was a dietary effect on juiciness, tenderness and acceptability on sensory scores of broiler drumsticks fed *I. belina* meal. Thighs and legs of broilers are inherently higher in fat than breast meat, hence are rated higher for flavour and juiciness (Bartlett and Beckford 2015). Flavour components of poultry are fat-soluble and are found at higher levels in thighs and leg meat than breast, hence the presence of fat also contributes to the juiciness attributes of meat. In addition, Moraes et al. (2016) pointed out that appearance, tenderness, juiciness and flavour are major factors leading consumers to commend or condemn the meat. Meat sensory evaluation provides a preference profile of the consumer market and hence ensures the quality of a more satisfactory product.

Many alternative sources of protein as animal feed have been explored including house fly maggots (Koné et al. 2017) terminates (Dao et al. 2020) grasshoppers, silkworm caterpillars (Sheikh et al. 2018) and earthworms (Istiqomah et al. 2017). *Imbrasia belina* worm feed on mopane leaves, have high breeding rates, easy to process and store. The quality of *I. belina* worm varies with instar larval stages, *I. belina* has been found to be comparable in nutrient composition with soybean meal. The present study aimed to assess the effect of inclusion levels of *I. belina* worm meal in the diets of broilers on growth performance, meat quality and sensory attributes of broiler breast muscle. The study is essential as it seeks to identify potential alternative protein sources.

**Materials and methods**

**Preparation of Imbrasia belina meal and dietary treatments**

The adult larvae of *I. belina*, were harvested by hand from the *Colophospermum mopane* tree leaves. The mopane worms were prepared following procedures stipulated in the literature (Gondo and Frost 2002). The specimen was ground to pass through a 2mm screen and then put in an air tight plastic container and refrigerated at 4°C until use. Each treatment had 6 replicate pens with fifteen birds per pen arranged in a complete randomised design (CRD). The diets were; IB1 (0%), IB2 (4%) IB3 (8%), IB4 (12%) *Imbrasia belina* inclusion levels replacing soya bean meal as a protein source. The diets were formulated to meet each bird’s dietary needs according to the dietary nutrient requirements (NRC 1994). The feed composition of experimental diets and nutrient composition of dietary treatments are shown in Tables 1 and 2 respectively.

**Analyses of Imbrasia belina nutrients**

Samples were oven-dried for the determination of dry matter content according to (AOAC 2016 number 930.15). Total nitrogen (N) content was determined using combustion analysis according to (AOAC 2016 number 990.03). Total protein was estimated for N content using a standard factor of 6.25 according to (AOAC 2016 number 990.03). Ash content was determined using a muffle furnace with samples subjected to 600°C and analysis according to (AOAC 2016 number 942.05). Crude fibre (CF), acid detergent (ADF) and neutral detergent fibre (NDF) were determined according to (AOAC 2016 methods number 962.09, 973.18 and 2016.04) respectively. Crude fat was determined through the ether extraction and analysis according to (AOAC 2016 modified number 920.39). A 0.5g sample of *I. belina* worm meal was digested with 7mL concentrated HNO3 and 3mL
HCLO4 at 200 °C. For Ca, Mg, P, K, Na and Fe were analysed using an ICP Mass Spectrometer (Perkin-Elmer Inc, USA, Model 3110) at ARC Laboratory, South Africa. Phosphorus was determined calorimetrically using sodium phenol and ammonium molybdate plus ascorbic acid as described by AOAC 2016, number 976.06. Essential amino acids analyses were performed using described methods by Cloutier (2015). Fatty acids were analysed using a modified version of the method described by Folch et al. (1957).

Management of the experimental birds and dietary treatments

A total of 360 unsexed Arbour Acre broiler chicks of an average weight of 43 g were purchased from Natureform hatchery in Port Elizabeth, South Africa. At placement, birds were weighed and randomly allotted to 24 floor pens with wood shavings as bedding material. The pen size was 1.5 x 1.5 m with each bird guaranteed 0.15 m² floor space. Wood shavings were utilised as bedding material applied at a depth of 8 cm, to absorb moisture and provide warmth for the chicks (Musa et al. 2012). Feed and water were available on ad libitum basis and were fed using three-phase feed (Broiler starter, Broiler grower and broiler finisher). Electric lighting was used throughout the rearing period, and infra-red lights were used for heating. During the first week of the experiment, the chicks were kept at 33 °C. The temperature was then reduced by 2–3 °C every week until the final temperature of 22–24 °C was reached. The behaviour of birds

Table 1. Feed composition of experimental diets (as fed basis).

| Ingredients, (%) | IB1 | IB2 | IB3 | IB4 | IB1 | IB2 | IB3 | IB4 | IB1 | IB2 | IB3 | IB4 |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Yellow maize     | 62.9| 63.9| 62.6| 60.5| 67.8| 68.6| 67.9| 66.8| 72.4| 72.3| 71.6| 70.7|
| Sunflower cake   | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Soya oil cake    | 29  | 23.6| 18.3| 15.3| 20.9| 18.1| 14.5| 14.8| 20.8| 17.5| 14.8| 11.7|
| Soya Oil crude   | 0.622| 0.275| 0.267| 0.206| 0.269| 0.248| 0.186| 0.139| 0.273| 0.228| 0.166| 0.108|
| Wheaten bran     | 1   | 1   | 1.2 | 2.4 | 0   | 0   | 0   | 0   | 1.157| 0.673| 0.311| 0   |
| Mopane worm      | 0.5 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| Lysine SINT      | 0.266| 0.275| 0.267| 0.206| 0.269| 0.248| 0.186| 0.139| 0.273| 0.228| 0.166| 0.108|
| Methionine DL    | 0.264| 0.249| 0.222| 0.194| 0.248| 0.231| 0.202| 0.172| 0.208| 0.184| 0.155| 0.126|
| Feed lime        | 1.59| 1.62| 1.63| 1.66| 1.39| 1.41| 1.43| 1.45| 1.25| 1.27| 1.29| 1.31|
| Monocalcium phosphate | 0.91| 0.91| 0.88| 0.86| 0.61| 0.61| 0.59| 0.57| 0.41| 0.4| 0.39| 0.37|
| Fine salt        | 0.339| 0.337| 0.34| 0.362| 0.163| 0.172| 0.196| 0.214| 0.16| 0.178| 0.202| 0.242|
| Sodium bicarbonate | 0.154| 0.156| 0.151| 0.119| 0.329| 0.315| 0.281| 0.256| 0.332| 0.306| 0.273| 0.242|
| Aztra PHY 10,000 P | 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01| 0.01|
| Hemicell broilers | 0.03| 0.03| 0.03| 0.03| 0.03| 0.03| 0.03| 0.03| 0.03| 0.03| 0.03| 0.03|
| Salinomycin      | 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05|
| Zinc bacitracin   | 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05| 0.05|
| Premix No Spec + choline | 0.25| 0.25| 0.25| 0.25| 0.25| 0.25| 0.25| 0.25| 0.25| 0.25| 0.25| 0.25|

Table 2. Analysed nutrient composition of the dietary treatments fed to broilers in 35-day study period on a dry matter basis.

| Nutrient, % | IB1 | IB2 | IB3 | IB4 | IB1 | IB2 | IB3 | IB4 | IB1 | IB2 | IB3 | IB4 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Dry Matter  | 18.69| 18.35| 18.08| 18.38| 18.32| 18.48| 18.59| 18.37| 18.96| 18.81| 18.86| 18.19|
| Moisture    | 11.31| 11.65| 11.93| 9.84| 10.07| 10.10| 10.08| 10.04| 10.22| 10.22| 10.19| 10.16|
| Protein     | 20.28| 20.49| 21.12| 21.97| 18.55| 18.97| 19.84| 20.70| 16.85| 17.54| 18.45| 19.32|
| Fat         | 3.68| 3.53| 3.94| 4.37| 4.37| 4.19| 4.27| 4.48| 4.41| 4.38| 4.46| 4.58|
| Fat AH      | 4.32| 4.15| 4.52| 4.91| 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| Fibre       | 4.06| 4.48| 5.15| 5.50| 3.95| 4.23| 4.51| 4.95| 3.92| 4.20| 4.49| 4.82|
| Ash         | 5.58| 5.44| 5.33| 5.32| 4.70| 4.58| 4.53| 4.47| 4.14| 4.06| 4.02| 3.96|
| CA          | 0.92| 0.92| 0.92| 0.92| 0.79| 0.79| 0.79| 0.79| 0.70| 0.70| 0.70| 0.70|
| P           | 0.50| 0.50| 0.52| 0.53| 0.41| 0.41| 0.41| 0.42| 0.35| 0.35| 0.36| 0.36|
| NA          | 0.18| 0.18| 0.18| 0.18| 0.16| 0.16| 0.16| 0.16| 0.16| 0.16| 0.16| 0.16|
| CL          | 0.30| 0.30| 0.30| 0.30| 0.20| 0.20| 0.20| 0.20| 0.20| 0.20| 0.20| 0.20|
| K           | 0.80| 0.75| 0.72| 0.71| 0.72| 0.68| 0.66| 0.64| 0.65| 0.62| 0.61| 0.59|

IB1 positive control, IB2, IB3 and IB4 contained graded levels of IBM at 4%, 8% and 12% of DM intake respectively.
was carefully monitored to control the room temperature.

In addition, the feed intake (FI), body weight gain (BWG), average daily gain (ADG) and food conversion ratio (FCR) were computed at 7, 14, 21, 28 and 35 day of the feeding trial (Aditya et al. 2018; Musa et al. 2012). Feed intake was calculated as feed given to the chickens on daily basis minus the refusals (Hossain et al. 2012). Body weight gain (BWG) was calculated as final body weight minus initial body weight. Average daily gain (ADG) was measured by final weight minus initial weight divided by the number of days between weighing periods (Huang et al. 2016).

**Slaughter procedure**

At 35 days of age, a total of 120 birds were randomly selected. Birds were individually weighed and fasted for 8 hours with water offered ad libitum. Birds were placed in chicken crates and taken from the fowl run to the abattoir, where they were electrically stunned, individually at 70 volts for 2–4 s and immediately exsanguinated. After bleeding, for 5 min, the carcasses were submerged in a water bath at 60 °C for 2 min, mechanically de-feathered in a rotating drum for 30 s washed and eviscerated.

**Sampling procedure**

Sixty birds were submitted for sensory analysis at the end of the feeding trial. Skins were removed from breast meat, harvested from the respective carcasses. Samples were vacuum packed, labelled and stored in a freezer at about −20 °C for 24 hours before sensory evaluation.

**Meat quality characteristics**

**Meat pH**

Breast meat pH of 120 birds was recorded at slaughter (pH<sub>15</sub>) and 24 h post slaughter (pH<sub>24</sub>) following the procedures stipulated by Zhang et al. (2014). For this purpose, a pH metre probe (Hach HQ11d, SA Alella Spain) after being calibrated with pH 4, pH 7 and pH 9 standard solutions, was inserted into the pectoralis major (the breast) meat. Three readings were taken from different sites of the pectoralis major and were used to compute the mean.

**Colour**

Colour of the breast meat (L* = Lightness, a* = Redness and b* = Yellowness) was determined on 30 birds using the left side breast meat, of individual chicken carcases at, 24 hours after slaughter. A Minolta colour guide machine (Model BYK-Gardener GmbH, Geretsried, German), with a 20 mm diameter measurement area and illuminant D65-day light, 10° standard observer was used. The colour guide was calibrated using the black and white standards before measurements. Three readings were taken by rotating the Colour Guide 90° between each measurement in order to obtain a representative average value of the colour (NSAI 2011). Colour measurements were made on freshly cut surfaces after dissection. Determination of Hue (H°) and Chroma (C°) attributes was calculated according to the following equations (AMSA 2012):

\[
H° = \arctan \left( \frac{b°}{a°} \right), \quad C° = \sqrt{(a°)^2 + (b°)^2}
\]

**Thawing and cooking loss**

Meat samples were weighed before freezing, using a hand-held weighing scale (Model LBK 12) and then frozen at −18 °C for 7 days. Thereafter samples were weighed again at frozen state and thawed at 4 °C for 24 hours. After thawing the samples were reweighed (weight after thawing) and were retained in waterproof PVC-plastic bags before boiling. Forty samples of breast meat, 50 mm thick were put in polythene bags, which were eventually immersed in an 85 °C water bath (Model TRH) for 15 min (Ding et al. 2010). After that, samples were removed from the water bath and cooled, removed from bags, blotted dry and weighed.

Cooking loss = \[\frac{\text{weight of sample before cooking} - \text{weight after cooking}}{\text{weight before cooking}}\] \times 100.

The thawing loss of the thawed samples was calculated using the formula (AOAC 2016).

Thawing loss % = \[\frac{\text{frozen sample weight} - \text{thawed sample weight}}{\text{frozen sample weight}}\] \times 100.

**Shear force**

The tenderness of broiler meat was determined using the Instron Warner-Bratzler Shear Force (WSBF) machine in the Laboratory at the Department of Livestock and Pasture Science. After cooking, 40 samples of breast muscle each with 10 mm core diameter, were cored parallel to the grain of the meat. The samples were sheared perpendicular to the fibre direction using a Warner Bratzler WB shear device mounted on
an Intron Universal Testing machine (Model 3344, Intron industries products, GC, USA) apparatus (cross head speed at 400 mm/min, one shear in the centre of each core). The mean of maximum load recorded for 6 cores represented the average of the peak force in Newtons (N) for each sample (Hoffman et al. 2009).

Meat sensory evaluation
Sensory evaluation was done in the Nutrition Laboratory, Department of Livestock and Pasture Science, at the University of Fort Hare. Meat sensory evaluation was undertaken according to the method described by Omojola and Adesehinwa (2007). The breast meat samples were cooked individually in polythene bags immersed in 80°C water bath for 30 min. Salt was added to taste, and after cooling for 30 min, the meat samples (2 x 3 x 1.5 cm) were placed in coded white dishes and served. The waiting period between sample tastings was 10 minutes. Distilled water was served to panellists to rinse their mouths between sub-sample assessments (AMSA 2012). The boiled samples were subjectively evaluated into an individual cabin, under white light. The individual cabins are necessary, in providing privacy. A 20 semi-trained panel of students (10 males and 10 females) was assigned to score the consumer preference test including, flavour, tenderness, juiciness, number of residues and overall acceptability. That was done on rating a scale from 1 to 9 (1: disliked extremely; 2: dislike very much; 3: dislike moderately; 4: dislike slightly; 5: neither like nor dislike; 6: like slightly; 7: like moderately; 8: like very much; 9: like extremely).

Statistical analysis
The SAS computer software package was used for all statistical analyses (SAS 2003). The effects of different inclusion levels of I. belina meal on growth performance, meat colour, pH, cooking loss, and shear force were analysed statistically using General Linear Model Procedure of (SAS 2003). The data obtained from breast meat sensory scores was subjected to the GLM procedure of SAS (2003). PDIFF option in SAS (2003) was used for comparison of means. Orthogonal polynomial contrasts were used to determine the linear, quadratic and cubic effects of I. belina inclusion levels.

Results
The influence of varying dietary inclusion levels of I. belina meal on BW, BWG, ADG, FI and FCR are depicted in Table 3. There were no significant differences in BW, BWG, ADG and FI among treatment on days 7, 14 and 21. However, differences (p < .05) were noted on days 28 and 35. On day 28, IB4 (1568.86 g) had the highest body weight, and was significantly different (p < .05) from IB2 (1405.45 g) and IB3 (1401.39 g). More so on day 35, IB4 and IB1 had the highest body weight (2232.06 g and 2210.28 g, respectively) and IB3 (2113.31 g) was lowest. On day 28, IB8 (616.40 g) recorded the highest BWG and was significantly different (p > .05) from other treatments, while IB3 (501.51 g) was the lowest. Meanwhile on day 35 IB2 (727.02 g) and IB1 (721.64 g) were not significantly different (p > .05) on BWG, while IB4 (713.20 g) and IB3 (711.92 g) were significantly different from other treatments. On day 28, the ADG in birds fed IB4 (88.06 g) and control (80.09 g) were statistically similar. On day 28 and 35 FI of broiler chickens fed control (147.47 g, 178.45 g) were the highest and IB4 (120.13 g, 139.82 g) recorded the lowest. On day 35, the FCR of broiler chickens fed control were the highest and the IB4 were the least, though statistically similar.

In this study, the characteristics of L* (luminosity), a* (red colour intensity), b* (yellow colour intensity) Chroma (satisfaction), and Hue angle (tonality), CL (cooking loss), TL (Thaw loss), and SF (shear force) of the breast meat are shown in Table 4. The control showed higher lightness and was significantly different (p < .05) from IB2. There was no significant difference (p > .05) among birds fed IB3 and IB4. There were significant differences (p < .05) in birds fed dietary treatment than control, though the IB3 did not differ significantly with IB1. Yellowness (b*2) of breast meat was not significantly different (p > .05) among the treatments. For the Hue (H*), there were significant differences (p < .05) observed among treatments IB4 and IB2 with no significant differences (p > .05) among control and IB3. While for the Chroma (C*), there was no significant differences (p > .05) observed among all the treatments. On pH values, the dietary inclusion levels of I. belina meal had no significant effect (p > .05) on pH45. At 24 h post mortem, IB2 (5.91) recorded a significantly (p < .05) higher pH value than other treatments. Physical attributes of the breast muscle were similar with no significant differences observed for percentage thawing and cooking loss, though, IB2 (15.54) recorded the highest thaw loss percentage, and control (14.22) showed the least loss. The highest cooking loss percentage was observed in control (18.30) and the least in IB3 (16.93). There was a significant difference (p > .05) for shear force, though breast meat from broiler chickens fed control (11.27) recorded the highest. On sensory evaluation, no
statistical differences \( (p > .05) \) were observed for chicken aroma, chicken flavour, and the amount of connective tissues (Table 4). The observed differences \( (p < .05) \) included chicken metallic aroma, metallic after taste, initial impression of juiciness, sustainable juiciness, toughness, initial juiciness at first bite, toughness and acceptability. Birds fed on IB3 (6.09) and IB4 (7.11) diet showed significantly higher \( (p < .05) \) metallic aroma scores than the control diet control (4.02). The tenderness of breast meat was found to be significantly influenced \( (p < .05) \) by the dietary treatment, with the breast meat from IB3 (7.00) having the highest scores and control (1.75) with the least. The amount of connective tissues was significantly observed across the dietary treatment with birds from control (7.97) having an abundant amount of connective tissue and birds from IB2 (5.24) with the least scores of connective tissues. The results show that the acceptability of the breast meat was significantly higher \( (p < .05) \) in dietary treatments than in control. The birds fed diet IB2 (7.80) had the highest score and control (5.94) showing the least (Table 5).

**Discussion**

Feed intake of chicks increases with age due to the protein and energy needed by chicks as they grow, as feed intake is directly proportional to the age of the
Sensory evaluation of broiler chicken fed varying dietary inclusion levels of Imbrasia belina meal.

Table 5. Sensory evaluation of broiler chicken fed varying dietary inclusion levels of Imbrasia belina meal.

| Attributes                  | IB1 | IB2 | IB3 | IB4 | SEM   | p-value | Linear  | p-value Quadratic | Cubic  |
|-----------------------------|-----|-----|-----|-----|-------|---------|---------|------------------|--------|
| Chicken aroma               | 6.63| 6.35| 6.84| 6.88| 0.2809 | .1368   | 0.3200 | .4032            | .2638  |
| Metallic aroma              | 4.02| 5.61| 6.09| 7.11| 0.3669 | <.0001  | <.0001 | .0003            | .9611  |
| Initial impression of juiciness | 7.23| 5.99| 5.52| 4.89| 0.4921 | .0052   | <.0001 | .9350            | .5360  |
| First Bite toughness        | 7.38| 6.21| 7.00| 6.00| 0.4180 | .1696   | <.0001 | .4655            | .2638  |
| Sustainable juiciness       | 6.14| 7.30| 7.35| 7.75| 0.2318 | .0009   | 0.0370 | .3800            | .1383  |
| Chicken flavour             | 5.27| 6.14| 5.27| 5.18| 0.3456 | .2134   | 0.4316 | .1489            | .0209  |
| Metallic after taste        | 4.37| 5.33| 6.30| 6.72| 0.6401 | .0289   | 0.5955 | .1361            | .2180  |
| Toughness                   | 1.75| 5.14| 7.00| 6.42| 0.5147 | .0014   | <.0001 | <.0001           | .8602  |
| Amount of connective tissue | 7.97| 5.24| 5.62| 7.06| 0.3936 | .0005   | 0.1317 | .0087            | .3708  |
| Acceptability               | 5.94| 7.65| 6.80| 7.63| 0.1294 | .0006   | 0.5808 | .1213            | .8538  |

IB1 = control; IB2, IB3 and IB4 graded levels of IBM at 4%, 8% and 12% of DM intake respectively.

abcMeans in the same row with different superscript are significantly different.

Also, birds using their taste can detect excessive dietary mineral and vitamins, hence resulting in refusal to consume the feed (Ferket and Gernat 2006). More so, the presence of condensed tannins in I. belina worm could probably have contributed to low feed intake (Madibela et al. 2009). Tanniferous ingredients render a bitter taste to the feed (Medugu et al. 2010; Onunkwo and George 2015), and the highest inclusion levels were affected because the tanniferous ingredient increase with inclusion levels of I. belina worm meal.

Increase in body weight is one of the birds’ growth performance indices chiefly utilised to monitor the nutritional status of the feed and animal growth. Dietary inclusion levels of I. belina at 12% to the basal diet increased body weight gains (BWG). This may indicate a synergistic effect between I. belina components and basal diet metabolites. Our findings concur with Radulović et al. (2018) who reported significantly higher body weight in birds fed Musca domestica meal and in broilers fed maggot larvae meal (Pretorius and Pieterse 2011). In addition, Hwangbo et al. (2009) recorded similar findings where broiler chickens fed larvae meal showed significantly higher weight than the control. This could be attributed to the enhanced nutrient composition of larvae meal. Essential amino acids from muscle protein (larvae) are of high value and easily digestible. More so, feed consumption is a basic and vital factor that determines the rate of growth and body composition achieved by an animal throughout its life cycle (Hossain et al. 2012).

In this current study, FCR improved proportionally to the birds fed I. belina worm meal. Moreki et al. (2012) affirmed that insect meal (I. belina worm) with good nutritive profile reduced feed intake, and increased BWG, ultimately improved FCR. The improved feed utilisation may be ascribed to the availability of extremely digestible protein in insects (Hwangbo et al. 2009). Hence, the birds were able to utilise their feed efficiently for growth.

Nowadays, scientists experiment ways to improve animal performance and wellbeing as well as the production of superior and enhanced meat. However, improvement of quality parameters of meat is influenced by many factors like (pH, colour and cooking loss) (Avcilar et al. 2019), and is imperative to meat economics and public health. Increased redness of the breast muscle observed from the other dietary treatments could be ascribed to increased motor activity as noted by Castellini et al. (2002). Hence, this indicates that dietary inclusion levels of I. belina meal have a positive impact on colour attributes to breast meat in broiler chickens. More so, a* values (redness) of the meat is most preferred by the consumers (Jiang et al. 2014). For this reason, we assume that high a* values
observed in this study are entirely appropriate for consumers. This could be due to the possible accumulation of insect meal pigment in the intramuscular fat (Schiavone et al. 2019). According to Petracci et al. (2004), the average lightness of broiler breast meat ranges between 50 and 56, pale meat is >56, and darker meat is <56. The lightness of breast meat obtained from chicken fed I. belina meal observed in this study falls within the normal lightness range and corroborate with Bovera et al. (2016).

The meat pH value is an essential factor that affects meat quality as it a direct indicator reflection of meat acid accumulation which affects meat colour and drip loss (Bahadori et al. 2017). The profound influence of the I. belina dietary inclusions on the subsequent decline in meat pH at 24 h post mortem may be attributed to the effect of chitin in the I. belina larvae (Kwiri et al. 2014). Furthermore, chitin possesses some antioxidant properties, which is reported to have enzymatic reactions optimising the conversion of glycogen into lactic acid resulting in decreased pH (Veldkamp et al. 2012; Loponte et al. 2017). The pHu ranges of the breast meat in this study are in agreement with Secci et al. (2018). They reported pHu ranges between 5.75 and 5.84 of Alectaris barbara diets containing Hermetia illucens and Tenebrio molitor. Of which, H. illucens and T. molitor contains 60% and 69% of crude protein (Barragan-Fonseca et al. 2017; Veldkamp et al. 2012) respectively. More so, our findings are comparable with Gunya et al. (2019) who reported breast meat pH 6.2 of broilers fed Eisenia fetida. Interestingly, E. foetida contains 56% crude protein (Fadaee 2012) comparable with I. belina 53.7% (Lautenschläger et al. 2017). The ultimate pH is influenced entirely by the degree of glycogen reserves in the meat of birds before slaughter. However, the lower pH values at 45 min in this study could be an indication of normal pH attained due to the inclusion levels of I. belina meal. It is also vital to note that pH values under 5.7 at 45 min are linked to pale soft and exudative (PSE) breast broiler meat. PSE conditions in chickens are chiefly attributed to a rapid post mortem decline in pH due to pre-slaughter stress and other factors (Petracci et al. 2015). Combination of low pH values and high temperatures in PSE meat causes denaturation of meat proteins leading to reduction in water holding capacity (Freitas et al. 2017). However, the birds of the current study were not affected by this condition because the pH values are within the ranges of normal pH reported for breast meat (Alvarado et al. 2007). While higher pH values than 6.2 are mostly a sign of the dark firm dry (DFD) syndrome (Secci et al. 2018), which is a result of depleted meat glycogen and is a post rigour condition resulting in high ultimate pH. As a result, the myofibrils protein present high water holding capacity and the meat surface becomes dry, resulting in a dark colour and firm appearance (Freitas et al. 2017). More so, high pH values shorten the meat shelf life, due to favourable substrate for microbial activity (Aberle et al. 2001). Hence, the pH levels of breast meat observed in the current study can be considered normal, and evidence of quality meat from broilers fed I. belina meal. More so, the pH values at 24 h recorded in the current study can be ascribed to a lower amount of glycogen in the meat, attributed to fasting regime and inadequate handling during loading and off-loading of birds, which may affect muscle activity after death and glycogen depletion leading to pH drop (Tijare 2015). In addition, meat pH is linked to characteristics like colour, tenderness, shelf life and cooking loss (Mir et al. 2017). Meat pH and colour are highly correlated. Once muscle rigour has set in, the pH of the meat drops due to lactic acid accumulation and glycolysis. This drop in pH to 5.6–5.8 has been associated with changes in meat colour (Tijare 2015). The impact that pH has on colour and functionality of the meat is imperative to marketers of fresh and processed products as it directly affects the profit and shelf-life of the product (Barbut 2015).

Cooking loss refers to the percentage of water that is lost during cooking (Al-Owaimer et al. 2014). High cooking loss percentage depicts the reduced ability of the meat to hold water during processing and storage (Petracci and Cavani 2012). The high cooking loss from breast meat of birds in the control group is probably linked to high nutrient loss during cooking (Al-Owaimer et al. 2014). Also, the breast meat from broilers in the control group was tougher. Hence we postulate that cooking loss was higher in the control group. This result clearly shows that I. belina produces meat with better cooking loss hence better and quality meat. Nevertheless, the value percentages of cooking and thaw loss observed in this study are in line with Hashim et al. (2013) for broiler breast meat.

Tenderness is one of the crucial meat quality traits influenced by factors like strain, diet, sex, age, as well as the environment (Rasul Abdulla et al. 2017). It is increased by post-mortem protein proteolysis and consequently, the degradation of myofibrillar protein (Lonergan et al. 2010). The decrease in shear force (increase in tenderness) observed in this study for dietary treatment could have been influenced by rigor resolution due to enzymatic breakdown of
collagen holding meat fibres together. Furthermore, this observation could be attributed to levels of fat 23.2% and protein 53.7% content detected in I. belina worm (Lautenschläger et al. 2017). Meat tenderness is indirectly affected by dietary protein in I. belina meal which influences the growth of the birds (Maltin et al. 2003). Also, fat improves appearance, juiciness and tenderness of meat (Teye et al. 2013). The shear force values observed in this study are close to Schilling et al. (2010) who reported shear force values of (15.1–16.3N), all shear force values in these studies were less than 30N an indication of tender meat that would be exceedingly acceptable to consumers. In addition, the current study is in agreement with (Gunya et al. 2019) whose findings reported that the inclusion of Eisenia fetida meal in broiler chickens positively influenced breast meat tenderness.

The detected metallic aroma taste and metallic aroma after taste mainly in the dietary treatments have been documented to be an undesirable sensory attribute, which impacts negatively to the acceptance of consumers and marketability of the product (Mahmoud and Buettner 2016). Furthermore, findings by Winiarska-Mieczan et al. (2016) reported that the presence of PUFA in meat results to peroxidation, leading to metallic aroma taste. In this study, the observed metallic aroma scores of breast meat may be attributed to iron levels in I. belina worm 31 mg/100g. However, the iron levels in I. belina are lower than soybean meal 82 mg/kg (Pehrsson et al. 2000) which may have imparted this metallic aroma.

Meat juiciness is one of the fundamental meat traits, and it enhances meat texture. It depends on the quality and composition of fat (Muchenje et al. 2010). The observed initial impression juiciness and sustained juiciness in this study were significantly influenced by dietary treatment. The juiciness improved with an increase in dietary protein levels. However, this is in contrast with Alonso et al. (2010), who reported that juiciness improved with a decrease in dietary protein levels. The observation in this current study concurs with Mareko et al. (2010) who reported that juiciness improved with a decrease in dietary protein levels. The observation in this current study concurs with Mareko et al. (2010) who reported that juiciness improved with a decrease in dietary protein levels. The observation in this current study concurs with Mareko et al. (2010) who reported that juiciness improved with a decrease in dietary protein levels. The observation in this current study concurs with Mareko et al. (2010) who reported that juiciness improved with a decrease in dietary protein levels.

Furthermore, tenderness is also an essential sensory attribute that can be determined by trained individuals (sensory) and physical methods (instrumental) (Li et al. 2013). In this study tenderness of breast meat was influenced by dietary treatment. The findings are in agreement with Borgogno et al. (2017); Radulović et al. (2018) who reported a significant difference in the tenderness of breast meat from broiler chickens fed M. domestica and H. illucens fed Rainbow trout fish. The sensory analysis of breast meat samples showed higher acceptability from broilers fed I. belina meal. The findings of the current study concur with Mareko et al. (2010); Radulović et al. (2018) who observed statistically higher acceptability of drumstick and breast samples from broilers fed M. domestica and I. belina meal respectively.

However, the introduction of insects in animal feed has raised challenges about food safety issues. These include allergies in animal and human, chemical and microbial contaminants. The nutritional benefits of edible insects for both animals and humans needs further investigation (Van Huis 2020). More so, the safety of insect products depends very much on substrates on which insects are fed. There are several contaminants such as pesticides and mycotoxins that can be degraded in the insect gut (Van Huis 2020).

**Conclusions**

The dietary inclusion levels of I. belina meal up to 12% partly influenced the meat qualities of the breast meat and growth performance of broiler chickens. However, it impacted profoundly on the sensory scores of the breast meat, though the metallic taste was detected mainly in the dietary treatments. Nevertheless, further research should be done with regards to the cost-effectiveness of utilising I. belina meal in comparison with the conventional soybean oil cake.

**Ethical approval**

The use of animals for experimentation was approved by the Animal Research Ethics Committee (AREC) of the University of Fort Hare (Clearance Certificate No: MUC531SMOY01).

**Disclosure statement**

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