Effect of dietary graded levels of *Imbrasia belina* on the chemical composition and fatty acid profile of meat from broiler chickens

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Abstract

The effect of dietary graded inclusion levels of *Imbrasia belina* worm meal on meat chemical composition and fatty acid profile of broiler chicken meat was evaluated. A total of 360 chicks were randomly allocated to four dietary treatments, with each treatment group replicated 6 times ($n = 15/\text{replicate}$). The inclusion levels of the *I. belina* worm meal in the treatments were 0% control = T1, T2 = 4%, T3 = 8% and 12%. A three-phase feeding program of starter (0–14d), grower (15–28d), and finisher (29–35d) was employed for the study. The results showed that crude protein content of breast meat was higher ($P < 0.05$) in dietary treatments than control, whereas crude fat content of thigh meat was higher ($P < 0.05$) than in breast meat. The fatty acid composition of breast meat myristic and myristoleic acid levels were significantly reduced ($P < 0.05$) in treatment groups than the control, whereas the levels of linoleic acid, Σ PUFA, Σ PUFA/SFA, Σ PUFA: MUFA, Σ (n-6) in thigh meat decreased significantly ($P < 0.05$) in treatment groups than control. The Σ (n-3) and atherogenic index in the thigh meat increased significantly ($P < 0.05$) with incremental levels of *I. belina* meal. In conclusion, *I. belina* meal improved the protein content of breast meat and reduced levels of some fatty acids.

Keywords *Imbrasia belina* · Protein content · Meat composition · Fatty acids · Broilers

Introduction

The chemical composition of meat is an essential aspect of meat quality, which is typically assessed by the amount of physically dissected tissues or chemically analyzed constituents such as protein, fat, water and ash (Shija et al. 2013). More so, meat chemical composition is strongly influenced by the diet (Winiarska-Mieczan et al. 2016). The nutrition can result either in an enhanced or deteriorated quality of meat (Morales-Barrera et al. 2013; Vet et al. 2015; Yogesh et al. 2015).

The increases in global production and consumption of chicken meat have been associated with quality nutritional components such as high protein, low fat and moderately high concentration of polyunsaturated fatty acid (PUFA) (Brenes and Roura 2010; Riovanto et al. 2012; Nkukwana et al. 2014). Currently, consumers are more concerned about the quality of nutrient in their diet, and lipid content and fatty acid are critical nutritional factors necessary in the diet (Rubayet et al. 2017). As a result, manipulation of the fatty acid composition of poultry diets is the most efficient method to elevate the desired n-3 PUFAs accretion in poultry meat (Bhalerao et al. 2014; Ahmed et al. 2015). In terms of human health, the fatty acid composition of meat products is an essential factor of meat quality (Hossain et al. 2012). Hence, when choosing a protein source, consumers seek low-fat sources high in omega 3 (n-3) fatty acids (Christiansen et al. 2012). Improved intakes of n-3 fatty acids have a beneficial effect of reducing the risks of diseases such as diabetes, arthritis and cancer (Sala-Vila and Calder 2011; Delgado-Lista et al. 2012). However, the higher levels of PUFAs in muscle membranes increases the susceptibility of oxidative deterioration of lipids (Lisiak et al. 2013).

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Despite *I. belina* being documented as a poultry feed (Chiripasi et al. 2013; Kwiri et al. 2014; Manyeula et al. 2019); there is a dearth of information on its effect regarding fatty acid profiles and chemical composition on broiler meat. Since feed composition directly affects the fatty acid composition in muscle tissue, this research was conducted to evaluate the effect of feeding broiler chickens, with varying levels of *I. belina* on fatty acid profile and chemical composition of chicken breast and thigh meat.

Materials and Methods

Ethical consideration

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).

Preparation of *I. belina* worm meal and dietary treatment

The adult larvae of *I. belina* were harvested by hand from the *Colophospermum mopane* tree leaves. The mopane worms were prepared following procedures as described by Gondo and Frost (2002). The dried larvae was ground and sifted using a 2 mm sieve, then put in an air tight plastic container and deep frozen at -18°C until use. The inclusion levels of the *I. belina* worm meal in the treatments were T1 = 0% (for the control group and T2 = 4%, T3 = 8% and T4 = 12% (for experimental or test groups) replacing defatted soya as a protein source. The diets were formulated to meet each bird's dietary needs according to the dietary nutrient requirements (NRC 1994). The nutrient composition of *Imbrasia belina* is shown on Table 1 and the feed composition of experimental diets is shown in Table 2. Table 3 shows the nutritional composition of the diets, and Table 4 shows the fatty acids of *I. belina* worm.

Table 1 Chemical composition of mopane worm *Imbrasia belina*

Parameters (Dry matter basis)	Mean value (n = 3)
Moisture (g/100 g)	7.95 ± 0.01
Dry matter (g/100)	92.06 ± 0.02
Crude Protein (g/100 g)	58.40 ± 0.10
Ash (g/100 g)	3.14 ± 0.01
Crude Fibre (g/100 g)	10.98 ± 0.38
Vitamin E (mg/100 g)	4.42 ± 0.01

Values are means (± Standard error)

Bird management and experimental design

A total of three-hundred-and-sixty-day old Arbor Acre broiler chicks, of mixed-sex with an average body weight of 43 g were purchased from Nature form hatchery in Port Elizabeth, South Africa. At placement, birds were weighed and randomly allotted to 24 floor pens (1.5 × 1.5 m) in a deep litter system, with each bird guaranteed 0.15 m² of floor space. Wood shavings were utilized as bedding material applied to a depth of 8 cm to absorb moisture and provide warmth for the chicks (Musa et al. 2012). Birds were randomly allocated to four dietary treatments in a complete randomized experimental design. Feed and water were available ad libitum. Chicks were fed according to their ages using three phase feeding: starter crumbs, from day 1 to 14, grower pellets from day 15 to 28 and finisher pellets from day 29–35. Changeover of feed according to ages was gradually done, to avoid stress from changing of the diet. Electric lighting was used throughout the rearing period 24 h/day. During the first week of the experiment, the temperature in the chicken house was kept at 33 °C inside the house, which was reduced by 2–3 °C every week, until the final temperature of 22–24 °C was reached. Infra-red bulbs were used as a heat source. Also, the behavior of the birds was closely monitored as an indicator of the appropriateness of the temperature in the house (Sassi et al. 2016).

Slaughter and sampling procedure

At 35 day of age, one broiler from each replicate (6 birds per treatment) was randomly selected and were then ferried in chicken crates from the fowl run to the abattoir. At the abattoir, electrical stunning at 70 V for 2–4 s was done and immediately followed by exsanguination. 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. The breast and thigh meat samples were excised from the carcasses by removing the skin, bones and connective tissue. The thigh and breast muscles for meat composition and fatty acid samples were labelled vacuum packed and stored for analysis at -18 °C.

Chemical composition of meat

After 24 h, the breast and thigh meat samples were minced through a 5 mm plate meat grinding machine. The minced meat was sampled, vacuum packed and frozen for subsequent chemical analysis. Chemical composition of minced meat samples was performed on wet basis to determine moisture, ash, crude protein and fat content (AOAC 2016).

Table 2 Feed composition of experimental diets (as fed basis)

Ingredients (%)	Starter				Grower				Finisher			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
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	02.5	03.5	6	6	2.5	2.5	2.5	3.5	2.5	2.5	2.5	2.8
Oil crude soya	29	23.6	18.3	15.3	25	20.9	18.1	14.5	20.8	17.5	14.8	11.7
Defatted soya	0.622	0	0	0	1.235	0.568	0.206	0	1.157	0.673	0.311	0
Wheaten bran	1	1	1.2	2.4	0	0	0	0	0	0	0	0
Mopane worm	0	4	8	12	0	4	8	12	0	4	8	12
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
Monodicalcium 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
Axtra 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
Volume	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Moisture	9.95	9.99	9.93	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

IBM: *Imbrasia belina* meal, T1: 0% IBM, T2: 4% IBM, T3: 8% IBM, T4: 12% IBM

Fatty acids profile determination

Total lipids from muscle sample was quantitatively extracted, as described by Laudadio et al. (2012), using chloroform and methanol in a ratio of 2:1. A rotary evaporator (Labotec, South Africa) was used to dry the fat extracts under vacuum, and the extracts were dried overnight in a vacuum oven at 50 °C, using phosphorous pentoxide as moisture adsorbent. Total extractable intramuscular fat was determined gravimetrically from the extracted fat and expressed as % fat (w/w) per 100 g tissue. The fat free dry matter (FFDM) content was determined by weighing the residue on a pre-weighed filter paper, used for Folch extraction, after drying. By determining the difference in weight, the FFDM could be expressed as % FFDM (w/w) per 100 g tissue. The moisture content of the muscle and BF was determined by subtraction (100%- % lipid -%FFDM) and expressed as %

moisture (w/w) per 100 g tissue as described by Laudadio et al. (2012).

Approximately 25 mg of extracted lipid muscle was transferred into a Teflon-lined screw-top test tube. Fatty acid methyl esters (FAME) were prepared for gas chromatography by methylation of the extracted fat, using methanol-BF₃ (Slover and Lanza 1979). FAMES from muscle was quantified using a Varian GX 3400 flame ionization GC, with a fused silica capillary column, Chrompack CPSIL 88 (100 m length, 0.25 mm ID, 0.2 µm film thickness). The analysis was performed using an initial isothermic period (40 °C for 2 min). Thereafter, the temperature was increased at a rate of 4 °C/minute to 230 °C. Finally, an isothermic period of 230 °C for 10 min followed. FAMES n-hexane (1 µl) was injected into the column using a Varian 8200 CX Auto sampler. The injection port and detector

Table 3 Analyzed nutrient composition of the dietary treatments fed to broilers in 35-day study period on a dry matter basis

Nutrient %	Dietary Treatments											
	Starter				Grower				Finisher			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
Dry Matter	88.69	88.35	88.08	88.38	88.32	88.48	88.59	88.37	89.06	88.31	88.36	88.19
Moisture	11.31	11.65	11.92	11.62	11.68	11.52	11.41	11.63	10.94	11.69	11.64	11.81
Protein	20.66	21.06	21.61	22.62	19.54	20.27	20.44	21.06	17.42	18.30	20.50	20.49
Fibre	2.77	3.06	3.85	4.36	2.71	2.76	3.05	3.71	2.61	2.67	3.07	3.19
Ash	4.87	4.97	5.03	5.17	4.43	4.50	4.52	4.80	4.07	4.11	4.22	4.35
Fat	2.95	3.06	3.29	4.09	3.83	3.95	4.34	4.26	3.91	4.23	4.18	4.41

T1 positive control, T2, T3 and T4 contained graded levels of IBM at 4%, 8% and 12% of DM intake respectively

were both maintained at 250 °C. Hydrogen, at 45 psi, functioned as the carrier gas, while nitrogen was employed as the makeup gas. Varian Star Chromatography Software recorded the chromatograms.

Table 4 Fatty acid composition of mopane worm (*Imbrasia belina*) meal

Parameters	Quantity (g/100 g of dietary fat (n=3))
Fat	16.67 ± 0.132
Fat free Dry Matter	70.83 ± 0.110
Moisture	10.10 ± 0.225
Fatty Acids	
Myristic C14:0	0.38 ± 0.010
Pentadecylic C15:0	0.07 ± 0.001
Palmitic C16:0	25.80 ± 0.294
Palmitoleic C16:1c9	0.63 ± 0.005
Margaric C17:0	0.33 ± 0.005
Stearic acid C18:0	13.50 ± 0.050
Oleic C18:1c9	15.76 ± 0.147
Nonodecanoic C19:0	0.28 ± 0.010
Linoleic C18:2c9,12 (n-6)	7.73 ± 0.170
Arachidic C20:0	0.23 ± 0.020
γ-Linolenic C18:3c6,9,12 (n-3)	0.12 ± 0.005
α-Linolenic C18:3c9,12,15(n-3)	35.19 ± 0.020
Eicosatrienoic C20:3c8,11,14(n-6)	0.06 ± 0.011
Eicosatrienoic C20:3c11,14,17(n-3)	0.08 ± 0.001
Fatty acid ratio	
Total saturated fatty acids (SFA)	40.64 ± 0.176
Total Monounsaturated fatty acids (MUFA)	16.39 ± 0.156
Total Polyunsaturated fatty acids (PUFA)	42.98 ± 0.207
Total Omega-6 fatty acids (n-6)	7.79 ± 0.030
Total Omega-3 Fatty acids (n-3)	35.33 ± 0.133
PUFA: SFA	1.06 ± 0.010
PUFA: MUFA	2.62 ± 0.030
n-6: n-3	0.22 ± 0.005

Values are means (± Standard Error)

Fatty acids methyl ester samples were identified by comparing the retention times of FAME peaks from samples with those of standards obtained from Supelco (Supelco 37 Component Fame Mix 47,885-U, Sigma-Aldrich Aston Manor, Pretoria, South Africa). All other reagents and solvents were of analytical grade and obtained from Merck Chemicals (Pty Ltd), Halfway House, Johannesburg, South Africa. Fatty acids were expressed as the proportion of each individual fatty acid to the total of all fatty acids present in the sample. Fatty acids data were used to calculate the following ratios of FAs: total SFAs, total MUFAs; total PUFAs; PUFA/SFA; desaturase index (C18:1c9/C18:0); total omega-6; total omega-3; the ratio of omega-6 to omega-3 (n-6)/(n-3) FAs. Atherogenicity index (AI) was calculated as: AI = (C12:0 + C16:0)/(MUFA + PUFA) (Chilliard et al. 2003).

Statistical analysis

Data obtained for the chemical composition of meat and fatty acid profile were analyzed using the generalized linear model of Statistical Analysis Software (SAS 2003). The significant differences between treatments means were compared using Tukey's LSD test. The statistical model used was

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

where: Y_{ijk} = response variables (chemical composition of meat and fatty acid profile).

μ = the common mean.

T_i = treatment effect.

ε_{ijk} = random error.

The differences were considered significant at $P < 0.05$.

Results

Meat proximate composition

As shown in Table 5, the dietary treatment showed a significant effect ($P < 0.05$) in the moisture content in the breast than

Table 5 Effects of dietary inclusion levels of *Imbrasia belina* meal on proximate composition of broiler chicken meat

Parameter %	Muscle	Treatment				Effect		
		1	2	3	4	Treatment	Muscle	Treatment*muscle
Moisture	Breast	73.52 ^b	75.55 ^a	75.26 ^a	74.93 ^a	<.0001	<.0001	0.0035
	Thigh	68.69 ^c	71.25 ^a	68.85 ^b	70.49 ^a			
Protein	Breast	21.27 ^b	21.01 ^{bc}	22.11 ^a	21.04 ^d	0.0008	<.0001	<.0001
	Thigh	17.80 ^a	16.73 ^{bc}	16.59 ^{bd}	16.85 ^{ab}			
Fat	Breast	4.02 ^a	2.46 ^b	1.73 ^{bc}	1.68 ^d	<.0001	<.0001	<.0001
	Thigh	12.41 ^a	10.53 ^c	12.77 ^a	11.61 ^b			
Ash	Breast	1.10	1.11	1.13	1.07	0.0511	<.0001	0.1857
	Thigh	0.95	0.90	0.94	0.93			

^{abc}Values with different superscript in the same row differ significantly ($P < 0.05$)

thigh meat. However, moisture content was explicitly, and significantly ($P < 0.05$) higher in breast and thigh meat of broilers fed T2 than in T1. Also, the crude protein content was higher in breast meat ($P < 0.05$) than thigh meat. The birds fed diet T3 had a higher ($P < 0.05$) crude protein in breast meat than other treatments. A lower protein, but higher fat content was recorded in thigh meat than breast meat. However, birds fed T4 had the lowest fat content in breast meat. Meanwhile, the dietary inclusion levels of *I. belina* had no significant difference ($P > 0.05$) in breast and thigh meat observed for crude ash across treatments.

Meat fatty acid composition

The effect of dietary treatments on the fatty acid composition of broiler breast and thigh meat is shown in Table 6 and 7, respectively. Dietary inclusion levels of *I. belina* meal resulted in a significant ($P < 0.05$) reduction of myristic and myristoleic acid in broiler breast meat. Among individual MUFA, the oleic acid was higher in dietary treatments than in control. In the thigh meat, broilers fed treatment T2, T3 and T4 increased the palmitic and Σ SFA and stearic acid, though not significant ($P > 0.05$). The Σ MUFA was higher in T2 and T3, but with a reduced concentration of oleic acid. In addition, the α -linolenic acid concentration was higher in T2, T3 and T4, along with the Σ (n-3) fatty acids. Inclusion of *I. belina* meal in the broiler diet led to a reduction of linoleic, γ -linolenic, eicosadienoic linoleidic, eicosatrienoic and arachidonic. However, the eicosatrienoic, arachidonic and linoleidic were not significant. The Σ n-6 fatty acids were significantly ($P < 0.05$) reduced in broiler thigh meat than in control. The PUFA/SFA ratio was also significantly ($P < 0.05$) reduced in dietary treatments, along with the n-6/n-3 ratio.

Discussion

Moisture content is one of the main determinants of chicken meat quality (Castellini et al. 2002). In this study, higher moisture content was observed in the birds fed *I. belina*

meal, which is in agreement with a study conducted in the Republic of Korea (Ahmed et al. 2015). Increase in meat moisture with a corresponding increase in inclusion levels of *I. belina* meal could have been due to the inverse relationship between meat moisture and fat content. Dietary fat content is positively correlated with the fat content of meat among monogastric animals (Tuunainen et al. 2016). For the current study, the inclusion of *I. belina* in the broilers diet significantly reduced the fat content of the breast meat. The reduction of the fat content of the breast meat could be attributed to the low fat content in *I. belina* larvae meal (Rapatsa and Moyo 2017). Nevertheless, low fat content in breast meat is desirable to consumers. The high fat content of the broiler thigh meat, observed in the current study could be attributed to the fact that thigh meat stores more energy (high glycogen) than breast meat, most probably as a source of energy for walking (Mbagi et al. 2014; Manap 2018). The fat content from various cuts of broiler chickens has been shown to differ significantly (Kumar and Rani 2014).

Our study also observed an increase in the protein content of breast meat of broiler chickens fed dietary treatment. This increment is in agreement with Ballitoc and Sun (2013), who reported an increase in protein content of breast meat of broilers fed *Tenebrio molitor* larvae meal. This increase of protein in the breast meat in these studies may be attributed to high levels of protein content in *I. belina* worm 56.8 g/100 g (Rapatsa and Moyo 2017) and mealworm larvae 44–70% protein (Islam et al. 2016). The increased crude ash content in breast meat observed in this study is substantiated by Islam et al. (2016) who recorded an increase of ash content in breast meat of broilers fed mealworm larvae.

Limited research has been done, to establish the effect of *I. belina* worm meal on the fatty acids' composition of breasts and thigh meat of the broiler chickens. In the present study, there was a reduction of myristic and myristoleic acid. The result contradicts the findings of Schiavone et al. (2019) who reported an increase of myristic acid content with incremental feeding of *Hermetia illucens* larvae

Table 6 Means ($\pm$ Standard error) of fatty acids methyl esters % FAME derived from breast meat of broiler chickens fed *Imbrasia belina* meal

Dietary Treatments							
FAME	Common Name	T1	T2	T3	T4	SEM	P-Value
C14:0	Myristic	0.42 ^a	0.31 ^b	0.35 ^a	0.36 ^a	0.0209	0.0344
C14:1c9	Myristoleic	0.12 ^a	0.08 ^b	0.07 ^c	0.10 ^a	0.0093	0.0130
C16:0	Palmitic	25.66	23.47	25.30	24.36	0.6605	0.1633
C16:1c9	Palmitoleic	6.02	5.30	5.12	5.79	0.4071	0.4224
C17:0	Margaric	0.04	0.05	0.06	0.06	0.0125	0.4505
C18:0	Stearic acid	6.42	6.30	7.72	6.71	0.3903	0.1562
C18:119	Elaidic	0.03	0.05	0.02	0.00	0.0191	0.4190
C18:1c9	Oleic	34.60	37.13	34.23	35.64	1.2335	0.4011
C18:1c7	Vaccenic	4.35	4.47	3.92	4.43	0.1639	0.1409
C18:219,12(n-6)	Linolelaidic	0.14	0.16	0.22	0.16	0.0507	0.6795
C18:2c9,12(n-6)	Linoleic	17.41	17.29	16.35	16.14	0.9008	0.6861
C20:0	Arachidic	0.03	0.04	0.04	0.03	0.0065	0.2843
C18:3c6,9,12 (n-6)	γ -Linolenic	0.07	0.10	0.10	0.09	0.0144	0.5838
C18:3c9,12,15, (n-3)	α -Linolenic	2.56	2.37	3.06	3.59	0.8236	0.7235
C20:2c11,14 (n-6)	Eicosadienoic	0.13	0.15	0.13	0.12	0.0183	0.5596
C20:3c8,11,14 (n-6)	Eicosatrienoic	0.36	0.42	0.44	0.40	0.0761	0.8646
C20:3c8,11,14,17(n-3)	Eicosatrienoic	0.03	0.02	0.04	0.05	0.0269	0.8599
C20:4c5,8,11,14,17 (n-6)	Arachidonic	1.05	1.43	1.47	1.38	0.2760	0.6995
C20:5c5,8,11,14,17(n-3)	Eicosapentaenoic	0.21	0.22	0.47	0.33	0.1368	0.5459
C20:5c7,10,13,16,19 (n-3)	Docosapentaenoic	0.24	0.24	0.50	0.38	0.1388	0.5112
C22:6c4,7,10,13,16,19(n-3)	Docosahexanoic	0.11	0.13	0.36	0.20	0.0943	0.2799
Σ SFA		32.58	30.42	33.47	31.52	0.9490	0.2032
Σ MUFA		45.12	47.04	43.37	45.63	1.2733	0.3080
Σ PUFA		22.30	22.54	23.15	22.85	0.9398	0.9210
Σ (n-6)		19.15	19.56	18.71	18.21	1.0622	0.8490
Σ (n-3)		3.15	2.98	4.44	4.56	1.0622	0.6260
PUFA: SFA		0.68	0.74	0.69	0.73	0.0377	0.0761
PUFA/MUFA		0.50	0.48	0.54	0.50	0.0343	0.6624
n-6/n-3		9.12	6.57	4.23	5.92	2.2090	0.5083
Atherogenic Index		0.40	0.37	0.40	0.38	0.0144	0.1329
Desaturase Index		0.19	0.18	0.23	0.19	0.0169	0.2198

^{abc}Values with different superscript in the same row differ significantly ($P < 0.05$)

meal to broilers. However, the reduction in myristic acid is associated with good nutritional value and health benefits. Myristic acid has hypercholesterolemic properties, which a precursor for many coronary diseases (Ahmed et al. 2015). The decrease of stearic acid and Σ SFA and increase of oleic acid and Σ MUFA observed in our study may be attributed to the fact that stearic acid is rapidly converted to oleic acid (Bruce and Salter 1996). Also, stearic acid improves meat quality, as indicated by observed highest scores in meat sensory quality (Mir et al. 2000).

More so, an increase in SFA and decrease of PUFA observed in this study agrees with Schiavone et al. (2017). They observed that the supplementation of *H. illucens* oil to broiler diet increased SFA and decreased PUFA in the breast muscle but did not affect MUFA content. Furthermore, Kierończyk et al. (2018) observed a decrease of SFA and an increase of MUFA in the breast of broilers fed *T. molitor* oil, but the level of PUFA was unchanged in comparison to the broilers fed soybean oil. The disagreement between the results of other trials using the same insect species could be

ascribed to the well documented variability of the fatty acid composition of the insect fat, due to the rearing substrate utilized for larvae production (Makkar et al. 2014). Also, the use of insect oil could have attributed to the difference noted in the current study. However, PUFAs are more susceptible to oxidative impairment (González-Ortiz et al. 2013) in breast meat that might affect the quality during storage. Besides the health benefits of PUFAs compared to SFAs, it has been observed in broiler chickens that the inclusion of PUFAs in the diet reduces abdominal fat and total body fat compared with SFA rich diet (Ferrini et al. 2008). The present study also detected an increase of n-3 PUFA, for both thigh and breast meat particularly α -linolenic acid. The level of n-3 PUFA could be attributed to the decrease in arachidonic acid, due to the action of delta-6/s-desaturase enzymes in the elongation and desaturation metabolism (Nuernberg et al. 2002).

The PUFA/SFA, n-6/n-3 ratio and atherogenic index are indicators of quality nutritional and improves meat sensory quality (Benzertiha et al. 2019). The PUFA/SFA ratio is an

Table 7 Means ($\pm$ Standard error) of fatty acids methyl esters % FAME derived from thigh meat of broiler chickens fed *Imbrasia belina* meal

Dietary Treatments		T1	T2	T3	T4	SEM	P-Value
FAME	Common Name						
C14:0	Myristic	0.30	0.33	0.35	0.35	0.0105	0.0596
C14:1c9	Myristoleic	0.06	0.09	0.08	0.08	0.0089	0.2283
C16:0	Palmitic	22.72 ^d	23.40 ^b	24.81 ^a	23.20 ^c	0.2647	0.0029
C16:1c9	Palmitoleic	4.87	5.70	5.59	5.42	0.2844	0.2433
C17:0	Margaric	0.04	0.05	0.04	0.08	0.0109	0.0951
C18:0	Stearic acid	6.99	6.88	7.79	7.66	0.2962	0.1428
C18:119	Elaidic	0.04	0.06	0.04	0.03	0.0091	0.2740
C18:1c9	Oleic	37.96	37.11	36.63	35.99	0.5602	0.5410
C18:1c7	Vaccenic	4.73	4.16	4.03	4.14	0.2059	0.1500
C18:219,12 (n-6)	Linolelaidic	0.12	0.08	0.10	0.13	0.0201	0.3779
C18:2c9,12 (n-6)	Linoleic	19.56 ^a	17.69 ^b	15.29 ^d	15.60 ^c	0.3674	0.0001
C20:0	Arachidic	0.03	0.04	0.04	0.04	0.0029	0.1631
C18:3c6,9,12 (n-6)	γ -Linolenic	0.11 ^a	0.11 ^a	0.07 ^b	0.06 ^c	0.0764	0.0013
C18:3c9,12,15 (n-3)	α -Linolenic	1.38 ^d	2.29 ^c	2.88 ^b	4.43 ^a	0.0861	<.0001
C20:2c11,14 (n-6)	Eicosadienoic	0.12 ^a	0.08 ^b	0.07 ^c	0.09 ^a	0.0085	0.0106
C20:3c8,11,14 (n-6)	Eicosatrienoic	0.37	0.28	0.28	0.30	0.0305	0.2247
C20:3c8,11,14,17 (n-3)	Eicosatrienoic	0.00 ^c	0.00 ^c	0.01 ^b	0.06 ^a	0.0101	0.0044
C20:4c5,8,11,14,17 (n-6)	Arachidonic	1.64	1.25	1.13	1.23	0.1602	0.1960
C20:5c5,8,11,14,17 (n-3)	Eicosapentaenoic	0.08 ^c	0.12 ^b	0.28 ^a	0.39 ^a	0.0373	0.0012
C20:5c7,10,13,16,19 (n-3)	Docosapentaenoic	0.13 ^d	0.18 ^c	0.29 ^b	0.47 ^a	0.0392	0.0013
C22:6c4,7,10,13,16,19 (n-3)	Docosahexanoic	0.06 ^c	0.10 ^b	0.20 ^a	0.25 ^a	0.0401	0.0362
Σ SFA		30.09 ^c	30.71 ^b	33.02 ^a	31.32 ^a	0.5097	0.0182
Σ MUFA		46.33	47.11	46.39	45.68	0.6729	0.5480
Σ PUFA		23.57 ^a	22.17 ^a	20.58 ^b	22.99 ^a	0.4402	0.0067
Σ (n-6)		21.93 ^a	19.49 ^b	16.93 ^d	17.40 ^c	0.3751	<.0001
Σ (n-3)		1.65 ^d	2.68 ^c	3.66 ^b	5.60 ^a	0.0861	0.0016
PUFA: SFA		0.78 ^a	0.72 ^a	0.62 ^b	0.73 ^a	0.0180	0.0461
PUFA/MUFA		0.51	0.47	0.44	0.50	0.0154	0.0457
n-6/n-3		13.29 ^a	7.26 ^b	4.63 ^c	3.11 ^d	0.1268	<.0001
Atherogenic Index		0.34 ^c	0.36 ^b	0.39 ^a	0.36 ^b	0.0060	0.0020
Desaturase Index		0.19	0.19	0.21	0.21	0.0107	0.2587

^{abc}Values with different superscript in the same row differ significantly ($P < 0.05$)

important indicator of lipid composition in a healthy diet. The value of the PUFA/SFA ratio in the current study was slightly below 0.93. Jennifer and Joan (2015), reported that in humans' diet, this ratio of PUFA/SFA should be maintained close to 1. Hence, this value represents meat that safe and healthy for consumers (Paul et al. 2017). A lower ratio of n-6/n-3 fatty acid in breast and thigh meat observed in this study is more desirable; it guarantees the equilibrium of coagulation, inflammation and immune response. In addition, the body needs more of w-3 than w-6 fatty acids. It further modulates many genes involved in oxidative processes, hence avoiding chronic diseases (Islam et al. 2016). In a similar study, n-6/n-3 was not affected by the inclusion of *H. illucens* larvae meal in the diet of broiler chickens (Schiafone et al. 2019). On the other hand, a significantly lower n-6/n-3 was reported in another study (Molee et al. 2012).

The inclusion of *I. belina* larvae meal in the diet of broiler chickens led to the modification of fatty acid profiles of breast meat, with higher MUFAs and lower PUFAs in dietary treatments than the control. This result agrees with the findings of Schiafone et al. (2019). However, in order to balance and overcome these potential negative effects

linked to *I. belina* larvae meal utilization, modulation of the larva rearing substrate should be recommended to attain an improved insect larvae fatty acid profile and provide meat that are safe for consumers.

Conclusion

The results of the current study established that inclusion of *I. belina* in broiler chicken diets would subsequently affect the composition of fatty acids in broiler chicken meat. Interestingly very few changes were detected in the fatty acid composition of broiler breast meat. Hence, *I. belina* can be used in broiler chicken feeding with positive effects on meat quality and human health. However further research is suggested to determine the fatty acid metabolism of *I. belina* using different larval stages of growth.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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