Agraarteadus
1 • XXXIII • 2022 1–10

Journal of Agricultural Science
1 • XXXIII • 2022 1–10

CARCASS CHARACTERISTICS AND MEAT QUALITY OF BROILER CHICKENS FED DIETARY WHITE AND CAYENNE PEPPER POWDERS AS ADDITIVES

Adeola Adegoke, Kehinde Sanwo, Lawrence Egbeyale, Munirat Abatan, Modupe Oluwasinmi, Oluwaseun Adebesin, Oluwaseun Williams

Department of Animal Production and Health, Federal University of Agriculture, P.M.B. 2240 Abeokuta, Nigeria

Saabunud: Received: 01.03.2022

Aktsepteeritud: Accepted: 10.06.2022

Avaldatud veebis: Published online: 10.06.2022

Vastutav autor: Corresponding author: Adeola Adegoke

E-mail: adegokeav@funaab.edu.ng

ORCID:
0000-0002-5973-3175 (AA)
0000-0002-2760-2453 (KS)
0000-0002-6908-4754 (LE)
0000-0001-8338-6237 (MA)
0000-0001-9029-3879 (MO)
0000-0003-3701-3262 (OA)
0000-0002-2293-7377 (OW)

Keywords: white pepper powder, cayenne pepper powder, carcass characteristics, lipid profile, enzymatic antioxidants, oxidative spoilage.

DOI: 10.15159/jas.22.18

ABSTRACT. A study was conducted to investigate the influence of dietary white pepper (wp) and cayenne pepper (cp) powders fed as additives on carcass characteristics and meat quality of broiler chickens. Fifty-six broiler chickens (two per replicate) were slaughtered (each close to average weight per replicate) from a total of 336 randomly allotted chickens given seven diets each apportioned to four replicates. Data obtained were subjected to a One-way Analysis of Variance with significant means separated at P <0.05. Results obtained reveal larger dressed and breast weights, as well as meat + skin:bone ratio was recorded among chickens fed addition of 200 g of cayenne pepper to the Control diet (C) (C+200cp). Notably, only chickens fed C+200wp and C+125wp+125cp diets had meat containing palmitoleic fatty acid; though the latter (1.28) had higher (P <0.05) linoleic than C+100wp+100cp (0.67). On the contrary, feeding C+125wp+125cp diet resulted in numerically least meat Index of Atherogenicity (IA) (0.49). Meat lipid cholesterol profile was preferred (P <0.05) in the meat of chickens fed C+200wp diet, though identical (P <0.05) to C+250wp diet. Feeding C+125wp+125cp diet resulted in a low (P <0.05) meat superoxide dismutase value (89.23). This study has shown that to gain a larger yield, C+200cp diet should be fed to chickens. Palmitoleic acid – a rare fatty acid occasionally consumed in Western diets was found only in the meat of chickens fed C+200wp and C+125wp+125cp diets, but for an overall balanced fatty acid profile - hazily depicted by Index of Atherogenicity, C+125wp+125cp diet is suggested as it indicates the impact of stress was minimized. Meat endogenous antioxidant profile reveals stress imposed on chickens in C+125wp+125cp group was lowered by antioxidant fed – a significance to poultry farmers.

Introduction

Encouraged by the rapid conversion of feed to meat coupled with short rearing cycles, rearing meat-type chickens is the trend in commercial poultry with special emphasis on carcass yield and quality meat. Marangoni *et al.* (2015) class poultry meat to be comparable to other meats in cholesterol content but offer superior nutrients when the protein, total fat and calorie content are compared with meat from other sources. Nutritional compositions have been adjusted with a significant impact on yield and quality of the product as findings abound on the application of additives such as probiotics, vitamins and mineral mixture mix on carcass characteristics of broiler chicken in tandem with production economics (Singh *et al*., 2018).

Meat quality is a critical field of study, especially considering meat is a common component of the diet of man. Limited advancement in technology can have negative effect on the quality of meat and meat products supplied to consumers. Animal products are traditionally preserved in a variety of ways but nutrients obtained post-slaughter and subsequent storage employed may result in depleted nutrients that are inadequate to sustain healthy living – especially in countries with developing economies. A positive, however is that meat can be enriched and the desired goal is to increase the profile of

essential but limited nutrients as well as minimize product spoilage. Lopez-Ferrer *et al.* (1999) posited that enrichment of poultry meat with health-promoting substances should be explored as modification of muscle tissue composition can be achieved via increased dietary polyunsaturated fatty acid profile (PUFA) content (Lopez-Ferrer *et al*., 2001) in tandem with its nutritional profile and characteristics (Galli *et al*., 2019).

Additives have been incorporated into poultry diets to elicit special effects desired by producers and consumers. Mondal *et al.* (2015) referred to feed additives as all products excluding commonly known feedstuffs that are incorporated into rations to obtain desired outcomes. Pepper powders have been added as additives in broiler rations with contrasting outcomes on performance (Galib *et al*., 2011; El Tazi *et al*., 2014), though a dearth of information exists on carcass yield and quality of meat produced afterwards. One of such few was conducted by Adegoke *et al*. (2016), who reported that cayenne pepper significantly affected carcass weight at lower levels of incorporation. Cayenne pepper (*Capsicum frutescens*) is a phytogenic substance that can stimulate endogenous enzymes that promote growth. Capsaicin, the principal antioxidant principle in cayenne and red peppers suppresses fat accumulation, oxidation and triglyceride levels as well as regulates the inflammatory process (Kang *et al*., 2011). On the other hand, Olalere *et al.* (2018) declared that *Piper nigrum* (white pepper) contains beneficial functional compounds as shown by the optimized oleoresin yield of 8.72 w/w %, while its analyzed compositional output of 31 bioactive compounds attests to its radical scavenging activity. A study on piperine showed that it possesses potential fat reducing and lipid-lowering effects, without any change in food appetite at a small dose (Shah *et al.,* 2011), but at a high dosage, fat content in animal products may be affected. On this premise, this study was designed to assess the impact of dietary white and cayenne pepper powders fed as additives on carcass characteristics and meat quality (lipid, antioxidant and storage potential) of broiler chickens.

Materials and Methods

Experimental site

Slaughtering of chickens and subsequent extraction of breast muscles from the carcass was carried out at the Animal Product and Processing Laboratory of the Department of Animal Production and Health. Meat quality assessment was performed at the College of Veterinary Medicine within the same Institution.

Feed offered before the experiment

Dietary layout chickens were subjected to prior to experiment comprised:

- Control diet (C) (No pepper added)
- T2 – Control diet + 200 g White Pepper (wp) (C+200wp)
- T3 – Control diet + 250 g White Pepper (C+250wp)
- T4 – Control diet + 200 g Cayenne Pepper (cp) (C+200cp)
- T5 - Control diet + 250 g Cayenne Pepper (C+250cp)
- T6 – Control diet + 100 g White Pepper +100 g Cayenne Pepper (C+100wp+100cp)
- T7– Control diet + 125 g White Pepper + 125 g Cayenne Pepper (C+125wp+125cp)

Proximate analysis of the seven diets fed before the experiment was determined according to AOAC (2005) and the values obtained are documented in Table 1.

Table 1. Composition of diets fed chickens prior to experiment

Ingredients, kg	Control	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp +100cp	C+125wp+125cp
Maize	54.00	54.00	54.00	54.00	54.00	54.00	54.00
Wheat offal	10.50	10.30	10.25	10.30	10.25	10.30	10.25
Soybean meal	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Groundnut cake	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Bonemeal	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral and vitamin premix*	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Methionine	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lysine	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Cayenne pepper	0.00	0.00	0.00	0.20	0.25	0.10	0.13
White pepper	0.00	0.20	0.25	0.00	0.00	0.10	0.13
Total	100.00	100.20	100.25	100.20	100.25	100.20	100.25
Determined analysis, %							
Crude protein	20.53	20.54	20.54	20.52	20.53	20.53	20.53
Metabolizable energy, Kcal	2 851.33	2 851.33	2 851.36	2 851.40	2 851.46	2 852.39	2 851.42
Ether extract	3.94	3.95	3.96	3.95	3.95	3.95	3.95
Crude fibre	3.68	3.74	3.76	3.73	3.74	3.73	3.74
Calcium	1.26	1.26	1.26	1.27	1.27	1.26	1.26
Phosphorus	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Lysine	1.55	1.55	1.55	1.55	1.55	1.55	1.55
Methionine	0.47	0.47	0.47	0.47	0.47	0.47	0.47

*Premix composition per kg diet – Vit A – 400 000.00 IU; Vit D3 – 800 000.00 IU; Vit E – 20 000 IU; Vit k – 800.00 mg; Vit B1 – 1 000.00 mg; Vit B6 – 500.00 mg; Vit B12 – 25.00 mg; Niacin – 6 000.00 mg; Pantothenic acid – 7 500.00 mg; Folic acid – 200.00 mg; Biotin – 8 mg; Mn – 300 000.00 g; Zn – 20 000.00 g; Cobalt – 80.00 mg; I – 40.00 mg; Choline – 80 000.00 g; Antioxidants – 125.00 mg

Management of chickens before the experiment

A total of fifty-six chickens were selected from three hundred and thirty-six (2-weeks old) collectively floor brooded Cobb-500 broiler chicks randomly distributed into groups (each comprising forty-eight chickens per treatment and twelve chickens per replicate) fed seven diets (laid out above) for 32 days. Chickens were raised under an intensive system and reared on deep litter using wood shavings up to a depth of 3 inches as bedding material. Post-brooding, chickens were distributed into replicates setup using 1 sq ft per spacing. Feed and water were provided *ad libitum*.

Experimental procedure

Upon expiration of feeding, a total of fifty-six (two per replicate) chickens, each with a weight close to the average of a replicate were selected for carcass evaluation. Chickens selected weighed between 2 003.75 and 2 087.75 grams. Afterwards, breast muscles were extracted from twenty-eight carcasses for meat quality assessment.

Data collection

Carcass analysis

Each selected bird was weighed, tagged, separated and fed-fasted overnight. After 12 hours, chickens were slaughtered with carcasses cleaned and drained post-slaughter. The plucked, eviscerated and dressed weights were taken using a Hana kitchen scale (Model J1109130189, China, Calibration – 20 kg x 50 g) and then the head, shank and viscera were removed before the documentation of the dressed weight. Thereafter, the weight of cut-up parts and organs was recorded with an Electronic Compact Scale (Model – SF- 400C, Venezia, Calibration – 500 g x 0.01 g), then expressed as a percentage of the live weight. Internal organs (heart, liver, kidney and gizzard) were harvested, weighed and expressed as a percentage of the live weight, while the whole intestinal weight was likewise recorded.

Meat and bone from the right drumstick of each carcass were separately weighed to obtain a meat + skin to bone ratio. Fat around the cloaca, bursa of *Fabricius*, proventriculus, and muscles adjacent to the abdomen were harvested as abdominal fat deposits were weighed and recorded.

Meat lipid profile assessment

Fifteen grams of meat from the breast muscles of each replicate was apportioned for lipid profile analysis. Apportioned meat was ground and formed into a compound paste by the addition of a known amount of chloroform and methanol mixture 1:1 (v/v). Thereafter, extract from meat was formed into a final volume by chloroform addition, followed by decantation, before meat cholesterol, triacylglycerol and high and low-density lipoprotein determination (Folch *et al*., 1957). Fatty acid methyl esters were obtained via acid catalysis as described by Hartman and Lago (1973). Thirty grams of meat from the breast muscle of each sample was injected (1 µL) in split mode (20:1) into a Varian 3400CX gas chromatography (USA), equipped with a flame ionization detector (GC-FID) and the GC column was an HP-88 (Agilent Technologies, USA) (100 m x 0.25 mm x 0.20 µm). The column temperature was held at 50 °C for 1 min. Afterwards, the temperature was increased to 185 °C, at the rate of 15° C min^{-1}, followed by an increase at 0.5 °C min^{-1} to 190 °C, and increased at 15 °C min^{-1}, to 230 °C, hand-held for 5 min. The injector and detector temperature was set at 250 °C. The absorbance of concentration of different standard solutions of each specific fatty acid and sample benzene extracts were taken on a spectrophotometer at a wavelength defined for each fatty acid. Fatty acid was identified via normalization of each peak area to the total peak area based on AOCS (1998) Ce1f-96. To obtain the Index of Atherogenicity of chicken meat, the connection between the sum of the proatherogenic and antiatherogenic fatty acids was calculated using a formula designed by Ulbricht and Southgate (1991):

$$IA = \frac{(4 \times C14{:}0 + C16{:}0)}{\sum MUFA + \sum(n-6) + \sum(n-3)} \quad (1)$$

Twenty grams of meat from the thigh muscles were cut out for oxidative analysis. Samples were placed in test tubes in homogenized Tris-HCL (Sigma Chemical Co. USA) for superoxide dismutase (SOD) and glutathione peroxidase activity. These were measured spectrophotometrically at 480 nm for SOD, and 340 nm for GPx respectively (Galli *et al*., 2019) respectively. Values were expressed as U mg^{-1} protein. To determine the malondialdehyde count in chicken meat, ten grams of meat from the breast muscles of each replicate was homogenized in 30 ml of distilled water to obtain meat malondialdehyde (MDA) count. Lipid oxidation was measured and recorded as a 2-thiobarbituric acid-reactive substance (TBARS) value according to the method described by Ahn *et al.* (1998). Lipid oxidization was reported as milligrams of MDA per gram of meat.

Statistical analysis

Data obtained were subjected to One-Way Analysis of Variance using Statistical Package for Social Sciences (SPSS) version 21 (SPSS, 2012). Significantly different means at $P < 0.05$ were compared and separated using the Duncan Multiple Range Test (DMRT) of the same statistical package.

Results

Carcass yield of broiler chickens fed dietary peppers as additives were documented (Table 2). Carcass yield was not significant ($P > 0.05$) except for dressed percentage. Highest ($P < 0.05$) dress percentage was recorded for groups fed C+200cp diet though a similar value was obtained when C+250wp (72.69%) C+250cp and C+100cp+100wp diets were fed. The head, neck, back and breast were influenced ($P < 0.05$) by the integration of peppers as additives in poultry feed. Head (2.69%) and neck parts for chickens fed no additive were highest ($P < 0.05$), though statistically identical to the neck weight of the group offered C+200cp diet. Back weight ranged

between 14.54 – 16.98%. Breast portions of groups that offered C+200cp and C+250cp diets were higher (P <0.05) than in the Control. Meat + skin:bone ratio was greater among groups given C+200cp diet than C+250cp, but similar (P <0.05) in weights to the other groups. Internal organs (heart, kidney, gizzard, spleen and liver), abdominal fat and intestine + ceca weights were not influenced (P >0.05) by dietary pepper powders offered.

Table 2. Carcass yield of broiler chickens fed dietary peppers (*Capsicum frutescens and Piper nigrum*) as additives

Parameters	Control	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp+100cp	C+125wp+125cp	SEM
Initial weight, g	318.63	323.42	323.56	323.69	323.29	322.40	318.10	1.01
Feed intake, g	3 858.04	3 861.88	3 692.42	3 729.46	3 818.85	3 767.66	3 630.13	17.81
Live weight (LW), g	2 041.50	2 003.75	2 022.50	2 026.25	2 087.75	2 024.00	2 066.25	11.08
Carcass yield								
Eviscerated weight, g	1 671.25	1 660.25	1 695.50	1 719.75	1 730.75	1 691.00	1 675.50	10.91
Dressed weight, g	1 437.50	1 445.75	1 470.00	1 530.50	1 517.50	1 490.25	1 470.00	11.83
Dressed, % LW	70.43^{c}	72.13^{bc}	72.69^{abc}	75.52^{a}	72.66^{abc}	73.62^{ab}	71.15^{bc}	0.43
Cut-up parts, % LW								
Head	2.69^{a}	2.36^{ab}	2.30^{ab}	2.06^{b}	2.47^{ab}	2.41^{ab}	2.28^{ab}	0.06
Shank	3.95	3.77	4.03	3.49	3.71	3.67	3.88	0.06
Neck	4.62^{a}	4.15^{abc}	4.27^{ab}	4.68^{a}	3.34^{c}	3.64^{bc}	4.38^{ab}	0.13
Wings	8.13	8.18	8.12	8.11	7.50	7.77	7.31	0.16
Back	14.57^{b}	14.89^{ab}	16.52^{ab}	14.54^{b}	14.87^{ab}	16.98^{a}	16.06^{ab}	0.30
Breast	23.53^{b}	25.16^{ab}	24.09^{ab}	26.81^{a}	26.70^{a}	25.71^{ab}	24.45^{ab}	0.38
Thigh	10.90	11.71	11.71	11.91	11.20	11.03	10.75	0.19
Drumstick	11.65	11.50	11.69	11.39	11.08	11.36	10.94	0.15
Meat + skin:bone ratio	4.96^{ab}	4.56^{ab}	5.08^{ab}	5.71^{a}	4.21^{b}	5.10^{ab}	5.47^{ab}	0.17
Internal organs, % LW								
Heart	0.42	0.35	0.47	0.41	0.48	0.41	0.41	0.03
Kidney	0.27	0.36	0.41	0.35	0.36	0.35	0.41	0.02
Gizzard	1.72	1.65	1.69	1.53	1.47	1.66	1.63	0.04
Spleen	0.05	0.04	0.04	0.04	0.03	0.03	0.04	0.00
Liver	1.38	1.46	1.46	1.38	1.40	1.46	1.45	0.04
Intestine + caeca	3.12	2.65	2.92	2.99	2.71	2.89	3.15	0.07
Abdominal fat	0.81	0.69	1.10	0.70	0.67	0.77	0.85	0.07

$^{a, b}$ – Means on the same row with different superscripts differ significantly (P <0.05).
cp – cayenne pepper powder; wp – white pepper powder

Saturated and unsaturated fatty acid (SFA and UFA), Index of Atherogenicity (IA) and n-3:n-6 ratio in the meat of chickens fed dietary additives are represented in Table 3. Monounsaturated fatty acids (MUFA) found in meat are palmitoleic and oleic fatty acids with the former significant (P <0.05). Lauric acid was higher (P <0.05) among groups fed the Control and C+200wp diets but lower (P <0.05) in meat of chickens fed C+100wp+100cp and C+125wp+125cp diets, while groups between the extremes exhibited similar (P >0.05) value. Myristic fatty acid count in the meat of chickens fed C+200wp diet was increased than in the Control, C+200cp, C+250cp and C+125wp+125cp groups, though similar as meat from groups given C+100wp+100cp diet. Groups given the Control, C+200cp and C+250wp diets had higher (P <0.05) palmitic fatty acid values than chickens fed C+125wp+ 125cp diets. The margaric fatty acid content in meat of chickens fed C+200wp diet was higher (P <0.05) than C+125wp+125cp diet, though the amount in the latter (C+ 125wp+125cp) was similar (P <0.05) as groups that had no margaric fatty acid. Meat MUFA values ranged from 0.000 to 0.310% for palmitoleic fatty acid. C+200wp diet-fed resulted in elevated (P <0.05) meat palmitoleic fatty acid count for C+200wp group than C+125wp+125cp group, though absent when other diets were fed. No effect (P >0.05) of dietary peppers was observed for PUFA except for linoleic fatty acid. Chickens given C+200wp diet had increased (P <0.05) meat linoleic acid than chickens offered C+100wp+ 100cp diet. Meat n-3:n-6 was significant (P <0.05) with values ranging between 1.560–3.372, with least (P <0.05) value recorded among C+125wp+125cp and C+200wp groups, compared to C+100wp+100cp group that higher value..

The meat lipid profile of chickens fed additives is shown in Table 4. Meat cholesterol and triglyceride were not influenced (P >0.05) by dietary additives. At 200 g wp addition with the Contol diet, meat HDL was highest (P <0.05). Meat from chickens on 0% pepper additive, C+250cp and C+125wp+125cp groups had lowest (P <0.05) HDL values though identical as C+100wp+100cp diet. The least LDL value was recorded in groups fed the Control diet, though statistically similar to chickens on C+250cp diet. Highest (P <0.05) meat LDL was recorded for groups on C+200cp diet. Enzymatic antioxidant profile in the meat of chickens given dietary *Capsicum frutescens* and *Piper nigrum* powders as additives is documented in Table 5. Meat superoxide dismutase for the Control and C+125wp+125cp groups were significantly (P <0.05) highest and lowest respectively, while other groups had similar (P >0.05) values. Glutathione peroxidase content in meat was not significantly (P >0.05) influenced by dietary additives fed.

Meat malondialdehyde (MDA) count from chickens offered dietary pepper (white and cayenne) powders was significantly influenced by the diet as presented in Table 4. Meat MDA count was least in meat from chickens fed C+250wp diet, followed by the Control group. All other groups had statistically higher (P <0.05) MDA count.

Table 3. Fatty acid profile of meat from broiler chickens offered dietary pepper powders as additives

Parameters (%)	Control (C)	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp+100cp	C+125wp+125cp	SEM
Lauric (12:0)	1.230^{a}	1.140^{a}	0.920^{ab}	1.080^{ab}	1.080^{ab}	0.770^{b}	1.020^{b}	0.045
Myristic (14:0)	0.180^{c}	0.390^{a}	0.210^{bc}	0.130^{c}	0.130^{c}	0.330^{ab}	0.160^{c}	0.025
Palmitic (16:0)	8.790^{a}	6.890^{ab}	7.850^{ab}	8.810^{a}	8.760^{a}	7.150^{ab}	5.110^{b}	0.405
Margaric (17:0)	0.040^{bc}	0.250^{a}	0.000^{c}	0.000^{c}	0.000^{c}	0.000^{c}	0.060^{b}	0.198
Stearic (18:0)	21.050	23.040	19.780	24.330	21.890	21.670	18.770	1.158
SFA	31.290	31.710	28.760	34.350	31.860	29.920	25.120	1.233
Palmitoleic (16:1; ω-7)	0.000^{c}	0.310^{a}	0.000^{c}	0.000^{c}	0.000^{c}	0.000^{c}	0.140^{b}	0.026
Oleic (18:1 ω-9)	11.030	8.260	9.890	11.040	12.050	8.260	8.050	0.550
MUFA	11.030	8.570	9.890	11.040	12.050	8.260	8.190	0.540
Linoleic (18:2; ω-6)	1.080^{ab}	1.280^{a}	1.030^{ab}	1.080^{ab}	0.910^{ab}	0.670^{b}	1.18^{ab}	0.065
Linolenic (18:3; ω-3)	2.950	2.330	2.970	2.790	2.980	2.810	2.090	0.147
Arachidonic (20:4; ω-6)	0.310	0.230	0.280	0.253	0.290	0.180	0.180	0.165
PUFA	4.340	3.840	4.280	4.123	4.180	3.66	3.450	0.155
IA	0.621	0.681	0.613	0.615	0.572	0.710	0.494	0.052
n-3:n-6	2.222^{ab}	1.570^{b}	2.324^{ab}	2.272^{ab}	2.482^{ab}	3.372^{a}	1.560^{b}	0.183

$^{a, b, c}$ – Means on the same row with different superscripts differ significantly (P <0.05)
cp – Cayenne pepper powder; wp – white pepper powder; SFA – saturated fatty acid; MUFA – mono-unsaturated fatty acid; PUFA – poly-unsaturated fatty acid; IA – Index of Atherogenicity

Table 4. Effect of dietary white and cayenne pepper powders on lipid profile of broiler chicken meat

Parameters	Control (C)	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp+100cp	C+125wp+125cp	SEM
Cholesterol, mg dL^{-1}	47.30	43.70	41.50	40.20	37.10	32.60	40.20	2.59
Triglyceride, mg dL^{-1}	170.90	165.50	163.10	189.30	152.30	143.40	112.90	9.12
HDL, mg dL^{-1}	10.10^{c}	18.30^{a}	16.10^{ab}	15.70^{ab}	10.40^{c}	13.10^{bc}	11.30^{c}	0.77
LDL, mg dL^{-1}	3.02^{d}	7.70^{b}	7.20^{b}	13.40^{a}	3.80^{cd}	9.20^{b}	6.30^{bc}	0.79
Antioxidant status								
SOD, U mg^{-1}	124.62^{a}	112.31^{ab}	112.31^{ab}	113.85^{b}	101.54^{ab}	102.95^{ab}	89.23^{b}	3.54
GP_x, U mg^{-1}	0.75	0.69	0.70	0.58	0.62	0.60	0.56	0.02
TBARs MDA g^{-1} tissue	0.15^{b}	0.20^{a}	0.10^{c}	0.15^{b}	0.20^{a}	0.21^{a}	0.20^{a}	0.12

$^{a, b, c, d}$ – Means on the same row with different superscripts differ significantly (P <0.05)
cp – cayenne pepper powder; wp – white pepper powder; HDL – high-density lipoprotein; LDL – low-density lipoprotein; SOD – superoxide dismutase; GP_x – glutathione peroxidase; TBARs – 2-thiobarbituric acid reactive substances; MDA – malondialdehyde

Discussion

The positive influence of pepper powders on carcass yield was observed in this study. Chickens fed a single dosage of dietary cayenne pepper had improved breast muscles per weight basis. Pepper according to Puvaca *et al.* (2015) plays an important role in regulating cholesterol and fat deposition by influencing triglycerides distribution to tissues. Carcass weight is consequently improved together with vascular system health via facilitation as tissue aggregation is enhanced with limited space for deposition of fat within the adipose layer for a fat deposition that translates into a higher dressed percentage. Ogbuewu *et al.* (2018) referred to concentrations of active ingredients and their interactions with other active components in feed as potent. Additives exert influence on energy and fat levels, affecting increased intestinal movements, turnover and yield. Notable high breast meat and meat + skin: bone ratio yield conforms to the group that had a greater dressing percentage. Though Puvaca *et al.* (2019) reported a significant impact of dietary additives on carcass yield of chickens fed 1.0 g 100 g^{-1} of additives in feed containing garlic, black pepper and hot red pepper, this study reveals an increased dressed percentage at 0.2 g kg^{-1} inclusion of cayenne pepper powder, corroborating outcome reported (Adegoke *et al.*, 2016). Better Meat + skin: bone ratio signifies efficient muscle deposition as a result of increased absorption and utilization of feed consumed optimally among chickens fed C+200cp diet. A consequence, however, is that high meat + skin: bone among groups given C+200wp diet reveal a possibility of lameness if rearing and feeding progresses beyond 32 days, along with a suppressed ability to withstand heat stress. On the contrary, low meat + skin: bone ratio when C+250cp diet was fed indicate higher bone strength, supported by the increased calcium and phosphorus proportion in cayenne pepper.

Dietary lipid sources have a direct and generally predictable effect on the fatty acid composition of livestock products as the total fatty acid in meat of chickens offered the Control diet correspond with the total combination of saturated fatty acid (SFA) and unsaturated fatty acid (UFA). Cayenne Pepper increases the production of certain receptors (lipase and connexin-4) that modify fat and fatty acid composition in tissues (Wood *et al.*, 2008). The report of the feeding trial by Milićević *et al.* (2014) indicates that the presence of saturated fatty acids in poultry meat is greatly dependent on their presence in the diet and/or synthesis in the liver. Galli *et al.* (2019) declared a reduction in saturated fatty acids in the meat of chickens fed the combination of herbal phytogenic and curcumin, while Toomer *et al.* (2020) elaborated on ways high-oleic peanut diet-fed chickens altered meat fatty acid composition which agrees in part with the outcome of SFA in this study. Lipid digestion occurs in the small intestine, as the pancreatic lipase breaks triacylglycerols down to mainly 2-monoacylglycerols and free fatty acids. Subsequent formation of micelles enhances absorption via lipid uptake mediated by the lipoprotein

lipase enzyme that is dispersed throughout the body with a notable deduction that additives included modified liver synthesis that altered SFA produced and subsequent deposition in tissue. The least SFA produced in the meat of groups supplied C+125wp+125cp diet was documented, however, SFA production by the body renders dietary SFA unessential to the body. High SFA yield is associated with increased serum cholesterol production. A report by Zong *et al.* (2016) associates increased dietary intakes of SFA with an increased risk of coronary heart disease. The presence of palmitoleic fatty acid in the meat of groups fed C+200wp and C+125wp+125cp diets but not C+250wp and C+100wp+100cp suggest a range that stimulates its production. Palmitoleic acid (16:1n-7) is a product of stearoyl-CoA desaturase (SCD-1), an enzyme produced in the liver that changes palmitic acid into palmitoleic acid. Possibly, addition at 125 g served as a minimum for the conversion of palmitic acid that was optimal at 200 g per 100 kg of the Control diet, but not C+250wp diet. Palmitoleic acid is a rare fatty acid consumed in Western diets as its primary dietary sources are occasionally consumed in food, such as macadamia and codfish liver oil. (Hodson, Karpe 2013; Norde *et al.*, 2019). High monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) documented for chickens offered C+200wp diet implies intake of white pepper in minimal quantity resulted in significantly higher palmitoleic and linoleic fatty acid deposition in muscle tissue. Linoleic acid is obtained principally from the diet and in this study, it can be inferred that the oxidative protection conveyed by the incorporation of white pepper with the Control diet at the stated level above translates into the transfer of unsaturated fatty acid from the feed to the diet with modification by the liver. Findings by Galli *et al.* (2019) that the widely accepted opinion that unsaturated fatty acids pass through the small intestine unchanged to be absorbed into the bloodstream and deposited in the tissues is not universally substantiated as modification in the liver determines refined obtainable fatty acid deposited in tissues. Additionally, an inference depicted by the overall picture of the susceptible relationship that exists between the balance between SFA and UFA when consumed on the cardiovascular health of human health is observed in the numerical values documented for the Index of Atherogenicity though not significant in this study. Conscious present-day consumers tend towards selective acceptance of meat and meat products, with special emphasis on decreased levels of fat, salt, cholesterol and caloric content enriched with dietary fibre for healthy living (Cherian, 2015; Nayeem *et al.*, 2017). Fatty acids, especially essential fatty acids, are gaining importance in poultry feeding systems not only for improving the health and productivity of chickens but also because health-conscious societies prefer properly balanced diets to minimize adverse health issues (Lee *et al.*, 2019). Novel studies today target the manipulation of diet composition to increase n-3 PUFA content and decrease n-3:n-6 ratio in poultry meat since n-6 PUFA act as a pro-inflammatory factor but n-3 PUFA – is an anti-inflammatory factor (Rahimi *et al*., 2011). With n-3:n-6 having a notable influence on immune functions and inflammatory processes in animals and humans, meat from chickens fed C+100wp+100cp appears to exhibits a better cardiovascular balance due to its high n-3:n-6 value. This however contradicts the Index of Atherogenicity value, which was numerically least in C+125wp+125cp group. A clarity can be derived from explanation of Wijendran and Hayes (2004), who declared that the absolute mass of essential fatty acid profile (MUFA and PUFA) in product should be considered foremost when considering implications of n-3:n-6 on human health. Hence, dietary n-3:n-6 is neither the sole nor foremost factor to be considered for assessment of cardiovascular balance for cardiovascular health.

The outcome of this experiment indicates both groups offered solely dietary white pepper and C+200cp diet had higher meat High-density lipoprotein (HDL) in comparison with the Control group. Puvaca *et al.* (2015) explained that significant lowering of plasma cholesterol, triglycerides, LDL and increased HDL production by *Piper nigrum* incorporation signifies effective regulation of lipid metabolism favourably for the prevention of atherosclerosis or coronary heart diseases. This indicates that phytochemicals in the diets of chickens offered dietary white pepper solely triggered increased transport of HDL-cholesterol which is associated with the removal of fat molecules from cells that are subsequently exported as lipids such as cholesterol, phospholipids, and triglycerides in variable quantities. HDL cannot be discussed in isolation but with LDL with cholesterol transport to the liver. Plasma LDL levels are determined by the rate of LDL production and clearance, both of which are regulated by the number of LDL receptors in the liver (Feingold, Grunfield 2018). The plasma LDL in turn define the quantity to be deposited or evacuated from tissues. Across the experimental groups, white pepper offered chickens as an additive resulted in a balanced lipid profile but the best lipid profile (HDL: LDL) was obtained in meat from groups given 200 g 100 kg^{-1} white pepper additive and it agrees with the study by Cardoso *et al.* (2012) whose study showed that the supplementation of piperine is toxic to liver tissue at a higher dosage which was observed from the reduced absorption surface of the jejunum; but lower inclusion dosage had piperine to be secure. Piperine is shown to be an effective antioxidant that offers protection against the oxidation of human low-density lipoprotein (LDL) (Naidu, Thippeswamy 2002). Palmitoleic acid functions as an adipose tissue-derived lipid hormone that triggers muscle insulin action, suppresses hepatosteatosis, has an antithrombotic effect, can prevent stroke, and lower LDL cholesterol but effect higher HDL production (Mozaffarian *et al.*, 2010; Yang *et al.*, 2011). An abundance of small dense LDL particles is associated with hypertriglyceridemia, low HDL levels, obesity, type 2 diabetes and infectious and inflammatory outcomes.

Superoxide dismutase (SOD) in meat was significantly influenced by the diet. Meat from chickens supplied with the Control diet (0% additive) showed increased SOD distribution within the tissue. Minimal or absence of external supplementary radical scavenging substances (additives) resulted in adaptative response at a cellular level to oxidative stress via increased SOD production to overcome homeostatic imbalance or a disturbance in the pro-oxidant – antioxidant balance. Oxidative stress results from imbalance and overload of stressors such as Reactive Nitrogen or Oxygen species (RNS/ROS) with potentially hazardous substances produced along with several biological and pathological processes (Trachootham *et al.,* 2008) that ultimately determine the fate of the stressed cell. The mechanism by which a cell dies (*i.e.*, apoptosis, necrosis, pyroptosis, or autophagic cell death) depends on various exogenous factors as well as the management/coping mechanism adopted by the cell to stress it is exposed (Fulda *et al.,* 2010). Though SOD is one of the cell's natural defences against oxidative imbalance, uncontrolled perturbation of this balance may result in either apoptosis or necrotic cell death (Orrenius *et al.*, 2007). Scavenging free radicals (piperine and capsaicin); detoxification/decomposition of the free radicals and non-radical toxic products (SOD, GPx *etc.*) are important steps in the antioxidant defence mechanism (Surai *et al*., 2019). The intake of C+125wp+125cp diet yielded the best complimentary activity to minimize overload in SOD production. The observed decrease in SOD expression as additive incorporation increased in this study contradicts the report of Surai *et al.* (2019) who declared that nutritional antioxidant (phytochemicals) in the feed increases SOD count but supports research published by Roehrs *et al.* (2011) that increased endogenous antioxidants increase oxidative damage, quality of lipids and possible effects associated with cardiovascular risk linked to atherogenic and haemodialysis (HD) patients.

Quality deterioration indicators such as colour changes, off-flavour and odours are outcomes of oxidative spoilage that results from the oxidation of susceptible PUFAs in chicken meat. Subsequent development of lipid oxidation products (LOPs), such as malondialdehyde (MDA) and 4-hydroxy-2-nonenal (4-HNE) can be detrimental post-consumption (Van Hecke *et al.*, 2017). The lowest malondialdehyde count for groups offered C+250wp additive was observed. While this does not signify that meat from C+250wp group had the overall best oxidative profile, the potency of white pepper (*Piper nigrum*) in limiting lipid oxidation or spoilage associated with rancidity is shown. For C+200wp diet, the meat lipid peroxidation product was highest, and it suggests polyunsaturated fatty acid formed with the inclusion of white pepper at 200 g 100 kg^{-1} of the Control diet was not sufficiently protected by antioxidants present. Morel *et al.* (2006) reported that lipid oxidation was significantly greater in tissues and processed products from PUFA-fed pigs supporting the outcome of this research. High PUFA levels may result in alterations in meat flavour due to their susceptibility to oxidation and the production of unpleasant volatile compounds (Jaworska *et al.*, 2016). An investigation by Martinez *et al.* (2006) points to *Piper nigrum* as best suited for shelf-life extension of fresh sausages because it effectively delayed off-odour formation owing to its richness in flavonoids, vitamin C and vitamin A. In addition, piperine – a bioactive alkaloid in white pepper has been demonstrated in in-vitro studies to protect against oxidative damage by inhibiting or quenching reactive oxygen species. Piperine treatment likewise alters (lowers) lipid peroxidation in vivo and beneficially influences the antioxidant status of cells.

Findings from this study likewise reveal all dietary pepper powders fed contributed to suppressed production and activity of endogenous antioxidants – a pointer to poultry farmers. Though C+125wp+125cp diet had a highly potent influence on endogenous enzymes, the radical scavenging activity post-slaughter was least effective in meat obtained from this group. Post slaughter, meat from chickens offered C+250wp diet strongly repressed the translation of primary radicals into secondary products of spoilage such as malondialdehydes. The meat of chickens fed C+250wp had the least MDA count. According to Olalere *et al.* (2018), bioactive compounds extracted from oleoresin extract of white pepper contribute to its peroxidation potency. Vasavirama and Upender (2014) similarly reported that white pepper is made up of piperine and pungent resins which possibly limited the translation of radicals produced post slaughter that could have been oxidized into aldehydes.

Conclusion

Feeding C+200cp diet resulted in heavier dressed and breast weights as well as meat + skin: bone ratio – a significant gain to poultry farmers and meat processors that sell meat according to its weight. Palmitoleic acid – a rare fatty acid consumed in Western diets occasionally found in foods such as macadamia and codfish liver oil was present in the meat of chickens fed C+200wp and C+125wp+125cp diets. Meat linolenic and palmitoleic fatty acid were increased and present respectively by the addition of 250 g of white pepper per 100 kg of the Control diet (C+250wp), however, the overall profile promoting healthier cardiovascular function appear obtainable by feeding chickens C+125wp+125cp diet (depicted by the IA and n-3:n-6 values) – contributing to consumer welfare. Meat endogenous antioxidant profile reveals stress imposed on chickens was lowered by feeding C+125wp+125cp diet. Poultry farmers can take advantage of this level of pepper combination, especially in tropical climates loaded with environmental stressors. White pepper offered at 2.5 g kg^{-1} of the Control diet (C+250wp) suppressed spoilage from rancidity post-slaughter as refrigeration storage progressed, therefore, indicating white pepper possesses bioactive compounds that can function as preservatives.

Acknowledgements

I would like to appreciate the laboratory staffs of the Department of Animal Production and Health, College of Animal Science and Livestock Production, Federal University of Agriculture, Abeokuta for the assistance rendered throughout the experiment.

Conflict of interest

The authors declare no conflict of interest exists.

Ethical statement

Approval for this research was obtained from the Departmental Ethical Committee (FUNAAB-APH20-03) of the College of Animal Science and Livestock Production Animal welfare board.

Author contributions

AA – design/sampling/analysis/writing;
KS, LE – design of experiment;
MA – editing and approving the final manuscript;
MO, OA, OW – sampling.

References

Adegoke, A.V., Abanikanda, I.A., Sanwo, K.A., Egbeyale, L.T., Abiona, J.A. 2016. Dietary addition of turmeric (*Curcuma longa*) rhizome powder and cayenne pepper (*Capsicum frutescens*) powder as antioxidants on carcass traits of broiler chickens. – In New Technology for Enhanced Animal Production in Nigeria. Proceedings of the 41st Annual Conference of the Nigerian Society for Animal Production (NSAP), pp. 371–374.

Ahn, D.U., Olson, D.G., Jo, C., Chen, X., Wu, C., Lee, J.I. 1998. Effect of muscle type, packaging, and irradiation on lipid oxidation, volatile production and color in raw pork patties. – Meat Science, 49:27–39. DOI: 10.1016/s0309-1740(97)00101-0

AOAC, 2005. 4. Animal Feed. – In Official Methods of Analysis. (18th ed.). Horwitz, W., Latimer, G.W. (Eds.) – AOAC International (Association of Official Analytical Chemists), Maryland, USA, 68 p.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS. (5th ed.). Firestone, D. (Ed.). – American Oil Chemists' Society. Press, Champaign, USA, 1200 p.

Cardoso, V.S., Ribeiro de Lima, C.A., Freire de Lima, M.E., Dorneles, L.E.D., Danelli, M.G.M. 2012. Piperine as a phytogenic additive in broiler diets. – Pesquisa Agropecuária Brasileira, 47(4):489–496. DOI: 10.1590/S0100-204X2012000400003

Cherian, G. 2015. Nutrition and metabolism in poultry: Role of lipids in early diet. – Journal of Animal Science Biotechnology, 6(1):28. DOI: 10.1186/s40104-015-0029-9

El Tazi, S.M.A., Mukhtar A.M., Mohamed, K.A., Tabidi, M.H. 2014. Effect of using black pepper as natural feed additive on performance and carcass quality of broiler chickens. – International Journal of Pharmaceutical Research and Analysis, 4(2):108–113.

Feingold, K.R., Grunfeld, C. 2018. Introduction to Lipids and Lipoproteins. – In Endotext. Feingold, K.R., Anawalt, B., Boyce, A., Chrousos, G., Dungan, K., Grossman, A., Hershman, J.M., Kaltsas, G., Koch, C., Kopp, P., Korbonits, M., McLachlan, R., Morley, J.E., New, M., Perreault, L., Purnell, J., Rebar, R., Singer, F., Trence, D.L., Vinik, A., Wilson, D.P. (Eds.) – South Dartmouth MA, USA. MDText.com, Inc.; 2000–. PMID: 26247089.

Folch, J., Lees, M., Sloane-Stanley, G.H.A. 1957. A simple method for the isolation and purification of total lipids from animal tissues. – Journal of Biology Chemistry, 266(1):497–509.

Fulda, S., Gorman, A. M., Hori, O., Samali, A. 2010. Cellular stress responses: Cell stress and cell death. – International Journal of Cell Biology, 2010(214074):23. DOI: 10.1155/2010/214074

Galib, A., Al-Kassie, M., Mamdooh, A., Al-Nasrawi, M., Saba, J.A. 2011. The effects of using hot red pepper as a diet supplement on some performance traits in broiler. – Pakistan Journal of Nutrition, 10 (9):842–845.

Galli, G.M., Roger, B.F., Dos Reis J.H., Gebert, R.R., Barreta, M., Griss, L.G., Casagrande, R.A., De Cristo, T. G., Santiani, F., Campigotto, G., Rampazzo, L., Stefani, L.M., Boiago, M.M., Lopes, L.Q., Santos, R.C.V., Baldissera, M. D., Zanette, R. A., Tomasi, T., Da Silva, A. S. 2019. Glycerol monolaurate in the diet of broiler chickens replacing conventional antimicrobials: Impact on health, performance and meat quality. – Microbial Pathology, 129:161–167. DOI: 10.1016/j.micpath.2019.02.005

Hartman, L.R., Lago, C. 1973. Rapid preparation of fatty acid methyl esters from lipids. – Lab Practice, 22(6):475–476.

Hodson, L., Karpe, F. 2013. Is there something special about palmitoleate? – Current Opinion Clinical Nutrition and Metabolic Care, 16(2):225–231. DOI: 10.1097/MCO.0b013e32835d2edf

Jaworska, D., Czauderna, M., Przybylski, W., Rozbicka-Wieczorek, Agnieszka, J. 2016. Sensory quality and chemical composition of meat from lambs fed diets enriched with fish and rapeseed oils, carnosic acid and seleno-compounds. – Meat Science, 119:185–192. DOI: 10.1016/j.meatsci.2016.05.003

Kang, J.H., Tsuyoshi, G., Le-Ngoc, H., Kim, H.M., Tu, T.H., Noh, H.J., Kim, C.S., Choe, S., Kawada, T., Yoo, H, Yu, R. 2011. Dietary capsaicin attenuates metabolic dysregulation in genetically obese diabetic mice. – Journal of Medicinal Food, 14(3):310–15. DOI: 10.1089/jmf.2010.1367

Lee, S.A., Whenham N., Bedford, M.R. 2019. Review on docosahexaenoic acid in poultry and swine nutrition: Consequence of enriched animal products on performance and health characteristics. – Journal of Animal Nutrition, 5(1):11–21.

Lopez-Ferrer, S., Baucells, M.D. Barroeta, A.C. Grashorn. M.A. 1999. Influence of vegetable oil

sources on quality parameters of broiler meat. – Archiv für Geflügelkunde, 63:29–35.

Lopez-Ferrer, S., Baucells, M.D., Barroeta, A.C., Grashorn, M.A. 2001. n-3 enrichment of chicken meat. 1. Use of very long-chain fatty acids in chicken diets and their influence on meat quality: Fish oil. – Poultry Science, 80(6):741–752. DOI: 10.1093/ps/80.6.741

Marangoni, F., Corsello, G., Cricelli, C., Ferrara, N., Ghiselli, A., Lucchin, L., Poli, A. 2015. Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: An Italian consensus document. – Food Nutrition Research, 59:27606. DOI: 10.3402/fnr.v59.27606

Martinez, L., Cilla, I., Beltran, J.A., Roncales, P. 2006. Effect of *capsicum* (Red Sweet and Cayenne) and *Piper nigrum* (Black and White) pepper powders on the shelf life of fresh pork sausages packaged in modified atmosphere. – Journal of Food Science, 71(1):S48–S53. DOI: 10.1111/j.1365-2621.2006.tb12405.x

Milićević, D., Vranić, D., Mašić, Z., Parunović,, N., Trbović, D., Nedeljković-Trailović, T., Petrović, Z. 2014. The role of total fats, saturated/unsaturated fatty acids and cholesterol content in chicken meat as cardiovascular risk factors. – Lipids in Health and Diseases, 13:42. DOI: 10.1186/1476-511X-13-42

Mondal, M.A., Yeasmin, T., Karim, R., Nurealam Siddiqui, M., Raihanum-Nabi S.M., Sayed. M. 2015. Powder on growth performance and carcass traits of broiler chicks. – South Asian Association for Regional Cooperation Journal of Agriculture, 13(1): 188–199. DOI: 10.3329/sja.v13i1.24191

Morel, P.C., McIntosh, J.C., Janz, J.A.M. 2006. Alteration of the fatty acid profile of pork by dietary manipulation. – Asian-Australian Journal of Animal Science, 19(3):431–437. DOI: 10.5713/ajas.2006.431

Mozaffarian, D., Cao, H., King, I., Lemaitre, R., Song, X., Siscovick, D., Hotamisligil, G. 2010. Trans-palmitoleic acid, metabolic risk factors, and new-onset diabetes in U.S. adults: a cohort study. – Annals of internal medicine. 153(12):790–799. DOI: 10.7326/0003-4819-153-12-201012210-00005

Naidu, K.A., Thippeswamy N.B. 2002. Inhibition of human low-density lipoprotein oxidation by active principles from spices. – Molecular Cellular Biochemistry, 229(1-2):19–23. DOI: 10.1023/a:1017930708099

Nayeem, N., Chauhan, K., Khan, M. A., Siddiqui, M., Sidduqui, H. 2017. Development and shelf-life studies of buffalo meat sausages incorporated with foxtail millet (*Setaria italica*). – International Journal of chemical Studies, 5(3):648–654.

Norde, M.M., Oki, E., Rogero, M.M. 2019. C-reactive protein and fatty acids: public health concerns and implications. – In The molecular nutrition of fats (1st edition). Patel, V. (Ed.) – Academic Press, pp. 117–133. DOI: 10.1016/B978-0-12-811297-7.00009-3

Ogbuewu, I.P., Okoro, V.M., Mbajiorgu, E.F., Mbajiorgu, C.A. 2018. Beneficial effects of garlic in livestock and poultry nutrition: A Review. – Agricultural Research, 8:411–426, DOI: 10.1007/s40003-018-0390-y

Olalere, A.O., Hamid, N.A., Rosli, M.Y., Oluwaseun, R.A., Malam, M.A., Yasmeen, H.Z., Hybat, Salih, M.A. 2018. Parameter study, antioxidant activities, morphological and functional characteristics in microwave extraction of medicinal oleoresins from black and white pepper. – Journal of Taibah University for Science, 12(6):730–737. DOI: 10.1080/16583655.2018.1515323

Orrenius, S., Gogvadze, V., Zhivotovsky, B. 2007. Mitochondrial oxidative stress: implications for cell death. – Annual Review of Pharmacology and Toxicology, 47:143–183. DOI: 10.1146/annurev.pharmtox.47.120505.105122

Puvaca, N., Kostadinovic, L., Ljubojevic, D., Lukac, D., Levic, J., Popovic, S., Novak, V.N., Vidovic, B., Duragic, O. 2015. Effect of garlic, black pepper and hot red pepper on productive performances and blood lipid profile of broilers chickens. – European Poultry Science, 79:1–13. DOI: 10.1399/eps.2015.73

Puvaca, N., Pelic, D. L., Cabarkapa, I., Popovic, S., Tomicic, Z., Nikolova, N., Levic, I. 2019. Quality of broiler chicken carcass fed dietary addition of garlic, black pepper and hot red pepper. – Journal of Agronomy, Technology and Engineering Management, 2(1): 218–227

Rahimi, S., Kamran, Azad S., Karimi, Torshizi M. A. 2011. Omega-3 Enrichment of Broiler Meat by Using Two Oil Seeds. Journal of Animal Science and Technology, 13 (3): 353-365

Roehrs, M., Valentini, J., Paniz, C., Moro, A., Charão, M., Freitas, F., Brucker, N., Duarte, M., Leal, M., Burg, G., Bulcão, R., Grune, T., Garcia, C.S. 2011. The relationships between exogenous and endogenous antioxidants with the lipid profile and oxidative damage in hemodialysis patients. – BMC Nephrology, 12:59. DOI: 10.1186/1471-2369-12-59

Shah, S.S., Shah, G.B., Singh, S.D., Gohil, P.V., Chauhan, K., Shah, K.A., Chorawala, M., 2011. Effect of piperine in the regulation of obesity-induced dyslipidemia in high-fat diet rats. – Indian Journal of Pharmacology, 43(3),296–299. DOI: 10.4103/0253-7613.81516

Singh, S.K., Sahu, S.P., Kumar P. 2018. Influence of supplementation of feed additives on carcass characteristics, mortality and economics of broiler production. – International Journal of Current Microbiological Applied Science, Special Issue-7:4810–4817

SPSS. 2012. Statistical package for social sciences. – IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

Surai, P.F. 2016. Antioxidant systems in poultry biology: Superoxide dismutase. – Journal of Animal Research and Nutrition, 1(1:8):1–17. DOI: 10.21767/2572-5459.100008

Surai, P.F., Kochish, II, Fisinin, V.I., Kidd, M.T. 2019. Antioxidant defence systems and oxidative stress in

poultry biology: An update. – Antioxidants (Basel), 8(7):235. DOI: 10.3390/antiox8070235

Trachootham, D., Lu, W., Ogasawara, M.A., Valle, N.R. Huan, P. 2008. Redox regulation of cell survival. – Antioxidants & Redox Signaling, 10(8): 1343–1374. DOI: 10.1089/ars.2007.1957

Toomer, O., Livingston, M., Wall, B., Sanders, E., Vu, T., Malheiros, R., Livingston, K., Carvalho, L., Ferket, P., Dean, L. 2020. Feeding high-oleic peanuts to meat-type broiler chickens enhances the fatty acid profile of the meat produced. – Poultry Science, 99(4):2236–2245. DOI: 10.1016/j.psj.2019.11.015

Ulbricht, T.L.V., Southgate D.A.T. 1991. Coronary heart disease: seven dietary factors. – The Lancet, 338(8773):985–992. DOI: 10.1016/0140-6736(91) 91846-M

Van Hecke, T., Ho, L-P., Goethals, S., De Smet, S. 2017. The potential of herbs and spices to reduce lipid oxidation during heating and gastrointestinal digestion of a beef product. – Food Research International, 102:785–792. DOI: 10.1016/j.foodres. 2017.09.090

Vasavirama, K., Upender, M. 2014. Piperine: a valuable alkaloid from piper species. – International Journal of Pharmaceutical and Pharmacological Science, 6(4):34–38.

Wijendran, V., Hayes, K.C. 2004. Dietary n-6 and n-3 fatty acid balance and cardiovascular health. – Annual Review of Nutrition. 24:597–615. DOI: 10.1146/annurev.nutr.24.012003.132106

Wood, J.D., Enser, M., Fisher, A.V. 2008. Fat deposition, fatty acid composition and meat quality: A review. – Meat Science, 78 (4):343–358. DOI: 10.1016/j.meatsci.2007.07.019

Yang, Z.-H., Miyahara, H., Hatanaka, A. 2011. Chronic administration of palmitoleic acid reduces insulin resistance and hepatic lipid accumulation in KK-Ay mice with genetic type-2 diabetes. – Lipids in Health and Disease, 10:120. DOI: 10.1186/s12944-021-01513-w

Zong, G., Li, Y., Wanders, A.J., Alssema, M., Zock, P.L., Willett, W.C., Hu, F.B., Sun, Q. 2016. Intake of individual saturated fatty acids and risk of coronary heart disease in US men and women: two prospective longitudinal cohort studies. – British Medical Journal, 355:i5796. DOI: 10.1136/bmj.i5796