Tropical Animal Health and Production (2021) 53: 109
https://doi.org/10.1007/s11250-020-02542-w

REGULAR ARTICLES

Growth performance, carcass characteristics, and fatty acid composition of breast and thigh meat of broiler chickens fed gradually increasing levels of supplemental blueberry extract

Mükremin Ölmez[1] · Tarkan Şahin[1] · Özlem Karadağoğlu[1] · Mehmet Akif Yörük[2] · Kanber Kara[3] · Sakine Dalğa[4]

Received: 6 October 2020 / Accepted: 22 December 2020 / Published online: 9 January 2021

Abstract

The effect of gradually increasing supplemental levels of blueberry extract on growth performance, carcass characteristics, and fatty acid composition of breast and thigh muscles of broiler chickens was investigated. One hundred ninety-two 7-day-old chickens were randomly distributed into four groups having four replicates with 12 birds in each replicate. Basal diets were prepared for starter (days 8 to 21) and finisher (days 22 to 42). Basal diets were offered to the control group only, whereas other treatments received basal diets fortified with 0.5, 1, and 2% blueberry extract (BB0.5, BB1, and BB2 groups, respectively). The duration of experiment was 35 days (days 8 to 42). During finisher and overall growth phases, broilers in the BB2 group had greater body weight gain than those in the BB0.5 and control groups, whereas the BB1 group had higher body weight gain than the control group ($P < 0.001$). Body weight gain remained unaffected during the starter phase. Feed intake was greater in the BB2 group than in the control group at days 8 to 21, 22 to 42, and 8 to 42 ($P = 0.002$, $P = 0.035$, and $P = 0.001$, respectively). The control group had poor FCR than the BB2 group in the starter phase ($P = 0.034$). At days 22 to 42, feeding blueberry extract (BB0.5, BB1, and BB2) improved the FCR of broilers compared with the control group, whereas the BB2 group had better FCR than the BB0.5 group ($P < 0.001$). At 8 to 42 days, broilers in the control group had poor FCR compared with the BB1 and BB2 groups, whereas the BB0.5 group had poor FCR than the BB2 group ($P < 0.001$). Slaughter weight was lower in the control group than in the blueberry extract groups, whereas the BB2 group had greater slaughter weight than the BB0.5 group ($P < 0.001$). Dressing percentage of broilers in the control and BB0.5 groups was lower than that in other groups ($P < 0.001$). Gizzard yield was higher in the BB0.5 and BB2 groups than in the control group ($P = 0.021$). In addition, feeding 2% blueberry extract increased the concentration of different fatty acids in breast and thigh meat of broiler chickens. Findings suggest that feeding 2% blueberry extract may improve growth performance, carcass characteristics, and fatty acid composition of breast and thigh muscles of broilers.

Keywords Blueberry extract · Broilers · Carcass characteristics · Growth performance · Fatty acids

Introduction

Sustainable animal nutrition involves fulfilling the food requirements of present generation while conserving it for the needs of future generations. Sustainability is comprised of social, environment, and economic pillars. This implies that any practice should be socially equitable, environmentally manageable, and economically viable (Commission B 1987). Animal nutrition has evolved over the years with many practices that are not sustainable from the perspectives of any of these three pillars. Use of antibiotics as growth promoters (AGPs) is an issue that has been classified unsustainable. The use of AGPs in animal nutrition has given rise to the

✉ Mükremin Ölmez
mukremin.olmez@hotmail.com

[1] Department of Animal Nutrition and Nutritional Diseases, Faculty of Veterinary Medicine, Kafkas University, 36100 Kars, Turkey

[2] Department of Animal Nutrition and Nutritional Diseases, Faculty of Veterinary Medicine, Ataturk University, 25100 Erzurum, Turkey

[3] Department of Animal Nutrition and Nutritional Diseases, Faculty of Veterinary Medicine, Erciyes University, 38280 Kayseri, Turkey

[4] Health Sciences Institute, Kafkas University, 36100 Kars, Turkey

phenomenon of resistance to antibiotics in microbes and increased general public concerns towards antibiotic resistance and drug residues. Consequently, the use of AGPs in animal feeding engrossed the complete ban from the European Union in 2006 (Directive 1831/2003/EC) that ushered a new era of research and development of new feed additives in order to replace the AGPs. Under practical conditions, the replacement candidates should exhibit similar properties as AGPs. Over the past decade or so, several feed additives belonging to different classes including isolated nutrients, dietary supplements, plant-based or herbal products (phytogenic feed additives; PFAs), and genetically modified foods have been used to spare the use of AGPs in animal feeding. While some feed additives like probiotic, prebiotic, and organic acids have shown promising AGPs replacement properties, PFAs yield other benefits in addition to being alternative to AGPs (Das et al. 2012; Ahsan et al. 2016).

Polyphenolic compounds are common bioactive molecules in PFAs usually that may differ in relation to the source. Previous studies have reported the anti-tumor (Bomser et al. 1999), cardioprotective (Demirkaya et al. 2009), antiatherosclerotic (Yamakoshi et al. 1999), immunomodulatory (Tong et al. 2011; Vaid et al. 2013), and antioxidative (Brenes et al. 2010; Iqbal et al. 2014; Iqbal et al. 2015) effects of polyphenols. Grape seed extract, grape pomace, black currant pomace, rosemary extract, green tea extract, and seedless strawberry pomace are rich in polyphenols that have been used in poultry diets (Brenes et al. 2010; Vossen et al. 2011; Iqbal et al. 2014; Iqbal et al. 2015; Juskiewicz et al. 2017; Karadağoğlu et al. 2020). There are contrasting reports in terms of beneficial effects of polyphenols despite the usefulness of dietary polyphenols in poultry. In addition, source, extraction method, and final concentration of polyphenols in extracts/pomaces result in the variation of physiological responses of poultry to dietary polyphenols (Juskiewicz et al. 2017). Blueberry is a source of polyphenols particularly proanthocyanidins (Krenn et al. 2007) that can be beneficial in poultry. To date, no study has reported the use of blueberry, blueberry extract, or proanthocyanidins extracted from blueberry in diets of broiler chickens. Therefore, the present study was carried out to investigate the beneficial effects of blueberry extract, if any, in terms of growth performance, carcass characteristics, and fatty acid composition of breast and thigh muscles of broiler chickens.

Materials and methods

We conducted the present study at Kafkas University, Kars, Turkey. Local committee for ethical use of animals granted the approval of all the procedures involved in the study (No. KAÜ-HADYEK/2019-149).

Study design and experimental groups

The present study was conducted as a completely randomized design involving four groups. One hundred ninety-two 7-day-old Ross 308 male chicks, weighing 161.73 ± 0.11 g on an average, were randomly distributed to 4 treatments. Chicks were sourced from a commercial hatchery (Garanti Inc., Turkey). Each group comprised of 4 replicate pens with 12 chickens/pen. One group was allocated as the control group whereas other groups received diets with supplemental blueberry extract at gradually increasing inclusion levels of 0.5 (BB0.5), 1 (BB1), and 2% (BB2).

Diets

Basal diets were formulated for starter (days 8 to 21) and finisher (days 22 to 42) phases in line with the recommendation of NRC (1994). The composition of basal diets is presented in Table 1. Feed ingredients were thoroughly mixed in a mixer to prepare the basal diets in mash form. The control group was fed basal diets only. Basal diets were supplemented

Table 1 Composition of basal diets for starter (days 8 to 21) and finisher phases (days 22 to 42)

Item (%)	Starter	Finisher
Corn	50.00	55.00
Soybean meal (44% CP)	25.00	20.73
Rice bran	1.00	2.40
Wheat	4.12	4.00
Bonkalite	3.90	3.73
Corn gluten	10.40	7.00
Vegetable oil	0.95	3.42
Dicalcium phosphate	2.10	1.50
Limestone	1.03	0.90
Salt	0.42	0.42
DL-Methionine	0.30	0.12
L-Lysine HCl	0.48	0.48
Vitamin and mineral premix[1]	0.30	0.30
Nutrient content		
Crude protein	23.50	20.00
Metabolizable energy (kcal/kg)	2999	3200
Crude fiber	3.32	3.24
Crude fat	3.10	5.63
Crude ash	6.33	5.45
Calcium	0.99	0.78
Phosphorus	0.49	0.39

[1] Vit A, 1.000.000 IU; Vit D3, 400.000 IU. Minerals: Fe (iron sulfate monohydrate), 30 mg; I (calcium iodide anhy-dride), 1.5 mg; Co (cobalt carbonate monohydrate), 0.5 mg; Cu (coppersulfate pentahydrate), 5 mg; Mn (manganese oxide), 80 mg; Zn (zincoxide), 80 mg; Se (sodium selenite), 0.3 mg (Vitamin-mineral mixture was provided per kg of diet)

with blueberry extract (Talya Herbal Products, Antalya, Turkey) at appropriate levels and mixed well to ensure homogeneous mixing. Blueberry extract was characterized by 25% proanthocyanidins according to the prescribed information from the manufacturer.

Rearing of birds

Experimental house was prepared by thorough cleaning followed by disinfection. A total of sixteen floor pens, each measuring 1 m^2, were installed. Approximately 6-cm-deep layer of wood shavings was spread in each floor pen as a bedding material. One bell feeder and three nipple drinkers were installed in each pen. One-day-old chicks were raised for 1 week in the brooding cages (brooding temperature 32 °C) using a commercial pre-starter diet. At day 8, broiler chickens were randomly assigned to the already installed floor pens. The temperature was reduced by 0.5 °C per day until day 21 and maintained between 24 and 26 °C thereafter. A 23L:1D lighting program was followed from day 8 onwards until the end of the experiment. Ad libitum feed and water were available throughout the study. The duration of experiment was 35 days (days 8 to 42).

Growth performance

Birds and feeds (leftover in the feeders) were weighed weekly on per pen basis. Body weight gain (BWG) was calculated by difference method for starter (days 8 to 21) and finisher (days 22 to 42) phases. Feed intake (FI) was calculated by difference between feed offered and feed not consumed. Feed conversion ratio (FCR) was calculated by division method: FI was divided by BWG. Adjustment was made in FCR in case of any mortality.

Carcass characteristics

At day 42, two birds were randomly selected from each pen (8 chickens per group; 32 birds in total), weighed, and slaughtered by decapitation, and feathers were plucked after scalding. Carcass, heart, liver, and gizzard were weighed. Dressing percentage, heart, liver, and gizzard yields were calculated.

Measurement of fatty acids in breast and thigh muscles

At day 42, breast (*pectoralis major*) and thigh muscle samples were collected from each slaughtered chicken (2 birds/replicate, 8 birds/group, and 32 birds in total). Lipids from each sample were extracted using Soxhlet apparatus. Fatty acid concentrations in lipids from breast and thigh muscle samples were measured by preparing fatty acid methyl esters followed by analysis using GC-MS (Hewlett Packard 6890/5972 GCMS system, Santa Clara, CA, USA) with capillary column 100 m × 0.25 mm × 0.2 μm (HP88 capillary column, Agilent J&W, Santa Clara, CA, USA) according to the procedure outlined by Sari et al. (2015).

Statistical analysis

One-way ANOVA with Duncan's multiple range test and polynomial contrasts was applied in order to assess the effect of treatments on measured traits of broiler chickens. P value less than 0.05 was assumed as significant. Results were presented as mean ± SEM. All the analyses were carried out in a computer-based statistical software package (SPSS version 22.0, IBM Corp., Armonk, NY, USA).

Results

Growth performance

The growth performance of broiler chickens is presented in Table 2. No difference was observed in the BWG among the groups at days 8 to 21. However, at day 22s to 42 and days 8 to 42, broiler chickens fed BB2 diets had greater BWG than the BB0.5 and control groups, whereas the BB1 group had better BWG than the control group ($P < 0.001$). During starter, finisher, and overall growth phases, the control group exhibited greater FI compared with the BB2 group ($P = 0.002$, $P = 0.035$, and $P = 0.001$, respectively); however, FI was not different among broilers fed different levels of blueberry extract. Feeding 2% dietary blueberry extract improved the FCR of broilers in starter phase in comparison with the control group ($P = 0.034$). In finisher phase, while the broiler chickens fed blueberry extract (BB0.5, BB1, and BB2) had better FCR than the control group, FCR of the BB2 group was lower than that of the BB0.5 group ($P < 0.001$). FCR of broilers in the control group was poor in overall growth period compared with the BB1 and BB2 groups, whereas birds fed BB0.5 diets showed greater FCR than those fed BB2 diets ($P < 0.001$).

Carcass characteristics

Carcass characteristics of broiler chickens fed gradually increasing supplemental level of blueberry extract are shown in Table 3. Broilers fed diets supplemented with blueberry extract were heavier at slaughter than those fed control diets only ($P < 0.001$). Slaughter weight of birds in the BB0.5 group was lower than that in the BB2 group ($P < 0.001$). The dressing percentage of broilers fed 1 or 2% blueberry extract was greater than that of other groups ($P < 0.001$). Dietary supplementation of gradually increasing levels of blueberry extract increased the gizzard yield of broiler

Table 2 Growth performance of broiler chickens fed gradually increasing supplemental levels of blueberry extract

Item	Groups[1]				Contrasts		
	Control	BB0.5	BB1	BB2	Linear	Quadratic	Cubic
BWG (g)							
d 8 to 21	758.25 ± 19.97	765.25 ± 10.98	765.67 ± 5.44	769.42 ± 12.79	0.678	0.898	0.904
d 22 to 42	2004.00 ± 45.61[c]	2086.25 ± 28.43[bc]	2131.08 ± 26.66[ab]	2225.33 ± 28.63[a]	<0.001	0.858	0.562
d 8 to 42	2762.25 ± 44.28[c]	2851.50 ± 33.03[bc]	2896.75 ± 27.72[ab]	2993.75 ± 29.9[a]	<0.001	0.911	0.536
FI (g)							
d 8 to 21	1247.10 ± 15.17[a]	1160.06 ± 13.19[ab]	1163.77 ± 15.79[ab]	1073.71 ± 28.05[b]	0.002	0.967	0.264
d 22 to 42	3697.10 ± 27.65[a]	3610.06 ± 24.04[ab]	3613.77 ± 28.78[ab]	3523.71 ± 39.36[b]	0.035	0.977	0.441
d 8 to 42	4944.21 ± 35.13[a]	4770.13 ± 30.54[ab]	4777.54 ± 36.57[ab]	4597.42 ± 46.23[b]	0.001	0.942	0.049
FCR							
d 8 to 21	1.67 ± 0.08[b]	1.53 ± 0.07[ab]	1.52 ± 0.05[ab]	1.40 ± 0.12[a]	0.034	0.942	0.557
d 22 to 42	1.86 ± 0.05[c]	1.73 ± 0.03[b]	1.70 ± 0.03[ab]	1.59 ± 0.05[a]	<0.001	0.900	0.387
d 8 to 42	1.80 ± 0.04[c]	1.68 ± 0.04[bc]	1.65 ± 0.03[ab]	1.54 ± 0.07[a]	<0.001	0.929	0.384

[a, b, c] Different superscript lowercase letters indicate significant differences among the means

[1] BB0.5 = 0.5% blueberry extract; BB1 = 1% blueberry extract; BB2 = 2% blueberry extract

chickens compared with the control group except those fed 1% blueberry extract ($P = 0.021$). Heart and liver yields were not different among the groups.

Fatty acid composition of breast meat

The concentrations of lauric acid (C12:0) and myristic acid (C14:0) were greater in broilers in the BB2 group ($P = 0.004$). Supplementation of blueberry extract in broiler chickens reduced the palmitic acid (C16:0) content of breast meat ($P = 0.032$) (Table 4). Oleic acid (C18:1) concentration of breast meat of the BB2 group was higher than that of the control group ($P = 0.005$). Eicosenoic acid (C20:1) increased cubically in breast meat of the BB0.5 and BB2 groups in comparison with other groups ($P = 0.038$). The control and BB0.5 groups had greater breast meat eicosadienoic acid (C20:2 n-6) content compared to other groups (P 0.003). Erucic acid (C22:1) levels in breast meat increased quadratically in response to dietary supplementation of 0.5 and 1% blueberry extract ($P < 0.001$). While there was a quadratic increase in dihomo-gamma-linoleic acid (C20:3 n-6; DGLA) in the BB1 group compared with the control and BB2 groups, BB0.5 had quadratically higher DGLA content than the control group ($P < 0.001$). A quadratic response was witnessed in arachidonic acid (C20:4 n-6; AA) concentration due to increasing supplemental levels of blueberry extract in which the BB2 group had greater AA content than the BB0.5 and BB1 groups, whereas AA concentration increased quadratically in the control group compared to the BB0.5 and BB1 groups ($P = 0.002$). Eicosapentaenoic acid (C20:5 n-3; EPA) content in breast meat of the control and BB0.5 groups was cubically higher than that of the BB1 group ($P = 0.013$). Broilers in the BB0.5 group exhibited elevated docosahexaenoic acid (C22:6 n-3; DHA) concentration in breast meat in comparison with

Table 3 Carcass characteristics of broiler chickens fed gradually increasing supplemental levels of blueberry extract

Item	Groups[1]				Contrasts		
	Control	BB0.5	BB1	BB2	Linear	Quadratic	Cubic
Slaughter weight (g)	2903.88 ± 16.29[c]	3014.50 ± 25.91[b]	3028.13 ± 34.55[ab]	3105.63 ± 30.79[a]	<0.001	0.555	0.205
Dressing (%)	72.42 ± 0.33[b]	73.04 ± 0.19[b]	73.91 ± 0.27[a]	74.00 ± 0.13[a]	<0.001	0.279	0.343
Heart (%)	0.52 ± 0.04	0.47 ± 0.02	0.48 ± 0.04	0.49 ± 0.02	0.552	0.476	0.681
Liver (%)	1.62 ± 0.09	1.37 ± 0.09	1.51 ± 0.12	1.54 ± 0.06	0.858	0.150	0.240
Gizzard (%)	1.01 ± 0.04[b]	1.20 ± 0.06[a]	1.11 ± 0.06[ab]	1.24 ± 0.06[a]	0.021	0.559	0.059

[a, b, c] Different superscript lowercase letters indicate significant differences among the means

[1] BB0.5 = 0.5% blueberry extract; BB1 = 1% blueberry extract; BB2 = 2% blueberry extract

Table 4 Fatty acid composition of breast meat of broiler chickens fed gradually increasing supplemental levels of blueberry extract

Fatty acid (%)	Groups[1]				Contrasts		
	Control	BB0.5	BB1	BB2	Linear	Quadratic	Cubic
C12:0	0.034 ± 0.00[b]	0.034 ± 0.00[b]	0.038 ± 0.00[b]	0.046 ± 0.00[a]	0.004	0.146	0.924
C14:0	0.524 ± 0.00[b]	0.543 ± 0.02[b]	0.559 ± 0.03[b]	0.628 ± 0.03[a]	0.004	0.291	0.601
C14:1	0.104 ± 0.02	0.100 ± 0.01	0.109 ± 0.01	0.119 ± 0.01	0.354	0.554	0.828
C16:0	22.92 ± 0.38[a]	21.62 ± 0.43[b]	21.32 ± 0.26[b]	21.84 ± 0.28[b]	0.032	0.015	0.917
C16:1	4.17 ± 0.16	3.88 ± 0.22	3.58 ± 0.28	3.88 ± 0.21	0.264	0.191	0.537
C18:1	33.51 ± 0.39[b]	34.15 ± 0.54[ab]	34.86 ± 0.49[ab]	35.66 ± 0.47[a]	0.005	0.881	0.997
C18:2 (n-6)	28.56 ± 0.62	26.98 ± 0.73	26.92 ± 0.90	27.76 ± 0.56	0.452	0.103	0.846
C20:0	0.207 ± 0.01	0.269 ± 0.02	0.224 ± 0.02	0.236 ± 0.02	0.650	0.227	0.086
C20:1	0.361 ± 0.02[b]	0.428 ± 0.03[a]	0.371 ± 0.01[b]	0.410 ± 0.02[a]	0.376	0.544	0.038
C18:3 (n-3)	0.084 ± 0.01	0.072 ± 0.00	0.092 ± 0.01	0.090 ± 0.01	0.190	0.432	0.069
C20:2	0.075 ± 0.01[a]	0.075 ± 0.01[a]	0.050 ± 0.01[b]	0.051 ± 0.01[b]	0.003	0.926	0.096
C22:1	2.11 ± 0.13[b]	3.22 ± 0.20[a]	3.66 ± 0.22[a]	2.28 ± 0.17[b]	0.265	<0.001	0.188
C20:3 (n-6)	2.16 ± 0.09[c]	2.74 ± 0.17[ab]	3.10 ± 0.18[a]	2.37 ± 0.12[bc]	0.154	<0.001	0.203
C20:4 (n-6)	0.032 ± 0.00[ab]	0.026 ± 0.00[bc]	0.019 ± 0.00[c]	0.043 ± 0.01[a]	0.254	0.002	0.103
C22:2	0.379 ± 0.09	0.321 ± 0.05	0.257 ± 0.05	0.219 ± 0.02	0.244	0.874	0.900
C20:5 (n-3)	0.106 ± 0.01[a]	0.106 ± 0.01[a]	0.063 ± 0.01[b]	0.093 ± 0.02[ab]	0.119	0.664	0.013
C22:6 (n-3)	0.315 ± 0.02[b]	0.425 ± 0.03[a]	0.230 ± 0.02[c]	0.246 ± 0.04[bc]	0.003	0.099	<0.001
∑SFA	26.37 ± 1.05	28.35 ± 1.17	26.01 ± 1.49	28.66 ± 1.05	0.406	0.781	0.096
∑UFA	73.63 ± 1.05	71.65 ± 1.17	73.99 ± 1.49	71.34 ± 1.05	0.406	0.781	0.096
∑MUFA	41.39 ± 0.56	41.56 ± 0.98	41.66 ± 0.75	42.63 ± 0.82	0.290	0.615	0.795
∑PUFA	30.56 ± 0.70	28.69 ± 3.17	30.18 ± 0.60	30.94 ± 0.63	0.727	0.441	0.591
n-3	2.63 ± 0.17[c]	3.50 ± 0.16[b]	4.37 ± 0.24[a]	2.78 ± 0.14[c]	0.113	<0.001	0.007
n-6	27.16 ± 0.68	23.96 ± 0.47	27.72 ± 0.59	28.63 ± 0.71	0.352	0.271	0.238
n-6/n-3	0.076 ± 0.01[c]	0.118 ± 0.01[b]	0.164 ± 0.02[a]	0.085 ± 0.01[c]	0.124	<0.001	0.010
MCFA	0.059 ± 0.005[b]	0.061 ± 0.005[b]	0.066 ± 0.004[b]	0.086 ± 0.007[a]	0.001	0.111	0.604
LCFA	94.96 ± 0.40	90.40 ± 3.90	96.26 ± 0.24	96.25 ± 0.31	0.279	0.257	0.075

[a, b, c] Different superscript lowercase letters indicate significant differences among the means

[1] BB0.5 = 0.5% blueberry extract; BB1 = 1% blueberry extract; BB2 = 2% blueberry extract

other groups ($P = 0.003$). In addition, a higher content of DHA was noted in breast meat of broilers in the control group than in that in the BB1 group ($P = 0.003$). Dietary supplementation of 1% blueberry extract quadratically and cubically increased ($P < 0.001$ and $P = 0.007$, respectively) the total n-3 polyunsaturated fatty acid (PUFA) composition of breast meat of broilers compared with other groups, whereas BB0.5 had greater n-3 PUFA than other groups. Similarly, n-6/n-3 ratio increased quadratically and cubically ($P < 0.001$ and $P = 0.010$, respectively) in the BB1 group in comparison with other dietary treatments, whereas BB0.5 had greater n-6/n-3 ratio than other groups. Broiler chickens fed diets supplemented with 2% blueberry extract exhibited higher total medium-chain fatty acid (MCFA) than those in other groups ($P = 0.001$).

Fatty acid composition of thigh meat

Thigh meat of broilers fed supplemental 2% blueberry extract showed greater C12:0 content ($P = 0.033$) (Table 5). Oleic acid (C18:1) increased quadratically in thigh meat of broiler chickens in response to dietary 0.5 and 1% blueberry extract compared with those fed 2% blueberry extract ($P = 0.004$). A cubic decrease was noted in erucic acid (C22:1) and DGLA (C20:3 n-6) in thigh meat of broilers in the BB1 group compared with other groups ($P = 0.039$ and $P = 0.042$, respectively). Feeding 2% blueberry extract quadratically reduced the total monounsaturated fatty acids (∑MUFA) content in thigh meat in comparison with the BB0.5 group ($P = 0.048$).

Discussion

This is the first study evaluating the use of blueberry extract in poultry diets. Blueberry extract consists of proanthocyanidins polyphenolic compounds. Inclusion of additives, rich in polyphenolic compounds, in poultry diets improves the digestibility of dietary amino acids, protein, and energy (Goñí et al. 2007; Brenes et al. 2010; Lichovnikova et al. 2015) essential for protein accretion, muscle formation, and growth of birds. Consequently, BWG and FI are increased and better FCR is noted as seen in this study. In addition, polyphenols have known to possess antimicrobial properties and thus can stabilize the gut microbiota by inhibiting the colonization of pathogenic microbes, by activating the endogenous defense mechanisms, and by modulating the signaling pathways in the cells

Table 5 Fatty acid composition of thigh meat of broiler chickens fed gradually increasing supplemental levels of blueberry extract

Fatty acid (%)	Groups[1]				Contrasts		
	Control	BB0.5	BB1	BB2	Linear	Quadratic	Cubic
C12:0	0.04 ± 0.00[a]	0.03 ± 0.00[b]	0.04 ± 0.00[b]	0.05 ± 0.00[a]	0.033	0.007	0.417
C14:0	0.60 ± 0.02	0.59 ± 0.05	0.63 ± 0.04	0.64 ± 0.02	0.286	0.707	0.591
C14:1	0.19 ± 0.04	0.13 ± 0.01	0.14 ± 0.01	0.13 ± 0.01	0.105	0.337	0.300
C16:0	21.77 ± 0.38	22.33 ± 0.79	21.80 ± 0.27	21.53 ± 0.32	0.567	0.402	0.545
C16:1	5.10 ± 0.35	4.60 ± 0.16	5.16 ± 0.26	4.49 ± 0.23	0.281	0.742	0.054
C18:1	34.82 ± 0.72[ab]	35.65 ± 0.51[a]	35.95 ± 0.34[a]	33.55 ± 0.44[b]	0.142	0.004	0.357
C18:2 (n-6)	27.24 ± 0.60	27.95 ± 0.54	28.34 ± 0.58	28.95 ± 0.73	0.056	0.938	0.847
C20:0	0.20 ± 0.02	0.28 ± 0.02	0.21 ± 0.01	0.25 ± 0.03	0.238	0.955	0.177
C20:1	0.40 ± 0.02	0.38 ± 0.02	0.43 ± 0.03	0.43 ± 0.03	0.164	0.563	0.293
C18:3 (n-3)	0.15 ± 0.08	0.19 ± 0.10	0.10 ± 0.01	0.10 ± 0.01	0.380	0.773	0.422
C20:2	0.07 ± 0.00	0.07 ± 0.02	0.05 ± 0.04	0.07 ± 0.04	0.550	0.622	0.080
C22:1	2.27 ± 0.21[a]	2.62 ± 0.45[a]	1.83 ± 0.08[b]	2.44 ± 0.15[a]	0.807	0.619	0.039
C20:3 (n-6)	2.23 ± 0.21[a]	2.56 ± 0.44[a]	1.79 ± 0.08[b]	2.37 ± 0.15[a]	0.773	0.641	0.042
C20:4 (n-6)	0.03 ± 0.01	0.02 ± 0.00	0.06 ± 0.02	0.041 ± 0.00	0.330	0.889	0.146
C22:2	0.32 ± 0.07	0.28 ± 0.03	0.31 ± 0.03	0.39 ± 0.07	0.281	0.282	0.963
C20:5 (n-3)	0.08 ± 0.01	0.08 ± 0.01	0.09 ± 0.01	0.08 ± 0.00	0.601	0.945	0.519
C22:6 (n-3)	0.25 ± 0.03	0.29 ± 0.06	0.24 ± 0.03	0.24 ± 0.02	0.651	0.678	0.364
∑SFA	26.26 ± 1.06	25.91 ± 1.14	25.15 ± 0.85	26.35 ± 1.10	0.916	0.464	0.614
∑UFA	73.74 ± 1.06	74.09 ± 1.14	74.85 ± 0.85	73.65 ± 1.10	0.916	0.464	0.614
∑MUFA	43.14 ± 0.90[ab]	45.39 ± 1.94[a]	43.85 ± 0.41[ab]	41.41 ± 0.65[b]	0.196	0.048	0.575
∑PUFA	30.56 ± 0.38	28.69 ± 2.55	30.99 ± 0.68	32.25 ± 0.76	0.251	0.263	0.404
n-3	2.92 ± 0.36	2.79 ± 0.47	2.21 ± 0.11	2.77 ± 0.18	0.458	0.276	0.271
n-6	27.67 ± 0.58	28.31 ± 0.56	28.78 ± 0.58	29.48 ± 0.70	0.214	0.958	0.889
n-6/n-3	0.11 ± 0.02	0.10 ± 0.02	0.08 ± 0.00	0.09 ± 0.01	0.244	0.317	0.288
MCFA	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.00	0.07 ± 0.00	0.430	0.343	0.504
LCFA	96.04 ± 0.33	95.73 ± 0.64	96.68 ± 0.16	95.77 ± 0.24	0.942	0.452	0.084

[a, b, c] Different superscript lowercase letters indicate significant differences among the means

[1] BB0.5 = 0.5% blueberry extract; BB1 = 1% blueberry extract; BB2 = 2% blueberry extract

(Abdel-Moneim et al. 2020). Moreover, polyphenols confer protection against oxidative damage through free radical scavenging activity, lowering lipid peroxidation, and activation of antioxidant pathways (Iqbal et al. 2014; Farahat et al. 2017). Polyphenols also improve the liver functions and lipid profile evident from levels of enzymes and lipoproteins in serum (Karadağoğlu et al. 2020) in addition to immunomodulation (Abdel-Moneim et al. 2020). All these effects help the birds to grow fast, healthier, and heavier yielding heavier parts. In the present study, broilers in the BB2 group showed improved growth performance and carcass characteristics in terms of BWG, FI, FCR, slaughter weight, dressing percentage, and gizzard yield. Improvement in growth performance, slaughter weight, and dressing percentage of broiler chickens in the present study might be attributed to these reasons. There are contrasting reports concerning the effect of polyphenol-rich extracts on the growth performance and carcass yield and characteristics of broiler chickens. Some studies have reported improved growth performance of broiler chickens fed grape proanthocyanidins (Wang et al. 2008; Yang et al. 2014, 2017) and polyphenol-rich grape seed extract (Chamorro et al. 2013). On the contrary, growth performance remained unaffected in response to sources of polyphenolic compounds such as dietary grape seed extract (McDougald et al. 2008; Brenes et al. 2010), grape pomace concentrate (Goñí et al. 2007; Brenes et al. 2008), and grape polyphenols (Iqbal et al. 2014). Even though depression in growth performance has been noted in broiler chickens fed higher levels of polyphenolic compounds (Lau and King 2003; Hughes et al. 2005; Viveros et al. 2011; Chamorro et al. 2013), most studies have reported no effect of sources of polyphenolic compounds on the carcass yield and characteristics of broilers (Brenes et al. 2008, 2010; Hajati et al. 2015; Abu and Ibrahim 2018). Differences in results might be attributed to the differences in the extracts, type and source of polyphenolic compounds, level of supplementation, composition of diets, genetic make-up of birds, and environmental conditions.

Broiler meat has become accessible due to cheap availability and shorter life cycle or faster growth of broiler chickens. Over the past two decades, there are increased concerns towards healthy lifestyle which has impacted the general preference of public to animal proteins or meat. As a consequence, nutritional allowance of broiler chickens and fatty acid composition of diets has played a greater role to provide meat with lower fat content that contains healthy fats. Lipids in broiler meat are vulnerable to peroxidation due to oxidative insults by free radicals or reactive oxygen and nitrogen species that affect the meat quality by altering the color, aroma and flavor, texture, and nutritive value (Sohaib et al. 2015). Polyphenolic compounds possess antioxidant properties. Polyphenols are absorbed through the intestine of broilers and transported to different body tissues as they are expressed in different tissues (Brenes et al. 2010). It has been reported that polyphenols show increased free radical scavenging activity by inhibiting the 1,1-diphenyl-2-picrylhydrazyl (DPPH) in thigh and breast muscles of broilers (Iqbal et al. 2014) and increased liver glutathione levels (Farahat et al. 2017). Polyphenols also reduce the lipid peroxidation by lowering the liver malondialdehyde levels in broiler chickens (Brenes et al. 2008; Farahat et al. 2017). Further improvement in antioxidant activity and lipid stability was observed in breast and thigh muscle of broiler chicken fed polyphenolic compounds extracted from grapes (Iqbal et al. 2015). Therefore, fatty acid content in the breast and thigh muscles can be improved in broiler chickens by feeding the naturally occurring antioxidants like polyphenolic compounds. Blueberry extract used in this study was rich in proanthocyanidins. It has been reported that antioxidant properties of proanthocyanidins are 50 times more potent than vitamin E (Konowalchuk and Speirs 2009). Consequently, the concentrations of different fatty acids increased in the breast and thigh muscle of broilers. Similarly, in our previous study, an improvement in concentration of different fatty acids was noted in breast muscle of broiler chickens fed increasing levels of polyphenolic-rich grape seed extract (Karadağoğlu et al. 2020).

It has not been found any study evaluating the effect of gradually increasing inclusion levels of blueberry extract on growth performance, carcass characteristics, and fatty acid composition of breast and thigh muscle of broiler chickens. The study revealed that supplemental 2% blueberry extract in broiler diets may improve growth performance, slaughter weight, dressing percentage, and concentrations of various fatty acids in the breast and thigh meat of broilers.

Authors' contribution MÖ and TŞ conceived, designed, and executed the study. MÖ, ÖK, and SD collected and prepared the samples for analysis. KK analyzed the samples by GC-MS. MÖ drafted the manuscript. TŞ and MAY reviewed, criticized, and corrected the drafted manuscript. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Ethical standards This study was approved by the Kafkas University Animal Care and Use Committee (KAÜ-HADYEK/2019-149).

References

Abdel-Moneim A.M.E., Shehata A.M., Alzahrani S.O., Shafi M.E., Mesalam N.M., Taha A.E., Swelum A.A., Arif M., Fayyaz M., Abd El-Hack M.E., 2020. The role of polyphenols in poultry nutrition, J Anim Physiol Anim Nutr (Berl), 00, 1-16.

Abu Hafsa S., Ibrahim S., 2018. Effect of dietary polyphenol-rich grape seed on growth performance, antioxidant capacity and ileal microflora in broiler chicks, J Anim Physiol Anim Nutr (Berl), 102, 268-275.

Ahsan U., Cengiz Ö., Raza I., Kuter E., Chacher M., Iqbal Z., Umar S., Çakir S., 2016. Sodium butyrate in chicken nutrition: the dynamics of performance, gut microbiota, gut morphology, and immunity, Worlds Poult Sci J, 72, 265-275.

Bomser J., Singletary K., Wallig M., Smith M., 1999. Inhibition of TPA-induced tumor promotion in CD-1 mouse epidermis by a polyphenolic fraction from grape seeds, Cancer Lett, 135, 151-157.

Brenes A., Viveros A., Goñí I., Centeno C., Sayago-Ayerdy S., Arija I., Saura-Calixto F., 2008. Effect of grape pomace concentrate and vitamin E on digestibility of polyphenols and antioxidant activity in chickens, Poult Sci, 87, 307-316.

Brenes A., Montoro A.V., Cambrodón I.G., Centeno C., Calixto F.S., Arija I., 2010. Effect grape seed extract on growth performance, protein and polyphenol digestibilities, and antioxidant activity in chickens, Span J Agric Res, 8, 326-333.

Chamorro S., Viveros A., Centeno C., Romero C., Arija I., Brenes A., 2013. Effects of dietary grape seed extract on growth performance, amino acid digestibility and plasma lipids and mineral content in broiler chicks, Anim, 7, 555–561.

Commission B. 1987.Report of the World Commission on Environment and Development: our common future. In: Hauff V., editor. Oxford University Press.

Das L., Bhaumik E., Raychaudhuri U., Chakraborty R., 2012. Role of nutraceuticals in human health, J Food Sci Tech 49, 173-183.

Demirkaya E., Avci A., Kesik V., Karslioglu Y., Oztas E., Kismet E., Gokcay E., Durak I., Koseoglu V., 2009. Cardioprotective roles of aged garlic extract, grape seed proanthocyanidin, and hazelnut on doxorubicin-induced cardiotoxicity, Can J Physiol Pharmacol, 87, 633-640.

Farahat M.H., Abdallah F.M., Ali H.A., Hernandez-Santana A., 2017. Effect of dietary supplementation of grape seed extract on the growth performance, lipid profile, antioxidant status and immune response of broiler chickens, Animal, 11, 771.

Goñí I., Brenes A., Centeno C., Viveros A., Saura-Calixto F., Rebole A., Arija I., Estevez R., 2007. Effect of dietary grape pomace and vitamin E on growth performance, nutrient digestibility, and susceptibility to meat lipid oxidation in chickens, Poult Sci, 86, 508-516.

Hajati H., Hassanabadi A., Golian A.G., Nassiri M.H., Nassiri M.R., 2015. The effect of grape seed extract and vitamin C feed supplements carcass characteristics, gut morphology and ileal microflora in broiler chickens exposed to chronic heat stress, Iran J Appl Anim Sci, 5, 155-165.

Hughes R.J., Brooker J.D., Smyl C. Year.Growth rate of broiler chickens given condensed tannins extracted from grape seed. In:Proceedings of the 17th Australian Poultry Science Symposium, Sydney, New

South Wales, Australia, 7-9 February 2005, Sydney, New South Wales, Australia: (Poultry Research Foundation), p. 65-68.

Iqbal Z., Ali R., Sultan J., Ali A., Kamran Z., Khan S., Ahsan U., 2014. Impact of replacing grape polyphenol with vitamin E on growth performance, relative organs weight and antioxidant status of broilers, J Anim Plant Sci, 24, 1579-1583.

Iqbal Z., Kamran Z., Sultan J., Ali A., Ahmad S., Shahzad M., Ahsan U., Ashraf S., Sohail M., 2015. Replacement effect of vitamin E with grape polyphenols on antioxidant status, immune, and organs histopathological responses in broilers from 1-to 35-d age, J Appl Poult Res Title, 24, 127-134.

Juskiewicz J., Jankowski J., Zielinski H., Zdunczyk Z., Mikulski D., Antoszkiewicz Z., Kosmala M., Zdunczyk P., 2017. The fatty acid profile and oxidative stability of meat from turkeys fed diets enriched with n-3 polyunsaturated fatty acids and dried fruit pomaces as a source of polyphenols, PLoS One, 12, e0170074.

Karadağoğlu Ö., Şahin T., Ölmez M., Yakan A., Özsoy B., 2020. Changes in serum biochemical and lipid profile, and fatty acid composition of breast meat of broiler chickens fed supplemental grape seed extract, Turkish J Vet Anim Sci, 44, 182-190.

Konowalchuk J., Speirs JI., 2009. Virus inactivation by grapes and wines, Appl Environ Microbiol, 32, 757-763.

Krenn L., Steitz M., Schlicht C., Kurth H., Gaedcke F., 2007. Anthocyanin-and proanthocyanidin-rich extracts of berries in food supplements–analysis with problems, Pharmazie, 62, 803-812.

Lau D.W., King A.J., 2003. Pre-and post-mortem use of grape seed extract in dark poultry meat to inhibit development of thiobarbituric acid reactive substances, J Agric Food Chem, 51, 1602-1607.

Lichovnikova M., Kalhotka L., Adam V., Klejdus B., Anderle V., 2015. The effects of red grape pomace inclusion in grower diet on amino acid digestibility, intestinal microflora, and sera and liver antioxidant activity in broilers, Turkish J Vet Anim Sci, 39, 406-412.

McDougald L., Hofacre C., Mathis G., Fuller L., Hargrove J., Greenspan P., Hartle D., 2008. Enhancement of resistance to coccidiosis and necrotic enteritis in broiler chickens by dietary muscadine pomace, Avian Dis, 52, 646-651.

NRC, 1994. Nutrient requirements of poultry. 9th revised edn National Academic Press, Washington, DC, USA.

Sari M., Onk K., Sisman T., Tilki M., Yakan A., 2015. Effects of different fattening systems on technological properties and fatty acid composition of goose meat, Eur Poult Sci,79.

Sohaib M., Butt M.S., Shabbir M.A., Shahid M., 2015. Lipid stability, antioxidant potential and fatty acid composition of broilers breast meat as influenced by quercetin in combination with α-tocopherol enriched diets, Lipids Health Dis, 14, 61.

Tong H., Song X., Sun X., Sun G., Du F., 2011. Immunomodulatory and antitumor activities of grape seed proanthocyanidins, J Agric Food Chem, 59, 11543-11547.

Vaid M., Singh T., Prasad R., Elmets C.A., Xu H., Katiyar S.K., 2013. Bioactive grape proanthocyanidins enhance immune reactivity in UV-irradiated skin through functional activation of dendritic cells in mice, Cancer Prev Res, 6, 242-252.

Viveros A., Chamorro S., Pizarro M., Arija I., Centeno C., Brenes A., 2011. Effects of dietary polyphenol-rich grape products on intestinal microflora and gut morphology in broiler chicks, Poult Sci, 90, 566-578.

Vossen E., Ntawubizi M., Raes K., Smet K., Huyghebaert G., Arnouts S., De Smet S., 2011. Effect of dietary antioxidant supplementation on the oxidative status of plasma in broilers, J Anim Physiol Anim Nutr (Berl), 95, 198-205.

Wang ML., Suo X., Gu JH., Zhang WW., Fang Q., Wang X., 2008. Influence of grape seed proanthocyanidin extract in broiler chickens: effect on chicken coccidiosis and antioxidant status, Poult Sci 87, 2273–2280.

Yamakoshi J., Kataoka S., Koga T., Ariga T., 1999. Proanthocyanidin-rich extract from grape seeds attenuates the development of aortic atherosclerosis in cholesterol-fed rabbits, Atherosclerosis, 142, 139-149.

Yang J., Wang J., Wu S., Yue H., Qi G., Zhang H., 2014. Combination effects between grape procyandins and wheat-based diet on growth performance and immunity of broiler chicks, Chin J Anim Nutr, 26, 2270-2280.

Yang J., Zhang H., Wang J., Wu S., Yue H., Jiang X., Qi G., 2017. Effects of dietary grape proanthocyanidins on the growth performance, jejunum morphology and plasma biochemical indices of broiler chicks, Animal, 11, 762-770.