



Emmer wheat (*Triticum dicoccum*)–based intervention in Japanese quail's diet and its impact on performance, carcass yield, meat fatty acids, and fecal volatile fatty acids

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Abstract

The high nutritional and nutraceutical qualities of emmer wheat make it a valuable cereal grain. The present study was designed to quantify the contribution of emmer wheat inclusion into Japanese quail's rations in terms of their productive responses, alterations in the fatty acid profile of their meat, and changes in the composition of volatile fatty acids in their feces. For this purpose, a total of 160, 1-day-old Japanese quails (*Coturnix coturnix japonica*) were randomly allotted to four dietary treatments (4 replicates and 10 quails/replicate) with different levels of emmer wheat including 0% (control), 5% (T5), 10% (T10), and 15% (T15). These dietary treatments were administered for a period of 35 days. The results obtained from the study showed that dietary changes led by incorporation of increasing levels of emmer wheat into quail rations had no negative impact on quail's health and production. Moreover, supplemental emmer could promote better feed conversion ratio and higher carcass yield, while it did not affect the relative weights of internal organs including liver, gizzard, and heart. In addition, the incorporation of increasing levels of emmer wheat into quail rations was characterized by a reduction in total saturated and monounsaturated fatty acids, whereas an increase was observed in the levels of total unsaturated and polyunsaturated fatty acids in breast meat. Emmer wheat inclusion also increased the levels of omega-3 and omega-6 fatty acids in breast meat. Regarding volatile fatty acid profile, a lower percentage of propionic acid while a higher percentage of acetic acid were recorded in feces of quails fed emmer wheat-based diets when compared to those fed control diets. Overall, as confirmed by the present findings, the incorporation of emmer wheat into quail diets could be proposed as a valuable strategy for the promotion of animal health and performance. More research is needed to further investigate the promising roles of using emmer wheat in poultry nutrition.

Keywords Emmer wheat · Quail diet · Performance · Fatty acids profile · Volatile fatty acids

Introduction

Japanese quails, akin to other commercially raised poultry, are granivorous birds with a monogastric digestive system. The cereal grains, legume seeds, and their by-products constitute a major component of their diet (Vargas-Sánchez et al. 2019). Despite the heavy reliance of commercial quail diets on maize grain as the primary energy source, which typically accounts for approximately 50% of the quail's ration, the inclusion of other cereals including wheat, barley, triticale, oat, and rye has been tested in quail nutrition either as substitutes or complementary additions to corn-based basal rations (González-Redondo et al. 2019). However, the rising demand for cereal grains and legumes as both food and fuel has led to increasing costs for these traditional feed materials used in poultry production (Muscat et al., 2020).

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Incorporation of cereals into avian diets can introduce appreciable amount of non-starch polysaccharides (NSPs) to bird's digestive tract that can impede nutrient digestion by increasing intestinal viscosity (Perera et al., 2022). These NSPs can also bind to bile acids, fats, and cholesterol, leading to poor absorption of lipids and lower energy intake, thus resulting in stunted growth (Singh and Kim 2021). The limitations associated with common cereals in terms of poultry nutrition, coupled with the scarcity and higher costs, present significant challenges to the poultry industry, necessitating the exploration of alternative feed ingredients and formulations.

Emmer wheat (*Triticum dicoccum*) is one of the primitive cereals in the world and has been a staple food in many countries. Referred to as “Kavılca,” emmer wheat continues to be cultivated by farmers in the vicinity of Kars city, located in the northeastern Anatolia region of Türkiye (Giuliani et al. 2009; Çetinkaya and Gülbaz 2022). From a nutritional perspective, emmer is a high-protein wheat, and it may also have a unique composition in terms of health-beneficial phytochemicals, carotenoids, antioxidants, dietary fiber, minerals, resistant starch, etc. (Serpen et al. 2008; Zaharieva et al. 2010; Lachman et al. 2013; Karakas et al. 2021). The literature has also highlighted the comparatively reduced antinutritional composition (β -glucans and arabinoxylans) of emmer wheat in comparison to common wheat and barley (Shewry and Hey 2015; Arzani and Ashraf 2017; Lovegrove et al. 2023).

Research activities on emmer wheat are generally concentrated on human-related health benefits instead of feed values for livestock. A study conducted by Yenagi et al. (2001) demonstrated that diabetic patients experienced changes in their lipidemic profile when consuming a diet that included emmer wheat. The results indicated an 11% reduction in total lipids, triglycerides, and cholesterol when compared to a diet primarily based on common wheat. The authors attributed this positive effect to the dietary fiber present in emmer wheat. In a study involving quails, it was observed that the group fed with emmer wheat exhibited reduced abdominal fat and a lighter gizzard compared to the group fed with common wheat (Konca and Beyzi 2013). However, there were no observed differences in the feed efficiency of the birds between the wheat groups. These observations suggest that emmer wheat could serve as a potential nutrient source with possible benefits for animal health and production. However, there is limited data available regarding the use of emmer wheat in poultry nutrition, as few attempts have been made to balance poultry diets with emmer wheat inclusion. Thus, taking into account the vital nutritional parameters of emmer wheat, the present study was conducted to shed light on the perspectives of emmer wheat in quail nutrition. The present study aimed to investigate the productive responses of Japanese quails to emmer-based diets. The secondary

objective was to gauge the plausibility of modification in meat fatty acid profile and fecal volatile fatty acids (VFAs) composition when different levels of emmer wheat are added to Japanese quail diets.

Materials and methods

Birds and management

All the procedures elected in this study were approved by the Kafkas University Animal Experiments Local Ethics Committee (KAÜ-HADYEK/2020–158). A total of 160, 1-day-old mixed-sex Japanese quails (*Coturnix coturnix japonica*) were randomly allocated to four dietary treatments including one control and three emmer wheat–incorporated groups. Each dietary treatment further consisted of four replicates with 10 quails per replicate. The control group received a basal diet primarily composed of maize, soybean, and barley, while the other groups were provided with diets formulated using emmer wheat at levels 5% (T5), 10% (T10), and 15% (T15). Pelletized feed was used for all the diets, and the dietary treatments were implemented for a duration of 35 days. All the rations (Table 1) were isocaloric and isonitrogenous

Table 1 Ingredients and chemical composition of quail diets¹

Ingredients (%)	Control	T5	T10	T15
Corn, yellow	50.70	52.35	46.00	44.25
Soybean meal, 48% CP	33.90	32.00	33.00	30.40
Barley grain	8.10	2.10	3.00	1.00
Emmer wheat grain	0.00	5.00	10.00	15.00
Corn gluten meal, 62% CP	3.50	4.90	4.00	5.70
Vegetable oil	0.90	0.58	1.00	0.55
Dicalcium phosphate	0.80	0.80	0.80	0.80
DL-methionine	0.10	0.10	0.10	0.10
L-lysine sulfate	0.05	0.17	0.10	0.25
Marble dust	1.35	1.40	1.40	1.35
Salt	0.30	0.30	0.30	0.30
Vitamin-mineral premix ²	0.30	0.30	0.30	0.30
<i>Calculated chemical composition</i>				
Dry matter, %	91.89	91.38	91.95	91.77
Crude protein, %	23.82	23.79	23.83	23.81
Metabolisable energy, kcal/kg	3004.75	3004.00	3004.25	3004.75
Ether extract, %	2.34	2.62	2.34	2.59
Crude fiber, %	4.56	4.41	4.21	4.72
Ash, %	6.43	6.69	6.66	6.73

¹Emmer wheat inclusion: control, 0%, T5, 5%; T10, 10%; T15, 15%

²Vitamin and mineral premix per kilogram of diet: Vit-A, 15,000,000 IU; Vit-D, 3,000,000 IU; Vit-E, 25.00 mg; Vit-B12, 0.03 mg; folic acid, 1.00 mg; Ca, 10 mg; Fe, 50 mg; Zn, 52.50 mg; Cu, 10.50 mg; Mn, 55.25 mg; Co, 0.2 mg; I, 1 mg; and Se, 0.40 mg; antioxidant, 100.00 mg; toxin binder, 3000 mg

(NRC 1994). The proximate composition of emmer wheat is provided in Table 2.

Quail chicks were reared in cages with dimensions of 60 × 20 × 100 cm. Water and diets were provided ad libitum and quails were housed in a controlled environment for 35 days. An initial house temperature was kept at 32–33 °C for the first 3 days and then gradually decreased to 25 °C. The house was artificially ventilated and 24L:0D light regimens were provided throughout the experiment.

Chemical analyses of emmer wheat

The sample of emmer wheat was milled in a grinder mill (IKA Werke, Germany) to a maximum of 1 mm particle size. The sample was analyzed for the determination of dry matter, ash, crude protein (nitrogen × 6.25), ether extract, and crude fiber (AOAC 2006). The total starch content of the sample was determined using the commercial kit (Total Starch Assay Kit AA/AMG, Product code: K-TSTA-100A, Neogen-Megazyme, Ireland).

Growth performance and carcass traits

All birds were weighed weekly using an electronic weighing balance (range 0.1 to 1000 g). Body weight gain (BWG) was measured by subtracting initial weight from final weight. Weekly feed intake (FI) was recorded for all replicates and calculated by subtracting the left-over feed from the weekly given feed. The feed conversion ratio (FCR) was measured by dividing FI with BWG. Adjustments were made for FI, BWG, and FCR in case of mortality (Ölmez and Yörük 2022). At the end of the experiment (day 35), eight quails per group (two quails/replicate) were randomly selected, weighed, and slaughtered. Feathers were plucked and quails were properly eviscerated before carcass assessments. Some internal organs (liver, gizzard, heart) were also removed, and their weights were recorded. Carcass yield and weights of different organs were expressed relative to slaughter weight (Eq. 1).

$$[\text{Carcass yield}(\%) = \text{Carcass weight}(\text{kg}) / \text{Live body weight}(\text{kg}) \times 100] \quad (1)$$

Quail meat sampling and fatty acid composition

On day 35, about 5 g samples of breast muscle were collected from each slaughtered quail ($n = 8$). After the tissue was purified from subcutaneous fat, it was homogenized using a homogenizer (Wisd Homogenizer Stirrer, HS-30E, Witeg Labortechnik GmbH, Wertheim, Germany). The homogenized samples were then methylated by the three-stage methylation technique (Wang et al. 2015) and fatty acid methyl esters (FAMES) were obtained. Fatty acid analysis was carried out using gas chromatography (Thermo Scientific, USA) equipped with a flame ionization detector (GC-FID). FAMES were separated using a capillary column (60 m × 0.25 mm × 0.25 µm; TRACE™, catalog number: 260M153P, USA) with injection split temperature of 255 °C, column temperature of 140 °C, flow rate of 30 ml/min, and processing time of 42 min. The FAMES identification was performed by comparing the sample retention times with that of the standard FAMES mix (Chem-Lab, catalog number: CL40.13093, Zedelgem, Belgium) in the chromatogram (Kara 2020). The fatty acid contents were calculated using chromatogram peak areas and were expressed as percentages (%) of total fatty acid methyl esters. In addition, the percentage of total saturated fatty acids ($\sum\text{SFA}$), total unsaturated fatty acids ($\sum\text{UFA}$), total monounsaturated fatty acids ($\sum\text{MUFA}$), total polyunsaturated fatty acids ($\sum\text{PUFA}$), ratio of $n-3$, ratio of $n-6$, and ratio of $n-6/n-3$ were calculated (Kara et al., 2022).

Fecal sampling and VFAs analysis

At the end of the experiment (day 35), fresh feces (4–5 g) from each replicate ($n = 4$) were properly collected in a plastic tube and immediately stored at -20 °C until analyzed for VFAs. The samples were prepared and analyzed using the procedure described elsewhere (Ersahince and Kara 2017). The diluted feces samples with distilled water (1:3 ratio) were thawed at 4 °C and centrifuged at 15000 × g for 15 min using a micro-centrifuge (Gyrozen 1524, Daejeon, South Korea). The analysis of VFAs [acetic acid—AA (C 2:0), propionic acid—PA (C 3:0), butyric acid—BA (C 4:0)] was carried out using a gas chromatograph (TRACE™ 1300, Thermo Fisher Scientific, Orlando, FL, USA) equipped with an auto sampler (AI 1310, Thermo Scientific, Orlando, FL, USA), a polyethylene glycol column (length: 60 m, id: 0.25 mm, film thickness: 0.25 µm) (TG-WAXMS, Thermo Scientific, Orlando, FL, USA), and a flame ionization detector (FID). The carrier gas helium was used at a constant flow rate of

Table 2 Chemical composition of emmer wheat (*Triticum dicoccum*)

Item	Content
Dry matter, %	89.67
Crude protein, %	11.46
Ether extract, %	1.99
Crude fiber, %	2.10
Ash, %	1.43
Total starch, %	57.28
Metabolisable energy, kcal/kg DM ¹	3262.00

¹DM dry matter

1.5 ml/min. The injection volume was 0.5 µl. The samples were injected with split mode. The injection port temperature was 280 °C. Oven temperature was programmed to increase from 160 to 180 °C at a rate 20 °C/min. Air flow was 350 ml/min, and hydrogen flow was 35 ml/min. The temperature of FID detector was 300 °C. Oven run time was 10 min. The individual VFAs concentrations were determined as mmol/l according to the standard mix using Xcalibur Software (Thermo Scientific, Orlando, FL, USA) in the GC-FID and the % ratios in total VFAs were also given (Kara et al., 2022).

Statistical analysis

Statistical analysis was performed using SPSS 20.0 (IBM Inc., Chicago, IL). One-way ANOVA was used to determine treatment effects while comparisons among means were done by the Duncan test. A value of $P < 0.05$ was considered statistically significant.

Results

Performance

Throughout the trial, all the birds showed optimum health signs, and no mortality was recorded in the experimental groups. Before the start of the trial, variations in day-old quail body weights were insignificant among treatments ($P = 0.901$, data not shown). Later, during the first 2 weeks of production, significant variations ($P < 0.05$) in weight gain and feed intake were observed in emmer wheat-added groups (T5 and T15) when compared to control; however, they did not translate into better performance (Table 3). Overall, throughout the experiment, no marked variations related to FCR were observed between experimental groups; however, for last week (days 28–35), a tendency of improvement was seen for FCR ($P < 0.10$) in response to dietary changes in quail rations with increasing levels of emmer wheat.

Table 3 Impact of dietary changes induced by different levels of emmer wheat (*Triticum dicoccum*) inclusion into Japanese quail diets on performance indexes

Item	Dietary treatments ¹				SEM ²	<i>P</i> -value
	Control	T5	T10	T15		
days 0–7						
BWG (g/bird/day)	3.75 ^b	4.08 ^a	3.71 ^b	4.09 ^a	0.06	0.012
FI (g/bird/day)	8.81 ^b	9.55 ^a	8.77 ^b	9.55 ^a	0.12	0.003
FCR	2.35	2.34	2.37	2.34	0.01	0.835
days 7–14						
BWG (g/bird/day)	4.43	4.64	4.45	4.65	0.06	0.511
FI (g/bird/day)	13.47 ^b	13.97 ^a	13.38 ^b	14.06 ^a	0.10	0.013
FCR	3.07	3.02	3.03	3.03	0.05	0.986
days 14–21						
BWG (g/bird/day)	4.73	4.67	4.68	4.69	0.04	0.671
FI (g/bird/day)	16.34	16.25	16.11	16.31	0.12	0.930
FCR	3.46	3.49	3.45	3.48	0.03	0.984
days 21–28						
BWG (g/bird/day)	5.26	5.29	5.37	5.34	0.05	0.883
FI (g/bird/day)	20.26	20.47	20.68	20.65	0.18	0.862
FCR	3.86	3.87	3.86	3.87	0.02	0.976
days 28–35						
BWG (g/bird/day)	5.65	5.96	5.91	5.98	0.06	0.171
FI (g/bird/day)	24.11	24.22	24.17	24.29	0.11	0.954
FCR	4.27	4.07	4.09	4.07	0.03	0.060
days 0–35						
BWG (g/bird/day)	4.75	4.86	4.79	4.88	0.02	0.118
FI (g/bird/day)	16.60	16.89	16.62	16.97	0.07	0.184
FCR	3.40	3.35	3.36	3.36	0.01	0.543

BWG, body weight gain; FI, feed intake; FCR, feed conversion ratio

¹Emmer wheat inclusion: control, 0%, T5, 5%; T10, 10%; T15, 15%

²Standard error of mean

Means not sharing a common superscript are significantly different ($P < 0.05$)

Carcass yield and organ weights

The carcass yield was significantly influenced by the dietary changes induced by addition of increasing levels of emmer wheat in quail rations (Table 4). In comparison to control group, there was a significant increase ($P=0.016$) in carcass yield when increasing levels of emmer wheat were added into quail diets. However, no marked variations were observed between emmer wheat-added groups. The group with 10% added emmer wheat (T10) presented with the highest carcass yield (73.15%). Furthermore, dietary changes with supplemental emmer wheat did not affect ($P>0.05$) various organ weights (liver, gizzard, heart) recorded in the study (Table 4).

Quail meat fatty acid profile

Quail rations with added emmer wheat resulted in considerable alterations in the fatty acid profile of breast meat (Table 5). Results showed a significant decrease ($P=0.008$) in total saturated fatty acids (Σ SFA) content of breast meat potentially attributable to reduction ($P=0.007$) in C16:0 (palmitic acid) levels with the addition of emmer wheat. Moreover, increasing levels of emmer wheat in quail diets resulted in significant decrement ($P=0.032$) in the total monounsaturated fatty acid (Σ MUFA) content of breast meat, specifically C18:1 (oleic acid) ($P=0.023$). Contrastingly, changes in quail rations with emmer wheat inclusion significantly increased the total polyunsaturated fatty acids (Σ PUFA) levels ($P=0.002$) in breast meat, particularly omega-6 C18:2 (linoleic acid) and omega-6 C20:4 (arachidonic acid) ($P=0.012$ and 0.001 , respectively). This increase in Σ PUFA levels also precipitated in increment ($P=0.009$) in total unsaturated fatty acid (Σ UFA) levels of breast meat. Furthermore, emmer wheat-added quail rations significantly increased the concentration of both omega-3 ($P=0.003$) and omega-6 ($P=0.002$) fatty acids; however, it did not result in any marked variation in their ratio ($P>0.05$) when compared to control.

Fecal VFAs composition

Fecal VFAs results presented in Table 6 showed that the dietary changes with the incorporation of emmer wheat into quail diets decreased ($P=0.002$) the concentration of propionic acid; however, it had no effect ($P>0.05$) on total VFAs levels. Furthermore, percentages of propionic and acetic acids were also modified, and a significant decrease ($P<0.001$) in the propionic acid percentage whereas an increase ($P=0.037$) in acetic acid percentage was observed with the addition of emmer wheat in quail diets.

Discussion

Feed ingredients play a vital role in livestock production, especially when considering the health benefits that they may offer. Recently, there has been increased interest in exploring lucrative but sustainable raw materials in animal nutrition. Emmer wheat, an ancient cereal crop known for its higher nutritional and nutraceutical properties, could be a good replacement for conventional feed ingredients in poultry diets. However, there is insufficient information available on the use of emmer wheat in poultry diets, and no studies have been done to balance quail rations with the inclusion of emmer wheat. Therefore, the present study was conducted to shed light on the perspectives of using emmer wheat in quail nutrition.

Overall, the dietary modifications involving the inclusion of emmer wheat in quail diets did not have any adverse impact on performance parameters. On the contrary, there was a slight tendency of improvement observed in FCR towards the end of the experiment (28–35 days). The late improvement in FCR can be attributed to the digestive tract's need to adapt to dietary changes, particularly in terms of the fiber source. A similar trend was seen in a study where Konca and Beyzi (2013) monitored the effects of free choice feeding of emmer wheat (~6% of ration) on performance indexes in Japanese quail. They found that quails that were fed a control diet performed better in terms of weight gain during the initial production period (days 3–10). However, in

Table 4 Impact of dietary changes induced by different levels of emmer wheat (*Triticum dicoccum*) inclusion into Japanese quail diets on carcass yield and some organ weights

Item	Dietary treatments ¹				SEM ²	P-value
	Control	T5	T10	T15		
Carcass yield, %	70.33 ^b	72.72 ^a	73.15 ^a	72.43 ^a	0.36	0.016
Liver, %	5.35	5.22	5.54	5.30	0.13	0.867
Gizzard, %	4.01	4.12	4.19	4.20	0.08	0.832
Heart, %	2.02	1.94	1.90	1.96	0.04	0.773

¹Emmer wheat inclusion: control, 0%, T5, 5%; T10, 10%; T15, 15%

²Standard error of mean

Means not sharing a common superscript are significantly different ($P<0.05$)

Table 5 Impact of dietary changes induced by different levels of emmer wheat (*Triticum dicoccum*) inclusion into Japanese quail diets on breast meat fatty acid profile (%)

Item	Dietary treatments ¹				SEM ²	P-value
	Control	T5	T10	T15		
C12:0	0.05	0.05	0.06	0.05	0.00	0.937
C14:0	0.51 ^b	0.72 ^a	0.54 ^b	0.53 ^b	0.02	0.006
C15:0	0.42 ^a	0.49 ^a	0.56 ^a	0.50 ^b	0.05	0.002
C16:0	23.78 ^a	21.97 ^b	21.13 ^b	21.26 ^b	0.32	0.007
C18:0	12.84 ^a	9.82 ^b	11.15 ^{ab}	12.06 ^a	0.34	0.018
C22:0	0.15 ^b	0.21 ^{ab}	0.29 ^a	0.20 ^{ab}	0.02	0.021
C24:0	0.38 ^b	0.42 ^b	0.68 ^a	0.48 ^{ab}	0.04	0.026
C14:1	0.17	0.25	0.16	0.12	0.02	0.259
C16:1	4.26 ^b	6.29 ^a	5.86 ^a	3.88 ^b	0.29	0.014
C18:1	29.76 ^a	26.07 ^b	24.26 ^b	24.65 ^b	0.73	0.023
C20:1	1.32	1.12	0.78	1.19	0.13	0.487
C18:2	19.46 ^b	24.17 ^a	23.67 ^a	25.39 ^a	0.72	0.012
C22:2	0.31 ^b	0.30 ^b	0.57 ^a	0.44 ^{ab}	0.03	0.002
C18:3	0.09	0.07	0.07	0.11	0.10	0.106
C20:3(n-6)	0.05 ^b	0.11 ^b	0.23 ^a	0.09 ^b	0.02	0.020
C20:3(n-3)	0.29 ^c	0.32 ^{bc}	0.51 ^a	0.46 ^{ab}	0.03	0.007
C20:4	4.08 ^c	5.98 ^b	7.91 ^a	6.42 ^{ab}	0.37	0.001
C20:5	0.44	0.56	0.69	0.77	0.05	0.096
C22:6	0.12 ^{ab}	0.07 ^{bc}	0.05 ^c	0.14 ^a	0.01	0.002
ΣSFA	39.17 ^a	34.42 ^b	35.07 ^b	35.78 ^b	0.54	0.008
ΣUFA	60.91 ^b	65.57 ^a	64.94 ^a	64.23 ^a	0.54	0.009
ΣMUFA	35.95 ^a	33.84 ^{ab}	31.10 ^b	30.27 ^b	0.77	0.032
ΣPUFA	24.96 ^b	31.74 ^a	33.84 ^a	33.96 ^a	1.04	0.002
n-3	0.95 ^b	1.00 ^b	1.32 ^a	1.46 ^a	0.06	0.003
n-6	24.01 ^b	30.74 ^a	32.52 ^a	32.50 ^a	0.99	0.002
n-3/n-6	0.039 ^{ab}	0.033 ^b	0.041 ^{ab}	0.045 ^a	0.00	0.030

SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; n-3, omega-3; n-6, omega-6

¹Emmer wheat inclusion: control, 0%, T5, 5%; T10, 10%; T15, 15%

²Standard error of mean

Means not sharing a common superscript are significantly different ($P < 0.05$)

Table 6 Impact of dietary changes induced by different levels of emmer wheat (*Triticum dicoccum*) inclusion into Japanese quail diets on fecal volatile fatty acids

VFAs	Dietary treatments ¹				SEM ²	P-value
	Control	T5	T10	T15		
mmol/l						
Butyric acid	0.34	0.22	0.28	0.08	0.07	0.709
Propionic acid	0.63 ^a	0.28 ^b	0.16 ^b	0.17 ^b	0.06	0.002
Acetic acid	2.92	4.77	2.17	2.33	0.44	0.123
Total VFAs	3.88	5.26	2.60	2.58	0.51	0.193
%						
Butyric acid	8.36	2.56	7.77	2.95	1.60	0.465
Propionic acid	16.26 ^a	5.36 ^b	5.69 ^b	6.52 ^b	1.31	0.000
Acetic acid	75.39 ^b	92.08 ^a	86.55 ^{ab}	90.54 ^a	2.40	0.037

VFAs, volatile fatty acids

¹Emmer wheat inclusion: control, 0%, T5, 5%; T10, 10%; T15, 15%

²Standard error of mean

Means not sharing a common superscript are significantly different ($P < 0.05$)

the later stage (days 24–38), the emmer wheat fed group had greater BWG than the control group though no significant changes in FI and FCR were reported. In a study with broilers, Nahas and Lefrancois (2001) stated better performance in finisher phase compared to grower phase when wheat was added to bird's diets. Previously, when substituting maize grain with ancient wheat lines by-products (up to 35%), Lombardi et al. (2020) reported decreased feed intake by laying hens which they ascribed to the low palatability of the wheat. Interestingly, the authors observed a more favorable FCR with ancient grains diet compared to the control group. The literature has shown that the fiber source and concentration in poultry diets can affect the development of their digestive system (Adli et al. 2022). Consistent with this, a study investigating the inclusion of ancient wheat middlings in hen's diet revealed enhancements in both the intestinal structure of the birds and the activities of digestive enzymes (Addeo et al. 2021). Research has also identified that the type of dietary starch and the ratio of amylopectin to amylose are crucial factors that have been linked to variations in feed efficiency (Arroyo et al. 2013). Thus, taking into account the comparable feed intake, the variations in nutritional characteristics of the diet, primarily resulting from substitution of barley, corn, and soybean for emmer wheat in quail diets, could also impact bird's performance. Overall, all these factors could be accounted for the possible improvement in FCR with emmer wheat-induced dietary changes in quail diets; however, additional research is needed to gain a more comprehensive understanding.

Furthermore, the dietary modifications involving the addition of emmer wheat in quail diets also had a positive impact on their carcass yield, though no changes in internal organ weights (liver, gizzard, heart) were recorded in this study. Analogous to our results, Addeo et al. (2021) also stated insignificant changes in the weights of gizzard, liver, and proventriculus when middlings of ancient wheat lines were added to quail diets. Konca and Beyzi (2013) stated no significant variations in carcass yield and weights of liver, proventriculus, and heart; however, they reported higher gizzard weight in the common wheat fed group compared to emmer wheat fed group. Nahas and Lefrancois (2001) reported no change in carcass yields of broilers fed increasing levels of either barley or wheat when compared to control group fed maize soybean-based diet. The literature revealed that the presence of dietary fiber, particularly NSPs, in bird's diet can impede optimal digestive functions with higher viscosity and longer passage rates, thus prompting birds to adapt to these changes, which subsequently leads to an enlargement of their gastrointestinal tract (Adli et al. 2022). Despite being statistically insignificant, the current study also observed a slight increase in gizzard weight when emmer wheat was added to the quail's diets. Annison and Choct (1991) stated that presence of pentosans

in wheat-based diets of broilers may stimulate their GIT enlargement, and exogenous enzyme supplementation to wheat-based diets in broilers can hydrolyze these NSPs resulting in decreased organ weights (Wang et al. 2005). In a study with quails, Yaşar and Gök (2014) revealed better performance results when fermented wheat grains were added to quail diets compared to fermented barley grains. They also stated well adaptation of quails to wheat-based diet than barley. Moreover, the authors noted that the groups fed with wheat exhibited higher carcass yields compared to those fed with barley. The authors linked this favorable outcome to the improved utilization of nutrients, which is attributed to the efficient digestive system of birds fed with wheat-based diets. In the study conducted by Kianfar et al. (2013), it was observed that quails fed processed wheat, which had a higher ratio of insoluble to soluble NSPs, exhibited better carcass yield and breast weight. In another study, supplementation of micronized wheat fiber to quail diets improved feed efficiency, increased weight of gizzard, GIT, and tibia (Rezaei et al. 2018). More research is necessary, particularly focusing on the evaluation of relative portions of the carcass such as muscle, bone, and adipose tissue. This will provide a better understanding of the beneficial effects of dietary emmer on carcass yield of quails.

This study further documented that the addition of emmer wheat to quail diets has a profound effect on the composition of breast meat fatty acids. In this study, compared to control group, the distinct dietary changes led by incorporation of increasing levels of emmer wheat into quail rations marked a significant reduction in $\sum$ SFA and $\sum$ MUFA levels, whereas a significant increase was observed in the levels of $\sum$ UFA, $\sum$ PUFA, omega-3, and omega-6 fatty acids in breast meat. The changes observed in fatty acid profile of quail meat could be linked to anticipated variations in fatty acid composition of the ration, particularly in relation to C16:0, C18:1, and C18:2. These changes were expected due to the alterations in the levels of emmer wheat, barley, and maize included in the quail's diet (Dhanavath and Prasad 2017; Rosentrater and Evers 2018). Thus, comprehensibly the increased intake of linoleic acid levels with emmer wheat addition resulted in an increase in meat linoleic acid content which was largely responsible for the increase in $\sum$ PUFA levels in meat. On the contrary, the marked reduction in $\sum$ SFA and $\sum$ MUFA in meat was primarily due to the decrease in the contents of palmitic acid and oleic acid, respectively. One study showed that elevated $\sum$ PUFA levels in poultry may reduce $\sum$ MUFA synthesis by inhibiting the activity of the Δ 9-desaturase complex, a key enzyme that converts SFA to MUFA (Jung et al. 2010). Meat fatty acid composition plays an important role in determining its quality as it relates to differences in organoleptic properties and nutritional value for humans (Jachimowicz et al. 2022), i.e., a higher ratio of PUFA to SFA and a more appropriate

balance between omega-3 and omega-6 fatty acids. In the current study, the incorporation of emmer wheat into quail diets not only increased the levels of omega-3 and omega-6 fatty acids but also modified the meat towards a more favorable omega-3 to omega-6 ratio. Research suggests that reduced antioxidant status in vivo would lead to decreased levels of PUFA (Wood et al. 2004). Thus, feeding of emmer wheat to quails and its regulatory effects on meat fatty acid profile can also be attributed to its nutraceutical components including antioxidants, and their ability to ameliorate lipid metabolism in favor of consumer demands. Inadequate literature is available determining the effects of ancient wheat lines on the meat fatty acid composition of animals. Further research is needed to fill these gaps in information and to thoroughly address the health-beneficial effects of emmer wheat when added to animal diets.

Carbohydrates in birds' diets are a major source of influence on the production as well as the composition of cecal VFAs which in turn can have a great impact on the host's health. VFAs have been reported to exert bacteriostatic effects against some pathogenic bacteria and a negative correlation between the acetate levels and Enterobacteriaceae including *Salmonella* spp. have been found in broilers (van der Wielen et al. 2000). In the current study, the use of emmer wheat in quail diets resulted in a reduction in the propionic acid percentage while an increase in the acetic acid percentage was observed. Previously, with the substitution of maize grain with ancient wheat lines by-products in laying hen's diet, Lombardi et al. (2020) reported a higher amount of butyric acid in the cecal content of hens while no changes in other VFAs were observed. Data evaluating the effects of emmer wheat on VFAs profile in poultry is insufficient; however, significant differences were registered in VFAs composition in poultry when fed common wheat- and maize-based diets. The variations in the VFAs profile recorded in the present study were comparable to the earlier results demonstrating higher concentrations of acetic as well as butyric acid while lower concentrations of propionic acid in broilers fed wheat-based diets compared to those fed maize-based diets (Kiarie et al. 2014; Masey-O'Neill et al. 2014; McCafferty et al. 2019). This trend in the VFAs changes could be attributed to the nutritional modifications brought by emmer wheat inclusion to quail's rations. The fermentation capability of dietary fiber in poultry can play a significant role in overall health and performance of birds. The incorporation of dietary fiber in poultry diets effectively supports the growth of beneficial bacteria, such as *Lactobacillus* and *Bifidobacterium*. This, in turn, enhances the production of VFAs which can help prevent digestive disturbances in poultry (Singh and Kim 2021). In chickens, rye exhibited the highest viscosity of gut contents, followed by barley, triticale, wheat, maize, and sorghum (Carré, 2004). Increasing concentration of β -glucans with barley supplementation has been reported

to linearly decrease cecal acetic acid while increasing the proportions of propionic acid (Lynch et al. 2007). It was also revealed that starches with distinct chemical structures have the potential to selectively target specific bacteria (Martínez et al. 2010). According to a study, it was found that diets rich in arabinoxylan and resistant starch have the ability to alter the gut microbiota by stimulating the growth of *Bifidobacteria* and increasing the production of short-chain fatty acids, particularly acetate and butyrate (Hald et al. 2016). Hence, the higher concentration of acetic acid and lower levels of propionic acid in the cecum of quails can be attributed to low dietary levels of β -glucans, along with higher levels of arabinoxylan or resistant starch. However, more research is needed to provide more comprehensive insights.

Conclusion

The results obtained from the study supported the usage of emmer wheat into quail rations at levels up to 15% without any adverse effects on performance indexes. In fact, substituting traditional grains with emmer wheat in quail diets can offer additional benefits such as increased carcass yield and improved fatty acid profile of the meat. Emmer wheat, being a source of dietary fiber, can also bring about modifications to the profile of volatile fatty acids in fecal matter. Although not explored in the current study, investigating the impact of emmer wheat inclusion in quail diets on detailed carcass characteristics would be of interest. Future research should also focus on the dietary types and levels of NSPs as well as resistant starch when emmer wheat is included as part of poultry diets.

Author contribution MÖ conceived the research idea, analyzed the data, and fitted the models. MÖ and TŞ conducted the animal trial and collected the data. KK analyzed the fatty acid profile of the meat and fecal samples. SR and RR interpreted the results, prepared the initial draft, and finalized the draft. All authors read and approved the final manuscript.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethics approval The entire experimental protocol was approved by the animal care and use committee of the Kafkas University via approval no. KAÜ-HADYEK 2020/158.

Consent to participate Not applicable.

Conflict of interest The authors declare no competing interests.

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