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Digestible threonine and its effects on growth performance, gut morphology and carcass characteristics in broiler Japanese quails *(Coturnix coturnix japonica)*

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Abstract

Threonine is the third limiting amino acid in corn-soy-based poultry diets and has an important role in body and intestinal development of chicken. Although work on threonine (Thr) in chicken is well established, information about the effects of digestible threonine (dThr) on quail performance is limited. Therefore, the current study was designed to determine the impact of increasing levels of dThr on growth performance, feed conversion ratio (FCR), gut health and carcass characteristics in meat-type quails. A total of 324 mixed-sex day-old quail were randomly allocated to three treatments with six replicates per treatment and 18 birds per replicate. There were three dietary treatments, namely control (C) with recommended levels of dThr according to the Brazilian Tables guidelines for Japanese quails: 10% dThr (C diet supplemented with 10% more dThr) and 20%dThr (C diet supplemented with 20% more dThr). At day 35 of the experiment, three birds from each pen were slaughtered. A duodenal sample was collected and preserved to evaluate gut health. The carcass characteristics were determined from the slaughtered birds. Total feed intake and average daily feed intake were higher in the C treatment than in 10% dThr. Final bodyweight (BW), weight gain and average daily gain (ADG) increased linearly. The birds fed diets supplemented with 20% extra dThr had the highest final weight and bodyweight gain (BWG) compared with those birds that were fed on C and 10% dThr supplemented diets. Feed conversion ratio was improved in 10% dThr compared with the C birds. Villus height (VH) was similar among treatments. The highest crypt depth (CD) was observed in C, followed by 10% dThr and 20% dThr. The birds fed 20% dThr had higher VH:CD than 10% dThr. The birds in the C treatment had lowest VH:CD. Carcass weights with and without giblets were higher in the 20% dThr than in the 10% dThr and C treatments. Breast mass yield (BMY) was greatest in 20% dThr compared with C and 10% dThr. It may be concluded that supplementation of Thr higher than the requirements referred to in Brazilian Tables improves growth performance and gut health of meat-type quail.

Keywords: Crypt depth, mucin, performance, quail, villus height
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Introduction

Threonine is a 2-amino-3-hydroxy butanoic acid with a molecular mass of 119.2 g/mol (Ayasan, 2004). For low protein diets, it is the third limiting amino acid in broilers (Kidd *et al*., 1999). Threonine is known to help to maintain gut barrier integrity and intestinal mucin synthesis (Bertolo *et al.,* 1998). It is integrated directly into mucin, which is a major glycoprotein for the protection of intestinal linings from injury (Schaart *et al*., 2005). A deficiency of threonine (Thr) leads to a decrease of mucin production in the small intestine in rats (Faure *et al.,* 2005). The layer of mucus is an essential part of the non-immune gut barrier. However, during the inflammation process, Thr accessibility may become restricted for mucin production, which impairs the gut protection system. Increasing dietary Thr inclusion may stimulate the synthesis of mucin and gut microbiota to favour mucosal healing and protect the intestine (Faure *et al*., 2006; Wang *et al*., 2009).

To date, several other investigators have evaluated dietary Thr requirements in broilers (Rosa *et al*., 2001; Rezaeipour *et al*., 2012; Rezaeipour & Gazani, 2014). The function of Thr is to maintain the digestive

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tract (Van der Schoor *et al*., 2002) and improve productivity (Kidd & Kerr, 1997; Kidd *et al*., 2003). It plays many roles, namely as a feather protein, a precursor of serine and glycine, a component of glycoprotein involved in gastrointestinal tract (GIT) mucin production (Lemme, 2001) and stimulate antibody production (Wang *et al*., 2006). Threonine, as, L isomer, is supplemented in the diets of commercial poultry and pigs to meet the nutritional requirements of amino acids for rapidly growing animals. Balancing essential amino acids enables animals to utilize feed more efficiently. To date, several studies have assessed whether dietary supplementation of Thr could improve the performance of pigs, layers, broilers and rabbits. Threonine requirements have been calculated for broilers from 0 to 8 weeks old (Kidd *et al*., 1997; Dozier *et al*., 2001), but the literature on Thr requirements for Japanese quail is limited. Japanese quail are raised mainly for meat and eggs, and are regarded as research animals (NRC, 1994). Their feeding requirements are lower (20–25 g/day) than those of chickens (120–130 g/day) (Ani *et al*., 2009). Typically, quail are marketed at 140–180 g at 5–8 weeks and reach peak egg production at the age of 5–8 weeks (Garwood & Diehl, 1987). Broiler quail Thr requirements are established and published in National Research Council (1994) and Brazilian Tables for Poultry and Swine (2011). Their requirements of digestible Thr are 1.02% and 0.79%, respectively.

Although work on Thr in chicken is well established, information about the effects of dietary L-Thr on quail performance is limited. The authors' aim was to evaluate dThr supplementation in quail diet using the Brazilian Tables (2011).

Materials and Methods

The experiment was performed at a commercial quail farm. Birds were reared in a mechanically ventilated quail battery system. Before the start of experiment, the shed was disinfected with a 35 mL solution of formalin, containing 40% formaldehyde and 10 $KMnO_4$ g/ft^3 according to farm protocols. A total of 324 day-old chicks were selected from the farm's own hatchery and randomly assigned to three dietary treatments with 108 chicks per treatment. Every treatment was further divided into six replicates with 18 chicks per replicate. The dietary treatments consisted of i) C, the control diet with the standard digestible threonine (dThr) level according to the Brazilian Tables for Poultry and Swine (2011); ii) 10% dThr, with 10% higher digestible threonine (dThr) than control; and iii) 20% dThr, with 20% higher dThr than control. The diets were formulated according to the Brazilian Tables for Poultry and Swine (2011). Diet formulation and nutrient composition are presented in Tables 1 and 2, respectively.

Table 1 Composition of experimental diets fed to broiler quail from 1 to 35 d of age

Ingredient (%)	Control	10% digestible threonine	20% digestible threonine
Corn	34.93	34.85	34.77
Rice tips	24.00	24.00	24.00
Soybean meal 45%	12.00	12.00	12.00
Canola meal	16.40	16.40	16.40
Corn gluten 60%	2.00	2.00	2.00
Poultry by-product meal	6.00	6.00	6.00
Vegetable oil	1.20	1.20	1.20
Mono calcium phosphate	1.00	1.00	1.00
Limestone	1.20	1.20	1.20
Soda bicarbonate	0.02	0.02	0.02
Common salt	0.17	0.17	0.17
DL-Methionine	0.09	0.09	0.09
Lysine sulphate	0.65	0.65	0.65
L-Threonine	0.14	0.22	0.30
Vitamins[1]	0.10	0.10	0.10
Mineral Mixture[2]	0.10	0.10	0.10

[1] Vitamins per kg of feed: vit. A 20000 IU; vit. D3 5400 KIU; vit. E 48.0 mg; folic acid 1.6 g; vit. K 3 4 g; niacin, 60 g; pantothenic acid 20.0 g

[2] Mineral Mixture per kg of feed: Cu 10 g, Zn 120 g, Mn 130 g, Fe 60 g, I 1.8 g, Se 0.36 g, Co 0.4 g

Table 2 Nutrient composition of experimental diets fed to broiler quail from 1 to 35 d of age

Nutrient	Control	10% digestible threonine	20% digestible threonine
Metabolizable energy Kcal/kg	2917	2917	2917
Crude protein %	21.00	21.00	21.00
Ether extract %	4.40	4.40	4.40
ASH %	5.80	5.80	5.80
Crude fibre %	3.80	3.80	3.80
Calcium %	0.90	0.90	0.90
Phosphorus-Dig %	0.38	0.38	0.38
Phosphorus-Total %	0.62	0.62	0.62
Sodium %	0.16	0.16	0.16
Potassium %	0.66	0.66	0.66
Chloride %	0.19	0.19	0.19
Meth-T %	0.47	0.47	0.47
Meth-D %	0.42	0.42	0.42
Lysine-T %	1.29	1.29	1.29
Lysine-D %	1.13	1.13	1.13
Threonine-T %	0.95	1.04	1.14
Threonine-D %	0.79	0.86	0.94

Chicks were given free access to experimental diets and fresh water was provided in each pen. Brooding temperature for the first week was kept at 95 °F. Every week the temperature was reduced by 5 °F until it reached room temperature (75 °F). Whole weight and bird mortality per replicate were recorded at the end of every week. A calculated amount of feed was offered to all birds in each replicate for the whole week. After the completion of each week, feed refusals were weighed to calculate the weekly feed intake of each replicate. Mortality weight was used to adjust the feed intake of that replicate. The birds in each replicate were weighed at day one and after that on a weekly basis. The data of the feed eaten by birds and gain in bodyweight, corrected for mortality, were used to calculate feed conversion ratio (FCR) as feed consumed by bird (g) divided by weight attained by bird (g).

At the end of the fifth week, three birds from each replicate were selected, weighed and humanely slaughtered for organ weights and morphometric measurements. Duodenal samples for morphometric study were collected from slaughtered birds as described by Gopinger *et al*. (2014). A section 2 cm long was collected from the middle of the duodenum, cleaned with normal saline (0.9% NaCl) and preserved in a volumetric plastic container with 10% formalin solution. Preserved intestinal sections were fixed in 10% formalin solution. Fixed tissue sections were dehydrated in ascending concentrations of alcohol (50%, 70%, 95%, absolute I, and absolute II) for cleaning. Dehydrated tissue samples were cleared in pure xylene. After clearing, the tissue samples were impregnated with paraffin wax I and paraffin wax II. The paraffin-impregnated tissue samples were divided into 5-µm thick sections with microtome and mounted on clean glass slides (covered with a thin layer of egg albumen), after slight warming at 58 °C in a hot water bath. The slides were dipped in pure xylene I and pure xylene II for 5 minutes each. The slides were then dipped in descending concentrations of alcohol (absolute, 90%, 80% and 70%) for 5 minutes each. Then the slides were dipped three times in distilled water. The slides were placed in haematoxylin stain for 2 to 3 minutes. The slides were washed under tap water for 1 to 3 minutes, dipped three times in distilled water and ammonia water (two dips) and stained with eosin for 1 to 2 minutes. After staining the samples were washed under tap water (1 to 2 minutes) and dehydrated in ascending concentrations of alcohol (70%, 80%, 90%, and absolute) for 3 minutes each. The samples were placed in xylol I and xylol II for 3 minutes each. A drop of DPX (distyrene plasticizer xylene) was placed on the slides and a cover slip was applied. The tissue slides were examined for VH and CD with a compound microscope (Olympus CX31, Olympus USA) equipped with a digital imaging system (Olympus DP20, Olympus USA).

Carcass evaluation was carried out. The slaughtered birds were cut into parts for carcass evaluation according to Ojewola *et al.* (2001). Breast yield and carcass with and without giblets were weighed with a digital balance. Liver, heart, gizzards and non-edible organs were weighed. The gastrointestinal tract (GIT) with and without ingesta were weighed and the weights of the relative organs were calculated.

The data for total feed intake, average daily feed intake, final weight, weight gain, average daily gain (ADG), FCR, villus height (VH), crypt depth (CD), VH:CD and carcass characteristics were analysed with one-way ANOVA in a completely randomized design. Means were compared with Tukey's multiple comparison test. All the data were analysed with SPSS software (SPSS version 21.0 Inc., Chicago, IL, USA).

Results

Means of total feed intake, average daily feed intake, weight gain, final weight, ADG and FCR are presented in Table 3.

Table 3 Effects of digestible threonine on feed intake, body weight and feed conversion ratio in Japanese quail from 1 to 35 days old

Variables	Treaments[1]			SEM	*P*-value	
	Control	10% dThr	20% dThr		Linear	Quadratic
TFI[2] (g/bird)	546.9[a]	478.6[b]	516.5[ab]	14.8	0.220	0.033
ADFI[3] (g/bird.d)	15.6[a]	13.7[b]	14.8[ab]	14.7	0.221	0.033
FW[4] (g/bird)	191.4[b]	196.1[ab]	204.8[a]	3.07	0.035	0.649
WG[5] (g/bird)	182.4[b]	187.1[ab]	195.8[a]	3.07	0.035	0.649
ADG[6] (g/bird.d)	5.21[b]	5.35[ab]	5.60 [a]	5.38	0.034	0.650
FCR (g/g)	3.00[b]	2.56[a]	2.64[ab]	0.04	0.000	0.001

[a-b] Means having different superscripts in a row differ significantly ($P < 0.05$)
[1]Treatments: C (control: digestible threonine according to 100% Brazilian requirements), 10% dThr (containing 110% Brazilian requirements), 20% dThr (containing 120% of Brazilian requirements)
[2]TFI: total feed intake; [3]ADFI: average daily feed intake; [4]FW: final weight; [5]WG: weight gain; [6]ADG: average daily feed gain

The total feed intake and average daily feed intake were significantly higher (quadratic) (P <0.05) in C than in 10% dThr. Final body weight (BW), weight gain and ADG increased linearly (P <0.05) with level of dThr in the diets. The birds fed diets supplemented with 20% dThr had the highest final weight and body weight gain (BWG) compared with those birds fed on C and 10% dThr, respectively. A treatment x week interaction was observed (P <0.05) for ADG in weeks 1, 4, and 5 (Figure 1). In week 1, ADG was significantly higher (P <0.05) in the 10% dThr quails than in the C and 20% dThr birds. During week 4, however, the growth rate was higher in the 10% dThr and 20% dThr birds than the C treatment. Interestingly, birds fed 20% dThr showed higher ADG than those in the 10% dThr and C treatments. The results showed clearly that FCR was improved (P <0.05) in the dTH10% compared with the C birds. A treatment x week interaction was observed in weeks 1, 4, and 5 (Figure 2).

Means of VH, CD, and VH:CD ratio are presented in Table 4. VH was similar (P >0.05) among treatments. C had numerically less VH compared with those fed 10% and 20% extra dThr. CD increased (P <0.05) linearly in C compared with those fed the 20% dThr supplemented diet. The birds fed the 20% dThr had the highest (P<0.05) VH:CD, followed by 10% dThr and C.

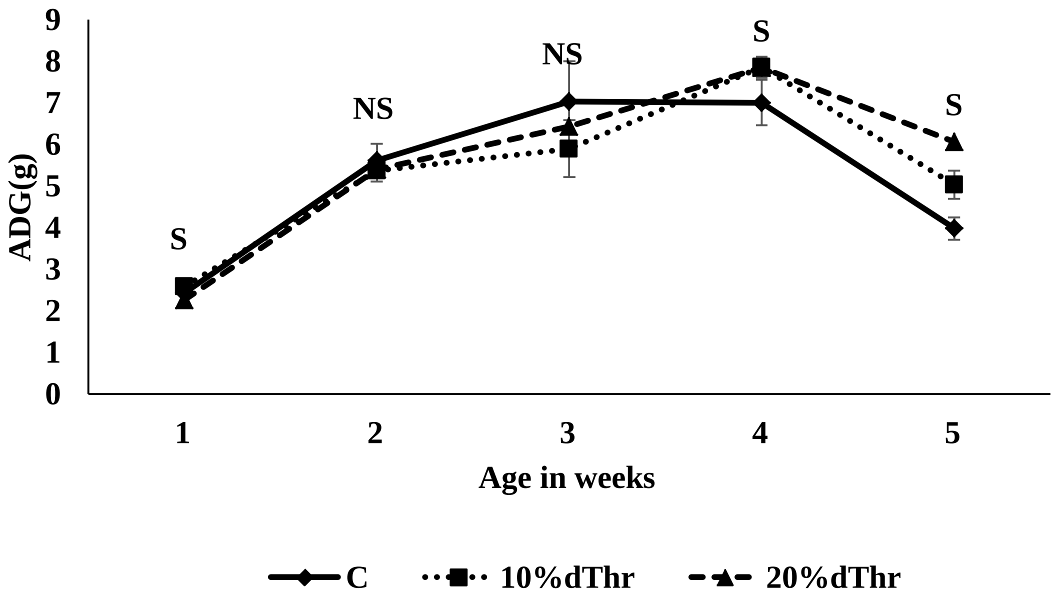

Figure 1 Weekly means of average daily weight gain of the birds
C: control group (100% digestible threonine according to Brazilian requirements); 10% dThr: 10 % more digestible threonine than control; 20% dThr: 20% more digestible threonine than control; ADG (g): average daily weight gain, S: significant results (*P* <0.05), NS: non significant results (*P* >0.05)

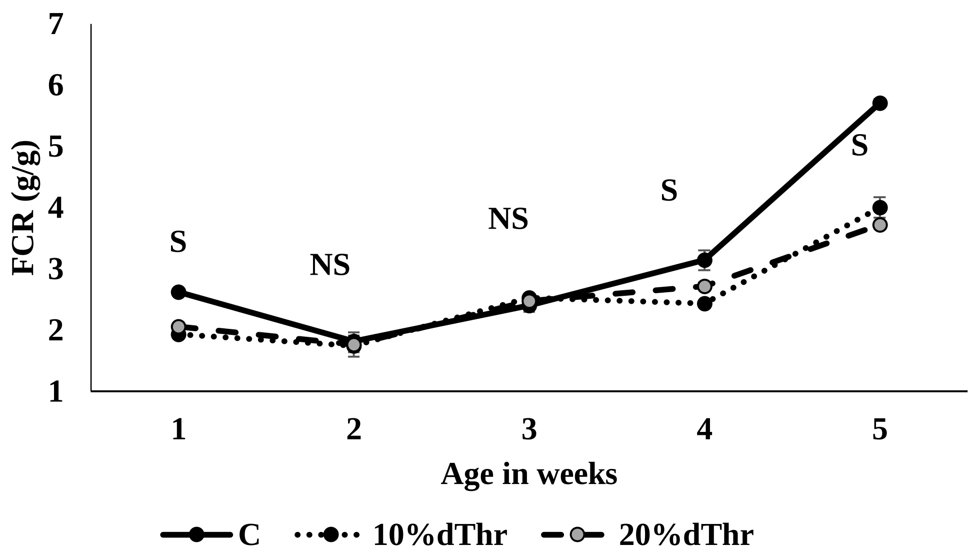

Figure 2 Means of weekly feed conversion ratio of birds
C: control group (100% digestible threonine according to Brazilian requirements), 10% dThr: 10% more digestible threonine than control, 20% dThr: 20 % more digestible threonine than control, FCR: feed conversion ratio, S: significant (*P* <0.05), NS: non-significant (*P* >0.05)

The results of the evaluation of carcass characteristics are shown in Table 5. Increasing levels of dThr in quail had no effects (*P* >0.05) on filled intestine, empty intestine, intestinal length, caecal length and leg weight. Carcass weight with and without giblets was higher (*P* <0.05) in 20% dThr compared with 10% dThr and C treatments. Similarly, heart, gizzard and liver weights were not influenced ($P > 0.05$) by increasing levels of dThr. The birds fed on 20% dThr had heavier BMY ($P < 0.05$) than the C and 10% dThr diets.

Table 4 Duodenal villus height, crypt depth and villus height to crypt depth ratio in Japanese quails fed various levels of digestible threonine

Variables	Treaments[1]			SEM	*P*-values	
	C	10%	20%		Linear	Quadratic
VH(µm)	1499.8	1675.2	1616.5	148.1	0.583	0.526
CD(µm)	397.2[a]	278.8[ab]	228.0[b]	34.01	0.010	0.523
VH : CD	4.17[b]	6.43[ab]	7.07[a]	0.638	0.005	0.328

[a-b] Means with different superscript in a row differ significantly ($P < 0.05$)
[1]Treatments C: control: digestible threonine according to 100% Brazilian requirements, 10% dThr: 10% more digestible threonine than control, 20% dThr: 20% more digestible threonine than control
VH: villus height, CD: crypt depth

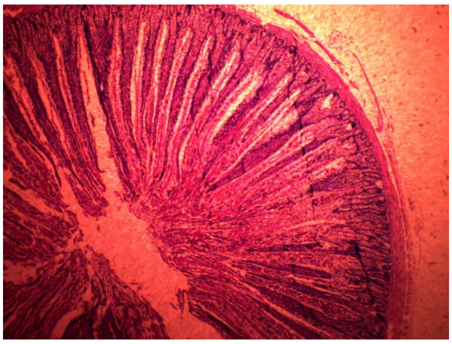

Figure 3 Microscopic photograph of duodenal section of meat type quail fed control diet

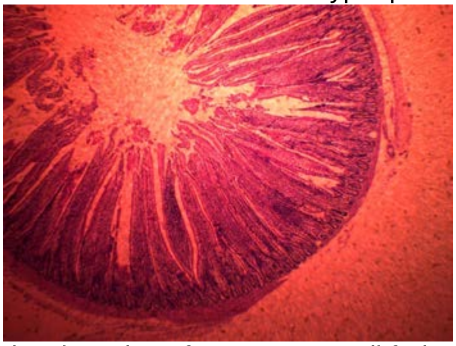

Figure 4 Microscopic image of duodenal section of meat type quail fed 10% digestible threonine higher than control

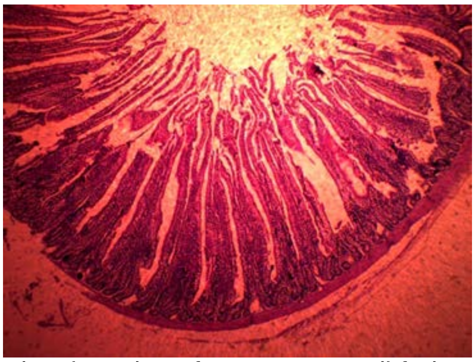

Figure 5 Microscopic image of duodenal section of meat type quail fed 20% digestible threonine higher than control

Table 5 Carcass characteristics in Japanese quails fed increasing levels of digestible threonine

Variables	Treatments[1]			SEM	*P*-value	
	Control	10% dThr	20% dThr		Linear	Quadratic
Live weight (g)	191.3[b]	199.3[b]	208.3[a]	2.34	0.000	0.865
Filled intestine (g)	6.03	5.25	5.59	0.32	0.396	0.211
Intestinal length (cm)	43.7	42.2	43.2	1.02	0.763	0.342
Empty intestinal weight(g)	4.86	4.66	5.12	0.23	0.442	0.271
Caecal length (cm)	15.2	15.4	16.0	0.55	0.329	0.807
Carcass with giblet (g)	127.1[b]	131.8[b]	141.9[a]	2.17	0.000	0.331
Carcass without giblet (g)	116.1[b]	120.8[b]	129.9[a]	2.11	0.000	0.402
Heart weight (g)	0.908	0.947	0.969	0.056	0.447	0.904
Liver weight (g)	2.27	2.25	2.15	0.09	0.345	0.757
Gizzard weight (g)	2.54	2.33	2.61	0.16	0.775	0.268
Breast weight (g)	28.4[b]	29.5[ab]	30.8[a]	0.51	0.004	0.868
Legs weight (g)	21.0	20.6	21.3	0.39	0.530	0.215

[a-b] Means with different superscripts in a row differ significantly (P <0.05).
[1]Treatments C: control: digestible threonine according to 100% Brazilian requirements, 10% dThr: 10% more digestible threonine than control, 20% dThr: 20% more digestible threonine than control

Discussion

It was hypothesized that the growth performance of quails could be improved with supplementation of Thr above the recommended levels. Gut health and carcass characteristics were studied as descriptive variables.

The results of the evaluation of growth performance of the present study showed that average daily and total feed intake were highest in the C treatment. In the C treatment, total and average daily feed intake were higher by 14.2% and 5.89% compared with the 10% dThr and 20% dThr diets, respectively. Final BW, weight gain and ADG increased linearly with increasing levels of dThr in the diets. The current results are in line with those of Lehmann *et al.* (1997), who supplemented Thr (0.82–0.88–0.94–1.00–1.06–1.12%) and stated that weight gain rose with increasing threonine in the diets of growing turkey toms. The data of the current experiment showed that 21.9% lower FCR was observed in C compared with 10% dThr. Similarly, Canogulları *et al*. (2009) stated that increasing Thr levels in laying quails improved FCR. In contrast to present study, Baylan *et al.* (2006) stated that increased dThr from 0.81 % to 1.06 % did not affect FCR in quails during the 1–35 day period. Poor FCR in C was due to poor utilization of feed compared with those fed 10% dThr and 20% dThr. Better FCR in 10% dThr and 20% dThr may be because threonine improved nutrient digestion owing to higher amylase secretion in the digestive tract (Block *et al.,* 1966). Improved FCR in 10% dThr may be associated with improved nitrogen retention. Similarly, Dozier *et al.* (2001) stated that nitrogen retention was higher in broilers fed 0.74% of total Thr compared with 0.52% Thr in the diet.

Work by Block *et al.* (1966) showed that Thr constitutes 11% of amylase protein contents, suggesting the importance of dThr in diets of growing birds, and consequent improvement in growth rate. Other investigators suggested that Thr serves as a precursor of lysine and serine and plays a vital role in body proteins (Ojano-Diranin & Waldroup, 2002). Similarly, Good (2013) conducted an experiment to find out the interaction of Actigen and graded levels of Thr (0.56%, 0.64%, 0.80%, 0.96%, and 1.04%). The author stated that bird fed diets containing the recommended level of Thr (0.56%) had the lowest BWG, feed intake, and poor FCR compared with those fed various levels of Thr (0.64, 0.80, 0.96, and 1.04%). Ospina-Rojaset *et al.* (2013) reported improved FCR in broilers fed diets containing 10% (0.77%) more Thr than Ross's recommendations (0.70%), which is in line with the current findings in broiler quails. Estalkhzir *et al.* (2013) stated that 110% and 115% levels of Thr resulted in improved BWG, FCR, and lowered feed intake. Mazraeh *et al.* (2013) reported improved BWG and FCR in broiler chicken. However, feed intake was not similar among treatments, indicating the impact of Thr on nutrient utilization in meat-type birds.

In this experiment, higher growth rates, lower feed intake and better FCR in 10% dThr and 20% dThr compared with C may be attributed to the stabilization and maintenance of gut barriers (Bertolo *et al.*, 1998; Schaart *et al*., 2005). One possible explanation for improved growth performance and FCR could be that Thr is a major component of mucin, a glycoprotein, which serves as a barrier and protects intestinal linings from injury. Mucin also serves as a protecting material from acidic chyme and pathogenic microbes (Horn *et al*., 2009). As a glycoprotein, mucin filters nutrients inside the gut lumen and helps in digestion and absorption (Smirnov *et al*., 2006).

Intestinal health and fitness of gut for digestion and absorption can be determined by measuring the VH and CD (Awad *et al*., 2009). In the small intestines, the duodenum is the principal site of absorption and digestion of nutrients. Duodenal morphometry was therefore used to indicate the impact of dietary treatments on gut health. An *in vivo* study in piglets showed that between 80% and 90% of dietary Thr is used by the intestine, most of which is incorporated into mucosal proteins (Schaart *et al*., 2005). The published data regarding Thr supplemental effects in quail are insufficient. The VH in meat type quails was similar and not influenced by the increasing level of dThr. The results in the present study are similar to those of Chen *et al.* (2016), who reported that supplementation of Thr (0.70% and 0.77%) did not improve VH in broilers from day 1 to day 35 of their experiment. Similarly, Eftekhari *et al.* (2015) reported that increasing levels of Thr (100%, 110%, 120% and 130%) did not influence VH in broilers. Good (2013) supplemented various levels of threonine (0.56%, 0.64%, 0.80%, 0.96% and 1.04%) and observed that VH was lower in birds fed 0.56% of threonine, and associated this decrease in VH to a deficiency of Thr in the diet. In broilers, those receiving ample amounts of threonine in the diet had better VH compared with those fed a Thr-deficient diet (Zaefarian *et al.,* 2008). Contrary to the current findings, a study evaluating the supplementation of higher Thr to Lys ratio resulted in improved gut health in broilers. The authors supplemented the Thr deficient diet with recommended or 25% greater Thr levels and reported that supplementation of higher levels of Thr resulted in improved VH in broilers (Valizade *et al*., 2014).

The depth of crypt gives an estimate of the number of cells in intestinal villi. A larger CD therefore indicates a greater turnover rate of enterocytes, which require more protein and energy and vice versa (Abdullah *et al*., 2010). The current results showed that decreases in CD were observed in the 10% dThr and 20% dThr by 29.8% and 42.6 %, respectively, compared with C. These results are in line with those of Abbasi *et al.* (2014), whose supplementation of 10% more Thr than the recommended level resulted in a 6% increase in VH, an 8.3% decrease in CD and a 12% increase in the VH to CD ratio. Intestinal mass and viability are maintained by dietary proteins, which serve as a source of energy for normal intestinal functions. The small intestine uses 30% to 50% Thr, along with other amino acids directly and does not spare them for other tissues, except the intestine. Lower CD in Thr-supplemented birds may be associated with a rapid turnover of intestinal tissues through an ample supply of dThr. The current results are in line with those of Valizade *et al.* (2014), who found that higher levels of Thr resulted in improved CD and VH:CD ratio in broilers.

Contrary to the current findings, Chen *et al.* (2016) reported that supplementation of dThr did not influence the CD and VH:CD ratio in broilers. Eftekhari *et al.* (2015) reported that various levels of Thr (100%, 110%, 120% and 130%) did not influence CD and VH:CD ratio in broilers. Similarly, Good (2013) reported that supplementation of Thr at various levels (0.56%, 0.64%, 0.80%, 0.96% and 1.04%) did not influence CD and the VH:CD ratio in the jejunum of broilers at seven days old. The higher dietary fibre might have caused sloughing of intestinal mucosa (Mushtaq *et al*., 2009), which in turn increases the amino acid requirements for the synthesis of new cells (Parsons *et al*., 1983). Choct (2009) reported that fast growing broilers allocate 12% of newly synthesized protein to the GIT. The lower CDs in the current experiment indicate a slower tissue turnover. Thus, a lower nutrient supply is required to support it (Boka *et al*., 2014). Threonine plays a significant role in the development of the intestines of chickens because it is involved in the synthesis of mucin (Faure *et al*., 2005).

Carcasses with and without giblets were higher in 10% dThr and 20% dThr by 3.70% and 11.64%, respectively, compared with the C treatment quails. Breast meat yield is the most desired part in the carcass of birds. In addition to lysine and methionine, Thr plays a key role in the development of breast muscles in birds. A suboptimal supply of dietary Thr may decrease breast meat growth breast meat yield by 3.8% and 8.45%, respectively, less than C. The current results are in accordance with the Estalkhzir *et al.* (2013). The authors reported 11.48% improved carcass weight, and 29.85% greater breast meat yield in broiler chickens. However, in quails, the response was low compared with broilers, which may be associated with genetically higher growth and better FCR potential in commercial meat type broilers. Thus, Baylan *et al.* (2006) stated that supplemental L-threonine did not affect carcass yield, breast meat, and thigh percentage in quails. For broilers, the requirement of threonine for carcass gain differs, depending on age, strain, sex and crude protein content of feed, dose and types of ingredients (Barkley & Wallis, 2001). Similarly, several researchers reported that Thr supplementation increased the breast meat yield (Mack *et al*., 1999; Dozier *et al*., 2000, 2001; Ciftci & Ceylan, 2004; Jahanian, 2010), which is in line with the current findings. In the current experiment supplementation of dThr had no effect on thigh weight, which corroborates the findings of Kerr *et al.* (1999) that supplementation of dThr did not influence the thigh yield.

Conclusions

In conclusion, the supplementation of dThr above the recommendations of Brazilian Tables for Poultry and Swine improved growth performance, FCR, gut health, and breast meat yield of broiler-type Japanese quails.

Authors' Contributions

M.F. Rasheed: Data collection, analysis and write up; M.A. Rashid: Experiment planning, execution of experiment, lab analysis and write up; Saima: Lab analysis; A. Mahmud:, Statistical analysis; M.S. Yousaf: Lab analysis and write up; M.I. Malik: Lab analysis and write up.

Conflict of Interest Declaration

The authors declare no conflict of interest.

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