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The impact of betaine supplementation in quail diet on growth performance, blood chemistry, and carcass traits



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ABSTRACT

The study aimed to investigate the effect of various doses of betaine supplemented dietary on Japanese quail performance, carcass characteristics, and blood chemistry. Therefore, 400 seven days old Japanese quails were classified randomly into four equal groups. Each group was subdivided into five replicates of 20 birds each. Four rations were formulated using four different betaine levels (0, 0.75, 1.5 and 2.25 g/kg, respectively) for five successive weeks. All groups received feed and clean water ad-libitum. The results of this trial indicated that the feed intake was lowered in groups fed with betaine ($p \leq 0.05$) when compared with the control one. The highest weight gain ($p \leq 0.05$) was noticed in groups fed diets BS4 (betaine supplementation at the rate of 2.25 g/kg). No difference among groups was observed in body length, shank length, shank diameter, and keel bone length or breast width. Also, the carcass weight and breast yield were highest ($p \leq 0.05$) in the group reared on the BS4 diet. In addition, intestinal length and weight were significantly higher ($p \leq 0.05$) in groups fed betaine with a concentration of 2.25 g/kg. Fat weight was lower in the group fed BS4 than in the untreated group. Significantly higher values of high-density lipoprotein ($p \leq 0.05$) were observed in the group fed BS4. All groups fed a ration containing betaine showed lower levels of liver enzymes such as alanine amino transferase, alkaline phosphatase, and aspartate amino transferase ($p \leq 0.05$) and lowered low-density lipoprotein level. The quails fed BS4 had the greatest growth hormones and insulin ($p \leq 0.05$) and the lowest thyroxin level. We concluded that dietary betaine supplementation positively impacts Japanese quail growth performance, carcass traits, and blood chemistry.

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1. Introduction

The poultry industry is a significant subsector of livestock production that contributes immensely to the economic growth (Salem and Attia, 2021). The overall trend in the poultry industry is to provide a safer feed to improve growth and physiological parameters (Elnesr et al., 2019). Several investigations have indicated the necessity of supporting poultry feed with additives that improve health status (Alagawany et al., 2019; Khafaga et al., 2019; Abd El-Hack et al., 2020a). Both betaine and methionine play critical roles in poultry nutrition (Reda et al., 2021a). Several stud-

ies showed that betaine is considered as both an osmolyte and a methyl donor. Because betaine includes methyl groups, it may reduce the need for methionine as a methyl group donor. In the 1860s, A German chemist named Scheibler was the first to isolate betaine from the sugar beet plant (*Beta vulgaris*) as a by-product during its processing so, betaine was attributed to the nutrient's source. The effects of betaine in poultry have been studied since the 1940s, with the early studies focusing mostly on the prevention of perosis and growth enhancement. In animal nutrition, betaine is known as "betaine," "trimethylglycine," or "glycine betaine," and it can be found in two forms: anhydrous betaine or betaine hydrochloride ($C_5H_{11}NO_2$ or $C_5H_{12}ClNO_2$, respectively). Betaine is extremely soluble in water and can be added to animal feed in the form of a dry powder, a liquid, or a crystalline powder that can be dissolved in drinking water (Metzler-Zebeli et al., 2009; Lever et al., 2010). Betaine's function as a methyl donor and osmolyte has been widely described in much different scientific literature while its effect on quail's performance is still under some investigation (Pillai et al., 2006; Frank et al., 2014; Al-Sagan et al., 2021). Many previous studies referred to the impact of betaine on the carcass composition, bird performance, breast meat yield, abdominal fat pad weights, poultry flock livability and its role during heat stress with varying results (Ratriyanto et al., 2009; De Paepe et al., 2017; Willingham et al., 2020). Also, methionine is a significant methyl donor essential amino acid in poultry nutrition (Elwan et al., 2019; Rehman et al., 2019). Although there is a link between methionine and betaine, the degree of their effects has yet to be determined (Zhan et al., 2006; Alagawany et al., 2016). Thus, this study aimed to assess the impact of dietary betaine supplementation on quails' body performance, carcass traits, hematology and biochemical blood parameters.

2. Materials and methods

This study was adopted at Poultry Research Station, College of Agriculture, University of Sargodha, Sargodha, Pakistan, for 35 days observation period. All procedures of this study followed the international ethical standards.

2.1. Experimental birds

Four hundred one-day-old, unsexed quail chicks were obtained from a local hatchery and randomly divided into four groups of five replicates (20 birds/replicate). Quails were fed a basal diet (without betaine addition) (control, BS1) and the basal diet plus 0.75, 1.5 and 2.25 g betaine/Kg (BS2, BS3 and BS4, respectively). The shed was cleaned thoroughly, cleaned and disinfected before the bird's arrival. Housing conditions were the same for all chicks throughout the experiment. The temperature was kept at 90F during the 1st week and then gradually decreased at the rate of 5F per week until it was maintained at 75F throughout the trial. Cages were used for the rearing of birds with the dimension of 2.5'×2.5'×1.5'. Twenty birds were reared in each cage and cages were randomly allotted to every treatment. Wood shavings were used as a bedding material on the floor of the cage. Same housing conditions were maintained for all the chicks.

2.2. Biosecurity considerations

The study was carried out under rigorous sanitary and hygienic circumstances. All bio-security preventative measures were properly adhered.

2.3. Experimental diets

Each treatment group was offered iso-caloric and iso-nitrogenous diets (Table 1). In this experiment, four levels of betaine (i.e., 0, 0.75, 1.5 and 2.25 g/Kg) were added to quail diets. Betaine was purchased from the local market and its composition was analyzed in a commercial laboratory. Each treatment was replicated 5 times and each replicate had 20 birds. Diets were randomly allotted to each group.

2.4. Growth performance

All growth performance parameters have been determined and calculated (Reda et al., 2020a, (Reda et al. 2020b, Reda et al. 2020c; Abd El-Hack et al., 2021a). Feed intake was weekly recorded, and it was estimated by subtracting feed refused from weekly feed offered. For all replicates, weekly feed intake was recorded to evaluate the total feed intake per bird in a complete experiment and it was calculated as:

$$\text{Feed intake} = \text{feed offered} - \text{Feed refused.}$$

At the end of every week, all birds were weighed by using an electrical weighing balance:

$$\text{Weight gain} = \text{Final weight} - \text{Initial weight.}$$

By using the above values of feed intake and weight gain, feed conversion ratio (FCR) was calculated by using the following formula:

$$\text{FCR} = \text{Feed intake/Weight gain.}$$

2.5. Slaughtering information

At the end of the trial (two birds/replicate) were selected randomly and weighed. After taking body measurements (body length, shank length, shank diameter, keel bone length, drumstick length, and breast width), birds were slaughtered to observe carcass characteristics, including carcass, breast and thigh muscles weight. The visceral organs weight, including liver, heart, gizzard,

Table 1
Ingredient and nutrient composition of basal diet.

Ingredients	Parts %
Corn	48.00
Rice polishing	9.00
Rice broken	8.00
Soybean meal	19.00
Sunflower meal	4.00
Canola meal	7.00
Feather meal	2.00
Fish meal	1.00
Molasses	1.00
Premix*	1.00
Total	100.00
Chemical Composition (%)	
Crude Protein %	20.93
Metabolizable energy Kcal/Kg	2892
Lysine	1.36
Methionine	0.37

* Provides per kg of diet: 20 MIU Vitamin A; 5 MIU Vitamin D3; 60 g Vitamin E 50; 2 g Vitamin K3; 6 g Vitamin B2; 45 g Vitamin B3; 12 g Vitamin B5; 5 g Vitamin B6; 12.5 g Vitamin B9; 12.5 g Vitamin B12; 275 g Manganese (MnSO4); 150 g Ferrous (FeSO4); 200 g Zn (ZnSO4); 75 g Cu (CuSO4); 75 g Selenium; 4 g Potassium Iodide.

spleen, bursa, reproductive organs, fat, and intestine, were recorded. Carcass weight was taken shortly after slaughtering the birds (Reda et al., 2020a, Reda et al., 2020b; Ashour et al., 2020; Reda et al., 2021b).

2.6. Blood collection

The blood samples were collected from (2 birds/replicate) from wing vein of the quails using gauge needles in labeled screw-capped tubes to obtain plasma as well as coated test tubes with 0.2 ml EDTA as an anticoagulant to study different blood parameters as; (red blood cells (RBCs), packed cell volume (PCV), hemoglobin, white blood cells (WBCs), eosinophil, lymphocytes, monocytes and neutrophils). Also, blood samples were collected in plain test tubes to separate serum. The collected blood samples were centrifuged for 15 min at 2000 rpm. The obtained plasma was stored in the refrigerator to obtain blood chemistry, insulin, thyroxin and growth hormones. The biochemical profiles (alkaline phosphatase-ALP, alanine aminotransferase-ALT, aspartate aminotransferase-AST, blood glucose, calcium, phosphorus, triglycerides, low and high-density lipoprotein) were determined using an automatic analyzer with a commercial kit from Bio-diagnostic Company according to the manufacturer's instructions.

2.7. Statistical analysis

The obtained data were statistically examined using analysis of variance technique under Complete Randomized Design (CRD). Means of all parameters were distinguished using Tukey's test. A level of $p < 0.05$ was used as the criterion for statistical significance.

3. Results

3.1. Productive performance

More feed intake was observed in the BS1 group as compared to other groups (Table 2). Betaine supplemented groups showed a higher significant effect on weight gain ($p \leq 0.05$). The highest weight gain ($p \leq 0.05$) was observed in the BS4 group. However, the lowest weight gain was observed in the BS1 group ($p \leq 0.05$). Dietary addition of betaine had a significant ($p \leq 0.05$) effect on FCR. Overall, FCR was significantly ($p \leq 0.05$) improved by dietary addition of betaine. Best FCR was observed in the BS4 group. No difference was observed in other body parameters like body length, shank length, diameter, keel bone length, or breast width (Table 3).

3.2. Carcass characteristics

Betaine supplementation in the diet was significantly affected ($p \leq 0.05$) carcass weight and breast yield (Table 4). The highest carcass weight was observed in treatment groups fed the BS4 diet.

Table 2
Effect of betaine supplementation on growth performance of quail chicks.

Item	Treatments				SEM
	BS1	BS2	BS3	BS4	
Final body weight, g	217.32 ^a	219.90 ^b	223.32 ^c	228.56 ^d	0.5333
Feed intake, g	506.40 ^a	487.35 ^b	485.06 ^b	484.46 ^c	1.8646
Body weight gain, g	182.16 ^a	184.85 ^b	188.41 ^c	193.53 ^d	0.4290
Feed conversion ratio, g feed/g gain	2.77 ^a	2.64 ^b	2.57 ^c	2.50 ^d	0.0135

BS1, BS2, BS3 and BS4 stand for diets having 0,0.75,1.5 and 2.25 g/Kg betaine

SEM = standard error mean.

^{a-d}Means having different superscripts within each effect in the same row are significantly different at $p < 0.05$.

Similarly, breast yield was highest in quails fed BS4. Non-significant ($p > 0.05$) changes were observed in leg quarter yield (Table 4). Both intestinal length and weight were significantly higher in groups fed betaine supplemented diets; the BS4 group had the highest values (Table 4). Dietary supplementation of betaine did not affect ($p > 0.05$) liver, gizzard, heart, spleen, bursa, or reproductive organ weights (Table 4). Fat weight was significantly affected by betaine supplementation. It was lowest in groups fed BS4 diet.

3.3. Hematology and biochemical blood parameters

Betaine supplementation did not affect ($P > 0.05$) blood glucose, Ca, P, and triglycerides (Table 6). Similarly, no effect was observed ($P > 0.05$) regarding hematology in quails fed diets with or without betaine supplementation (Table 5), except WBCs and hemoglobin values. Quails fed the BS4 diet had higher hemoglobin values ($p \leq 0.05$) than other treatment groups. Significantly higher HDL values ($p \leq 0.05$) were observed in the group fed BS4 diet (Table 6). Low-density lipoprotein significantly decreased ($p \leq 0.05$) in groups fed betaine supplemented diets. Comparatively lower values ($p < 0.05$) of hepatic enzymes like alkaline phosphatase (ALP), alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were observed in groups fed diets containing betaine. Significantly higher levels of growth hormones and insulin were observed in quails fed the BS4 diet. The lowest thyroxin level was observed in the group fed BS4 diet (Table 6).

4. Discussion

There are different types of feed additives in poultry to stimulate production and raise the efficiency of productive birds. Examples of these additives are plants derivatives (El-Saadony et al., 2021a; Abd El-Hack et al., 2021b), aromatic herbs (Abou-Kassem et al., 2021), essential oils (El-Tarabily et al., 2021; Alagawany et al., 2021a), probiotics (Abd El-Hack et al., 2020b; Alagawany et al., 2021b; El-Saadony et al., 2021b), prebiotics (Yaqoob et al., 2021; Abd El-Hack et al., 2021c), green synthesized nanoparticles (Yousry et al., 2020; El-Saadony et al., 2021c; El-Saadony et al., 2021d), acidifiers, organic acids, herbal extracts (Abd El-Hack et al., 2016; Abd El-Hack et al., 2020c), enzymes (Llamas-Moya et al., 2019), bioactive peptides (El-Saadony et al., 2021e; El-Saadony et al., 2021f), and Phytogetic supplements (Abdelnour et al., 2020a; Abdelnour et al., 2020b). Betaine is one of the promising feed additives that improves birds' performance. From our observations, adding betaine to broiler quail's diet greatly impacts their performance. These results in concur with Singh et al. (2015). They reported that birds supplemented with betaine obtained more body weight than those without betaine supplementation unless the results of Singh et al. (2015) indicated that feed intake improved parallel with the betaine dose. Also, Mahmoudnia and Madani (2012) concluded that under warm weather, nutritional supplementation of betaine provides positive effects on perfor-

Table 3
Effect of betaine supplementation on growth parameters of quail chicks.

Item	Treatments				SEM
	BS1	BS2	BS3	BS4	
Body length (cm)	31.8	31.9	32.0	32.10	0.5462
Shank length (cm)	1.61	1.64	1.65	1.63	0.0196
Shank diameter(cm)	1.91	1.92	1.93	1.93	0.0507
Keel bone length (cm)	2.70	2.69	2.70	2.70	0.0411

BS1, BS2, BS3 and BS4 stand for diets having 0,0.75,1.5 and 2.25 g/Kg betaine
SEM = standard error mean.

Table 4
Effect of betaine supplementation on carcass characteristics and absolute organs of quail chicks.

Item	Treatments				SEM
	BS1	BS2	BS3	BS4	
Carcass weight, g	146.0 ^b	152.60 ^{ab}	155.5 ^{ab}	159.9 ^a	2.5110
Breast yield, g	91.40 ^b	96.60 ^{ab}	98.10 ^{ab}	101.10 ^a	1.9879
Leg quarter yield	51.60	53.0	54.4	55.8	1.1860
Intestinal length, cm	71.00 ^b	73.00 ^{ab}	74.1 ^{ab}	76.3 ^a	0.8898
Intestinal weight, g	9.98 ^c	11.06 ^{bc}	11.63 ^{ab}	12.60 ^a	0.3626
Liver weight, g	5.29	5.26	5.26	5.27	0.1462
Gizzard weight, g	3.50	3.52	3.54	3.54	0.1317
Heart weight, g	2.03	2.02	2.05	2.04	0.0814
Spleen weight, g	0.211	0.214	0.213	0.214	0.0193
Bursa weight, g	0.223	0.229	0.225	0.225	0.0205
Reproductive organ weight, g	0.394	0.348	0.332	0.334	0.0263
Fat, g	2.205 ^a	2.105 ^a	1.968 ^{ab}	1.697 ^b	0.0882

BS1, BS2, BS3 and BS4 stand for diets having 0,0.75,1.5 and 2.25 g/Kg betaine
SEM = standard error mean.

^{a-c}Means having different superscripts within each effect in the same row are significantly different at $p < 0.05$.

Table 5
Effect of betaine supplementation on hematology of quail chicks.

Item	Treatments				SEM
	BS1	BS2	BS3	BS4	
WBCs ($10^3/\mu\text{L}$)	3.348 ^a	3.350 ^b	3.409 ^{ab}	3.428 ^a	0.0189
Eosinophil (%)	2.199	2.297	2.403	2.493	0.1587
Lymphocytes (%)	91.7	90.8	91.6	90.600	0.3227
Monocytes (%)	2.13	2.29	2.52	2.30	0.1690
Neutrophils (%)	2.461	2.663	2.469	2.570	0.1611
PCV (%)	40.9	40.8	40.8	41.0	0.2848
RBCs ($10^6/\mu\text{L}$)	3.798	3.789	3.791	3.718	0.0231
Hemoglobin (g/dl)	11.34 ^{ab}	11.29 ^{ab}	11.24 ^b	11.880 ^a	0.1622

BS1, BS2, BS3 and BS4 stand for diets having 0,0.75,1.5 and 2.25 g/Kg betaine WBCs = white blood cells; RBCs = red blood cells; PCV = packed cell volume
SEM = standard error mean.

^{a-b}Means having different superscripts within each effect in the same row are significantly different at $p < 0.05$.

Table 6
Effect of betaine supplementation on blood chemistry of quail chicks.

Item	Treatments				SEM
	BS1	BS2	BS3	BS4	
Glucose (g/dl)	98.13	97.77	97.7	97.700	0.6852
Calcium (mg/dL)	11.16	11.18	11.10	11.11	0.0545
HDL (mg/dL)	111.24 ^b	112.42 ^{ab}	112.55 ^{ab}	113.52 ^a	0.5551
LDL (mg/dL)	20.90 ^a	18.50 ^b	18.50 ^b	18.12 ^b	0.4848
Triglyceride (mg/dL)	110.83	110.43	110.02	110.33	0.4129
Phosphorus (g/dl)	5.20	5.25	5.15	5.16	0.0869
ALP (g/dl)	1054.3 ^{ab}	1050.1 ^a	1048.4 ^b	1048.0 ^b	0.3704
ALT (g/dl)	36.696 ^a	35.812 ^a	34.219 ^b	33.816 ^b	0.3356
AST (g/dl)	118.52 ^a	117.73 ^a	115.59 ^b	115.30 ^b	0.3523
Growth Hormone ($\mu\text{IU/ml}$)	0.394 ^b	0.416 ^b	0.45 ^{ab}	0.563 ^a	0.0328
Insulin ($\mu\text{IU/ml}$)	8.122 ^b	8.696 ^b	8.501 ^b	11.51 ^a	0.2940
Thyroxine ($\mu\text{g/dL}$)	2.822 ^a	2.763 ^a	2.505 ^{ab}	2.238 ^b	0.1364

BS1, BS2, BS3 and BS4 stand for diets having 0, 0.75, 1.5 and 2.25 g/Kg betaine HDL = high density lipoprotein; LDL = low density lipoprotein; ALP = alkaline phosphatase; ALT = alanine aminotransferase; AST = aspartate aminotransferase

SEM = standard error mean.

^{a-b}Means having different superscripts within each effect in the same row are significantly different at $p < 0.05$.

mance criteria such as body weight gain and FCR during early stages of birds' development. In addition, betaine improves chicks' respiration and immune response under heat stress (Khattak et al., 2012; Al-Tamimi et al., 2019). In addition, Cera and Schinckel, (1995) and Matthews et al., (1998) noticed that the addition of betaine on animal ration revealed reduced feed intake. On the other hand, Kermanshahi (2001) noticed that betaine has no impact on FCR. Also, Saunderson and Mckinlay (1990) found that dietary change of methionine with betaine did not affect bird's growth performance. Also, Casarin et al., (1997) and Kitt et al., (1999) found that betaine has no impact on feed intake. Campbell et al., (1995) recorded that animal fed a ration containing betaine showed lower energy requirement for maintenance, which in concur with the response of quails fed betaine in our study. The decrease in feed intake may contribute to increased nutrient availability and absorption at the gut level. Birds consume to meet their energy needs (Ferketet al., 2006) so, better utilization of nutrients caused early satisfaction of energy requirement also, increased intestinal weight and length are an indication of better nutrient absorption, which is attributed to increasing in the mass of intestinal epithelial cell (Yasar et al., 2003; Al-Sagan et al., 2021a, 2021b).

The addition of betaine improves energy generation and muscular endurance and following two weeks of betaine administration, the level of anabolic hormones (GH and IGF-1) is increased and maintenance of anabolic muscle signaling while catabolic hormone (cortisol) and inhibitory muscle signaling were decreased (Apicella, 2011). On the other hand, Kermanshahi, (2001) reported that betaine supplementation decreased breast muscle weight.

Virtanen and Rosi, (1995) discovered that the percentage of fat in the body reduced as the amount of betaine in the diet increased. Also, Stryer, (1988) found that replacing methionine with betaine, and it may potentially interfere with lipid metabolism. Because betaine is involved in the synthesis of carnitine, which is essential for the transfer of long-chain fatty acids across the inner mitochondrial membrane for oxidation, it may help to reduce the fat content of the carcass and revealed a leaner carcass (Ridder and Dam, 1973; Saunderson and Mackinlay, 1990). Although betaine is implicated in lipid metabolism, there is no clear evidence of a reduction in carcass fat in chicken due to betaine administration. Our results agreed with Virtanen and Rosi (1995), who found that betaine was more efficient than DL-methionine in supporting breast meat yield. Contrarily, Schutte et al., (1997) mentioned that DL-methionine when added to the basal diet with no betaine supplementation, increased the breast yield. Similarly, Singh et al., (2015) found that betaine supplemented meals did not affect carcass characteristics.

From our findings, carcass traits were positively affected by betaine supplementation in quail feed. Also, quails fed betaine increased lean meat, increased daily weight gain, and reduced carcass fat contents (Chen et al., 2020). Ko et al., (1994) found that betaine has been found to have a positive effect in various stress circumstances, such as enhanced osmotolerance and chick development performance. However, the effect of betaine on carcass characteristics has been inconsistent. While Singh et al., (2015) reported that the addition of betaine resulted in lowered blood serum triacylglycerol. The present results agree with Øverland et al., (1999), who noticed that betaine has no impact on plasma triglycerides. According to our results, plasma HDL cholesterol was improved. All treatment groups fed betaine supplemented feed showed increased insulin levels compared to the untreated quails. The level of blood thyroxin in quails fed betaine supplemented feed was significantly depressed compared to the untreated quails. All treatment groups fed betaine supplemented diets showed increased growth hormone levels as compared to the control group. The importance of insulin in growth may be emphasized in terms of its role in the entry of five essential amino acids into cells (phenylalanine, leucine, isoleucine, valine, and tyrosine) so,

when insulin level increases, it has a positive impact on bird development (Nutautaitė et al., 2020). In terms of numbers, the decrease in thyroxin may be attributed to the good effects of additives in reducing the detrimental impacts of environmental conditions such as high temperatures in the summer (Sabrieta et al., 2006). In the present study, supplementing the diet with betaine raised insulin and growth hormone levels while decreasing thyroxin hormone levels, as shown in the study of Teshfam et al., (2011). Thyroid hormone activity is inversely linked with ambient temperature, and at high ambient temperatures, thyroid hormone activity decreases, lowering bird performance. This suggests that it has an indirect effect on the birds' growth performance. Treatment groups eating betaine supplemented meals had reduced levels of hepatic enzymes as; alkaline phosphatase & alanine aminotransferase. Betaine is quickly absorbed in the duodenum soon after ingestion, and peak blood levels occur around 1–2 h later (Craig, 2004). Betaine is a methyl group donor and an organic osmolyte with two primary functions in the body and when betaine is catabolized in the hepatic and renal mitochondria, many transmethylation events were obtained, the most important of which is the convert of a methyl group from betaine to homocysteine (Craig, 2004). Betaine is a "compensatory" solute that stabilizes proteins and is particularly efficient in counteracting the denaturing impact of urea, in addition to cell volume control (Ueland, 2011). Betaine, in particular, preserves muscular myosin ATPases and inhibits urea deposition in muscles, which can contribute to protein synthesis inhibition (Sahebi-Ala et al., 2021).

Furthermore, Brigotti et al., (2003) demonstrated that adding betaine to rabbit reticulocyte lysates enhanced globin mRNA translation. Betaine has also been connected to a wide range of additional beneficial effects. Betaine is a lipotropic that has been shown to prevent and decrease fat deposition in the liver (Craig, 2004). Betaine has an antiatherosclerotic action and its supplementation is revealed in increased energy production through aerobic metabolism and increased oxygen consumption (Armstrong et al., 2008). When compared with the untreated quails, the betaine supplemented groups had higher serum GH and insulin concentrations. Furthermore, an increase in GH and insulin may theoretically activate PI-3 K, which would then transmit the signal down to the Akt/mTOR pathway, promoting protein synthesis as well as, GH and insulin can perform their actions directly or through muscle signaling, these hormonal alterations cause phenotypic changes in the animals (Al-Sagan et al., 2021a, 2021b).

5. Conclusion

Betaine supplementation improved growth performance of quails. Betaine did not affect blood glucose, calcium, phosphorus, triglycerides, and hematology parameters (except hemoglobin). Quails fed the BS4 diets (2.25 g/kg) declined liver enzymes and improved lipid profile and carcass compared to the un-treated quails. The BS4 group showed a significant increase in growth hormones, insulin, and the lowest thyroxin level than the control.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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