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The growth, carcass yield traits, viability, meat quality and internal organ development of broiler fed betaine-supplemented diet

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ABSTRACT

The study was undertaken to appraise the productive performance of broilers raised on a betaine-fed ration. A number of broilers (Cobb500, n=280) were taken as research materials and distributed randomly into 4 treatments in a CRD. D_0 (Control), D_1 (0.15 % betaine), D_2 (0.20 % betaine), and D_3 (0.25% betaine) were considered as treatments. Ten birds were assigned per replication, with seven replications per treatment. A battery cage was used to rear the chicks from d1-33. Starter diet was used from d1-14, then formulated diets were fed to the chicks from d15-33. Similar energy content and protein (%) were used for all the formulated diets. The results showed that feed intake, live weight, and feed conversion ratio were affected ($P<0.05$) by treatment. The live weight of the birds fed the D_3 diet was heavier ($P<0.05$) in the birds fed the D_3 diet than that of the other treatments. There was no difference ($P>0.05$) found in the survivability and intestinal organ weights. Meat yield traits were insignificant ($P>0.05$) except for dressing % and thigh weight. Broilers fed the D_3 diet had a greater ($P<0.05$) dressing % and thigh weight % than those of other groups. It can be concluded that better growth performance and higher profit can be obtained by rearing broilers with a betaine-supplemented diet.

Keywords: Growth, Carcass trait, Visceral organ, Survivability, Betaine, Broiler chicken

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Introduction

Feeding an increasing number of people is becoming problematic day by day across the globe, because it is projected that by 2050 the intake of livestock products, poultry, dairy, and fish products will be doubled (Al-Dawood, 2015). A more efficient, sustainable, and cost-effective solution to these rising problems is to feed the animals properly to enhance their productivity to some extent. Broiler chicken is growing faster and more profitable all over the world. The salient point of poultry integrators is to attain the best productive performance by investing low capital/money in the poultry enterprise. This tendency of poultry farmers always pushes poultry integrators to find cheaper strategies for viable and lucrative poultry production.

However, poultry researchers are searching for different ways to promote poultry productivity, due to restrictions on animal by-products and the free use of antibiotics in livestock production by the E.U. (Adil *et al.*, 2010). Using natural plant extract betaine in poultry diets as feed additives for promoting poultry production can be a means of a sustainable solution. Nowadays, emphasis is being given to the use of natural plant extracts in animal science. Improving broiler productivity is still a major issue in the micro-livestock sector, particularly under adverse climatic or environmental conditions. The use or utilization of numerous supplements in poultry has been tried for a long time to explore the best production potentialities (Michiels *et al.*, 2012; Carvalho *et al.*, 2013).

Betaine, as a derivative of micronutrients (amino acids) in nature, is commonly available (Liu *et al.*, 2019). Natural betaine is usually obtained from beet root (Botch *et al.*, 1997). It is considered a valuable common supplement that affects animal performance (Dunshea *et al.*, 2019). Now, this betaine, in synthetic form or as natural feed additives, is commonly available to prepare livestock or poultry rations. It is seen that betaine can serve numerous functions in the body, such as fat metabolism, an anti-heat stress agent, an osmo-protectant, and helps in various physiological systems (nervous, renal) (Eklund *et al.*, 2005; Hamidi *et al.*, 2010; Alirezaei *et al.*, 2012; Sakomura *et al*, 2013). The body weight gain or growth under stress conditions and feed utilization ability of poultry (broilers and ducks) are found to be improved when betaine is used as a feed supplement in the poultry diet (Zhan *et al.*, 2006; Attia *et al.*, 2009b; Rao *et al.*, 2011; Akhavan-Salamat and Ghasemi, 2016).

Animals have to face a lot of challenges or environmental stressors every day, which could affect broiler performance adversely. In this view, nutritional intervention or supplementation of various feed additives in the diet could be an appropriate means to reduce severe negative effects of climate on broilers (Attia *et al.*, 2009a; Silanikove and Koluman, 2015; Cheng *et al.*, 2018). Owing to the continuous changes in the climate scenario, the negative impact of heat stress derived from high environmental temperature on poultry production has now become an emerging issue around the globe, particularly in tropical climatic conditions (Virden and Kidd, 2009; Nawab *et al.*, 2018). The data on betaine application in broiler diets are scarce, and inconclusive results of previous works have warranted further study. Under the above circumstances, the current study was adopted to ascertain the growth performances, viability, carcass traits, meat quality, and gastrointestinal organ growth of broilers fed a betaine-included ration.

Materials and Methods

The experimental animal shed of CVASU was used to conduct the feeding trial following the standard procedures as guided by CVASU, Chittagong. A total of 280 (Cobb500, 45±0.45g) broiler chicks were collected from a reputed poultry farm. The collected chicks' weight was recorded first. The chicks were assigned randomly into four treatments with 7 replicates, and ten birds were allotted in each replication in a completely randomized block design (CRD) in cages from d1 to 33 days. An electric bulb hanging at the top of each replicate cage or pen was used to brood the chicks at a temperature of 33°C for the first two days. After that, heat was decreased by 5°C every week until 19 days old, then 24°C temperature was maintained until the last day of the trial. Plastic feeders and plastic drinkers were given to each pen to facilitate the feeding and watering of birds. The lighting program for the chicks was continuous lighting (23h:1). Medication and vaccination were used to increase the immunization of the birds. Two vaccines, BCRDV and IB, were applied for the prevention of Ranikhet and Gumboro diseases. Besides, some saline solution along with a vitamin supplement was also used for the birds to reduce the risk of heat stress.

Diet formulation

Locally available feedstuffs were used to formulate four different diets (D_0, D_1, D_2 and D_3). All prepared feeds had similar energy and protein (%) content. Basal or control feed (D_0) was formulated with betaine. In contrast, test diets (D_1, D_2 and D_3) were made by including the additive betaine (Betafin®, 96% Natural Betaine, Biochem Co., Brinkstrasse 55, D-49393 Lohne, Germany) at the rate of 0.15%, 0.20 %, and 0.25%, respectively (Table 2). Compound feed, i.e., starter ration (Nourish™), was purchased from the market, and this diet was used for 14 days (Table 1). Later, the test ration was fed to the broiler chicks from 15 to 33 days (Table 2). Broilers had access to feed and clean drinking water *ad libitum*. Prepared diets were also included with the multi-enzyme (Natuzyme). The nutritive values (analyzed in the lab) of the compound or ready feed starter and prepared diets (Tables 1 and 2).

Table 1. Nutrient composition of ready-made starter diet.

Nutrient contents (%)	Proximate values of ready-made	Reporting values of ready-made
ME (kcal/kg)	3356.68	2950
Moisture	9.95	9.98
DM	90.05	90.02
CP	21.20	21.00
CF	4.77	5.00
EE	6.98	5.00
Ash	5.23	6.00
Ca	1.00	1.00
Total P	0.58	0.45
Lys	-	1.30
Met	-	0.55

Table 2. Nutrient and ingredient composition of finisher diet.

Ingredient (%)	Treatment			
	D_0	D_1	D_2	D_3
Maize	58.00	58.00	58.20	58.12
Wheat	3.00	2.54	2.30	2.10
Soybean meal	30.00	30.00	29.30	29.30
Protein concentrate	2.34	2.36	3.00	3.00
Palm oil	3.70	3.87	3.80	3.89
DCP	0.40	0.37	0.34	0.34
Limestone	1.50	1.60	1.80	1.89
Table salt	0.25	0.30	0.25	0.30
Choline chloride	0.04	0.04	0.04	0.04
Vitamin-mineral-premix	0.25	0.25	0.25	0.25
L-lysine	0.18	0.18	0.18	0.18
DL-methionine	0.25	0.25	0.25	0.25
Betafin	0.00	0.15	0.20	0.25
Enzymes (Natozyme)	0.04	0.04	0.04	0.04
Toxin binder	0.05	0.05	0.05	0.05
Nutrients (%)-calculated value				
ME(Kcal/kg)	3118	3119	3120	3119
CP	20.54	20.51	20.57	20.54
CF	3.43	3.42	3.40	3.39
EE	3.49	3.48	3.50	3.48
Ca	1.12	1.14	1.15	1.18
P	0.63	0.62	0.62	0.63
Nutrients –analyzed values (%)				
DM	88.00	88.50	88.00	87.30
CP	21.20	21.40	21.20	21.23
CF	4.20	4.80	4.30	4.50
EE	5.10	5.20	5.40	5.30
Ash	5.60	5.90	5.60	5.700
Ca	1.67	1.60	1,62	1.70
P	0.84	0.80	0.83	0.88

[Except for diet D0, the rest of the diet was supplemented with 0.15, 0.20, and 0.25% betaine in D_1, D_2, and D_3, respectively]

Data collection

Weekly live bird weight, feed intake, and survivability, etc., were taken for data recording. The feed intake and weight gain of the bird were used to calculate the weekly feed conversion ratio (FCR) of the broiler. Records on carcass yield traits, such as dressing percentage and relative weight of breast, thigh, drumstick, shank, abdominal fat, proventriculus, gizzard, heart, liver, pancreas, etc., were also taken on 33d.

Sample collection and chemical analyses

Feed samples collected from the starter and finisher diets were processed in the lab. The proximate components, such as dry matter (DM%), moisture%, crude protein (CP%), crude fiber (CF%), ether extract (EE%), and ash, were analyzed by following standard laboratory methods as instructed by AOAC (2007). Apart from these, atomic absorption and spectrophotometry were used to analyze calcium (Ca%) and phosphorus (P%), respectively.

Statistical analyses

Minitab software (Minitab, 2010) was used to analyze all procured data of this study using the one-way ANOVA procedure. Statistical significance was considered at *P≤0.05.*

Results and Discussion

Gross responses of broiler chicken fed a betaine diet

Except for 33d, the results showed that feed intake (FI) and live weight (LW) of broilers up to 28 days were identical between treatments (P>0.05) (Table 3). The FI and LW of broilers on the D3 diet were (P<0.05) greater than those of others for 28-33 and 1-33 days, respectively. The FCR of broilers was also influenced (P<0.05) during d1-33 (Table 3).

Table 3. Feed intake (FI), live weight (LW) and feed conversion ratio (FCR) of broiler chicken fed a diet supplemented with betaine.

	Age (days)	Treatment				SEM	P-value
		D_0	D_1	D_2	D_3		
LW(g/b)	1-14	508.62	517.29	492.00	512.81	10.188	0.828
	1-21	974.60	1028.40	1004.30	1012.10	1.799	0.596
	1-28	1441.00	1524.00	1447.40	1538.40	22.026	0.334
	1-33	1742.20 ^{b}	1862.40^{a}	1784.50^{a}	1902.40^{a}	14.261	0.015
FI(g/b)	14-21	804.43	905.00	918.57	895.57	15.225	0.102
	21-28	977.10	984.00	992.20	1035.00	13.626	0.477
	28-33	715.81^{b}	631.95^{c}	659.52^{c}	741.38^{a}	12.970	0.015
	14-33	2497.40	2321.00	2570.30	2712.00	30.600	0.136
	1-33	3300.10^{c}	3210.20^{b}	3370.10^{a}	3450.30^{a}	15.762	0.050
FCR	14-21	1.58	1.63	1.66	1.67	0.0242	0.662
	21-28	1.92	1.82	2.04	1.82	0.449	0.306
	28-33	2.30	1.87	2.03	2.18	0.096	0.335
	14-33	2.02	1.87	1.98	1.95	0.022	0.184
	1-33	1.94^{a}	1.77^{c}	1.94^{a}	1.86^{b}	0.018	0.042

*[Data indicate mean values of 10 birds per replicate from days 1-33; D_o refers to the control diet with no supplemental betaine, whereas D_1, D_2 and D_3 diets are supplemented with 0.15, 0.20, and 0.25% betaine, respectively; Values (mean) bearing different superscripts in a row differ significantly at *P<0.05; SEM- standard errors of mean]*

Growth or productivity (body growth, feed intake) and feed efficiency of broilers were ameliorated when the broilers were fed a betaine diet. The findings of our current study coincide with the reports found by earlier investigators (Sun *et al.*,2008; Attia *et al.*, 2009; Nofal *et al.*, 2015; Afrin *et al.*, 2018). The LW of broilers was promoted when a greater amount of betaine was added to diets. The increased LW and better FCR might be due to greater feed consumption, nutrient digestibility, feed utilization, increased metabolic heat production, and absorption of birds on a supplemental diet balanced with amino acids (Hassan *et al.*, 2005; Eklund *et al.*, 2006; Honarbaksh *et al.*, 2007; Bunchasak, 2009).

Livability

The viability (%) of broilers was not affected (P>0.05) by dietary treatment (Figure 1). It denotes that betaine has no adverse impact on the livability of broiler chicken, and we can add betaine in broiler diets without any hesitation as supplemental feed additives. It is reported that betaine has a positive effect on the immune system of broilers and rats (Zhang *et al.*, 1996; Klasing *et al.*, 2002).

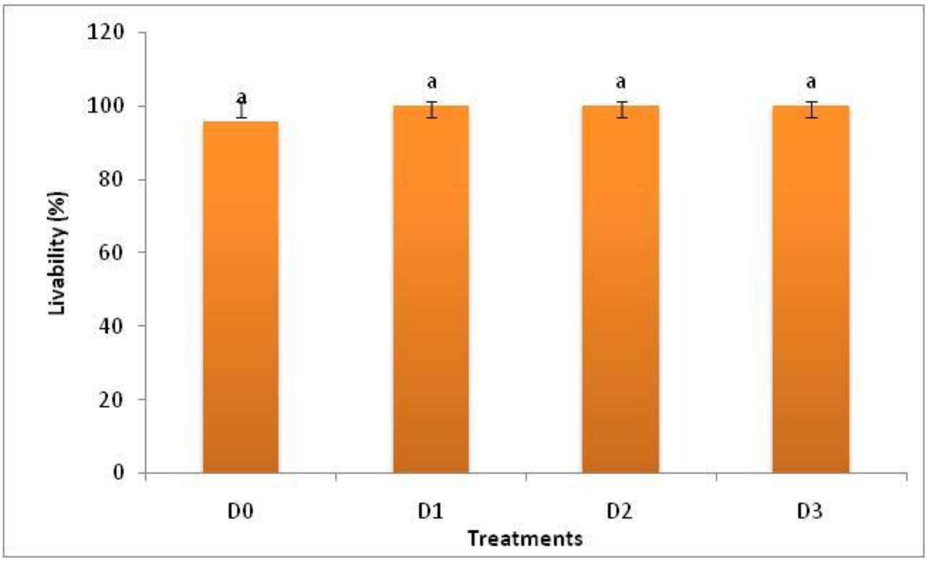

Fig. 1. Livability (%) of broilers fed betaine diets on day 33; Bars with similar letters have no significant differences (P>0.05) between treatments.

Table 4. Meat yield traits (g/100g) of broilers of different body parts fed a diet supplemented with betaine.

	Treatment				SEM	P-value
	D_0	D_1	D_2	D_3		
Dressing%	62.64^c	64.94^b	66.91^a	67.58^a	0.146	0.050
Breast weight	22.72	25.39	26.74	27.18	0.570	0.143
Drumstick weight	7.17	8.57	8.57	8.49	0.129	0.432
Thigh weight	8.50^b	9.09^a	10.25^a	9.17^a	0.118	0.050
Wing weight	4.33	4.77	5.05	5.53	0.162	0.209
Shank weight	4.00	3.75	3.98	4.00	0.080	0.616

*[Each value indicates the mean of five replicates consisting of 10 birds per replicate cage at 33 days; Values (mean) bearing different superscripts in a row differ significantly at *P<0.05]*

Carcass yield traits of broiler chicken

Only dressing (%) (P<0.05) and thigh weight% (P<0.05) were found to be improved, except for other meat characteristics (breast, drumstick, shank, and wing), as seen in Table 4. Broilers fed the D_3 diet had greater dressing yield and thigh weight than those of other groups, which might be due to greater live weight gained in broiler chickens fed the betaine diet. The improved broiler weight on the betaine-fed diet might enhance better dressing percentage as well as other parts of the broiler chicken.

Table 5. Relative visceral organs weight (g/b) of broiler chickens fed a diet supplemented with betaine on day 33.

	Treatment				SEM	P-value
	D_0	D_1	D_2	D_3		
Proventriculus + gizzard weight	62.05	71.97	60.45	59.74	1.619	0.152
Liverweight	36.96	39.57	37.27	39.56	1.804	0.921
Heart weight	8.43	8.63	8.75	9.53	0.352	0.719
Pancreas weight	3.21	3.32	4.27	3.57	0.192	0.373

[Data represent mean values of five replicates consisting of 9 birds on day 33; Treatment D_0 refers to control diet, D_1, D_2 and D_3 refer to diets supplemented with 015%, 0.20% and 0.25% betaine, respectively;]

Yang *et al.* (2016) reported that betaine is often deemed as a carcass modifier for protein deposition, which could promote the quality carcass of broiler chicken. The findings of our study are correlated with the research done by earlier researchers (El-Shinnawy, 2015; Nofal *et al.*, 2015; Afrin *et al.*, 2018; Akter *et al.*, 2020).

Betaine on the quality of the meat of broiler chicken

The result indicates that abdominal fat content was unaffected (P>0.05) between treatments in this study (Figure 2).

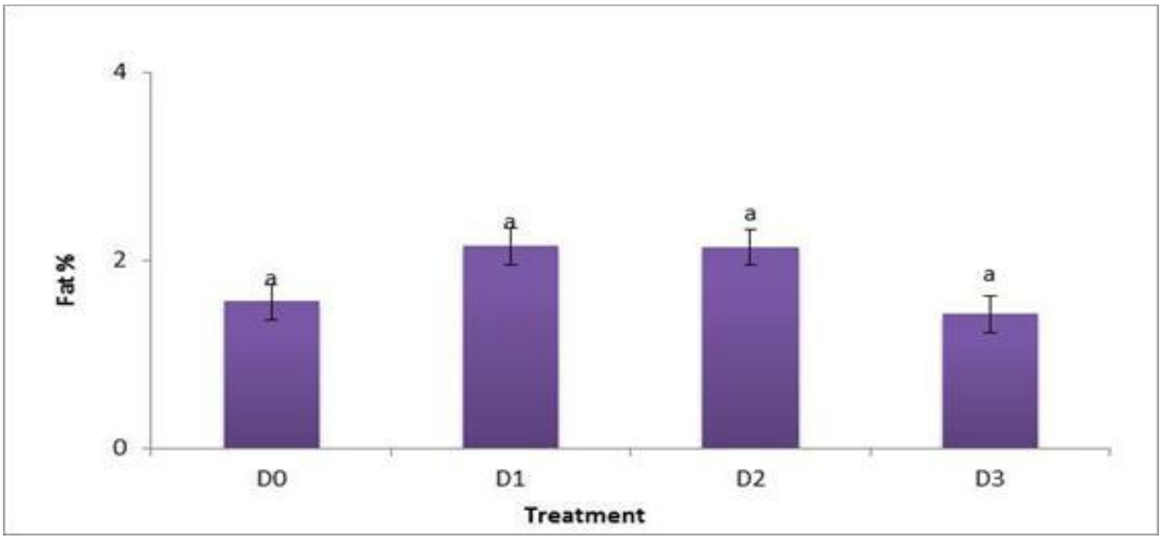

Fig. 2. Abdominal fat (%) of broilers fed betaine diets on day 33; Bars with similar letters have no significant differences (P>0.05) between treatments.

The data showed that broilers fed the D_3 diet had lower fat (1.43%) numerically than those of other treatments. The broiler carcass had equal fat content when fed a betaine diet. It denotes that betaine ration does not exhibit any significant impact on fat accretion in the carcass of broilers. Broilers fed a D_3 diet attained reduced fat content in their meat, which implies a reduced fat accumulation trend in the betaine-fed diet. The lower the fat%, the greater the quality of meat, which is preferred by consumers worldwide, as it confers increased protein and reduced fat content in the meat. Betaine is deemed a carcass modifier for its nature of fat dispersion, as stated by Eklund *et al.* (2006).

Gastrointestinal development

The data shown in Table 5 denote that the relative weights of internal organs (proventriculus, gizzard, liver, heart, and pancreas) of broiler chicken were not influenced (P>0.05) by dietary treatments, which confirms the previous findings done by many earlier researchers (Zhan *et al.*, 2006; Konca *et al.*, 2008; El-Shinnawy, 2015; Hossain *et al.*, 2013, 2014, 2015). Most of the internal organs of broiler chicks occur within 2 weeks of hatching (Nitsan *et al.*, 1991; Iji *et al.*, 2001a,b). The internal fat content decreased significantly by inclusion of betaine in the broiler diet without affecting other internal organs of broiler chickens (liver, gizzard, and giblets), as reported by El-Shinnawy (2015).

Conclusion

It can be inferred that the overall productivity of broiler-fed betaine-supplemented diet was enhanced, as better body growth, feed efficiency, and dressing yield with reduced fat content were obtained in this study. It can be surmised from the research results that supplemental betaine can be added to broiler diets as an innovative feed additive, which has a better potential for providing reduced fat through improving productivity, greater dressing, and profitability of broiler raising under commercial farming conditions.

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References

Adil, S., Banday, T., Bhat, G.A., Mir, M.S. and Rehman, M. 2010. Effect of dietary supplementation of organic acids on performance, intestinal histomorphology, and serum biochemistry of broiler chicken. *Vet. Med. Int.* 2010: 479485. https://doi.org/10.4061/2010/479485

Afrin, K., Shiblee, A.S., Das, G.B. and Hossain, M.E. 2018. Effects of betaine supplementation on productive performance, blood parameters and carcass characteristics of broiler. *Indian J. Poult. Sci.* 53(1): 28–36. https://doi.org/10.5958/0974-8180.2018.00014.4

Akhavan-Salamat, H. and Ghasemi, H.A. 2016. Alleviation of chronic heat stress in broilers by dietary supplementation of betaine and turmeric rhizome powder: Dynamics of performance, leukocyte profile, humoral immunity, and antioxidant status. *Trop. Anim. Health Prod.* 48: 181–188. https://doi.org/10.1007/s11250-015-0941-1

Akter, N., Islam, M.S., Zaman, S., Jahan, I. and Hossain, M.A. 2020. The impact of different levels of L-methionine on carcass yield traits, serum metabolites, tibial characters, and profitability of broilers fed conventional diet. *J. Adv. Vet. Anim. Res.* 7(2): 253–259. https://doi.org/10.5455/javar.2020.g417

Al-Dawood, A. 2015. Adoption of agricultural innovations: Investigating current status and barriers to adoption of heat stress management in small ruminants in Jordan. *American-Eurasian J. Agril. Environ. Sci.* 15: 388–398.

Alirezaei, G., Jelodar and Ghayemi, Z. 2012. Antioxidant defense of betaine against oxidative stress induced by ethanol in the rat testes. *Int. J. Peptide Res. Therap.* 18: 239–247. https://doi.org/10.1007/s10989-012-9297-9

Alirezaei, M., Gheisari, H.R., Ranjbar, V.R. and Hajibemani, A. 2012. Betaine: A promising antioxidant agent for the enhancement of broiler meat quality. *British Poul. Sci.* 53: 699–707. https://doi.org/10.1080/00071668.2012.728283

AOAC. 2007. *Official methods of analysis* (18th ed.). Association of Official Analytical Chemists, USA.

Attia, Y.A., Hassan, R.A. and Qota, E.M.A. 2009a. Recovery from adverse effects of heat stress on slow-growing chicks in the tropics: Effect of ascorbic acid and different levels of betaine. *Trop. Anim. Health Prod.* 41: 807–818. https://doi.org/10.1007/s11250-008-9256-9

Attia, Y.A., Hassan, R.A., Shehatta, M.H. and Abd El-Hady, S.B. 2009b. Growth, carcass quality and serum constituents of slow growing chicks as affected by betaine addition to diets containing different levels of methionine. *Int. J. Poult. Sci.* 4: 856–865. https://doi.org/10.3923/ijps.2005.856.865

Botch, J., Kempf, B. and Bremer, E. 1997. Osmoregulation in *Bacillus subtilis*: Synthesis of the osmoprotectant glycine betaine from exogenously provided choline. *J. Bacteriol.* 176(17): 5364–5371. https://doi.org/10.1128/jb.176.17.5364-5371.1994

Bunchasak, C. 2009. Role of dietary methionine in poultry production. *J. Poult. Sci.* 46(3): 169–179. https://doi.org/10.2141/jpsa.46.169

Carvalho, C.M.C., Fernandes, E.A., de Carvalho, A.P., Maciel, M.P., Caires, R.M. and Fagundes, N.S. 2013. Effect of creatine addition in feeds containing animal meals on the performance and carcass yield of broilers. *Revista Brasileira de Ciência Avícola* 15: 269–275. https://doi.org/10.1590/s1516-635x2013000300015

Cheng, Y.F., Du, M.F., Xu, Q., Chen, Y.P., Wen, C. and Zhou, Y.M. 2018. Dietary mannan oligosaccharide improves growth performance, muscle oxidative status, and meat quality in broilers under cyclic heat stress. *J. Therm. Biol.* 75: 106–111. https://doi.org/10.1016/j.jtherbio.2018.06.002

Dunshea, F.R., Oluboyede, K., DiGiacomo, K., Leury, B.J. and Cottrell, J.J. 2019. Betaine improves milk yield in grazing dairy cows supplemented with concentrates at high temperatures. *Animals* 9: 57. https://doi.org/10.3390/ani9020057

Eklund, M., Bauer, E., Wamatu, J. and Mosenthin, R. 2005. Potential nutritional and physiological functions of betaine in livestock. *Nutri. Res. Rev.* 18: 31–48. https://doi.org/10.1079/nrr200493

Eklund, M., Mosenthin, R., Tafaj, M. and Wamatu, J. 2006. Effects of betaine and condensed molasses solubles on nitrogen balance and nutrient digestibility in piglets fed diets deficient in methionine. *Arch. Anim. Nutriti.* 60: 289–300. https://doi.org/10.1080/17450390600785525

El-Shinnawy, A.M. 2015. Effect of betaine supplementation to methionine adequate diet on growth performance, carcass characteristics, some blood parameters and economic efficiency of broilers. *J. Anim. Poult. Prod.* 1: 27–41. https://doi.org/10.21608/jappmu.2016.52726

Hamidi, H., Jahanian, R. and Pourreza, J. 2010. Effect of dietary betaine on performance, immunocompetence and gut contents osmolarity of broilers challenged with a mixed coccidial infection. *Asian J. Anim. Vet. Adv.* 5(3): 193–201. https://doi.org/10.3923/ajava.2010.193.201

Hassan, R.A., Attia, Y.A. and El-Ganzory, E. H. 2005. Growth, carcass quality and serum constituents of slow growing chicks as affected by betaine addition to diets containing different levels of choline. *Int. J. Poult. Sci.* 4: 840–850. https://doi.org/10.3923/ijps.2005.840.850

Honarbakhsh, S., Zaghari, M. and Shivazad, M. 2007. Can exogenous betaine be an effective osmolyte in broiler chicks under water salinity stress? *Asian-Australasian J. Anim. Sci.* 20: 1729–1737. https://doi.org/10.5713/ajas.2007.1729

Hossain, M.A., Bhuiyan, M.M. and Iji, P.A. 2015. Nutritive value of vegetable protein diets for broiler chickens and selection of diets containing different vegetable or animal proteins. *World's Poult. Sci. J.* 71(1): 15–26. https://doi.org/10.1017/s0043933915000021

Hossain, M.A., Islam, A.F. and Iji, P.A. 2013. Growth responses, excreta quality, nutrient digestibility, bone development and meat yield traits of broiler chickens fed on vegetable or animal protein diets. *South African J. Anim. Sci.* 43(2): 208–218. https://doi.org/10.4314/sajas.v43i2.11

Hossain, M.A., Islam, A.F. and Iji, P.A. 2014. Effects of production phase on growth, enzyme activities and feed selection of broilers raised on vegetable protein diets. *Asian-Australasian J. Anim. Sci.* 27(11): 1593–1599. https://doi.org/10.5713/ajas.2013.13712

Iji, P.A., Saki, A. and Tivey, D.R. 2001a. Body and intestinal growth of broiler chicks on a commercial starter diet: Development and characteristics of intestinal enzymes. *British Poult. Sci.* 42: 514–522. https://doi.org/10.1080/00071660120073142

Iji, P.A., Saki, A. and Tivey, D.R. 2001b. Body and intestinal growth of broiler chicks on a commercial starter diet. *British Poult. Sci.* 42: 505. https://doi.org/10.1080/00071660120073151

Klasing, K.C., Adler, K.L., Remus, J.C. and Calvert, C.C. 2002. Dietary betaine increases intraepithelial lymphocytes in the duodenum of coccidia-infected chicks and increases functional properties of phagocytes. *J. Nutri.* 132: 2274–2282. https://doi.org/10.1093/jn/132.8.2274

Konca, Y., Kırkpınar, F., Selim, M. and Yaylak, F. 2008. Effects of betaine on performance, carcass, bone and blood characteristics of broilers during natural summer temperatures. *J. Anim. Vet. Adv.* 7(8): 930–937. https://doi.org/10.5713/ajas.2008.70399

Liu, W., Yuan, Y., Sun, C., Balasubramanian, B.K., Zhao, Z. and An, L. 2019. Effects of dietary betaine on growth performance, digestive function, carcass traits, and meat quality in indigenous yellow-feathered broilers under long-term heat stress. *Animals* 9(8): 506. https://doi.org/10.3390/ani9080506

Michiels, J., Maertens, L., Buyse, J., Lemme, A., Rademacher, M., Dierick, N. A. and de Smet, S. 2012. Supplementation of guanidinoacetic acid to broiler diets: Effects on performance, carcass characteristics, meat quality and energy metabolism. *Poult. Sci.* 91: 402–412. https://doi.org/10.3382/ps.2011-01585

Minitab. 2010. *Minitab statistical software user's guide 2: Data analysis and quality tools*. Minitab Inc.

Nawab, A., Ibtisham, F., Li, G.H., Kieser, B., Wu, J., Liu, W.C., Zhao, Y., Nawab, Y., Li, K.Q. and Xiao, M. 2018. Heat stress in poultry production: Mitigation strategies to overcome future challenges. *J. Therm. Biol.* 78: 131–139. https://doi.org/10.1016/j.jtherbio.2018.08.010

Nitsan, Z., Avraham, G.B., Zerof, Z. and Nir, I. 1991. Growth and development of the digestive organs and some enzymes in broiler chicks after hatching. *British Poult. Sci.* 32: 515–523. https://doi.org/10.1080/00071669108417376

Nofal, M., Magda, A.G., Mousa, S., Doaa, M. and Bealsh, A. 2015. Effect of dietary betaine supplementation on productive, physiological and immunological performance and carcass characteristics of growing chicks under heat stress. *Egyptian Poult. Sci. J.* 35: 237–259.

Rao, S., Raju, M., Panda, A., Saharia, P. and Sunder, G.S. 2011. Effect of supplementing betaine on performance, carcass traits and immune responses in broiler chickens fed diets containing different concentrations of methionine. *Asian-Australasian J. Anim. Sci.* 24: 662–669. https://doi.org/10.5713/ajas.2011.10286

Sakomura, N.K., Barbosa, N.A.A., Silva, E.P., Longo, F.A., Kawauchi, I.M. and Fernandes, J.B.K. 2013. Effect of betaine supplementation in diets for broiler chickens under thermoneutral environment. *Brazilian J. Poult. Sci.* 8: 336–341.

Silanikove, N. and Koluman, N. 2015. Impact of climate change on the dairy industry in temperate zones. *Small Ruminant Res.* 123: 27–34. https://doi.org/10.1016/j.smallrumres.2014.11.005

Sun, H., Yang, W., Yang, Z., Wang, Y., Jiang, S. and Zhang, G. 2008. Effects of betaine supplementation to methionine-deficient diet on growth performance and carcass characteristics of broilers. *American J. Anim. Vet. Sci.* 3: 78–84. https://doi.org/10.3844/ajavsp.2008.78.84

Virden, W.S. and Kidd, M.T. 2009. Physiological stress in broilers: Ramifications on nutrient digestibility and responses. *J. Appl. Poult. Res.* 18: 338–347. https://doi.org/10.3382/japr.2007-00093

Yang, Z., Wang, Z.Y., Yang, H.M., Zhao, F. Z. and Kong, L.L. 2016. Response of growing goslings to dietary supplementation with methionine and betaine. *British Poult. Sci.* 57: 833–841. https://doi.org/10.1080/00071668.2016.1230663

Zhan, X.A., Li, J.X., Xu, Z.R. and Zhao, R.Q. 2006. Effects of methionine and betaine supplementation on growth performance, carcass composition and metabolism of lipids in male broilers. *British Poult. Sci.* 47: 576–580. https://doi.org/10.1080/00071660600963438

Zhang, F. Warskulat, U. and Häussinger, D. 1996. Modulation of tumor necrosis factor-α release by anisoosmolarity and betaine in rat liver macrophages (Kupffer cells). *FEBS Letters* 391: 293–296. https://doi.org/10.1016/0014-5793(96)00754-5