



REVIEW

Exploring the Potentials of Betaine Supplementation in Poultry and Pig: A Review

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ABSTRACT

The present review explores the nutritional and performance boosting functions of betaine in poultry and pig ration as a feed additive. Betaine, a trimethyl derivative of glycine is a normal metabolite in many plant and animal tissues. In all the animals, betaine is produced by oxidation of choline or supplied through feed. Its characteristics chemical structure makes betaine a dipolar zwitterion, conferring it osmoprotective and methyl donating properties. Over the past decades, numerous studies have investigated and published the favorable effects of betaine on performance in different animal species. Betaine is involved in transmethylation reactions for the synthesis of several metabolically active substances like creatine, carnitine *etc.* Also, it has shown evidence to increasing nutrient utilization, digestibility and methionine availability. Boosting immune status and reducing oxidative or heat stress are also some of the important functions of betaine. Most of the researches have specifically studied the growth promoting, carcass modulating, immune boosting or stress reducing properties of betaine in different species. Literature covering on different benefits of betaine as an essential feed supplement is not yet abundant. As both poultry and pig are important species of domesticated animals, betaine can be a better and cheaper, alternative feed supplement for enhancing the nutrient utilization and performance of poultry and pig. Therefore, an attempts have been made to delineate the functional effects of supplementary betaine in poultry and pig.

Key words: Betaine; Feed supplement; Stress reducer; Performance, Immune booster, Poultry, Pig

INTRODUCTION

There will be an exponential increase in human population by the year 2067 (United Nations, 2013, 2017) placing tremendous pressure on the food industry. Agriculture and animal husbandry enterprise currently employs more than 1.3 billion people globally and contribute to 40 % of the world's gross domestic product. This sector needs to deliver in accordance with increased demand for animal products that is expected to be doubled by 2050 (Hurst and Karl, 2005; Gaughan *et al.*, 2010; Rojas-Downing *et al.*, 2017). On the other hand, a steady increase in environmental temperature up to 4.8°C is predicted at the end of 21st century (IPCC, 2014, 2018). Consequently, there could be decline in animal production, which is going to be further

aggravated by 2050 and 2080, respectively (Mauger *et al.*, 2015). Only, climate resilient and smart animal husbandry interventions will make the agriculture sustainable in the coming times (Wright *et al.*, 2012).

Poultry and pigs are important agricultural animal, and demand for the products derived from these two food species is ever increasing globally. The broiler industry is also taking leaps and bounds and there are over 23 billion poultry and our consumption of poultry meat per annum increased from 2.88 kg to 14.13 kg (FAOSTAT, 2016). This increase in poultry production and exports are mainly from China, Brazil, US, EU, Russia, India, Britain and Mexico. The market affected by the COVID-19, African swine fever (ASF) and avian influenza (AI) in 2019-2020 is now back on the growth,

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with expected 102.9 million tons by 2021 (USDA, 2020). Currently, there are total 677.7 million pigs in the world producing 94.33 million metric tons of pork in the year 2020 (Shahbandeh, 2020a). The major exporters and importers for pork are, EU, United States, China and Mexico, Japan, South Korea and Canada, respectively (Shahbandeh, 2020b). Both poultry and pig have tremendous potential for growth and trade, but one of the main constraint is the availability of grains (Gerber *et al.*, 2015). On the contrary, the ruminant species which utilize the fodder, food by-products and crop residues do not substantially challenge the existing resources. Therefore, the poultry and pig production is constantly challenged by grain prices which are dependent on many market-driven factors. The search for quality and cheap feed additives that will improve the efficiency of nutrient utilization, performance, profitability and welfare of the animals is continuously going on, and till date many new or modified additives have been identified and incorporated into animal feed.

One such additive for poultry and pig ration is betaine, having an extensive application on animal welfare and performance. Betaine (trimethyl glycine) is a quaternary stable, nontoxic, ammonium compound having osmo-protective and methyl donor characteristics (Yancey, 1982; Cronje, 2018). Betaine is a potent methyl donor supplying methyl group to the various biological methylation reactions including DNA methylation (Dominguez *et al.*, 2013), thereby can exert epigenetic change and alter modulate the expression of genes at the transcriptional levels. Maternal betaine supplementation also improves methionine metabolism with enhanced hepatic expression of metabolic genes (Lee *et al.*, 2014) and modulating embryonic and fetal development in pigs (Cai *et al.*, 2014). The beneficial effects of betaine supplementation in animals have been reported before (Dunshea *et al.*, 2008; DiGiacomo *et al.*, 2014; Dunshea *et al.*, 2019). Betaine has also been successfully used as feed additive for poultry and livestock with improvement in growth, performance and other economic traits (Eklund *et al.*, 2005; Alirezai *et al.*, 2012). Therefore, this paper will explore the potential

benefits of betaine as a feed additive and its role in improving nutrient utilization, animal growth of carcass characteristics, performance and wellbeing of poultry and pig.

Dietary sources of betaine

A large number of natural and processed products contain betaine in appreciable levels (Table 1). Grains, some vegetables, fruits, meats and some dairy products are good source of betaine. Grains, especially whole grains, wheat bran (Westberg, 1951), wheat (Virtanen *et al.*, 2005, Kidd *et al.*, 1997), some marine organisms (Clarke *et al.*, 1994), spinach and beets are also good betaine source. The highest levels of this compound can be found in sugar beet, which naturally accumulates in condensed molasses as soluble by-product. Not all the available forms of betaine are equally potent; food grade anhydrous betaine and betaine monophosphate are more readily soluble and available as compared to betaine hydrochloride (EU-Safety Data Sheet, 1999a,b,c). Betaine hydrochloride supports the pH decline in the stomach, that aid in improving nutrient digestibility. Processing pure betaine from soluble molasses involves extraction process which might interfere with the osmolytic capacity.

Mechanism of action of betaine

There are two major working mechanisms for betaine; which acts as an osmolytic agent and as methyl donor. Betaine has a dipolar structure, which is neutral in charge, hence readily forms bonds with water (hydrogen bonding). This property facilitates, its easy absorption within the cellular structures, effectively raising the osmoconcentration inside the cell (Hammer *et al.*, 2002). Hence, minimum cellular energy is expended for osmoregulation, that upscale the normal proteins and enzyme synthesis and other metabolic pathways.

Methylation is essential for a variety of metabolic processes, including protein synthesis, neurotransmission, muscle contraction, hormonal signaling, cell growth and membrane integrity. Betaine is one of the important methyl donors (Cronje, 2018). Synthesis of phospholipids, epinephrine, DNA expression regulation,

muscle contraction, protein synthesis and cell growth require betaine (Sharma *et al.*, 2006; Cronje, 2018). In protein or amino acids (methionine and other sulphur containing amino acids) deficit diets, betaine might act as a methyl donor (Pesti *et al.*, 1980; Campbell *et al.*, 1995). Once inside the intestines, betaine is rapidly and nearly fully absorbed (Kettunen *et al.*, 2001) and its metabolism principally occurs in liver and kidney mitochondria by the enzyme betaine homocysteine methyltransferase (BHMT). Here, by trans-methylation via methionine cycle, methionine is spared, homocysteine is detoxified and S-adenosylmethionine is produced (Barak *et al.*, 1996; Schrama *et al.*, 2003).

Betaine when used as a feed additive in poultry and pig diet can reduce the inclusion cost of choline or methionine, thereby significantly reducing the feed expenditure. Due to its potent osmoprotective and methyl donor characteristics, poultry and pigs fed

betaine manifest better metabolism, optimum growth rates and carcass traits. As an alternative to choline and methionine, betaine fed animals showed higher thermotolerance and better heat stress tolerance and adaptability.

Effect of betaine supplementation on nutrient utilization and digestibility

The benefits of feeding betaine on nutrient digestibility and utilization are shown in Table 2. In coccidiotic or diarrheal broilers, supplementation of betaine resulted in higher absorption of amino acids like, lysine and methionine than the control group (Remus *et al.*, 1995; Augustine and Danforth, 1999). Similarly, total G.I. tract nitrogen digestibility and energy digestibility was observed to be greater in broilers fed 0.12% betaine (Park and Kim, 2019). El-Husseiny *et al.* (2007) have reported that supplementation of higher doses of betaine from 0.05 to 0.08% significantly promoted crude fiber digestibility in broiler chickens.

Table 1. Betaine content of selected feed ingredients

Feed ingredient	Betaine content (mg/kg)	Reference
Wheat bran	2675	Westberg, 1951
Wheat middlings	2675	
Lucerne meal	3175–3850	
Maize	Below detection limit	
Wheat	3960	Chendrimada <i>et al.</i> , 2002
Wheat middlings	4980	
Groundnut meal	2520	
Lucerne meal	1770	
Fish meal	1180	
Maize gluten meal	Below detection limit	
Sesame meal	Below detection limit	
Soyabean meal	Below detection limit	
Maize	Below detection limit	
Condensed molasses soluble	11600	Eklund <i>et al.</i> , 2005
Wheat	1400	Virtanen <i>et al.</i> , 2005
Fish meal	400	
Oats	590	
Barley	730	
Rapeseed meal	Below detection limit	
Soyabean meal	Below detection limit	

In eight weeks old piglets betaine supplementation improved the overall digestibility and absorption of amino acids, neutral detergent fibre (NDF), acid detergent fibre (ADF), minerals and other nutrients in the gut, without any variations in the AA absorption in ileum (Eklund *et al.*, 2006 a, b). Similarly, Xu and Yu (2000), reported higher dry matter (DM) and crude protein (CP) digestibility's by 4.2% and 6.4%, in weaned piglets supplemented with betaine. The bacterial derived metabolite of betaine, trimethylamine oxide ((CH₃)₃NO) also had a beneficial effect on digestibility of crude fat in pigs (Overland *et al.*, 1999). The digestibility of CP, nitrogen free extract (NFE), crude fibre (CF) and other nutrients also increased significantly in pigs fed 1.0 and 1.5 g betaine/kg diet (Awad *et al.*, 2014). Others have observed similar improvement in organic matter, as well as DM digestibility in animals fed betaine (Eklund *et al.*, 2006a, b; Mosenthin *et al.*, 2007; Ratriyanto *et al.*, 2007). This higher CF digestibility might be attributed to functional properties of betaine, making the fiber fractions available to microbes, resulting in better fermentation and absorption (Wenk *et al.*, 1993). The osmolytic action of betaine might alter the electro-physiological functions of the enterocytes synergizing the microbial fermentation, short-chain fatty acids production and improving the mineral absorption in animals (Butzner *et*

al., 1994). Other than the osmolytic and methyl donor functions of betaine, the stress reducing property cannot be overlooked which may be due to osmo-protective function in intestine (Amerah and Ravindran, 2015), resulting in better morphology and function leading to improved nutrient absorption.

Effect of betaine supplementation on animal performance and carcass characteristics

Faster growth rate, feed conversion efficiency and lean mass production are some of the most desirable traits for meat animals as they upscale the profitability and reduce the production costs (Campbell, 1997). In laying hens supplementation of betaine at the dose of 0.06 to 0.08% improved the performance by up to 8.7% (Zou *et al.*, 1998; Zou and Lu, 2002). Others have reported increased average daily weight gain in broilers when betaine was supplemented at 0.05–0.15% and 0.65%, respectively (Virtanen and Rosi, 1995; Garcia *et al.*, 2000). The methyl transfer activity of betaine, might improve the weight gain and feed efficiency by up to 15% in supplemented growing chicks (Hassan *et al.*, 2005). Improved performance in birds on low methionine diets confirms the methionine sparing action of betaine (Virtanen and Rosi, 1995; Kidd *et al.*, 1997). Not only the performance and efficiency increased but, there also was a reduction in abdominal fat and increase in breast lean meat in commercial poultry supplemented

Table 2. Effect of dietary betaine supplementation on nutrient digestibility in poultry and pigs

Animal	Response to betaine supplementation	Reference
Poultry	↑ CP, EE digestibility	Remus <i>et al.</i> , 1995
Poultry	↑ Methionine digestibility	Augustine and Danforth, 1999
Poultry	No effect	Hassan <i>et al.</i> , 2005
Poultry	↑ OM, CP, EE, CF, NFE digestibility	El Hussein <i>et al.</i> , 2007
Poultry	No effect	Attia <i>et al.</i> , 2009
Piglets (5 weeks)	↑ DM, CP digestibility (total tract)	Xu and Yu, 2000
Barrows (13.50-15.10kg)	↑ OM, CF, NDF, ADF, NFE digestibility	Eklund <i>et al.</i> , 2006a
Barrows (5 weeks)	↑ DM, CF digestibility	Mosenthin <i>et al.</i> , 2007
Barrows, 5 weeks	↑ OM, CF digestibility (Ileum)	Ratriyanto <i>et al.</i> , 2007
Grower pigs (30.00 kg)	No effect (total tract)	Fernandez Figares <i>et al.</i> , 2008

DM, dry matter; OM, organic matter; CP, crude protein; CF, crude fibre; EE, ether extract, NFE, nitrogen free extract; NDF, neutral detergent fibre; ADF, acid detergent fibre; ↑, increase; ↓, decrease

with betaine (Noll *et al.*, 2002; Wang *et al.*, 2004; Zhan *et al.*, 2006). However, others have reported no improvement in carcass characteristics in betaine fed poultry (Waldroup and Fritts, 2005). The beneficial effects of betaine supplementation in *Eimeria* and *coccidia* infected poultry included decrease in pathogenesis, protection of the intestinal structural integrity and functions (Augustine *et al.*, 1997; Matthews *et al.*, 1998; Matthews and Southern, 2000). Alleviation of stress is also one of the potent functions of betaine, mainly due to its methyl donor and osmo-protectant functions, resulting into improved growth rates, feed efficiency, enhanced egg production rate and egg shell quality in poultry (Ryu *et al.*, 2002; Honarbakhsh *et al.*, 2007a, b).

In swine production the current challenge is to increase the lean mass by reducing the excess back fat. Information available on back fat thickness lowering effect of betaine are compiled in Tables 3 and 4. However, response of betaine on lean meat production may also depend on energy levels, energy metabolism, lysine:calorie ratio of the diet, sex of animal and prevailing environmental conditions (Haydon *et al.*, 1995; Matthews *et al.*, 1998). There was substantial reduction in back fat by 14.8 % in betaine fed female pigs (Cadogan *et al.*, 1993). Since then many researchers have established the potency of betaine in reducing body fat and increasing lean mass in pigs

(Matthews *et al.*, 2001; Yan, 2001). Huang *et al.* (2006) reported that supplementation of betaine at 0.125% improved carcass traits, increased in lean mass and reduced back fat thickness in barrows (Lawrence *et al.*, 2002) and increased leanness in finishing gilts (Casarin *et al.*, 1997). However, there are some reports which indicate that betaine supplementation may not always be effective in influencing the back fat thickness, leanness and other desirable carcass traits (Lawrence *et al.*, 1995; Matthews *et al.*, 1998; Overland *et al.*, 1999). Albuquerque *et al.* (2017) evaluated the effects of betaine supplementation at the dose of 1 g/kg for a period of 20 weeks and found increase in total cholesterol in different muscles. But, the betaine supplementation didn't result in any significant improvement in other carcass characteristics or yield. Also, no appreciable effect of added betaine was observed in pigs for leaf fat weight and dressing percent (Huang *et al.*, 2006). Fernandez-Figures *et al.* (2002) showed a linear relationship between supplemental levels of betaine (0-0.5%) and rate of protein deposition in carcass. They observed significant decrease in carcass fat concentration, fat depth and viscera weight (between 10-26%) with an incremental betaine dose, but no changes were evident on growth performance, tissue chemical composition, carcass fat deposition rate, and visceral fat deposition rate in young pigs. From the above findings the role of

Table 3. Effect of dietary betaine supplementation on performance in poultry and pigs

Animal	Dose of betaine, %	Response to betaine supplementation	Reference
Laying hen	0.13–0.50	No effect	Cere and Schinckel, 1995
Barrows and gilts	0.20	↑ growth, 7.00%	Urbanczyk, 1997
Pigs (56–113 kg)	0.11	↑ growth	Cromwell <i>et al.</i> , 1999
Barrows (20–65 kg)	0.15	↑ growth, 10.30%	Wang and Xu, 1999
Gilts (20–65 kg)	0.15	↑ growth, 15.60%	
Piglets	0.06	↑ growth, 11.70%	Xu <i>et al.</i> , 1999b
Barrows (36–64 kg)	0.13–0.50	No effect	Fernandez-Figures <i>et al.</i> , 2002
Grower pigs	0.10	↑ growth, 13.30%	Feng and Yu, 2001
Finisher pigs	0.10	↑ growth, 5.70%	Feng and Yu, 2001

ADG, average daily gain; ↑, increase; ↓, decrease

betaine in nutrient partitioning is clear, protein is deposited at the expense of fat in carcass and visceral tissue. Feeding of supplementary betaine also improved performance and exhibited improved feed efficiency (Wray-Cahen *et al.*, 2004). Similarly, Siljander-Rasi *et al.* (2003) reported improved feed efficiency and growth rates when dietary betaine levels were raised from 0.125 to 0.5%, indicating a dose dependent response in pigs. These results were later corroborated by Huang and colleagues (Huang *et al.*, 2006) who supplemented crossbred barrows and gilts with 0.125% levels of betaine to obtain superior average daily gain than the control group. The growth performance and energy balance improved in Iberian pigs when combination of betaine and conjugated linoleic acid at 0.5 and 1% of diet were used, respectively (Rojas-Cano *et al.*, 2013).

Ramis *et al.* (2011) supplemented betaine at 2 kg/ton of feed throughout the gestation length to 48 sows and gilts and observed higher average live weight and litter weight of piglets at weaning. Also, the weaning to estrus duration was shorter in betaine supplemented sows (4.7±0.4 versus 5.8±0.4 days). In another study, it was observed that there was no variation in average live weight and weight gain in piglets, farrowing rates (0.79), but total litter size was greater in sows having daily betaine intake of 7.6–9.0 g/sow, throughout the length of gestation (Van Wettere *et al.*, 2012). Supplementation of betaine at 3 g/kg feed during late

gestation improved litter size and weight of piglets and reduced the gap between weaning to estrus. In betaine supplemented sows the concentrations of tri-iodothyronine (T₃) and thyroxine (T₄) were higher at the time of farrowing, while serum cortisol levels were lower during the pregnancy (Mishra *et al.*, 2019 a,b), indicating modulation of hypothalamic-pituitary axis. Similarly, Mendoza *et al.* (2020) reported reduction in weaning to estrus interval (6.64 vs. 7.50 days) and a subsequent increase in litter size and total number of pigs born in fourth parity and first parity sows. Betaine could help in survival of the fetuses via reduction in homocysteine concentrations, by altering methionine metabolism, energy turnover and modulating the growth hormones (Finkelstein, 1990; Schrama *et al.*, 2003; Huang *et al.*, 2007; Van Wettere *et al.*, 2012).

Effect of betaine on serum metabolites and hormones

Serum metabolites and hormones are well recognized marker for assessing metabolic profile of animals. Park and Kim (2019) reported increased level of total protein, albumin and glutathione peroxidase (GPx) when betaine was supplemented at 0.12% level in poultry ration. The higher levels of total protein were positively correlated with body tissue growth, confirming the essential protein sparing action of betaine in broilers. Supplementation of betaine had a positive effect of lipid profile, and there was a

Table 4. Effect of dietary betaine supplementation on carcass characteristics of pigs

Animal	Response to betaine supplementation	Reference
Gilts (60-103 kg)	↓ Backfat thickness	Cadogan <i>et al.</i> , 1993
Barrows, gilts	↓ Backfat thickness	Urbanczyk, 1997
Gilts (55-110 kg)	↑ Carcass length	Matthews <i>et al.</i> , 1998
Barrows and gilts (66-88 kg)	↑ Carcass length, ↓ 10 th rib back fat	Matthews <i>et al.</i> , 2001
Finishing barrows (>62.50 kg)	↓ Carcass fat ↓ 10 th rib backfat	Feng <i>et al.</i> , 2006
Boar, gilts (>58.00 kg)	↓ Lean tissue	Dunsha <i>et al.</i> , 2007
Barrows and gilts (55-90 kg)	↑ Carcass lean, ↓ back-fat thickness	Huang <i>et al.</i> , 2008

significant increase in serum triglycerides (TG) and cholesterol concentration in 42- day old broilers (Ghasemi and Nari, 2019). There are also some contradictory reports that betaine resulted into lowering the total cholesterol and TG in ducks (Shin *et al.*, 2019). While, others have observed significant increase in serum cholesterol when betaine was fed at 800 mg/kg (Rao *et al.*, 2011). In commercial ducks supplementation of betaine at 0.5, 1.0 and 1.5 g/kg diet led to decreased level of total cholesterol and LDL with an increase in HDL concentration (Awad *et al.*, 2014).

Supplementation of betaine resulted in increase in total cholesterol and non-esterified fatty acids (NEFA) without any influence on urea nitrogen, total protein,

serum albumin, triglycerides and HDL- cholesterol in finishing pigs (Matthews *et al.*, 2001). Similarly, Mishra *et al.* (2019b) reported that supplemented of betaine at 3 g/kg feed resulted in decreased serum concentration of cholesterol and triglycerides, with no significant effect on enzymes like aspartate amino transferase (AST), alanine amino transferase (ALT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH), and creatine kinase (CK) in pigs (Mishra *et al.*, 2019a). In another study it was observed that supplementation of betaine reduced serum concentration of triglycerides and cholesterol in gestating sows (Mishra *et al.*, 2019c). However, Matthews *et al.* (1998) and Overland *et al.* (1999) reported no effect of betaine

Table 5. Effect of betaine supplementation on endocrine profile in pigs and poultry

Animal	Dose of betaine, %	Response to betaine supplementation	Reference
Laying hen	0.08	↑ T ₃ & T ₄	Zou <i>et al.</i> , 1998
Duck > 0.21	0.03–0.10	↑ GH	Wang <i>et al.</i> , 2000
Laying hen > 0.20 weeks	0.06	↑ T ₃ , week 50(43.30%) & week 70 (44.00%)	Zou and Lu, 2002
Laying hen	0.08	↑ FSH, LH, parathyroid hormone, estradiol & progesterone	Zou, 2001
Barrows and gilts, (20–65 kg)	0.15	↑ GH, barrows (62.50%); gilts (71.00%); ↑ GH, barrows (74.3%); gilts (45.00%)	Wang and Xu, 1999
Grower pigs	0.10	↑ GH (101.80%); IGF-1 (44.80%); T ₃ (26.50%) & T ₄ (16.80%)	Xu <i>et al.</i> , 1999a
Finishing pigs	0.10	↑ GH (59.10%)	Xu and Feng, 1998
Piglets, male and female >10 kg	0.08	↑ GH & IGF-1	Yu and Xu, 2000
Weaned, grower and finishing pigs	0.08–0.18	↑ GH, weaned pigs (46.20%); grower pigs (102.10%); finishing pigs (58.30%); ↑ IGF-1, weaned pigs (38.70%); grower pigs (44.70%); finishing pigs (48.00%)	Yu <i>et al.</i> , 2001

T₃, tri-iodo-thyronine; T₄, throxine; FSH, follicle stimulating hormone; LH, letinizing hormone; GH, growth hormone; IGF-I, insulin like growth factor I; ↑, increase; ↓, decrease

supplementation on serum cholesterol and NEFA levels in pigs.

Supplementation of betaine at optimum levels may also improve the endocrine function via modulation of the hypothalamus-pituitary axis in animals (Table 5). In poultry, betaine addition in feed resulted in increase in hormone-sensitive lipase activity, which might modulate the lipid metabolism and also decrease the cholesterol and TG levels (Zou *et al.*, 1998; Zhan *et al.*, 2006).

In pigs supplemented with betaine (0.125% of diet) resulted in elevated concentrations of growth hormone, insulin-like growth factor I (IGF-1), free tri-iodothyronine, and free thyroxine and insulin by 45.6, 55.5, 57.9, 51.8 and 42.3%, respectively. They also reported an elevated fatty acid synthase activity (Huang *et al.*, 2006). Mishra *et al.*, (2019b) found that the levels of triiodothyronine (T₃) and thyroxine (T₄) were higher and that of cortisol was lower in sows fed supplementary betaine. However, other studies reported no any influence of betaine on serum cortisol levels in sows (Cools *et al.*, 2010; Cabezon *et al.*, 2016).

Effect of betaine on antioxidant profile and heat stress

Due to global warming and climate change our livestock are now more susceptible to heat stress, especially in tropical and sub-tropical regions (Reynolds *et al.*, 2010). Inter-Governmental Panel on Climate Change has already confirmed that, the global temperature is higher by 1.5°C and further predicted a future rise by 0.3 to 4.8°C by end of 21st century (IPCC 2014, 2014a, 2018). This sustained heat stress will challenge the homeothermy and can lead to metabolic disturbances and oxidative imbalance, thereby negatively affecting performance and production in livestock (Collier *et al.*, 2019). The need for amelioration of heat stress is thus of paramount importance. In recent times betaine has emerged as a potent feed additive that may ameliorate stress (Sizeland *et al.*, 1993; Suzuki *et al.*, 2003; Lever and Slow, 2010). The antioxidant activity of betaine can be attributed to its ability to reduce mitochondrial lipid peroxidation, scavenge free radicals and preserve optimum cellular functions (Ganesan *et al.*, 2007; Lu and Cederbaum, 2008). Although the exact

molecular mechanism is not yet clear, feeding betaine significantly reduced reactive oxygen species (ROS), free radicals and improved the total antioxidant machinery in animals (Decker and Zhimin, 1998; Gheisari and Motamedi, 2010). The effect of both acute and chronic heat stress, is well documented in different species like poultry (Mujahid *et al.*, 2005; Mujahid, 2011), pigs (Montilla *et al.*, 2013, 2014; Liu *et al.*, 2015), and also in ruminants (Bernabucci *et al.*, 2002; Chauhan *et al.*, 2014; Wankar *et al.*, 2017, 2020). Supplementation of betaine hydrochloride (2 g/kg diet) resulted in lower rectal temperatures and respiration rates, which is indicative of optimum heat loss function in poultry reared under different environmental conditions (Singh *et al.*, 2015). Alirezaei *et al.* (2011) reported significantly higher glutathion peroxidase and catalase activity with improved meat quality in betaine fed broilers. Supplementation of different doses of ascorbic acid and betaine in combination resulted in decreased body temperature, alongwith significantly increased growth rate and performance in heat stressed broilers birds (Attia *et al.*, 2009).

Mishra *et al.* (2019a) reported higher serum levels of catalase and total antioxidant activity with significant reduction in malondialdehyde level in sows fed supplementary betaine as compared to control group. Total heat production was substantially lower in pigs supplemented with betaine at 1.25 g/kg feed, indicating optimum thermoregulation (Schrama *et al.*, 2003). Similarly, Gabler *et al.* (2013) reported beneficial effects of betaine supplementation (0.125%) on normal physiological functions when growing pigs were exposed to 36°C continuously for six hours.

CONCLUSION

In case of poultry, betaine supplementation improved the growth rate, meat quality and laying performance. Also, the improved feed conversion efficiency, which is the direct measure of profitability was evident in betaine fed animals. In case of swine, there is reduction in back fat or body fat with concurrent increase in lean meat and increased growth which is a very promising attribute of betaine. While,

Betaine can be a powerful nutri-biotic compound to alleviate heat stress in growing pigs and poultry. In future, betaine can be a major additive in animal feed due to its cost effectiveness as compared to purified proteins or amino acids and as performance enhancer or growth promoter. Further research is essential to unveil the underlying cellular pathways to elucidate the full potential benefits of this compound in pregnant sows, newborn piglets, growing pigs, broilers, layers and other livestock alike.

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