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NUTRITIONAL ADVANCES IN PRODUCTION PERFORMANCE AND PRODUCT QUALITY OF POULTRY HUSBANDRY UNDER HEAT STRESS

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ABSTRACT: The objective of this review is to explore the nutritional additives to combat heat stress in high production targeted fowls. Many diseases and stress dynamics are liable for heavy mortality nowadays. High production targets and heat stress initiate free radical injuries and gastrointestinal oxidative insults resulting in poor bioavailability and feed efficiency. Accordingly, the quality of the eggs and meat is compromised along with the bird's health. Dietary schemes and relevant feed formulation with the provision of vital elements like selenium, zinc, calcium, vitamin E, vitamin C, vitamin A, electrolytes, essential amino acids, and plant extracts can conflict with all sorts of stress in birds and improve the immune system. The occurrence of many contagious diseases, nervous ailments, and metabolic syndromes can be decreased via appropriate feeding routines. It will not only control the bird's health but also increase the quality and market value of the products and consumer satisfaction. Scientists have struggled to prevent immuno-depression, egg and meat quality impairments by dietary influences. Poultry welfare is facing many problems currently which should be properly coped with innovative nutritional maneuvers. This review anticipates illuminating the probable nutritional approaches to manage stress in poultry birds.

Keywords: Heat stress, Poultry, Electrolytes, Phytogenic, Product quality

INTRODUCTION

The poultry sector faces several stress dynamics including feather pecking, vaccination, molting, increased stocking density, and high temperature. Although sometimes stress seems to be harmless, continuing stress circumstances can undesirably upset the vigor and production of the birds. Poultry birds need more nutrient requirements and metabolic rate is higher as compared to ruminants (Akşit et al., 2006). Poultry birds are very prone to heat stress as compared to other farm animals. Commercial broilers produce more metabolic heat as compared to other indigenous pure genotypes (Kang and Shim, 2021). Under heat stress, feed intake, feed conversion ratio, productivity, meat quality, egg quality, and immune status are compromised. Heat stress is a primary menace that deleteriously changes bird performance (Liu et al., 2020). Poultry birds uphold their body temperature at 40.6–41.0°C regardless of the ecological high temperature because of the homoeothermic activity (Ryder et al., 2004). Nevertheless, birds, whose bodies are covered with plumages and raised for high productivity are extra profound to heat stress (Mahmoud et al., 2015). Broiler meat and eggs are the most cost-effective animal protein nowadays. Globally poultry farming will progressively be exaggerated as birds are unprotected to periodic and prolonged heat stress associated with global warming (Wankhade et al., 2020).

The optimal temperature for the best productivity of birds is 19-22°C for laying hens and 18-22°C for growing broilers (Shahzad et al., 2021). High temperature in poultry causes reduced fertility, growth and production, poor quality meat and egg production, and more mortality (Ranjan et al., 2019). Furthermore, genetically modified layers kept for high production generate more metabolic heat so they are more prone to heat stress (Holik, 2015).

For the period of initial summertime, the poultry husbandry faces considerable damages in production, and particularly pale, soft, exudative (PSE) meat. PSE meat has a low water-holding ability and meat consistency. Certainly, these fluctuations are strictly interrelated to biochemical variations of skeletal muscles due to heat stress (Song and King, 2015). Immunity (Siddiqui et al., 2021), production, and bird welfare are undesirably affected due to heat stress in birds (Iyasere et al., 2021). The major reason for production loss due to stress is less feed intake of the birds and for every 1°C after 30°C, almost 5% feed intake drops which results in essential nutrient deficiencies (Bilal et al., 2021). To cope up with this, the supplementation of vitamin C and E, chromium, zinc, and methionine, high protein and energy, phytogenic extracts can be operative in decreasing the deleterious effects of heat stress (Khan et al., 2014; Surai et al., 2019).

This review is considered to anticipate the importance of nutrition in responding to the negative effects of heat stress on poultry production. Maximum of the possibilities and remedies of heat stress and negative impacts are illustrated.

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DISCUSSION

Feeding and drinking response during stress

Undoubtedly feed intake decreases significantly when housing temperature upsurges. In a study, it was determined that feed intake was reduced and water intake was increased in broiler chicks and this behavior was in response to high metabolic heat (Chowdhury and Furuse, 2013). As a thumb rule, birds can be nourished at midnight during hot weather. Nevertheless, to avoid high metabolic heat overlapping ecological heat, it is usually recommended not to feed at 1.00-4.00 pm. Feed conversion rate or feed efficiency of the birds is reported to increase during heat stress periods irrespective of the feed intake and crop filling (Sohail et al., 2012). In a study, it was concluded that if broilers eat more finely ground feed particles during stress time, little metabolic heat is produced as compared to coarse particles of maize and the birds adapt to the environment with panting (Santos et al., 2019).

A study was conducted on 3060 broilers kept in tropical, subtropical, and temperate areas. FCR and body weight at 42 days were considerably higher ($p \leq 0.05$) in the subtropical area during winter (Osti et al., 2017). Temporary feed restriction appears to improve the productivity and feed efficiency of the birds during the hot season. A study was conducted on one-week-old broiler chicks kept in open housing and it was seen that feed restriction for 3 hours along with vitamins and mineral supplementation reduced mortality and improved production and quality of the meat (Mohamed et al., 2019). Similarly in another study, feed restriction for 2 hours per day improved the growth performance in broiler chicks (Liew et al., 2003). Conversely, feed restriction for a longer period decreased considerably the body weight gain and feed efficiency of broilers but reduced mortality (Lin et al., 2006).

It was shown in a study conducted on various genetic lines of broilers kept in semi-intensive housing and the results showed that all chicks showed maximum feeding intake at early morning 7:00 and late evening 17:00 when the temperature is decreased (Gonçalves et al., 2017). Hens under heat stress walk very little drink more water and do more rest as compared to control (Mack et al., 2013). The increase in water intake under stress is a physiological response of birds to homeostat body temperature and dehydration. Similarly in a study betaine was used in broilers due to its osmoregulation property to decrease heat damage and increase water intake (Ratriyanto and Mosenthin, 2018). The most economical way to decrease stress effects on birds is to feed them in the early morning and late evening and this will enhance feed efficiency (Liverpool-Tasie et al., 2019). Birds eat more in day time normally and less at night time but to compensate for the stress-induced decrease in feed intake in the daytime, nighttime feeding can be encouraged with synthetic illumination (Daghir, 2009).

Negative impacts of heat stress on poultry

Due to oxidative stress and cellular injuries during heat stress immunity and feed efficiency of the birds drops. There happens massive economic loss due to less production and mortality. The negative effects of heat stress on poultry are shown in figure 1 and table 1.

Nutritional intermediations improving product quality and production

Nutritional management is an auspicious way to enhance productivity, feed efficiency and reduce disease outbreaks by increasing the immunity of the birds during stress (Mujahid, 2011). Nutritional strategies include balancing of energy, provision of essential amino acids, adequate minerals and vitamins and many phytogenics that are discussed below and shown in figure 2.

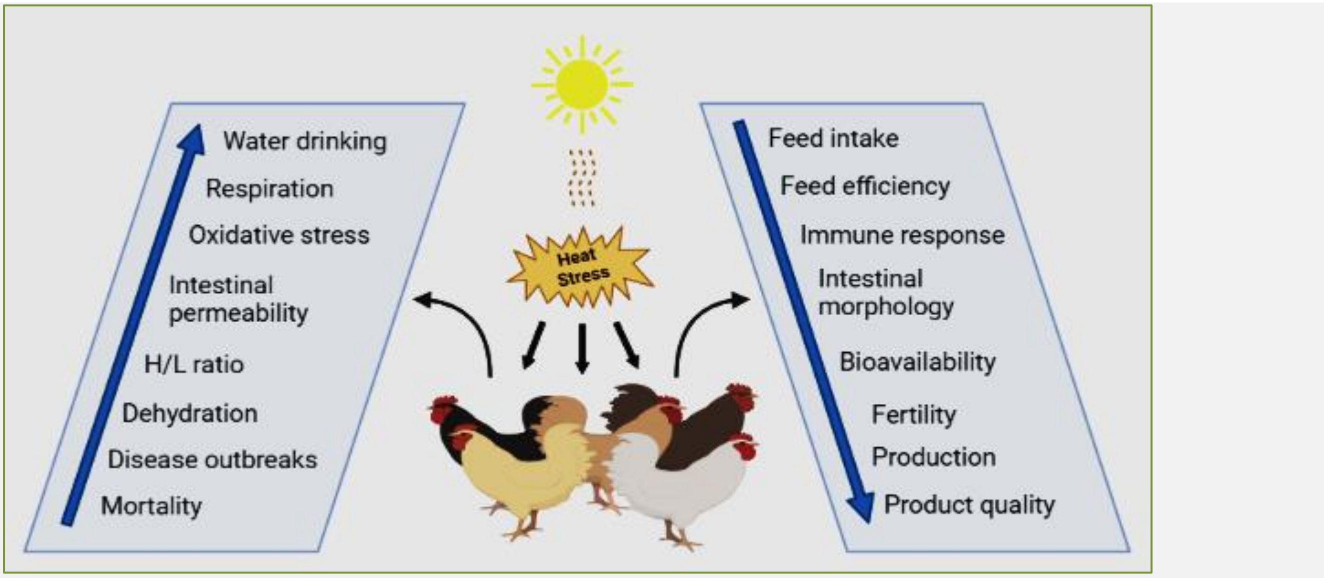

Figure 1 - Negative impacts of heat stress

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Table 1 – The negative impacts of heat stress

Heat Stress	Effects	Birds	References
Chronic heat stress (10-days)	↓ Weight gain ↑ Inflammatory cytokines (IL-2 and TNF-α), and rectal Temperatures. ↑ Intestinal bacterial permeability	Broilers	Alhenaky et al. (2017)
Chronic heat stress	↓ Feed intake and body weight.	Cobb-500 broiler	Attia et al. (2017)
Acute heat stress	↑ Mitochondrial Super-Oxide formation in bird's skeletal muscles.	Broilers	Sahin and smith (2016)
38°C (2, 5, and 10 hr.)	An efficient ↑ TLR4 expression in kidneys, liver, and heart.	28 days old broilers	Huang (2017)
23.9-37°C Cycling	↑ Heterophil-lymphocyte ratio, serum levels of cholesterol, glucose, and triglycerides. ↓ Feed intake, body and organ weight, primary and secondary antibody and IgM and IgG titers, HDL-cholesterol (serum concentration).	Broilers	Habibian et al. (2014)
31°C (12 HR.)	↓ In laying rate and egg production. ↑ (In mRNA levels) of ghrelin and amphetamine- and cocaine-regulated	12 weeks old hens	Song et al., (2012)
30°C (2 weeks)	↑ Serum corticosterone conc., and sodium-dependent glucose transporter-1 expression. ↓ Bodyweight.	28 days old broilers	Garriga et al. (2006)
32°C (acute heat stress)	Acid-base level disturbance (in the blood), negative effects on the integrity of muscle membrane, and changes in meat characteristics.	35-63 days old broilers	Sandercock et al. (2001)

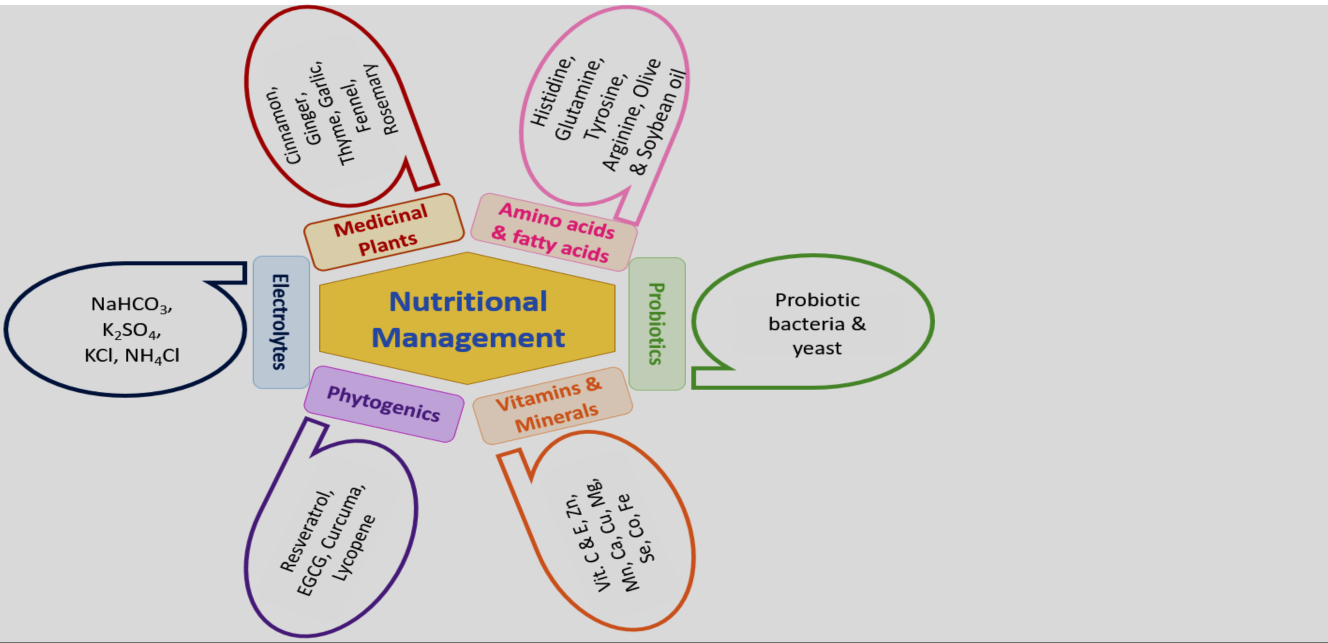

Figure 2 - Nutritional strategies for decreasing heat stress

High-energy formulations

The benefits of giving high-energy formulations by supplementing fat and protein to broilers kept in high-temperature areas are familiar globally (Srinivasa Rao et al., 2016). For instance, a study was conducted on Ross-308 and chicks were fed with 21% and 23% crude proteins. The results showed a significant increase ($P< 0.05$) in body weight gain and feed conversion ratio as compared to the low protein diet. In short, it was declared that 23% protein and 3000 kcal/kg energy was better for growing stage and for the finishing period 20% protein and 3200 kcal/kg energy was suitable (Ahmed and Arabi, 2015). Feeding broilers with less protein-based diets during finishing has reduced microbial contents in feces and improved productivity during stress (Laudadio et al., 2012). In another study, for layers kept at 31 °C, supplementation of 5% fats to layers increased their feed intake by 17% while for hens kept at 11-18°C, there was a 4.5% increase in feed intake (Daghir, 2008). Abdel-Moneim et al. (2020) reported that full-fat canola meal in Japanese quails under heat stress has resulted in improved growth and egg-laying along with egg quality.

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Lowering metabolic heat

As compared to carbohydrates and protein, supplementary fat leads to a slight rise in metabolic heat (Laganá et al., 2007). Serving wet feed to broilers during stressful environmental conditions increases weight gain, feed conversion rate, and feed intake (Koh and Macleod, 1999). Mashed feed or crumbled feed particles are easily digested with little effort of gizzard i.e. high digestibility and hence reduced metabolic heat is produced (Amerah et al., 2007).

Betaine and methyl donors' supplementation

Betaine has good osmoregulation properties and its supplementation to quails at 0.06-0.12% has shown more feed intake and better egg quality during heat stress (Ratriyanto et al., 2017). Similarly in another study on quails, 16.5, 18, and 19.5% protein levels were augmented with 0, 0.06, 0.12% betaine respectively. The results showed that 18% protein with 0.12% betaine showed maximum crude fiber digestibility but less fat digestibility. Betaine improved all egg quality parameters and improved the digestibility of all nutrients (Raei et al., 2020). In another study, betaine was used in broiler chicks to decrease harmful effects of heat stress and it resulted in decreased mortality, improved body weight gain and feed intake, and humoral immune response of the chicks under stress in treatment groups as compared to the control (Ghasemi and Nari, 2020).

Reduced use of usual amino acids in diets during heat stress with supplementation of methionine, lysine, and betaine can improve the feed intake and efficiency along with a reduction in metabolic heat (Cronje, 2018; He et al., 2021). Moreover, these methyl group donors have value-added the carcass traits of broilers during heat stress (Ratriyanto et al., 2014). Glutamine supplementation in broilers under heat stress has resulted in intestinal epithelial cells multiplication increasing intestinal barrier function and tight junction proteins (Wu et al., 2018).

Taurine supplementation

Taurine has now made its position in animal nutrition as an antioxidant agent because of stress in poultry birds. In a study, taurine was used in broilers in drinking water for 35 days during heat stress. The results showed that there was a significant increase in weight gain and feed intake in taurine supplemented groups as compared to control. The gut fat was reduced along with improvement in muscle histopathological characters (Hafeez et al., 2021).

Probiotics and prebiotics supplementation

Probiotics and prebiotics are very valuable in poultry farming under heat stress. In laying hens provided with a high-temperature environment, 1g of mannan-oligosaccharides was used and it resulted in improvement of weight gain and feed conversion ratio, eggshell weight and thickness, albumen weight, and height in treatment groups (Bozkurt et al., 2012). Similarly, in broilers under heat stress, 24mg/kg of the diet was used for 42 days and it resulted in improvement of intestinal morphometric characters including villus width and surface area, and crypt depth and production of the birds (sohail *et al.* 2012). In laying hens probiotic mixture including 0.1% symbiotic and 0.1% culture of *Bacillus subtilis and Enterococcus faecium* and 0.5% mannan-oligosaccharide was used and it resulted in daily feed intake increase along with an increase in egg weight, egg-laying capacity, and egg quality parameters under heat stress. It also enhanced beneficial intestinal microbes (Zhang et al., 2017). In commercial broilers, strains of *Bacillus subtilis* were used and it increased daily body weight gain and lipid peroxidation reduction (Chao et al., 2017). Similarly, dietary supplementation of *Bacillus subtilis* at 0, 200 and 400 mg/kg of feed in broilers under heat stress increased significantly IgM levels in serum and improved cell-mediated immunity (Fathi et al., 2017). In a study, microalgae astaxanthin obtained from *Haematococcus pluvialis* was used in broilers and layers to evaluate its effects on molecular parameters of stress and lipid metabolism during heat stress and it decreased hepatic mRNA activity of many redox regulatory genes, heat shock transcription factor 1, heat shock protein 70 and tumor necrosis factor-α (Tolba et al., 2020). In a study, post-biotic obtained from *Lactiplantibacillus plantarum* was used in broilers to decrease the negative impacts of heat stress on production and bird's health. It resulted in upregulation of the glutathione peroxidase, superoxide dismutase, and catalase activity so it is a natural source of anti-oxidation (Humam et al., 2021).

Electrolytes supplementation

Electrolytes are very important for poultry that should be balanced during heat stress and it is recommended to be 250 mEq/kg during stressful conditions (Sarwar, 2007). For better productivity of broilers during heat stress, 0.21-0.25% sodium and 0.30% chloride should be provided during the finishing stage (Mushtaq et al., 2007). In a meta-analysis, it was predicted that for every 1°C increase in ambient temperature there was a 1.4% reduction in average daily feed intake and 2.1% reduction in average daily weight gain and dietary electrolyte balance has a strong effect on chicks less than 21 days old (Andretta et al., 2021). Due to decreased feed intake during heat stress, there comes dietary deficiency of vital minerals that are important for digestibility and oxidative stress neutralization. Hence, there should be controlled supplementation of calcium, zinc, iron, phosphorous, sodium, chloride, potassium, copper, magnesium, selenium, manganese, chromium, and iodine (Hassan Mir et al., 2018). In a study, broilers during the finishing stage were provided with minerals in water and feed during heat stress maintaining the electrolyte balance as 240 mEq. The results showed a 34% increase in water consumption as compared to control. Moreover, mineral supplementation reduced significantly metabolic heat, hyperventilation, and mortality (Farfán et al., 2010).

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Vitamin C and vitamin E supplementation

Birds open to high-temperature present fall in the size of immune organs like the bursa, thymus, and spleen. Oxidative damage happens in birds prone to heat stress so, dietary addition of antioxidants is common dietary involvement. The provision of 250 mg/kg of vitamin E has been seen to decrease undesirable effects that occur during heat stress (Kazim Sahin et al., 2001). In another study, vitamin E was supplemented as 250 mg/kg of the diet in broilers and it resulted in increased activity of glutathione peroxidase and reduced expression of HSP60 (Kumbhar et al., 2018), and in layers, at 150 mg/kg it has shown to increase egg number and quality (Zhao et al., 2011). Ascorbic acid or vitamin C is being synthesized by the kidneys of the chicken and during heat stress, it becomes insufficient to cope with the bird's requirements. Vitamin C improves immunity, body weight, anti-oxidative potential, semen quality, and carcass characteristics in chicks (Abidin and Khatoon, 2013). A study was conducted to evaluate the effects of vitamin and mineral premix and vitamin C in broiler chicks during 0-35 days of the growing stage under artificially induced heat stress. The results showed that vitamin and mineral premix in water increased body weight gain and feed intake linearly, and the corticosterone level was reduced in serum in all treatment groups as compared to control (Saiz del Barrio et al., 2020). Similarly in another study, Vitamin C was provided to broiler chicks during the growing stage and the feed intake and body weight gain was improved due to a decrease in metabolic heat in birds as compared to the control group where no vitamin C was provided (Abudabos et al., 2018). In another study, Vitamin A, C, E, capsaicin from red pepper, selenium, and zinc were evaluated in layers kept under a heat stress environment. The supplementation increased weight gain, feed efficiency, and immune organs such as spleen and thymus weights, egg weight, shell thickness, and egg-laying percentage as compared to the control. Red pepper improved egg yolk color and decreased total cholesterol and lipids vice versa to selenium (Malekizadeh et al., 2012).

ALA and GAA supplementation

The α-Lipoic acid (ALA) and guanidinoacetic acid (GAA) are naturally synthesized in body and they are also present in many feed ingredients good antioxidants and if supplemented during heat stress, show positive response on production. In a study, α-Lipoic acid was used in broiler chicks kept at high temperatures and it increased average daily weight gain, feed intake, and volatile fatty acids in treatment groups as compared to the control. Moreover, villus height and villus to crypt depth ratio were improved along with the increase of beneficial microbes in the cecum (Wasti et al., 2021). In laying quails, guanidinoacetic acid (GAA) was supplemented during heat stress conditions and it resulted in increased laying capacity, better egg quality parameters, increased activity of superoxide dismutase, glutathione peroxidase, and reduction of malondialdehyde in serum (Raei et al., 2020).

Chitosan and galacto- oligosaccharides supplementation

In a study, chitosan oligosaccharides at 200 mg/kg were supplemented to broilers kept at high temperatures and it resulted that in the treatment group average daily weight gain, feed efficiency, weights of the immune organs, muscle oxidative enzyme activities were increased along with decreased malondialdehyde and corticosterone content as compared to control (Chang et al., 2020). Galacto-oligosaccharides were used in broilers kept at high temperatures and it resulted in improvement of feed conversion rate and weight gain along with a 5% reduction in mortality in treatment groups as compared to the control group (Slawinska et al., 2020).

Copper and zinc nanoparticles supplementation

In a study, nanoparticles of copper oxide were used to decrease heat stress effects on broiler chicks. The results showed that there was a reduction in metabolic heat and an increment in body weight gains in copper nanoparticles supplemented groups. Moreover, the stress biomarker, malondialdehyde (MDA) was decreased along with increased activities of catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase. Moreover, the liver tissue histology parameters were improved along with modulation of heat shock protein 70 and heat shock protein 90 (El-Kassas et al., 2019). In another study nanoparticles of zinc oxide were fed to layers as 80 mg/kg under heat stress and it resulted in a significant increase in egg numbers, egg weight, eggshell thickness, superoxide dismutase (SOD) activity, and zinc bioavailability in the treatment group as compared to control (Abedini et al., 2018).

Zinc, chromium, selenium, and methionine chelates supplementation

Effects of supplementation of zinc, chromium, and selenium in feeds were recorded in broiler chicks during the growing stage under heat stress. The results showed that there was an increase in feed intake and body weight gain in Zn, Se and Cr supplemented groups along with a reduction in lipid peroxidation as compared to the control. Moreover, the activity of superoxide dismutase was increased (Rao et al., 2016). Similarly, Zn bound to methionine and zinc oxide was supplemented to broilers under heat stress and it increased weight gain, nutrient bioavailability, thymus and bursa weights, egg quality, and reduction of malondialdehyde (MDA) and cholesterol in serum (Abd El-Hack et al., 2018). Similarly in another study, Zn-methionine (20, 40, and 80 mg/ kg of feed) provision to layers under heat stress has resulted in increased production, immunity, and egg quality parameters and reduced lipid peroxidation as compared to inorganic Zn and control group (Min et al., 2018). Chromium is well-thought-out to be a valuable trace element. It has been stated that its supplementation encourages the productivity of broilers during heat stress. In a study, chromium was

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supplemented methionine in broilers and the results showed an increase in body weight gain, feed conversion ratio along with the coefficient of energy metabolism, serum glucose, cholesterol, and triacylglycerol (Santos Dalólio et al., 2021). Amino acid-bonded trace minerals were provided to broilers under heat stress and it resulted in a decrease of the corticosterone levels and cytokines in serum and resultantly improved productivity of chicks (Baxter et al., 2020). In another study, ethoxyquin and mineral-methionine chelate were used in broilers and it resulted in a reduction of development of wooden breasts in broilers and the lipid peroxidation of muscles was significantly lower as compared to control when both were used together (Kuttappan et al., 2021).

$NaHCO_3$ and KCL supplementation

Dietary supplementation of $NaHCO_3$ was performed in layers and immune response was improved against ND virus after vaccination, and digestibility of nutrients was significantly higher in treatment groups as compared to the control (Abbas et al., 2019). Potassium chloride was used in broiler chicks under heat stress and it increased the digestibility coefficients of dry matter, protein, fat, fiber, and crude ash. Moreover, the bioavailability of calcium and phosphorous was more for potassium chloride supplemented chicks as compared to the control. The red blood cells and total hematocrit were more in treatment groups as compared to the control (Gorlov et al., 2020).

Propolis supplementation

Propolis is obtained from honeybees and it has several beneficial effects under stressful environments. In a study on quails kept under high temperatures, propolis was used for minimizing the adverse effects of heat stress. It resulted in improvement of weight gain and feed intake, increases in intestinal crypts depth, and immune organ weights (Mehaisen et al., 2017).

Phytogenic supplementation

Many phytogenic feed supplements are being used nowadays to combat stress in poultry birds. Phytogenic feed additives have medicinal properties and natural to use without any side effects. They also enhance feed palatability with the flavor, taste and texture that the birds love to eat. Phytogenics enhance feed intake, promote gastrointestinal health status of the birds, improve immune system, reduce cellular oxidations, and improve production and product quality. There are many phytogenics that are mentioned below.

Ginseng

In a study, ginseng was used in broilers and it resulted in lowering the gene expression of HSPA1A, HSP1, and HSP-16.2, and it was reported to be the most suitable additive to reduce heat stress undesired effects (Sandner et al., 2020).

Dried plums

Dried plums were used in a study on broilers to reduce the harmful effects of heat stress. It increased the daily weight gain, feed intake, and feed conversion rate of the broilers, and it increased the expression of the genes related to anti-oxidation, heat shock proteins, and immune system activation genes as compared to the control (Wasti et al., 2021).

Watermelon juice

Watermelon juice was added as 20% and 40% to water and it was used during the finishing stage of the broilers for 21 days under heat stress. The results showed that the survival rate was improved and it was 100% in the 40% supplemented group. Moreover, weight gain and feed intake were increased significantly in all treatment groups as compared to the control (Jimoh et al., 2020).

Curcumin

Curcumin is obtained from turmeric and it was used in laying hens to improve the immunity during heat stress and it resulted in a reduction of Interleukins-6, interleukins 1β, and tumor necrotic factor- α in treatment groups as compared to the control (Nawab et al., 2019). In another study, curcumin supplementation in broilers at 100 mg/kg of the diet (Zhang et al., 2018) and laying hens at 150 mg/kg of the diet (Liu et al., 2020) has increased growth performance and anti-oxidative and immune regulating gene activities, and egg and meat quality. In another study, curcumin nanoparticles were used in broilers and they were provided with 25, 50, and 100 mg/kg of the diet under heat stress. The results showed a significant increase in body weight gain, feed intake, immune organ weights reduction in malondialdehyde, and an increase in glutathione peroxidase and superoxide dismutase activity. Curcumin nanoparticles at 50 and 100 mg/kg of diet showed more significant results as compared to other groups (Badran, 2020). Similarly, cumin seed oil was supplemented to layers as 500 g/ ton of feed and it resulted in increased egg quality, feed conversion, immunity, and drop in serum malondialdehyde level (Saleh et al., 2019).

Cumin seeds

Cumin seed powder supplementation in broilers under heat stress has resulted in increased weight gain, feed conversion ratio and dressing percentage (Chawke et al., 2021). In a study, the effects of phytogenic feed additive

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"comfort" (PFA-C) was evaluated in broilers and it resulted in down-regulation of heat shock protein 70 gene expression, increase in water and feed intake, and average weight gain and low mortality (Greene et al., 2021).

Cinnamon and clove

In a study, cinnamon and clove powders and their oils were used in quails reared under heat stress and it resulted in a significant drop in heat shock protein HSP70, HSP40, and HSP90, and tissue malondialdehyde, corticosterone, and cytokines in serum were reduced along with the increased activity of catalase, superoxide dismutase and glutathione peroxidase in treatment groups as compared to the control. Moreover, the oils were more beneficial as compared to the powders (Mustafa and Wasman, 2020). Similarly in broilers, cinnamon powder as 0.5% has increased the weight gain and activity of serum glutathione peroxidase, catalase, and superoxide dismutase enzymes and reduction in malondialdehyde content (Sadeghi and Moghaddam, 2018).

Siam weed

Siam weed (*Chromolaena odorata*) was used in broiler chicks to decrease the heat stress effects. Its Ethanol extract at 25–400 µg/ml presented a resilient antioxidant activity in vitro, comparable to 10–80 µg/ml ascorbic acid supplementation. Chromomoric acid obtained from siam weed (*Chromolaena odorata)* at 10 µg has anti-inflammatory activity. Moreover, the toxicity trials have shown that only the aerial fragments of it are nontoxic for animal feeding (Lartey et al., 2020).

Fennel seeds

A study was performed in laying hens where fennel (*Foeniculum vulgare*) at 0, 10, and 20 g/kg were used to decrease harmful effects of heat stress and it resulted that malondialdehyde and egg carbonyl contents were reduced along with egg triglyceride and yolk cholesterol contents (Gharaghani et al., 2015).

Herbal mixture

In a study, extracts of *Phyllanthus emblica, Tribulus terrestris, Withania somnifera, Ocimum sanctum Asparagas racemosus, Mangifera indica,* and *Glycrrhiza glabra* were mixed and used in broilers under heat stress and it resulted in a significant increase in body weight and feed intake. Moreover, free radical formation, blood urea nitrogen, serum cholesterol, and glucose level were decreased significantly in treatment groups as compared to control at 42 days of age (Rao et al., 2021).

African moringa

African moringa (*Moringa stenopetala)* leaf meal was used in broilers and layers kept in a high-temperature environment and it resulted that 2% supplementation of it improved egg yolk color and there was no significant effect on egg and meat quality (Tamiru et al., 2020).

Lycopene

Lycopene is a carotenoid that is being found in tomatoes (*Solanum lycopersicum*) and it has shown anti-oxidative, anti-inflammatory activities along with improved productivity and feed efficiency, and better broiler meat and egg quality (Arain et al., 2017). Similarly in another study in laying hens, lycopene as 20 mg/kg of the diet has shown a decrease in lipid peroxidation and increase in egg yolk color along with mineral and vitamin levels (An et al., 2019).

Licorice

In a study, Licorice (*Glycyrrhiza glabra*) was used in egg-laying quails under heat stress and it resulted in a reduction of egg yolk cholesterol and total lipids in licorice fed groups at 500 mg as compared to the control. Moreover, total serum cholesterol, low-density lipoproteins, triglycerides, and total serum lipids were decreased significantly in treatment groups as compared to control (Dosoky et al., 2021).

Willow

Willow (*Salix*) bark has been used in poultry birds to alleviate the negative impact of heat stress on birds' health and production because of the important source of flavonoids, tannins, salicin, and glucosides of saligenin (Saracila et al., 2021). Organic acids and essential oils are safe and have been approved by European Union for supplementation in animal feeding as anti-oxidative, antimicrobial, immune stimulators, and stress relieving additives (Doneria et al., 2020).

Syrian oregano

In a study, Syrian oregano (*Origanum syriacum*) oil and Avilamycin, an antibiotic, effects were compared in broilers under heat stress for 42 days and the results showed no significant difference between the effects of the 600 mg/kg *Origanum syricaum* and avilamycin as compared to the control and it has shown improvement in production and immune status of the birds under heat stress (Tekce et al., 2021).

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Garlic

Individual and combined effects of probiotic, garlic powder, citric acid was evaluated in broiler chicks under chronic heat stress. It resulted in improvement of productivity and feed efficiency, immunity, intestinal microbial population, and intestinal morphometric characters in treatment groups as compared to the control (Elbaz et al., 2021).

Thyme

In a study on rabbits, thyme leave powder was used for 90 days to minimize the deleterious effects of heat stress and it resulted in a significant increase in the feed intake, body weight gain, liver and kidney functionality, improved testosterone and semen parameters in all treatment groups as compared to the control and particularly for 16 g/kg diet supplementation of the thyme leave powder the results were highest for all the above parameters (Ahmed et al., 2020). In another study, thyme oil as 150, 200 mg/kg of diet in broilers under heat stress has resulted in a significant increase in weight gains, immunity, and reduced oxidative stress biomarkers (Khafar et al., 2019).

Onion

Onion powder as 2.5 kg/ton of feed and 2.5% onion extract in drinking water was used for broiler chicks under heat stress for 42 days and the results showed an increase in production and feed intake of the chicks, immunity, and heat tolerance as compared to control (Al-Ramamneh, 2018).

Grade seeds

In a study on the broiler, grape seed extract and vitamin C was supplemented for 42 days to cope with chronic heat stress and it resulted that 300 mg/kg grape seed extract caused a significant increase in body weight gain, decrease glucose, cholesterol, triglycerides and low-density lipoproteins in serum of the chicks of treatment groups as compared to the control (Hajati et al., 2015).

Saffron

Saffron (*Crocus sativus*) petal extract 300, 500, and 700 mg/kg of diet was used in broiler chicks for 42 days under heat stress and it resulted in a significant increase in feed intake and body weight gain, glutathione peroxidase, and superoxide dismutase activities and significant decrease of serum cholesterol, uric acid and malondialdehyde in treatment groups as compared to the control (Hosseini-Vashan and Piray, 2021).

Sweet wormwood

Sweet wormwood (*Artemisia annua*) was used in a study on broilers under heat stress to evaluate its antioxidant potential and relative meat quality parameters and it resulted in a significant increase of redness and energy status of breast muscles and decreased drip loss, reactive oxygen species production and the recommended level of use was 1-1.25 g/kg of diet (Wan et al., 2018).

Tulsi leaf and fenugreek seed

In a study, tulsi (*Ocimum sanctum*) leaf powder and fenugreek (*Trigonella foenum-graecum*) seed powder was used in broilers and the results showed that under a high level of temperature during experimentation the feed cost was not significantly changed but the production was improved in treatment groups as compared to the control (Prajapat et al., 2020).

Resveratrol (Red grapes)

Resveratrol obtained from red grapes was supplemented to layers under heat stress at 0, 200, 400, and 600 mg/kg of the feed and it resulted in improved productivity and humoral immunity and reduced serum malondialdehyde and gene expression of heat shock proteins (Liu et al., 2014). Similarly, ducks were supplemented with resveratrol under acute heat stress exposure and it resulted in increased villus heath to crypt depth ratio, a higher number of goblet cells, increased tight junction proteins and reduced gastrointestinal artifacts, reduced gene expression of heat shock proteins (Yang et al., 2021). Similarly in another study on broilers, resveratrol supplementation has shown an increase in activity of superoxide dismutase and glutathione peroxidase and reduction in serum and meat malondialdehyde (He et al., 2019).

Green tea

Catechin extracted from green tea was supplemented to broilers under heat stress as 300 and 600 mg/kg of the feed and it resulted in a significant increase in weight gain and feed intake, enzymatic activities and immune response, and reduction in serum cholesterol as compared to control (Xue et al., 2017). Similarly in quails under heat stress catechin supplementation has resulted in increased feed intake and egg numbers and better antioxidant profile (Sahin et al., 2010).

Black cumin seeds

Black seeds (*Nigella sativa*) supplementation as 1-2% in broilers has increased weight gain and meat quality, reduced oxidation, and serum corticosterone levels (El-Shoukary et al., 2014).

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Rosemary

Rosemary powder supplementation as 0.4% in broilers under heat stress has shown an increase in weight gain and feed intake (Petričević et al., 2018). Similarly, rosemary extracts in broilers under heat stress have resulted in improved weight gains, reduced serum malondialdehyde, and decreased gene expression for heat shock proteins (Tang et al., 2018). Similarly, many studies have been done and showed that dietary manipulations are very beneficial in poultry production.

CONCLUSION

Due to environmental risks and global warming, heat stress is the prevailing menace to the poultry industry which should be handled to prevent economic loss and improve bird welfare. Management strategies are not sufficient to decrease deleterious effects. Therefore, for optimal upgrading of poultry production under stressful conditions and improving their health and immunity valuable nutritional adaptation should be used. Dietary management can be actual in incapacitating the harmful influences of heat stress and can increase production and welfare in terms of improved broilers weight gains and egg-laying capacity, better egg and meat quality, reduce oxidative stress, and enhance immunity. Nevertheless, more studies are required to explore the mutual outcomes of more or less of the above-mentioned nutritional plans, either single-handedly or in combination with management strategies, to decrease the damaging effects of heat stress and to observe their efficiency and economical value in poultry husbandry.

DECLARATIONS

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Authors' contribution

Syed Rizwan Ali contributed for the write up of the study design and the final manuscript. Ibrahim Sadi critically revised the manuscript for important academic contents.

Conflict of interests

The authors have not declared any conflict of interests.

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