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REVIEW ARTICLE

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Impact of selected antioxidant vitamins (Vitamin A, E and C) and micro minerals (Zn, Se) on the antioxidant status and performance under high environmental temperature in poultry. A review

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ABSTRACT
The aim of this review was to discuss the effects of heat stress on antioxidant status and performance in poultry. Based on the recent literature data, the following conclusions can be drawn: (1) Heat stress can cause harmful effects in birds (e.g. increased ROS (Reactive Oxygen Spices) production and lipid peroxidation, decreased vitamin concentrations, changed enzyme activity) and consequently in production parameters (e.g. feed intake, body weight and feed conversion ratio). (2) Diets containing high Vitamin A (9000–15 000 IU/kg diet), E (150–500 mg/kg diet), C (150–500 mg/kg diet) and Zn (30/60 mg/kg diet) and Se (0.1–1 mg/kg diet) can decrease the amounts of free radicals, support enzyme activity and prevent lipid peroxidation in poultry. (3) Application of antioxidant vitamins and micro minerals in poultry nutrition is more effective in combination than separately.

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Introduction

Climate change can cause severe damage in the production of food of animal origin for human consumption. Heat stress is one of the prominent environmental elements which can influence meat quality (Lara & Rostagno, 2013; Wang et al., 2017). The high environmental temperature may cause reduced performance and increased mortality. A solution for the prevention of heat stress includes biological (e.g. genetics, thermal conditioning, nutrition) (Daghir, 2008; Lin et al., 2006) or keeping technology devices (e.g. air conditioning, intensive ventilation, humidification) (Armstrong, 1994; Wolfenson et al., 2001) However, housing methods are expensive and not always adequate. Therefore, reducing the biochemical and physiological negative effects of heat stress with different nutritional tools is one of the primary interests for the economical production of food produced from animals. Generally, feed additives with direct or indirect antioxidant effects can be used: vitamins alone or with micro minerals. According to several studies (Daghir, 2009; Gous & Morris, 2005; Lin et al., 2006; Mujahid, 2011; Sahin et al., 2009), we selected the primary vitamins and micro minerals which are most commonly used in poultry nutrition during times of heat stress and we also describe their significance. Therefore the aim of the present study based on relevant researches is to outline the connection between different antioxidant nutritional compounds on the antioxidant status and performance of poultry under heat stress.

Supporting the balance between redox homeostasis: the three level antioxidant system

Based on the literature data, it is known that heat stress can cause severe damage to organisms. There can be biochemical and physiological changes: e.g. altered antioxidant status, increased free radical formation and stress hormone appearance, upset homeostasis (acid/base balance) and decreased resistance capacity (Akbarian et al., 2015; Li, 2011; Yang et al., 2010).

The antioxidant defence system plays a key role in the reduction of the heat stress generated lipid peroxidation process (Altan et al., 2003; Lin et al., 2006). In the acute phase (heat stress), the antioxidant-prooxidant balance is upset, with the balance shifted to the prooxidant phase. To re-establish this balance, the antioxidant defence system will be activated. The elimination of

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the free radicals activates the three level antioxidant system (Irshad & Chaudhuri, 2002; Min et al., 2018).

This first level (direct enzymatic pathway) includes the neutralization of free radicals by enzymes. The principal enzymes which regulate this are superoxide dismutase (SOD), glutathione peroxidase (GPx) and catalase (CAT) (Conner & Grisham, 1996; Jeeva et al., 2015). The second level includes the detoxification and regeneration reactions of the small molecule antioxidants working at the same time with the first level: Vitamin A, E, C and glutathione (Conner & Grisham, 1996; Irshad & Chaudhuri, 2002). The third level is activated when damaged systems (proteins, DNA) have to be repaired and/or removed from the cells by chaperones and DNA-repair enzymes (Irshad & Chaudhuri, 2002).

Impact of heat stress on the antioxidant system in poultry

Poultry is more sensitive to heat stress than other domestic animals, because they do not have sweat glands, their metabolism is rapid and they have high body temperatures. Increased environmental temperature caused increased lipid peroxidation (in addition induced the formation of malondialdehyde (MDA), which is an indicator for lipid peroxidation). Therefore, the antioxidant defence system is altered (Altan et al., 2003; Chauhan et al., 2014; Costantini et al., 2009; Lara & Rostagno, 2013).

In general, it can be concluded that a large amount of ROS causes disruption of mitochondrial function, increased lipid peroxidation, decreased vitamin concentrations, induces stress gene expression, leads to dysfunction in antioxidant enzymes and also causes DNA damage. According to Yang et al (2010), who studied short term heat stress (35°C for 3 h/day) in broilers, the activity of the mitochondrial respiratory chain is reduced by heat stress, which leads to over-production of ROS. This resulted in lipid peroxidation and oxidative stress in the birds. Lipid peroxidation and SOD activity was measured in broilers under heat stress (32°C for 6 h/day) in another study (Lin et al., 2006). The results showed that high temperature disturbed the equilibrium between the synthesis and catabolism of ROS production. GSH-Px and SOD activity increased under heat stress (34°C 5 h/day from d28 to d38) (Akbarian et al., 2015). When SOD level increased, manganese (Mn) and copper (Cu) level increased also. Zink (Zn) level which in addition of increased SOD also altered Cu/Zn ratio. GPx level decreases Selenium (Se) ROS level and also the CAT activity is decreased. ROS production reduces Vitamin A and E level. Vitamin C concentration decreased under heat stress in poultry (Kutlu & Forbes, 1993). It has been reported that heat stress increases Zn mobilization from tissues and thus may cause marginal Zn deficiency and increase requirements (Anderson, 1994). ROS has effects on gene expression: heat stress proteins will be formed.

Birds can consume dietary antioxidants or upregulate their endogenous antioxidant systems to mitigate the effects of the increased amount of ROS (Cooper-Mullin & McWilliams, 2016).

Antioxidant vitamins and micro element supplementation in poultry diets under heat stress

Several methods (biological or technological) are available to alleviate the negative effects of heat stress in poultry. As it is usually more expensive to cool buildings, most methods focus on nutritional tools. Different nutritional strategies are known to reduce the negative effects of heat stress, e.g. decreased protein level and different amino acid composition in the diet, increased fat intake, electrolytes in water, probiotics and betaine supplementation (Balnave & Brake, 2005; Daghir, 2009; Gous & Morris, 2005; Lin et al., 2006). The high environmental temperature decrease the concentrations of vitamins and micro minerals in serum and increase the excretion (Khan et al., 2012); therefore, supplementation of direct or indirect antioxidant compounds (e.g. vitamins and micro nutrients) at higher levels is commonly recommended (Yun et al., 2012). These additives support mechanisms against lipid peroxidation, improve immune status and performance.

Vitamin A

Based on the studies using Vitamin A supplementation (15 000 IU/kg diet) in poultry under heat stress (32 and 34°C for 24 h), it can be concluded that performance improved. Feed intake (FI) and weight gain (WG) increased, feed conversion ratio (FCR) decreased. Kucuk et al. (2003), Sahin et al. (2001c) and Lin et al. (2002) found that Vitamin A (9 000 IU/kg diet) increased FI, laying rate and egg weight in layers under heat stress (31.5°C for 24 h). Vitamin A can act as an effective radical-tapping antioxidant and quencher of singlet oxygen (Sahin et al., 2001c; Sahin et al., 2002b) (Table 1).

Vitamin C

Although chickens are known to synthesize ascorbic acid, increased supplementation has proved to have beneficial effects in broilers reared under heat stress (Mahmoud et al., 2004). Ascorbic acid is actively transported into tissues. Their requirements increase under

Table 1. Effects of Vitamin A supplementation under heat stress based on different studies.

Author(s)	Spices	Duration of the study	Environmental temperature	Amount of Vitamin A supplementation (/kg diet)	Effects on performance	Other effects
Kucuk et al. (2003)	broiler	1–42 d	34°C (24 h/day)	15 000 IU/kg	↑ BW, FI ↓FCR	↓MDA
Sahin et al. (2001b)	broiler	21–42 d	32°C (24 h/day)	15 000 IU/kg	↑ FI, WG ⦰ FCR	
Lin et al. (2002)	layers	56–61 week	31.5°C (24 h/day)	9 000 IU/kg	↑FI, laying rate, egg weight	

BW = body weight (kg).
FI = feed intake (kg).
FCR = feed conversion ratio (kg gain /kg feed).
MDA = malondialdehyde concentration in blood.
↑ increase.
↓ decrease.
⦰ no change.

heat stress. Therefore, it is suggested that the bird's synthesizing capacity may become inefficient by reducing plasma ascorbic acid concentrations under high environmental conditions. According to different studies, ascorbic acid supplementation (200 mg/kg feed) caused significant increases in plasma ascorbic acid levels (Kumar et al., 2017; Mahmoud et al., 2004) in broilers under heat stress.

Literature data on the effect on the performance of poultry with different Vitamin C supplementation is presented in Table 2.

Production parameters of broilers improved under various high temperature conditions with Vitamin C supplementation (150–500 mg/kg diet) (Attia et al., 2011; Farooqi et al., 2005; Kutlu & Forbes, 1993; Mckee et al., 1997; Sahin et al, 2001a; Sahin et al., 2002a) which can be explained by its function of scavenging free radicals. Other results show that heat stress decreases the production of layers. However, ascorbic acid supplementation affected egg production, egg weight and egg mass in layers (Ajakaiye et al., 2011; Asli et al., 2007).

Vitamin E

Results of different studies of various Vitamin E supplementation on the performance of poultry are presented in Table 3.

Vitamin E is known as the first line defence against lipid peroxidation caused by heat stress. It has free radical quenching activity and attacks free radicals in

Table 2. Effects of Vitamin C supplementation under heat stress based on different studies.

Author(s)	Spices	Duration of the study	Environmental temperature	Amount of Vitamin C supplementation (/kg diet)	Effects on performance	Other effects
Ajakaiye et al. (2011)	layers	39 week	35.9°C (24 h/day)	150 mg	↑egg weight	
Asli et al. (2007)	layers	62 week	33 ± 2°C (4 h/day)	200 mg	↑egg production, egg mass ↓FCR	
Attia et al. (2011)	broiler	21–84 d	38°C (4 h/day)	250 mg	↑FI, protein digestibility ↓FCR	
Farooqi et al. (2005)	broiler	10–32 d	35°C (24 h for first week) 32.5°C (24 h for second week)	400 mg (20 g/5 kg)	↑BW, FI	
Kutlu & Forbes (1993)	broiler	1–28 d	36°C (6-10 h/day)	250 mg	↑BW, FI ↓FCR	
Mahmound et al. (2003)	broiler	1–42 d	30°C (3.5 h/ for 3 days)	500 mg		↑plasma Aa concentration ↓Hsp70 expression
Mckee et al. (1997)	broiler	8–17 d	34°C (24 h/day)	150 mg	↑WG ⦰ FI, FCR	
Kumar et al. (2017)	broiler	1–45 d	37 ± 5°C	200 mg		↑plasma Aa concentration
Sahin et al. (2003)	broiler	1–42 d	32°C (24 h)	250 mg/kg diet	↑BW, FI ↓FCR	
Sahin et al. (2002a)	Japanese quails	10–40 d	34°C (24 h)	200 mg/kg diet	↑BW, FI ↓FCR	

BW = body weight (kg).
FI = feed intake (kg).
FCR = feed conversion ratio (kg gain /kg feed).
MDA = malondialdehyde concentration in blood.
Aa.= ascorbic acid.
↑ increase.
↓ decrease.
⦰ no change.

Table 3. Effects of Vitamin E supplementation under heat stress based on different studies.

Author(s)	Spices	Duration of the study	Environmental temperature	Amount of Vitamin E supplementation (/kg diet)	Effects on performance	Other effects
Ajakaiye et al. (2011)	layer	39 w	35.9°C (24 h/day)	150 mg	↑egg weight	
Asli et al. (2007)	layer	62 w	33 ± 2°C (5 h/day)	200 mg	↑egg production, egg mass ↓FCR	
Habibian et al. (2014)	broiler	1–27 d	37 °C (8 h/day)	125 mg	⦰ BW, FI ↓FCR	
Harsini et al. (2012)	broiler	1–49 d	37°C (8 h/day)	250 mg	↑BW, FI	↑zinc concentration in serum
Hashizawa et al. (2013)	broiler	28–38 d	30°C (24 h/day)	200 mg	↑BW, FI ⦰ FCR	
Maini et al. (2007)	broiler	1–49 d	38.6 ± 1.3°C (24 h/day)	200 mg		↓MDA, GSH, CAT, SOD, GR
Sahin et al. (2001b)	broiler	21–42 d	32°C (24 h/day)	250 mg	↑FI,WG ⦰ FCR	
Sahin et al. (2006)	Japanese quail	10–42 d	34°C (8 h/day)	250 mg	↑FI,WG ↓FCR	
Sahin et al. (2002a)	Japanese quails	10–40 d	34°C (24 h/day)	500 mg	↑BW, FI ↓FCR	
Sahin et al. (2002b)	Japanese quail	10–40 d	34°C (24 h/day)	250 mg	↑FI, WG ↓FCR	↑Vitamin E,A concentration in serum ↓ MDA

BW = body weight (kg).
FI = feed intake (kg).
FCR = feed conversion ratio (kg gain /kg feed).
MDA = malondialdehyde concentration in blood.
GSH = reduced glutathione concentration in blood.
GPx = glutathione peroxidase concentration in blood.
GR = glutathione reductase concentration in blood.
SOD = superoxide dismutase concentration in blood.
CAT = catalase concentration in blood.
↑ increase.
↓ decrease.
⦰ no change.

the early stages. In the following studies, which can be seen in Table 3**,** lipid peroxidation decreased and the enzymatic and non-enzymatic antioxidant systems improved (Harsini et al., 2012; Maini et al. 2007; Sahin et al., 2002b). Heat stress also decreased the production parameters which can be improved with Vitamin E supplementation (150–500 mg/ kg diet). The results show that feed intake (FI), body weight (BW) and feed conversion ratio (FCR) improved in poultry (Habibian et al., 2014; Harsini et al., 2012; Hashizawa et al., 2013; Sahin et al., 2001b) and, in addition, the nutrient digestibility also improved in Japanese quail (Sahin et al., 2001a, 2001b; Sahin et al., 2002a). Egg production, egg weight and egg mass in layers were also positively affected with Vitamin E supplementation (Ajakaiye et al., 2011; Asli et al., 2007).

Zinc

Table 4 presents the literature data about zinc supplementation in poultry under heat stress.

Zinc supplementation has positive effects on the performance and antioxidant status of birds (Brandae-Neto et al., 1995; Roberson & Edwards, 1994). Zinc protects pancreatic tissue against oxidative damage, may improve nutrient digestibility and therefore improve production parameters. Studies noted increased FI, WG and decreased FCR in broilers and quails (Kucuk et al., 2003; Kucuk, 2008; Sahin et al., 2003; Sahin et al., 2006; Sahin et al., 2009). Zinc may play an important role in suppressing free radicals because it works as a cofactor (Cu/Zn-SOD) and also inhibits NADPH-dependent lipid peroxidation (Prasad & Kucuk, 2002) and thus improved antioxidant status: increased serum Vitamin C and E concentration (Sahin et al., 2006) and decreased MDA level (Kucuk et al., 2003; Kucuk, 2008).

Selenium

It can be seen in Table 5 that heat stress induced oxidative stress can be partially ameliorated by supplementing selenium in poultry due to its cofactor properties.

Performance (Harsini et al., 2012; Niu et al., 2009; Sahin et al., 2001b) and antioxidant status (Harsini et al., 2012; Mahmound & Edens, 2003; Sahin et al., 2001b) were both improved. It is suggested that the metabolic role of selenium is to protect cells against oxidation and tissue damage. Rapid oxidation of GSH to GSSG is necessary to compensate the heat stress caused ROS production. However, the selenium supplementation increases the level of available NADPH to promote the activation of glutathione reductase, leading to increased GSSG reduction

Table 4. Effects of zinc supplementation under heat stress based on different studies.

Author(s)	Spices	Duration of the study	Environmental temperature	Amount of zinc supplementation (/kg diet)	Effects on performance	Other effects
Sahin et al. (2005)	Japanese quail	10–42 d	34°C (8 h/day)	30 or 60 mg	↑FI, WG ↓FCR	↑Vitamin C concentration in serum ↓MDA
Kucuk et al. (2003)	broiler	1–42 d	34°C (24 h/day)	30 mg	↑BW, FI ↓FCR	↓MDA
Kucuk, 2008	Japanese quail	10–40 d	35°C (8 h/day)	30 mg	↑FI, WG ↓FCR	↓ MDA
Sahin et al. (2006)	Japanese quail	10–42 d	34°C (8 h/day)	30 mg	↑FI, WG ↓FCR	
Sahin & Kucuk (2003b)	Japanese quail	52–73 d	34°C (24 h/day)	30 or 60 mg	↑FI, egg production ↓FCR	

BW = body weight (kg).
FI = feed intake (kg).
FCR = feed conversion ratio (kg gain /kg feed).
MDA = malondialdehyde concentration in blood.
↑ increase.
↓ decrease.
⦰ no change.

Table 5. Effects of selenium supplementation under heat stress based on different studies.

Author(s)	Spices	Duration of the study	Environmental temperature	Amount of selenium supplementation (/kg diet)	Effects on performance	Other effects
Harsini et al. (2012)	broiler	1–49 d	37°C (8 h/day)	1 mg	↑ BW, FI ↓FCR	⦰Zn concentration ↑GPx
Mahmound & Edens (2003)	broiler	1–28 d	33°C (24 h/day for 4 weeks)	0.46 ppm		↑GSH, GSSG,GPx, GPx/GR ratio
Liao et al. (2012)	broiler	22–42 d	33 ± 1°C (8 h/day) 27 ± 1°C (8 h/day)	0.30 mg	↑FI	↑GPx, selenium concentration
Niu et al. (2009)	broilers	1–42 d	38°C (5 h/day)	0.2 mg	⦰ FI, WG ↓FCR	
Sahin et al. (2002b)	Japanese quail	10–40 d	34°C (24 h/day)	0.1 / 0.2 mg	↑FI, WG ↓FCR	↑serum Vitamin E, A, zinc ↓MDA

BW = body weight (kg).
FI = feed intake (kg).
FCR = feed conversion ratio (kg gain /kg feed).
MDA = malondialdehyde concentration in blood.
GSSG = glutathione disulphide concentration in blood.
GSH = reduced glutathione concentration in blood.
GPx = glutathione peroxidase concentration in blood.
GR = glutathione reductase concentration in blood.
↑ increase.
↓ decrease.
⦰ no change.

to GSH (Suchý et al., 2014). Therefore, selenium supplementation effected GPx activity and GPx/GSH ratio.

Interactions between vitamins and micro minerals

Based on the studies done with separated supplementation of Vitamin A (9000–15000 IU/kg diet), Vitamin E (150–500 mg/kg diet), Vitamin C (150–500 mg/kg diet), zinc (30 or 60 mg/kg diet) and selenium (0.1–1 mg/kg diet) it can be concluded that performance (FI, WG, FCR) and antioxidant status improved in poultry under heat stress. The antioxidant potential has been reported to be more efficient and important in combination than single antioxidant nutrients (Gallo-Torres, 1980). The latest research studies show that vitamin and/or minerals used in combination have more improved effects than they have separately on the antioxidant status and performance of poultry under heat stress. Literature data of vitamin and mineral supplementation used together in poultry nutrition can be seen in Table 6.

Vitamin C (200 mg/kg diet) and *Vitamin E* (250 mg/kg diet) supplementation in combination improved performance (BW and FCR) and meat quality in quails under heat stress (Sahin and Kucuk, 2001a). Both vitamins had beneficial effects on egg quality under heat stressed layers (Ajakaiye et al., 2011). Vitamin C (200 mg/kg diet) and E (100 mg/kg diet) supplementation increased the total antioxidant capacity, SOD, GPx enzyme activities in broilers under oxidative stress (El-Senousey et al., 2017). Vitamin C interacts with tocopheroxyl radical and regenerate the reduced tocopherol. A higher dietary level of Vitamin C increased the tissue and plasma concentrations of Vitamin E.

Table 6. Effects of vitamin and mineral interaction under heat stress based on different studies.

Supplementation	Author(s)	Spices	Duration of the study	Environmental temperature	Amount of supplementation	Effects on performance	Other effects
Vitamin C+ E	Sahin et al. (2002)	Japanese quails	10–40 d	34°C (24 h/day)	200 mg Vit. C +250 mg Vit. E	↑BW ↓FCR	
Vitamin C+ E	Ajakaiye et al. (2011)	Layer	39 w	35.9°C (24 h/day)	150 mg Vit C + 150 mg Vit.E	↑egg weight	
Vitamin A + E	Sahin et al. (2001b)	broiler	21–42 d	32°C (24 h/day)	15 000 IU/kg Vit. A + 250 mg Vit E	↑FI, WG ⦰ FCR	
Vitamin A+ zinc	Kucuk et al. (2003)	broiler	1–42 d	34°C (24 h/day)	15 000 IU Vit A + 30 mg	↓FCR ↑BW, FI	↓MDA
Vitamin E+ zinc	Sahin et al. (2006)	Japanese quail	10–42	34°C (8 h/day)	30 mg Vit E + 250 mg Zn	↑FI, WG ↓FCR	
Vitamin E+ zinc	Hosseini-Mansoub et al. (2010)	broilers	10–42	35°C (24 h/day)	100 mg Vit E + 50 mg zinc	⦰ FCR ↑BW, FI	↓MDA
Vitamin E+ selenium	Harsini et al. (2012)	broiler	1–49 d	37°C (8 h/day)	0.5 mg Se + 152 mg Vit.E	↑BW ↓FCR	↓MDA ↑SOD
Vitamin E+ selenium	Habibian et al. (2014)	broiler	21–49 d	37°C (8 h/day)	0.5 mg Se +250 mg Vit. E	⦰ BW, FI ↓FCR	↑antibody response

BW = body weight (kg).
FI = feed intake (kg).
FCR = feed conversion ratio (kg gain /kg feed).
MDA = malondialdehyde concentration in blood.
SOD = superoxide dismutase concentration in blood.
↑ increase.
↓ decrease.

Vitamin A (15 000IU retinol/kg diet) and *Vitamin E* (250 mg α-tocopherol-acetate/kg diet) supplementation in combination improved FI and WG in broilers under heat stress (32°C) and also decreased lipid peroxidation and increased serum zinc concentrations (Sahin et al., 2001c, 2002b). Vitamin E has an important effect on the absorption and utilization of carotenoids: Vitamin E can protect the double bonds of carotene from oxidation.

Vitamin A (15 000 IU retinol/ kg diet) and *Zn* (30 mg/kg diet) has a proved connection: Zinc plays a role in Vitamin A transport mediated protein synthesis and in the oxidative alteration of retinol to retinal (zinc dependent retinol dehydrogenase enzyme) (Christian & West, 1998) Vitamin A supports the utilization and perhaps the transport of zinc and also the absorption in ileum mucosa in broilers (Christian & West, 1998); however, the absorption and transport of Vitamin A is affected by zinc status (Berzin & Bauman, 1987). Dietary supplementation of Vitamin A and zinc in combination had additive effects therefore increased the FI and BW and decreased FCR and lipid peroxidation of broilers under heat stress (Kucuk et al., 2003).

Vitamin E (100 mg/kg diet) and *Zn* (50 mg/kg diet) combination in diet increase the production parameters (FI, BW) and decreased FCR and lipid peroxidation in broilers under heat stress (Hosseini-Mansoub et al. 2010; Sahin et al, 2006). It is suggested that Vitamin E causes zinc release into the serum, thus increasing the serum zinc concentration (Sahin et al., 2006).

Vitamin E (152, 250 mg/kg diet) and *Se* (0.5 mg/kg diet) in combination decreased FCR and lipid peroxidation, increased enzyme activity (GPx, SOD) therefore indicated oxidative stability in broilers under heat stress (Habibian et al., 2014; Harsini et al., 2012). Selenium increased the intestinal Vitamin E absorption and also has a protective effect on pancreatic tissue against oxidative damage.

Conclusions and suggestions

The following conclusions can be drawn from the present data review:

- Heat stress can cause harmful effects in birds (e.g. disruption of mitochondrial function, increased ROS production and lipid peroxidation, decreased vitamin concentrations, changed enzyme activity) and consequently in production parameters (e.g. feed intake, body weight and feed conversion ratio). However, the three level antioxidant defence system plays a very important role in the reduction of the heat stress generated lipid peroxidation process.
- Vitamin A, E and C are capable of reacting with free radicals, thereby reducing their amounts and preventing lipid peroxidation in the birds. Micro minerals (Zn, Se) are not directly capable of preventing or reducing ROS formation. However, they are essential cofactors for those enzymes which have the attribute of reacting with free radicals. Supplementation is necessary for preventing the negative effects of heat stress.
- Increased amount (above requirements) of vitamins and micro minerals should be supplemented to poultry diets. Diets containing high vitamin A (9000–15 000 IU/kg diet), Vitamin E (150–500 mg/kg diet),

Vitamin C (150–500 mg/kg diet) and Zn (30/60 mg/kg diet) and Se (0.1–1 mg/kg diet) can decrease the amounts of free radicals, support enzyme activity and improve performance in poultry.

- Antioxidant potential of vitamins and micro minerals is more efficient in combination under heat stress in poultry nutrition. The latest research studies show that interactions have more improved effects on the antioxidant status and performance of poultry under heat stress.
- It is important to have more comprehensive knowledge about the members of the antioxidant system under heat stress. Therefore, further systematic studies should be carried out to learn how the system can be supported with other nutritional tools, to better understand the interaction effects between supplements and how they influence production parameters. A 'special summer' premix must be developed to reduce the harmful effects of high ambient temperature (heat shock).

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No potential conflict of interest was reported by the authors.

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