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NATURAL ALTERNATIVES TO MITIGATE THE EFFECTS OF HEAT STRESS IN BROILER CHICKENS

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Abstract

Heat stress is one of the main challenges facing modern broiler production, having a significant impact on it, thus leading to reduced growth performance, the onset of physiological dysfunctions, and disruption of the oxidative balance. In recent years, numerous studies have been conducted on the use of natural feed additives as a sustainable alternative to mitigate the adverse effects of heat stress. This review article provides a comparative analysis of the main natural bioactive compounds used in the modern poultry industry (antioxidant molecules, plant-derived phytochemicals, and essential oils), highlighting their role in increasing heat tolerance, maintaining intestinal integrity, and supporting physiological homeostasis in broiler chickens. The results presented in the literature, highlight the fact that these natural alternatives can reduce oxidative stress, stimulate feed conversion performance, and partially restore productive performance without the disadvantages associated with the use of antibiotics. Summarizing the analysed information, it can be concluded that the rational integration of natural bioactive compounds into effective and sustainable nutritional programs supports both the resilience and productivity of broiler chickens exposed to heat stress conditions.

Key words*: broiler chicken, heat stress, nutrition, bioactive compounds.*

INTRODUCTION

Heat stress (HS) is defined as a physiological state in which animals, especially birds, cannot maintain a balance between internal heat production and the inability to dissipate it into the environment (Akbarian et al., 2016; Ahmad et al., 2022; Apalowo et al., 2024).

Birds are particularly sensitive to heat stress due to specific physiological and anatomical characteristics, such as full body feather coverage, which acts as a thermal insulator, reducing the efficiency of heat loss through convection and radiation, favouring the accumulation of body heat (Vandana et al., 2021; Emami et al., 2021; Nawaz et al., 2021; Ahmad et al., 2022; Apalowo et al., 2024). Another peculiarity is the lack of sweat glands, which severely limits one of the most effective physiological mechanisms of thermoregulation, namely sweat evaporation at skin level, thus relying on alternative mechanisms such as behavioural changes, peripheral vasodilation, and polypnea (Vandana et al., 2021; Emami et al., 2021; Apalowo et al., 2024; Insawake et al., 2025).

Heat stress is the result of the interaction of several environmental factors, such as high ambient temperature, humidity (which hinders cooling through evaporation), solar radiation, and air movement (Lara et al., 2013; Akbarian et al., 2016; Ahmad et al., 2022; Olayiwola & Adedokun, 2025).

Physiologically, birds are homeothermic organisms capable of maintaining a constant body temperature through a complex thermoregulatory system, but its efficiency critically depends on the ambient environment in which birds can maintain an average internal temperature of 41-42°C without the need for additional energy expenditure for thermoregulation, which is between 18-24°C (Apalowo et al., 2024; Oke et al., 2024). When the ambient temperature exceeds the critical threshold of 25-28°C, physiological stress reactions are triggered, leading to a decrease in feed intake and an increase in water consumption, with a negative effect on body weight and feed conversion rate (Wasti et al., 2020; Ahmad et al., 2022; Li & Wang, 2024).

The scientific literature classifies heat stress according to the temporal profile of exposure into acute heat stress and chronic heat stress, each type triggering different physiological and molecular responses (Oluwagbenga & Fraley, 2023; Moise et al., 2024).

Acute heat stress is defined by short-term exposure, from 1 to 24 hours to a sudden and rapid increase in ambient temperature (27°-38°C) (Ahmad et al., 2022; Oluwagbenga & Fraley, 2023). The initial phase of acute stress is characterized by an acceleration of mitochondrial substrate oxidation and electron transport chain activity, thus generating an exaggerated production of reactive oxygen species (ROS). At this stage, the antioxidant enzymes (superoxide dismutase, SOD; catalase, CAT; glutathione peroxidase GPx), which form the cellular defence mechanism, are often rapidly activated to neutralize free radicals (Akbarian et al., 2016).

Chronic heat stress is prolonged exposure to high temperatures for 7 days or more (Vandana et al., 2021; Ahmad et al., 2022; Oluwagbenga & Fraley, 2023) and can be subdivided into two types: cyclic and constant. Cyclical heat stress is characterized by limited exposure to high temperatures during the day, followed by periods of comfortable temperatures, allowing for partial recovery, while constant heat stress involves exposing birds to constant heat without periods of cooling. The chronic form of exposure to high temperatures is characterized by a decrease in mitochondrial oxidative capacity and the depletion of antioxidant reserves in the body (vitamins A, C, E, and minerals such as Zn, Se), (Akbarian et al., 2016), which can influence overall enzyme activity and hormone levels, such as the T3 hormone (Gheorghe et al., 2022).

Phytogenic (phytobiotic or botanical) additives have gained particular importance in recent years, being integrated into feed rations for broiler chickens, identified as a natural, safe, and sustainable alternative to growth-promoting antibiotics, supporting consumers' growing interest and preference for poultry products obtained without drug residues.

The main advantages identified in the literature are: they do not cause the development of antibiotic resistance among pathogens (Rachwał & Gustaw, 2025); no residues in food products (Aminullah et al., 2025); multifunctional biological action, offering a wide range of benefits due to antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory properties that can improve intestinal barrier integrity, modulate immune response, and reduce oxidative stress (Obianwuna et al., 2024; Urban et al., 2024; Rachwał & Gustaw, 2025; Khatun et al., 2023), safety and reduced toxicity, being considered non-toxic, biodegradable, and environmentally friendly (Mandey & Sompie, 2021; Ivanova et al., 2024). Other benefits of introducing feed additives into the diet of heat-stressed broilers include stimulating digestibility (certain feed additives can improve the aroma and taste of feed by stimulating appetite and digestive enzyme secretion) (Custură et al., 2019; Abdelli et al 2021; Urban et al., 2024), as well as improving the quality of the final product, with the use of phytobiotics being associated with higher meat quality (better retention capacity, favourable amino acid and ketone profile) (Custură et al., 2012; Ruff et al., 2021; Michalczuk et al., 2024).

The purpose of this article is to provide an overview of the main classes of natural bioactive compounds used in broiler nutrition, with a focus on their chemical structure, classification, mechanisms of action, and relevance of their use in the context of heat stress.

MATERIALS AND METHODS

A systematic review of the literature was conducted using the main international scientific databases, Google Scholar, Web of Science, Scopus, ScienceDirect, ResearchGate, and PubMed. The search strategy used predefined keywords such as broiler, heat stress, oxidative stress, phytobiotics, bioactive compounds, natural feed additives, and was structured according to the year and type of publication. Following the application of predefined inclusion and exclusion criteria, 90 studies were identified as relevant and included in the final synthesis.

RESULTS AND DISCUSSIONS

Natural bioactive compounds, also known as phytogenics or phytobiotics, are a class of secondary metabolites synthesized by plants to protect themselves against pathogens and environmental stress. To date, over 5,000 such compounds have been identified in fruits, vegetables, cereals, legumes, nuts, and medicinal plants (Urban et al., 2024). The effectiveness of these compounds is due to their

multiple biological actions, which not only inhibit the proliferation of pathogens by destroying bacterial cell membranes, but also optimize gastrointestinal health by stimulating the secretion of digestive enzymes (Obianwuna et al., 2024). Phytobiotics are also essential in reducing the effects of heat stress, helping to reduce oxidative stress and regulate inflammatory responses, thus contributing to maintaining growth performance and meat quality (Greene et al., 2021; Iliopoulou et al., 2025).

Phytobiotics are derived from a variety of botanical sources and can be classified according to their origin into herbs, spices, essential oils, and oleoresins (Pashtetsky et al., 2020; Abdelli et al., 2021; Mandey et al., 2021). The classification of feed additives into these four categories reflects both their botanical origin, the part of the plant used, and the method of processing (Abdelli et al., 2021; Mahasneh, 2024; Aminullah et al., 2025; Papatsiros et al., 2022).

From a chemical point of view, phytobiotics are an extremely heterogeneous class, including major groups such as phenolic compounds and polyphenols, terpenes and terpenoids, alkaloids, saponins, glycosides, and polysaccharides (Panaite et al., 2019; Pashtetsky et al., 2020; Abdelli et al., 2021; Obianwuna et al., 2024; Urban et al., 2024; Rachwał & Gustaw, 2025).

Phenolic compounds, considered the main bioactive components of feed additives, represent one of the most important groups of secondary metabolites, defined by the presence of at least one hydroxyl (-OH) group directly attached to an aromatic ring (Rachwał & Gustaw, 2025). They are generally divided into two main categories, the first being simple phenolic compounds containing a single phenol unit, such as hydroxyphenols and dihydroxybenzenes, phenolic acids such as hydroxybenzoic acids (gallic acid), hydroxycinnamic acids (ferulic acid, caffeic acid, cinnamic acid) and coumarins (umbelliferone and scopoletin). The second main category is polyphenols, defined by the presence of two or more hydroxyl groups attached to an aromatic ring, classified into four major groups, flavonoids, stilbenes, lignans, and tannins, found in various parts of plants, such as leaves, bark, stem, roots, fruits, and flowers (Goel et al., 2025).

Mechanisms of action and biological activity

In poultry farming, phenolic compounds exert a wide range of beneficial effects on broiler chickens, especially under heat stress conditions, such as mitigating oxidative stress through molecular mechanisms, activating the nuclear factor erythroid 2-related factor 2 (Nrf2/ARE) molecular pathway (stimulation of the Nrf2 transcription factor, which migrates to the nucleus activating the genes responsible for the synthesis of endogenous antioxidant enzymes (superoxide dismutase, SOD; catalase, CAT; glutathione peroxidase GPx), facilitating the neutralization of free radicals before the initiation of lipid, protein, and DNA degradation processes) (Abd El-Hack et al., 2025; Madkour et al., 2025; Aminullah et al., 2025; Zhao et al., 2021) and inhibition of pro-oxidants by blocking pro-oxidant enzymes such as xanthine oxidase and by chelating transition metal ions (Fe^{2+}, Cu^{2+}), limiting the formation of extremely toxic hydroxyl radicals (Basiouni et al., 2023).

It also has anti-inflammatory and immune-regulating effects by suppressing nuclear factor kappa-b (NF-kB) activity and a decrease in pro-inflammatory cytokine levels, including IL-1β, IL-6, and tumour necrosis factor alpha (TNF-α), thereby reducing tissue damage induced by chronic inflammation (Madkour et al., 2025).

Studies conducted on broiler chickens subjected to heat stress (Table 1), have shown that the use of phenolic compounds in the diet acts on heat stress regulation mechanisms by:

- improving the physiological response to stress by reducing body temperature (Ruff et al., 2021), decreasing stress hormones (Oni et al., 2024), and improving biological indicators (Mohiti-Asli & Ghanaatparast-Rashti, 2017; Griela et al., 2021; Jimoh et al., 2022);
- protecting the intestinal barrier and modulating the microflora, intervening in reducing intestinal permeability (Ruff et al., 2021), balancing the microbiome (Saracila et al., 2021), improving morphology by increasing intestinal villi, optimizing nutrient absorption (Oni et al., 2024; Olayiwola & Adedokun, 2025);
- improving meat quality and slaughter parameters, directly influencing physicochemical properties, water retention

capacity, texture and composition, increasing aroma units (aromatic profile), as well as reducing defects (white streaks) in the breast (Chodkowska et al., 2022; Michalczuk et al., 2024);
- stimulating antibody production, increasing the ability to defend against infections (Mohiti-Asli & Ghanaatparast-Rashti, 2017) and reducing the concentration of pro-inflammatory cytokines, limiting heat-induced systemic inflammation (Ruff et al., 2021; Michalczuk et al., 2024; Obianwuna et al., 2024);
- have a hypolipidemic effect, helping to reduce triglyceride and cholesterol levels in meat and blood (Oni et al., 2024, Saracila et al., 2021).

Table 1. Phenolic compounds used in poultry farming

Phytogenic formulation	Hybrid HS (°C)	Dosage	Outcome	Source
Bioactive lipid compounds (oregano & mint)	Ross 308 38.2 ± 2.6°C (max 40.2°C)	150 mg/kg	- improvement in BW, BWG, FCR; - ↓ abdominal fat; - ↓ cholesterol, triglycerides, AST, ALT, urea creatinine; - ↓ water loss through cooking and dripping.	Abdel-Wareth & Lohakare, 2023
Encapsulated EOs (cinnamon, thyme, cloves)	Cobb 500 (THI = 30.52)	100 mg/kg	- ↑ BW, BWG, FCR; - ↑ TAC serum; - ↓hepatic expression of stress genes HSP70, HSP60.	Madkour et al., 2025
Polyphenols (resveratrol)	Yellow - feather 37 ± 2°C (8 h/day)	350-500 mg/kg	- improvement in SMZ; - ↓ rectal temperature; - ↓ corticosterone, ACTH; - ↑ SOD, CAT, GPx.	He et al., 2018
EO (*Lippia origanoides*) + vegetable betaine	Cobb 500 35°C (8 h/day)	350 mg/ton	- improvement in BW, BWG; - ↓ intestinal permeability; - ↑ intestinal villi.	Señas-Cuesta et al., 2023
Plant extracts (olive)	Arbor Acres (chronic)	15 ml/L (water)	- ↑ T3 plasmatic; - ↑ SOD; - ↓ MDA.	Pang et al., 2021
Powder (*Lippia citriodora*)	Ross 308 35°C	0.5% - 1%	- improved BW, FI, FCR; - ↓ cholesterol, LDL, triglycerides; - ↑ leukocytes; - improved meat quality.	Mehrparvar et al., 2016
Powder *(Salix alba)*	Cobb 500 32°C	50 g/100 kg (diet)	- ↓ cholesterol, triglycerides; - ↓ MDA in the liver; - ↓ E. coli, ↑ lactobacilli in the cecum.	Soica et al., 2019
Powder (*Mentha piperita)*	Ross 308 34°C 8 h/day (days 35 - 42)	1%, 2% (diet)	- ↓ cholesterol, triglycerides; - ↓ MDA in the liver; - ↓ *E. coli*, ↑ lactobacilli in the cecum.	Ameri et al., 2016
Dried oregano	Cobb 500 32°C, constant (days 14 - 35)	2%	- balancing the intestinal flora; - ↓ *Enterobacteriaceae* in the intestine.	Criste et al., 2017
Powder *(Rosa canina)*	Cobb 500 32°C, constant (days 14 - 35)	2%	- ↓ BW than in the control group; - colonization of the digestive tract with beneficial lactic acid bacteria.	Criste et al., 2017
Extract (grape seeds)	Cobb 500 (males) 34 ± 1°C, 5 h/day (days 29 - 42)	150, 300, 450 mg/kg	- 300 mg/kg dose: ↑ BW, EPEF; - 450 mg/kg dose: ↓ cholesterol, triglycerides, HSP70 gene expression in the heart and liver.	Hajati et al. 2015
Powder *(Artemisia annua)*	Cobb 500 32°C, constant (days 14 - 35)	2%	- limiting colonization with *Enterobacteriaceae* in the intestine; - ↑ concentration of lactobacilli; - did not improve growth performance.	Panaite et al., 2018
PSPP (steam-exploded pine particles)	Indian river 31°C (6 h/day)	0.5% - 1%	- improved oxidative status; - ↓ rectal temperature;	Goel et al, 2025

Phytogenic formulation	Hybrid HS (°C)	Dosage	Outcome	Source
			- suppression of stress marker genes HSP70, HSP90, NOX4; - ↑ number of beneficial intestinal ba.teria.	
Resveratrol	Crossbred 37 ± 2°C 8 h/day (14 days)	500 mg/kg	- improved ADG; - ↓ FCR; - ↓ corticosterone and ACTH; - ↓ splenic apoptosis and inflammation.	Meng et al., 2022
Curcumin (turmeric)	Ross 34°C (8 h/day)	100 mg/kg	- ↑ carcass yield; - ↓ abdominal fat; - ↓ MDA; - ↓ MUFA, PUFA fatty acid profile; - equilibrates hepatic ATP levels.	Salah et al., 2021
EGCG (green tea)	Huainan partridge 33 ± 1°C	400 mg/kg	- ↑ antioxidant enzyme activity; - ↓ muscle lactic acid; - activates the Nrf2 signalling pathway; - ↓ drip losses.	Zao et al., 2021
Tannic acid	Cobb500 35°C	1%	- ↓ weight gain and feed consumption; - ↑ FCR; - improvement of the lipid profile in muscles.	Ebrahim et al., 2015
ECGC (green tea)	Arbor Acres (males) 35°C (12 h/day)	300, 600 mg/kg	- ↑ BW, FI; ↓ FCR; - ↓ CK, LDH, AST; - improvement in SOD, CAT, GPx.	Luo et al., 2018
Ellagic acid	Arbor Acres 35 ± 2°C	75, 150, 300, 600 mg/kg	- improvement in BWG; - ↓ corticosterone, LPS, DAO; - ↑ antioxidant enzyme activity; - modulation of cecal microbiota.	Yang et al., 2022
Ginestein and hesperidin	Arbor Acres 34 - 37.3°C	5. 20 mg/kg + mix	- ↓ heterophil/ lymphocyte ratio; - improved growth performance BW, FI, CFR; - ↓ CK, LDH; - ↓ HSP70 in the breast muscle.	Kamboh et al., 2013
Liposomal resveratrol (nanoparticles)	Ross 308 36 ± 2°C (6 h/day)	50, 100, 150 mg/kg	- improvement in BWG, FCR; - restoration of renal and hepatic functions; - ↑ expression of SIRT1, SIRT3, SIRT7; - ↓ restoration of HSP70, HSP90 to normal levels.	Kishawy et al., 2023
Resveratrol	Arbor Acres 33 ± 1°C (10 h/day)	400 mg/kg	- ↑ final weight and average daily gain; - activation of the Nrf2 pathway in the intestinal mucosa; - increase in the height of intestinal villi.	Wang et al., 2021

[1]ACTH - adrenocorticotropic hormone; [2]ALT - alanine aminotransferase; [3]AP-1 - activator protein-1; [4]AST - aspartate aminotransferase; [5]ATP - adenosine triphosphate; [6]ADG - average daily gain; [7]BW - body weight; [8]BWG - body weight gain; [9]CAT - catalase; [10]CK - creatin kinase; [11]CKMB - creatine kinase MB; [12]CRYAB - alpha-crystallin B chain; [13]DAO - diamine oxidase; [14]EO - essential oil; [15]EPEF - European production efficacy factor; [16]FCR - feed conversion ratio; [17]FI - feed intake; [18]GPx - glutathione peroxidase; [19]H/L - heterophil/lymphocyte ratio; [20]HSP - heat shock protein; [21]Ig - immunoglobulin; [22]IL - interleukin; [23]LDL - low density lipoprotein; [24]LPS - lipopolysaccharide; [25]MDA - malondialdehyde; [26]MUFA - monounsaturated Fatty Acid; [27]NF-Kb - nuclear factor kappa-b; [28]Nrf2 - nuclear factor erythroid 2-related factor 2; [29]PUFA - polyunsaturated fatty acid; [30]SIRT - sirtuins; [31]SOD - superoxide dismutase; [32]T3 - triiodothyronine; [33]TAC - total antioxidant capacity; [34]THI - temperature - humidity index.

Terpenes/terpenoids are another significant class of secondary metabolites synthesized by plants, major components of essential oils, the largest group of natural products, with over 35000 known components (Dewick, 2009). Structurally, terpenes are hydrocarbons formed by the repetition of isoprene units, while terpenoids are natural organic compounds derived from terpenes by the introduction of oxygen units or the removal of methyl groups, modifications that confer diversity in structure and chemical functionality (Rachwał & Gustaw, 2025).

Terpenes are classified according to the number of isoprene units in their structure, as follows: hemiterpenes (C5) contain a single isoprene unit; monoterpenes (C10) consisting of two units (limonene, γ-terpinene, α-phellandrene, and oxygenated monoterpenes such as carvacrol, thymol, 1.8-cineole); sesquiterpenes (C15) consisting of three units, such as β-caryophyllene and α-humulene; diterpenes

(C20), four units (carnosic acid, carnosol, rosmanol); triterpenes (C30), ginsenosides, consisting of six units, often precursors of steroids; tetraterpenes (C40) represented mainly by carotenoids (astaxanthin, canthaxanthin, lutein, lycopene) and polyterpenes with high molecular weight, such as natural rubber (Dewick, 2009; Tang et al., 2018; Rammuni et al., 2019; Sandner et al., 2020; Jiang et al., 2021; Señas-Cuesta et al., 2023; Urban et al., 2024; Rachwał & Gustaw, 2025; Abeeb, 2025; Zhou et al., 2025).

In poultry farming, terpenes and terpenoids, especially in the form of essential oils (Table 2), exert multifunctional biological effects. The results published by Attia et al. (2017), demonstrate that the administration of thyme essential oil, rich in thymol and carvacrol, has a significant beneficial effect in mitigating heat stress, with direct effects on growth performance by improving feed conversion ratio (FCR); exercises a significant protective role by reducing malondialdehyde (MDA) levels, while also standing out through its high antioxidant activity, manifested by its ability to neutralize free radicals; improved immune protection by achieving higher antibody titers (infectious bursitis), as well as liver protection by lowering the level of liver stress enzymes (AST).

Table 2. Terpenic compounds used in poultry farming

Phytogenic formulation	Hybrid HS (°C)	Dosage	Outcome	Source
Thyme oil	Arbor Acre 33°C	1.0 g/ kg	- improvement in FCR, EPEI; - ↑ WBCs; - ↓ plasma AST.	Attia et al., 2017
Oregano leaf extract	Indian River (males) 32 ± 2°C	50 mg/kg	- ↑ BW, ↓FCR; - ↓ hepatic expression of stress genes HSP70, HSP60, HSP90A.	Madkour et al., 2024
Rosemary extract	Indian River (males) 32 ± 2°C	100 mg/kg	- improved TAC; - ↓ LDL cholesterol, AST enzymes; - ↑ T3 vs. control;	Madkour et al., 2024
EO (*Lippia origanoides*)	Cobb 500 35°C (12 h/day)	37 ppm	- improvement in BW, BWG, CFR; - ↑ SOD; - ↓ IgA and IFN; - ↑ tibia resistance to fracture.	Ruff et al., 2021
EO (*Lippia origanoides)* + EO (*Rosmarinus officinalis)* + Beetroot extract	Cobb 500 35°C (12 h/day)	45 ppm LO + 45 ppm RO + 300 ppm extract	- improvement in BW; - ↓ internal body temperature; - ↓ inflammatory biomarkers; - ↓ intestinal permeability; - ↑ bone mineralization.	Ruff et al., 2021
EO (*Lippia origanoides*) + EO (*Rosmarinus officinalis*) + Natural betaine	Cobb 500 35°C (12 h/day)	45 ppm LO + 45 ppm RO + 300 ppm betaine	- optimal improvement of FCR; - optimal improvement of carcass components (breast, legs); - ↓ intestinal permeability; - ↑ SOD; - improvement of bone mineralization.	Ruff et al., 2021
Thymol	Ross 308 35°C (8 h/day)	250 mg/kg (diet)	- ↑ BWG by 6%, - ↓ FCR by 4%; - ↓ heterophil/lymphocyte ratio (H/L), indicating ↓ stress levels; - ↑ % carcass, breast.	Shad et al., 2015
Carvacrol	Ross 308 35°C (8 h/day)	300 / 500 mg/kg (diet)	- = BWG, FCR; - ↓ cholesterol and H/L ratio; - ↑ GPx activity.	Shad et al., 2015

Phytogenic formulation	Hybrid HS (°C)	Dosage	Outcome	Source
1.8-Cineol / Eucalyptol (microencapsulated)	Ebayka broiler 30 ± 2°C (chronic)	1mg/kg (microcapsules)	- ↑ BWG; - ↓ inflammation (NF-κB, IL-1β, IL-6, TNF-α); - ↑ IL-10; - balancing the gut microbiota (↑ Lactobacillus, ↓ Salmonella).	Jiang et al., 2020
Eucalyptus oil	Cobb 500 32°C (chronic)	1 L oil/ 4000 Lwater / 1 L oil/ 200 L water (spray)	- no effect on growth performance, haematological parameters, leukocytes; -↓ haematocrit (indicator of physiological adaptation); - spray: ↓ Gram-negative bacteria in the respiratory tract.	Petrolli et al., 2019
EO blend (*Eucalyptus globulus labill, Tymus vulgaris, Cymbopogon nardus, Syzgium aromaticum*)	Ross 308 (males) 36°C	250, 500, 750 ml/ 1000 L (water)	- 250 ml/1000l water: - ↓ liver weight; - ↑ abdominal fat; - improved meat colour parameters (a* and L*).	Tekce et al., 2020
Oregano (BLCO)	Ross 308 29.5-38.3°C	150 mg/kg	- improvement in BW; BWG, FCR; - ↑ slaughter yield; - ↓ cholesterol, triglycerides, and liver enzymes (ALT, AST); - ↓ water loss in meat.	Abdel-Wareth & Lohakare, 2023
Mint (BLCP)	Ross 308 29.5-38.3°C	150 mg/kg	- improved growth performance; - ↓ creatinine and urea - ↓ abdominal fat; - improved meat quality.	Abdel-Wareth & Lohakare, 2023
Mint (powder)	Ross 308, 34°C, 8 h/day (days 35 - 42)	1%, 2% (diet)	- ↑ IgG, IgM; - ↑ leukocytes and lymphocytes; - ↓ LDL cholesterol, VLDL.	Ameri et al., 2016
Mint (powder)	Cobb 32-40°C	0.2% (diet)	- optimisation of comfort; - ↑ slaughter yield; - ↓ mortality; - ↑ erythrocytes and haemoglobin.	Elbaz et al., 2022
Mint (extract)	Arbor Acres 31°C (constant)	300 mg/kg	- reduction of splenic lesions; - suppression of inflammatory cytokines (IL-1β, IL-6, TNF-α) by regulating NF-kB and AP-1 signaling pathways.	Ma et al., 2024
Astaxanthin	Cobb 500 32-35°C (days 21-42)	1.33 mg/kg	- ↑ expression of cytoprotective genes / epithelial integrity of the ileum; - ↓ hepatic oxidative stress; - ↓ inflammation.	Kuehu et al., 2024
(*Yucca schidigera*) (powder)	Yellow featherd 34 ± 2°C (days 29-56)	100 mg/kg	- no changes in SOD, CAT, GPx; - ↓ rectal temperature; - ↓MDA.	Luo et al., 2022
Rosemary (purified extract)	SPF broiler 42 ± 1°C	3% nanoemulsion concentration 40 mg/day (water)	- ↓ LDH, CK, CKMB; - more pronounced oxidative stress; - ↑ CRYAB, HSP70.	Tang et al., 2018

[1]ACTH - adrenocorticotropic hormone; [2]ALT - alanine aminotransferase; [3]AP-1 - activator protein-1; [4]AST - aspartate aminotransferase; [5]ATP - adenosine triphosphate; [6]BLCO - bioactive lipid compounds of orindex; [7]BLCP - bioactive lipid compounds of peppermint; [8]BW - body weight; [9]BWG - body weight gain, [10]CAT - catalase; [11]CK - creatin kinase; [12]CKMB - creatine kinase MB; [13]CRYAB - alpha-crystallin B chain; [14]DAO - diamine oxidase; [15]EO - essential oil; [18]EPEI - enzyme protein efficiency index; [19]FCR - feed conversion ratio; [20]FI - feed intake; [21]GPx - glutathione peroxidase; [22]H/L - heterophil/lymphocyte ratio; [23]HSP - heat shock protein; [24]Ig - immunoglobulin; [25]IL - interleukin; [26]LDL - low density lipoprotein; [27]LO - *Lippia origanoides*; [28]LPS - lipopolysaccharide; [29]MDA - malondialdehyde; [30]NF-Kb - nuclear factor kappa-b; [31]RO - *Rosmarinus officinalis*; [32]SIRT - sirtuins; [33]SOD - superoxide dismutase; [34]T3 - triiodothyronine; [35]TAC - total antioxidant capacity; [36]THI - temperature - humidity index; [37]TNF - α-tumour necrosis factor alpha; [38]VLDL - very low density lipoprotein.

Alkaloids are a class of nitrogenous secondary metabolites with a low molecular weight, identified in over 27,000 structures, of which approximately 21,000 come from plants, demonstrating pronounced pharmacological effects (Dewick, 2009), They are used in poultry nutrition both for their digestive stimulation properties and to improve growth performance and the ability of birds to adapt to stress factors. The main alkaloids used in poultry farming are piperine, capsaicin, and isoquinoline alkaloids.

Experimental data presented by Ahammad & Kim (2025) show that piperine acts as a bio-improver, improving nutrient absorption by modifying the dynamics of lipids in the intestinal membrane. Research conducted on a flock of 640 Ross 308 chickens, without heat stress, showed that supplementing the diet with piperine in the form of micelles helps stimulate digestive enzymes (lipase, amylase, protease) and linear body weight gain. Another study conducted on 360 Ross 308 chickens subjected to heat stress revealed that supplementing the diet with capsaicin reduces oxidative stress by decreasing MDA and increasing the GPx enzyme, increases the number of red blood cells, hemoglobin, and total proteins, and decreases cholesterol, uric acid, and glucose levels. In the same experimental design, two groups were supplemented with chili pepper powder (*Capsicum anuum*), an intervention that stimulated GPx (antioxidant protection) and significantly improved erythrocyte count and haematocrit value (Abed & Al-Shukri, 2024). Kikusato et al., 2021, demonstrate that the administration of isoquinoline alkaloids (sanguinarine and chelerythrine) can mitigate growth retardation induced by heat stress (Ross 308, 33°C constant) by protecting the barrier function and inhibiting inflammatory factors, as well as suppressing the secretion of uric acid and corticosterone in plasma.

Saponins, glycosides, and polysaccharides

Experimental studies have shown that the use of saponins as heat stress modulators, especially steroidal and triterpenic saponins derived from *Yucca schidigera* and *Gynostemma pentaphyllum,* have beneficial effects in reducing heat stress in broiler chickens, leading to a decrease in plasma corticosterone levels, and indicating a favourable modulation of the hypothalamic-pituitary-adrenal axis (Luo et al., 2022). Research conducted by Yu et al., 2025, highlighted that, at the molecular level, saponins exert antioxidant and anti-inflammatory effects by improving the antioxidant activity of superoxide dismutase, (SOD). catalase (CAT), glutathione peroxidase (GPx) enzymes and inhibiting the activation of the nuclear factor kappa-b (NF-kB) pathway.

Glycosides also play a role in supporting the immune response and maintaining redox balance, Saracila et al., 2021, providing evidence of the ability of salicin, extracted from *Salix alba*, to increase the total antioxidant capacity (CAT) and reduce (MDA) malondialdehyde concentrations, indicating a decrease in lipid peroxidation. In the case of the Ross 308 hybrid, subjected to a constant temperature of 32 ± 2°C, the combination of stevia flour (20 g/kg) and xylanase (100 FXU/kg) significantly increased carotenoid concentrations in the liver (stevia), while xylanase improved nitrogen retention, metabolizable energy, and hepatic vitamin E, as well as butyric acid concentration in the cecum (Pirgozliev et al., 2021). Improvements in economic performance and structural integrity of the intestine were reported by Sadner et al., 2020, who provided evidence that the administration of ginsenosides (90 mg/kg) to Cobb 500 hybrids subjected to cyclic heat stress of 34°C, in the form of ginseng extract, has a positive effect on feed conversion ratio and body weight, as well as increasing the expression of tight junction proteins, occludin and claudin-1. Similarly, a relevant example are polysaccharides derived from the marine algae *Enteromorpha prolifera* and the microalgae *Euglena gracilis*, which have been shown to improve intestinal antioxidant status (increased total antioxidant capacity and decreased malondialdehyde), significant improvement in intestinal barrier function by decreasing tumor necrosis factor alpha TNF-α, interleukin IL-1β; increase in nuclear factor beta IκBα alpha inhibitor) (Liu et al., 2021), reduction in cell apoptosis and histological lesions, associated with negative regulation of the nuclear factor kappa-b (NF-kB) pathway in Fabricius' bursa (Liu et al., 2021), improvement of feed conversion rate, increase in energy digestibility, and reduction of ileal *E. coli* population (Zhang et al., 2020).

In an experimental model of heat stress in broiler chickens (37 ± 1°C), dietary supplementation with 200 mg/kg *Atractylodes macrocephala* proved to be beneficial, both in terms of oxidative stress (increased antioxidant parameters and decreased pro-oxidant markers) and in terms of splenic immune modulation, along with reduced apoptosis (Xu et al., 2017).

CONCLUSIONS

For modern poultry production, heat stress is one of the most important challenges due to its negative effects on growth performance, immunity, oxidative balance, and intestinal function, generating nonspecific physiological reactions such as oxidative stress, intestinal barrier dysfunction, and systemic inflammation. A review of the literature highlights that the integration of phytogenic bioactive compounds into the broiler chicken diet is a viable and effective nutritional strategy for mitigating the physiological and metabolic effects induced by high temperatures, being the most sustainable alternative to antibiotic growth promoters, without the risk of residues or microbial resistance.

It is unanimously accepted that bioactive compounds exert complementary and often synergistic effects; for example, phenols and terpenes act pleiotropically by activating the nuclear factor erythroid 2-related factor 2 (Nrf2) pathway, stimulating antioxidant defense and modulating the inflammatory response, saponins and polysaccharides play an important role in maintaining the integrity of the intestinal mucosa, while glycosides and alkaloids can influence energy metabolism and the neuroendocrine response to stress.

The use of additives, especially in microencapsulated form, improves zootechnical performance and the quality of the finished product, while contributing to improved feed conversion ratio (FCR), body weight gain (BWG) and increased oxidative stability of meat. Although the beneficial effect of phytobiotics is recognized, their effectiveness depends on the optimization of doses and synergistic combinations, botanical source, chemical structure, and form of administration, elements that must be adapted to the stressor (intensity and duration of heat stress).

Therefore, further research is needed to elucidate the molecular mechanisms of action, structure, and optimal dosage, but especially to validate the effectiveness of these interventions under production conditions.

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