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RESEARCH ARTICLE

Nutritional Mitigation of Heat Stress in Broilers with Comparative Effects of Vitamin C, Vinegar, and Sodium Bicarbonate on Growth Efficiency, Carcass Traits, and Public Health Significance

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ABSTRACT

In poultry, heat stress causes oxidative stress, acid-base imbalance, decreases feed intake and feed efficiency, damages meat quality, increases disease risk and raises mortality rate. This study aimed to evaluate the comparative effects of vitamin C, vinegar and sodium bicarbonate supplementation on growth performance and carcass characteristics of broiler chickens under heat stress. After a one-week adaptation period, chicks were divided into four experimental groups. Group I was provided with ideal environmental conditions and served as the control group without any medication. Group II was provided with heat stress at 37.5°C. Group III obtained heat stress with vitamin C supplementation at 300 mg/kg feed; Group IV received heat stress with vinegar supplementation at 5ml/L of drinking water, and Group V received heat stress with sodium bicarbonate supplementation at 200 mg/kg feed). Birds had free access to feed and fresh drinking water throughout the experimental period. The results showed that vitamin C, vinegar and sodium bicarbonate supplementation enhanced the broiler growth performance with lower mortality rate during heat stress as compared to control group. In contrast, the heat stress group demonstrated lowest growth performance with higher mortality ratio as compared to other groups. Furthermore, carcass dressing percentage was measured on day 35. Group III demonstrated the best FCR (1.77), highest ($p < 0.05$) final body weight (2350 g) with dressing percentage (73.8%) followed by Group IV and V. Vitamin C, vinegar and sodium bicarbonate had a significant effect on growth performance and carcass dressing percentage reared under heat stress, indicating their potential as protective management practices during heat stress, thereby reducing potential public health risks from contaminated poultry products.

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INTRODUCTION

The global poultry sector is continuously expanding due to the increasing demand for high-quality poultry meat and egg products. Poultry meat and eggs are rich in protein, minerals, and vitamins. Significant advancements in chicken genetics have been implemented in the past decade in order to meet the increasing demand. These improved broilers and laying hens possess higher metabolic rates as well as production performances. Owing to higher metabolic rate, high stocking density and high ambient temperature, birds generate more body heat and are prone to heat stress (Wasti *et al.*, 2020). Under heat stress conditions, physiological, digestive and immunological disturbances, e.g., hypoxia, reduced feed intake, inflammation and infections in the intestinal tract occur in birds (Rostagno *et al.*, 2020). When birds are subjected to heat stress, their behavioral, physiological and immunological responses change, leading to detrimental effects on overall production in poultry birds (Pawar *et al.*, 2016).

Rising global temperatures have resulted in heat stress and have emerged as a serious concern for the global poultry industry. Heat stress compromises avian immunity, thereby enhancing susceptibility to *Salmonella*, which is a major etiological agent of human salmonellosis and the most significant foodborne disease worldwide (Zhang *et al.*, 2025). Heat stress mainly affects poultry production since modern-day birds are extremely vulnerable to high temperatures and have restricted heat dissipation capacity (Uyanga *et al.*, 2023). Heat stress impaired growth performance via decreasing protein digestibility up to 9.7% in broilers (Nawaz *et al.*, 2021).

Vitamin C functions as an effective antioxidant that helps reduce the harmful physiological effects associated with heat stress. Since vitamin C is not an essential nutrient for poultry, no requirement was established by the National Research Council (NRC). It is recommended to increase vitamin supplementation by 2.5% per additional degree Celsius when the ambient temperature exceeds 28 °C. Environmental stressors, specifically heat stress, can result in inadequate endogenous synthesis, enhancing the requirement for exogenous vitamin C (Pečjak *et al.*, 2022). Vitamin C is a water-soluble vitamin possess antioxidant action, thus protecting animals under stress (Attia *et al.*, 2016).

Vitamin C, also known as ascorbic acid, can be used to lessen oxidative stress caused by heat stress. Ascorbic acid supplementation at 250 mg/kg feed improved feed intake, body weight, and feed efficacy as well as enhanced immune response along

with antioxidant status of broiler chickens. Vitamin C mitigates immunity and production problems caused by heat stress, such as suppressed immunity, decreased feed consumption, impaired body weight gain, oxidative stress, elevated rectal temperature and higher mortality in birds. Ascorbic acid supplementation can impact body energy stores, favoring improved productivity when feed limitation reduces energy consumption in broilers (Desoky and Kamel, 2018). Dietary supplementation with Vitamin C could improve intestinal health by positively modulating microbial structure and intestinal morphology, thus enhancing immunity as well as antioxidant ability. Consequently, the production performance of broilers may improve and help in reducing potential public health risks (Gan *et al.*, 2020).

Apple cider vinegar (ACV) is a fermented product, categorized as a functional food attributed to its nutrients and compounds, such as vitamins and minerals. Additionally, it has an inhibitory efficacy towards several microorganisms via inhibition of nutrients transport through the cell membrane (Al-Hadidy *et al.*, 2023). Apple cider vinegar has been reported to support intestinal health and improve nutrient digestion and absorption in broiler chickens. Organic acids decrease the gastrointestinal tract pH (3.5-4), which supports the development of *Lactobacilli* and *Bacilli* species. The addition of ACV in drinking water (1 ml vinegar/1L water) improved the weight gain of broilers (Ibrahim *et al.*, 2023). Consumption of ACV enhances immune responses against microbes and also maintains acid-base balance (Jahantigh *et al.*, 2021). Acetic acid is the primary biologically active component of vinegar. Past reports have confirmed that dietary and drinking water supplementation with acetic acid shows favorable effects on growth performances, egg productivity, and some physiological parameters of broilers raised under thermoneutral conditions. Acidic acid supplementation at concentrations of 400-600 ppm in drinking water enhanced egg quality characteristics during the hot season (Berrama *et al.*, 2018). Domestic vinegar (6%) can be used as a substitute for quaternary ammonium compounds in the sanitation process in chicken meat production to ensure safe chicken meat for consumers and public health protection (Hrustemović, 2025).

As a dietary supplement, sodium bicarbonate plays a significant role in maintaining acid-balance and electrolyte balance as well as mitigating respiratory alkalosis triggered by high temperatures. Supplementation of sodium bicarbonate can improve shell quality in hens as well as body weight in chickens (Yin *et al.*, 2018). Sodium bicarbonate is extensively used as a regulatory agent for birds to lessen the deleterious effects of heat stress via

maintenance of acid-base balance (Salman *et al.*, 2019). Sodium bicarbonate can enhance the antibacterial activity of egg white proteins, leading to inhibition of bacterial growth, thus reducing potential hazards related to human health (Wellman-Labadie *et al.*, 2008).

Birds fed with various sources of sodium (sodium bicarbonate, sodium carbonate, or sodium sulphate) at a dietary electrolyte balance (DEB) of 250 mEq/kg revealed improved performance, maintained blood pH, heterophil, bicarbonate, lymphocytes, hemoglobin, and blood nutrients (K, Na, glucose and Cl). Severe heat stress causes panting, deficiency of carbon dioxide (CO₂), high blood pH, loss of HCO₃ and cations, mainly potassium ion (K⁺) from urine and reduction in blood partial pressure of CO₂ (pCO₂). During heat stress, lymphocytes decrease and heterophils increase, as well as an increase in H to L ratios have been widely recognized. The heat-stressed broiler chickens indicated higher blood glucose levels and lower blood hematocrit values. When ambient temperature increases, the concentration of blood potassium ions and sodium ions decreases, while chloride ions increase, leading to low blood electrolyte balance (Popoola *et al.*, 2020; Ahmad *et al.*, 2008). This investigation was conducted to determine the influence of vitamin C, vinegar, and sodium bicarbonate supplementation on productive performance and carcass characteristics of broilers subjected to heat stress.

MATERIALS AND METHODS

Birds and Experimental Design: The current study was conducted at the C Block, Muhammad Nawaz Sharif University of Agriculture, Multan, Pakistan, using 200 broiler chicks from a commercial hatchery. Before the arrival of chicks, the poultry house and equipment were cleaned carefully, disinfected with 5% formalin solution, and subsequently fumigated. The house was completely arranged before the arrival of chicks in demand to ensure the preferred temperature and humidity. Sand was utilized as a litter material. Chicks were provided fresh, clean water and non-toxic feed. After one week i.e. acclimatization period, chicks were divided into four treatment groups. Electric brooders were used for heating.

Animal ethics: All study procedures were conducted with approval from the Animal Ethics Committee of the MNS-University of Agriculture, Multan, and in compliance with the IACUC.

Experimental Design: Group I was provided with ideal environmental conditions and served as the control group without any medication. Group II was given heat stress at 37.5°C. Group III was supplied heat stress with vitamin C supplementation at 300 mg/kg feed, Group IV was provided heat stress with

vinegar supplementation at 5ml/L of drinking water, and Group V was administered heat stress with sodium bicarbonate supplementation at 200 mg/kg feed.

Data collection: Feed was weighed, and average feed consumption as well as feed conversion ratio (FCR) for each group were determined on day 35. Mortality rate was recorded regularly for each group. The following formula was used for calculating weight gain and FCR as follows: $FCR = \text{Total feed consumed} / \text{Total weight gain}$

Carcass characteristics: Carcass characteristics, including body weight, dressing percentage, as well as weights of breast, thigh and drumstick, were determined at the end of the experiment. It was analyzed that vitamin C, vinegar and sodium bicarbonate have a significant effect on body weight, dressing percentage, breast, thigh and drumstick. The body was sectioned into individual parts. At the end of the 35-day experiment, five birds were chosen at random, weighed up and slaughtered. To ensure effective bleeding, the jugular veins of birds were cut off with a sharp knife. The carcass dressing percentage was determined by the given formula: $\text{Carcass dressing percentage} = \text{Weight of carcass} / \text{Weight of live bird} \times 100$

Statistical analysis: To compare means between groups, data were evaluated using one-way ANOVA and Tukey's post hoc test. $P < 0.05$ was considered significant. The results are presented as mean $\pm$ standard error of the mean (SEM).

RESULTS

The impacts of vitamin C, vinegar, and sodium bicarbonate supplementation on the growth performance of broilers under heat stress are shown in Table 1 and Fig. 1.

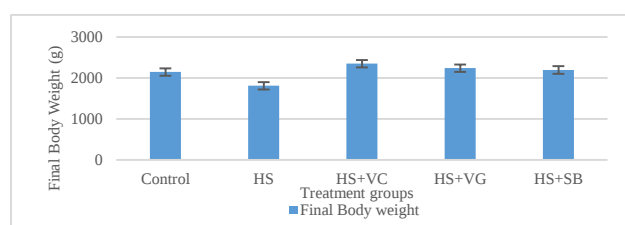


Fig. 1: Effect of vitamin C, vinegar, and sodium bicarbonate supplementation on final body weight of broiler chickens under heat stress.

When compared to the control group kept at room temperature, exposure to heat stress significantly ($p < 0.05$) decreased final body weight, body weight gain, feed intake, and feed efficiency. Birds supplemented with vitamin C revealed the best FCR (1.77) and the highest ($p < 0.05$) final body weight (2350 g) among the supplemented groups, followed by Groups IV and V. The heat stress group demonstrated the worst growth performance, characterized by the lowest feed efficiency and the

Table 1. Effect of vitamin C, vinegar, and sodium bicarbonate supplementation on growth performance of broilers under heat stress

Parameters	Control (Normal Temp)	Heat stress only	Heat stress + Vitamin C (300 mg/kg)	Heat stress + Vinegar (5 mL/L)	Heat stress + NaHCO ₃ (200 mg/kg)	SEM	p-value
Final Body Weight (g)	2145 ± 36 ^b	1810 ± 40 ^c	2350 ± 37 ^a	2240 ± 42 ^{ab}	2195 ± 38 ^b	22.60	0.001
Feed Intake (g/bird)	3640 ± 41 ^b	3410 ± 45 ^c	3790 ± 46 ^a	3715 ± 43 ^{ab}	3681 ± 44 ^b	25.81	0.05
Feed Conversion Ratio (FCR)	1.85 ± 0.02 ^b	2.14 ± 0.06 ^c	1.76 ± 0.03 ^a	1.83 ± 0.02 ^{ab}	1.84 ± 0.04 ^b	0.03	0.001
Mortality (%)	3.35 ± 0.55 ^b	8.31 ± 0.90 ^a	2.45 ± 0.31 ^b	2.95 ± 0.33 ^b	3.14 ± 0.31 ^b	0.43	0.05

Means within a row with different superscripts (a–c) differ significantly ($P < 0.05$). Heat stress; Vitamin C; Vinegar; Sodium bicarbonate; SEM: Standard error of mean.

Table 2: Effect of vitamin C, vinegar, and sodium bicarbonate on carcass characteristics of broilers under heat stress

Parameters	Control (Normal Temp)	Heat stress only	Heat stress + Vitamin C (300 mg/kg)	Heat stress + Vinegar (5 mL/L)	Heat stress + NaHCO ₃ (200 mg/kg)	SEM	p-value
Live Weight (g)	2145 ± 36 ^b	1810 ± 40 ^c	2350 ± 37 ^a	2240 ± 42 ^{ab}	2195 ± 38 ^b	22.60	0.001
Dressing Percentage (%)	69.20 ± 0.81 ^b	66.5 ± 0.95 ^c	74.80 ± 0.69 ^a	71.5 ± 0.87 ^{ab}	71.78 ± 0.86 ^{ab}	0.45	0.001
Breast Meat (%)	31.50 ± 0.54 ^b	29.0 ± 0.59 ^c	35.8 ± 0.52 ^a	33.80 ± 0.50 ^{ab}	33.30 ± 0.46 ^{ab}	0.25	0.01
Thigh (%)	18.48 ± 0.32	17.88 ± 0.35	19.02 ± 0.34	18.81 ± 0.33	18.59 ± 0.32	0.21	0.20 (NS)
Drumstick (%)	14.01 ± 0.25	13.2 ± 0.28	16.30 ± 0.24	15.12 ± 0.25	15.09 ± 0.26	0.19	0.32 (NS)

Means within a row with different superscripts (a–c) differ significantly ($P < 0.05$). NS: Non-significant; SEM: Standard error of mean.

highest mortality rate. Overall, broilers raised in high ambient temperatures indicated improved growth performance upon supplementation with vitamin C, vinegar, and sodium bicarbonate, with vitamin C causing the most noticeable outcome. The carcass evaluation results of 35 days are shown in Table 2. In comparison to the control group, dressing percentage and breast meat production were significantly ($p < 0.05$) declined by heat stress. However, under heat stress conditions, sodium bicarbonate, vinegar, and vitamin C supplementation significantly enhanced carcass properties. The broilers in Group III showed the highest dressing percentage (73.8%), followed by Group IV (72.5%) and Group V (71.8%). The lowest dressing percentage (65.5%) was observed in the heat stress group. Differences in thigh and drumstick percentages were found statistically non-significant ($p > 0.05$) among supplemented groups but numerically higher than those observed in the heat-stress group without supplementation. These results suggest that supplementing broilers with vitamin C, vinegar, and sodium bicarbonate can improve carcass yield performance while decreasing the detrimental effects of heat stress.

DISCUSSION

The present study demonstrated the comparative effect of vitamin C, vinegar, and sodium bicarbonate on growth performance and carcass characteristics of broiler chickens during heat stress. Broilers raised under heat stress indicated improved growth performance and carcass properties upon supplementation with vitamin C, vinegar, and sodium bicarbonate, with vitamin C (300 mg/kg feed) causing the most noticeable outcome. The heat stress group revealed the worst growth performance,

characterized by the lowest feed efficiency and the highest mortality rate.

Thermal stress is considered one of the major environmental challenges affecting poultry production across the world. Heat stress causes decreased feed intake, increased water intake, less movement and birds spend more time in resting. High environmental temperature alters the activity of the neuroendocrine system in poultry. Heat stress impairs overall poultry and egg production via modifying the neuroendocrine system in birds by reducing feed intake and by activation of the hypothalamic-pituitary-adrenal axis (Lara and Rostagno, 2013).

Under heat stress conditions, the diet supplemented with 250 mg/kg of vitamin C was effective in improving broiler performance and relieving heat stress; however, the effect of vitamin C on immune organs was not declared (Sun *et al.*, 2023). Acidic acid supplementation at a range of 400-600 ppm in drinking water improved egg quality traits during the hot season (Berrama *et al.*, 2018). Intestinal morphology of broilers improved due to apple vinegar supplementation, which contributed to enhanced digestion and absorption of nutrients. However, organic acids decrease the intestinal tract pH (3.5-4), which supports the development of Lactobacilli and Bacilli species. The addition of ACV in drinking water (1 ml vinegar/1 L water) improved the weight gain of broilers (Ibrahim *et al.*, 2023). A lower mortality rate was observed with supplementation of different sodium salts, such as sodium bicarbonate (15.15%), sodium carbonate (13.64%), and sodium sulphate (15.15%), than with the control (33.33%) treatment (Ahmad *et al.*, 2006). Dietary supplementation with vitamin C, vinegar, and sodium bicarbonate can enhance intestinal

health, egg and meat quality, and antibacterial defense in poultry, thus improving growth performance and food safety while reducing potential public health risks (Wellman-Labadie *et al.*, 2008; Berrama *et al.*, 2018; Gan *et al.*, 2020; Hrustemović, 2025).

Conclusion

The highest growth performance and carcass dressing percentage were recorded with vitamin C supplementation, indicating a lower mortality ratio. Conversely, the heat stress group exhibited the lowest growth performance and carcass dressing percentage with a higher mortality ratio as compared to other groups. It was concluded that supplementation of vitamin C, vinegar, and sodium bicarbonate indicated a significant effect on broiler growth performance and carcass dressing percentage reared under heat stress and can be considered as a protective management practice in poultry diet during heat stress.

Authors' contribution: AAS and MZY Conceptualization, Methodology, Formal analysis, Drafted manuscript, Writing-original draft, Writing-review and editing. RMS, MAR, MZY, SAR, KS, AAS and AR Provided assistance in experimentation, Data analysis, Data curation, and statistical guidance. SAR and MAR. Project administration, Funding acquisition, Resources, Supervision. All authors have read and agreed to the published version of the manuscript.

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