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Integrative Technological Strategies in Poultry Nutrition: Synergistic Effects of Cinnamic Acid and Magnetized Water on Broiler Growth and Carcass Quality

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Abstract | In the global efforts to reduce the application of antibiotics in chicken production, the search of natural substitutes with bioactive properties has become a priority. Cinnamic acid is a natural phenomenon-phenolic molecule, and magnetized water are considered possible agents in enhancing the health and performance of poultry. The purpose of the study was to examine how cinnamic acid and magnetized water (individually, and together) enhanced growth performance, carcass characteristics, meat quality, antioxidant status, and sensory characteristics in broiler chickens. Broiler chicken was subjected to six dietary treatments T1 (control) T2 (magnetized water), T3 (0.5% cinnamic acid), T4 (1% cinnamic acid), T5 (magnetized water + 0.5% cinnamic acid), and T6 (magnetized water + 1% cinnamic acid). Parameters were evaluated finally body weight, total feed consumption, feed ratio, weight gain, dressing percentage, carcass meat cuts yield, sensory (appearance, texture, aroma, and flavor), and enzymatic antioxidant (GSH-Px and SOD) activities. The integrated treatments (T5 and T6) were much better than the other groups in most performance indices. T6 recorded the greatest body weight (2.35 kg), improved feed to weight ratio (1.60), greater dressing percentage (75.34%), and better sensory scores. Further on, the GSH-Px and SOD activities were also remarkably high in T5 and T6, which implies enhanced antioxidant defense. The combination of cinnamic acid and magnetized water in chicken feed can become an effective feeding selection to improve growth, meat quality, and oxidative stability without using antibiotics. This strategy has the power to enhance productivity and satisfy consumer demand of naturally raised poultry.

Keywords | Broiler performance, Cinnamic acid, Magnetized water

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INTRODUCTION

Given the tendency in the world to decrease the consumption of antibiotics in the poultry food, there is an immediate necessity to investigate the natural options with several functional features that could improve productive activity and the quality of products without harming the health of consumers and the environment. The overconsumption of antibiotic growth promoters (AGPs) has posed a threat to the health of people, as they have led to the development of antibiotic-resistant bacteria and the possibility of their residues in animal products

(Obianwuna *et al*., 2024; Gadde *et al*., 2017; Eggleston *et al*., 2010; Puri *et al*., 2025). As a result, there has been an interest in plant-based compounds, organic acids, and functional water treatments as suitable and sustainable feed additives (Hashemi and Davoodi, 2011; Yang *et al*., 2015).

One of these promising alternatives is cinnamic acid which is a natural phenolic compound present in a range of aromatic plants (cinnamon and cloves) and possesses antioxidant, anti-microbial, anti-inflammation and metabolism-regulating activities (Shan *et al*., 2005; Ma *et al*., 2025). Cinnamic acid and its derivatives have been shown to regulate gut flora, prevent pathogenic intestinal bacteria like *E. coli, Salmonella* spp. and promote enzymatic activities in the gut (Upadhyay *et al*., 2014; Freitas *et al*., 2024). Also, its oxidative damage reduction and nutrient absorption enhancement effects have been associated with an increase in weight gain and feeding ratio in poultry (Ali *et al*., 2021).

Conversely, magnetized water is a non-pharmacological and ecological treatment that is having precedence in the scientific arena. The attribute of magnetizing water by subjecting it to a certain magnetic field changes the physicochemical properties of water, such as surface tension, viscosity, pH, and mineral solubility, potentially resulting in higher absorption of water, enzymatic activity, and metabolic efficiency in animals (Stefanuto *et al*., 2024; Mushattat *et al*., 2018; Abdelsalam *et al*., 2025). The presentation of magnetized water has been claimed to boost the growth rate, feed ratio, oxidative stress biomarkers and immunity and carcass characteristics in poultry (Kirkpinar *et al*., 2023).

Although the effects of cinnamic acid and magnetized water have been documented in detail, limited studies have been done to determine the possible synergies between cinnamic acid and magnetized water in the diet of poultry, especially in relation to the growth performance, feed efficiency, and meat quality of the different birds. Combining a powerful natural antioxidant with biophysically enhanced water could have a synergistic effect, including better immunity, lower gut pathogenicity, and better bioavailability of nutrients, The objective of this study is to determine the functional attribute of cinnamic acid and magnetized water alone and in combination with other agents with respect to their effects on productive, carcass characteristics, and some physiological and health parameters, including markers of oxidative stress and liver functionality. It aims at having an applied scientific foundation on how these natural additives can be incorporated into poultry nutrition programs as a component of an antibiotic-free sustainable model of production.

MATERIALS AND METHODS

Study location

This experiment was carried out in the Agricultural Research Unit of the Department of Agricultural Biotechnology Techniques in the Al-Kut Technical Institute of Middle Technical University in Iraq. The study was conducted on the basis of the facilities and research infrastructure which were located in the unit and according to the accepted scientific standards of applied research in the areas of poultry nutrition, flock health, and product safety.

Experiment design

The test was done on 180 one-day-old Ross 308 strain broiler chicks, having an average initial body weight of 40 g. There were 6 experimental treatments randomly assigned to birds with 10 birds each, and each treatment had three replicas. The chicks were kept in a closed poultry house over a litter of wood shavings with a thickness of 5 cm that was partially changed as necessary to ensure hygiene and comfort, as per usual husbandry practices (Aviagen, 2019a, b).

The environment was managed to ensure that the physiological needs of the broilers were met. The temperature was set to 34 °C in the first week and then gradually decreased to 24 °C at the end of the trial. Relative humidity was kept at the range of 55 to 65 and ventilation was well taken care of with the help of exhaust fans as a way of promoting proper air exchange and eliminating harmful gases. The use of an artificial lighting program was implemented, beginning with 23 hours of light and 1 hour of darkness, progressively changing to 18 hours of light and 6 hours of darkness, as per the recommended management protocols (Aviagen, 2019a, b; North and Bell, 1990).

Feeding and watering system

The feeding program applied was a typical two-phase feeding program which was a starter diet (0, 21 days) and a finisher diet (22, 35 days) as shown in Table 1. The diets were well balanced to serve the energy, protein, vitamin and mineral needs of the birds and were the same in all the treatments and only contained certain additives, whose presence created the foundation of the experimental design. These additives consisted of cinnamic acid in two concentrations (0.5% and 1.0%), magnetized water in 1500 Gauss and mixtures. Automated drinkers were used to administer clean drinking water and libitum and water temperature kept between 20 °C and 25 °C to guarantee maximum intake and physiological comfort as recommended by broiler management (Aviagen, 2019a, b).

The measured traits

During the experimental process, a detailed system of standardized indicators was used to measure the real impacts of the experimental dietary additives cinnamic acid and magnetized water and their interaction on broiler chicken. Such measurements were productive performance, carcass characteristics, and chosen biochemical indicators related to physiological condition and oxidative stress.

Table 1: Broiler diet ingredients and their chemical composition used in the experiment.

Feed ration	Starter diet (0-21 days)	A finisher diet (22-35 days)
Corn (kg)	58	60
Wheat (kg)	4	5
Soybean Meal (kg)	32	29
Protein concentrates (kg)	4	4
Sunflower oil (kg)	1	1
Limestone (kg)	0.70	0.70
Vitamins and Minerals (kg)	0.30	0.30
Table Salt (kg)	0.30	0.30
Total	100	100
Chemical composition of the feed ration		
Metabolizable Energy (kcal/kg)	2965.80	3018.4
Protein %	22.68	21.47

Protein concentrates contain 2100 kcal/kg of Metabolizable Energy, 40% protein, and a mixture of minerals and vitamins.

The last feed intake was measured between day 1 and day 35 about productive performance. The end-of-trial weight of each bird (FBW) was recorded and total weight gain (TWG) of each bird was calculated as a difference between initial and final body weights. Moreover, the feed ratio (FCR) was calculated by dividing the received amount of feed by the respective weight gain, therefore, indicating the efficiency of the feed consumption (NRC, 1994; Aviagen, 2019a, b).

About carcass quality, a representative sample of birds was slaughtered at the conclusion of the rearing period based on standard poultry slaughtering and carcass grading procedures (Al-Fayad *et al*., 2010). The evaluation covered the calculation of dressing percentage and relative mass of the breast and thigh muscles, which are significant predictors of meat quality and commercial value (Guo, 2021; Fanatico *et al*., 2007).

At the physiological level, selected birds that were subjected to the trial were taken to the end of the trial after having an overnight fast, after which blood samples were collected. Various biochemical indicators of oxidative stress were measured on these samples, which gave some information of the metabolic condition and antioxidant defense capacity of the birds. Precisely, the evaluation of the glutathione peroxidase (GPx) and superoxide dismutase (SOD) activity was performed by using commercially available assay kits based on accurate laboratory calibration and analytical procedures (Cohen and Hochstein, 1963; Aebi, 1984; Paglia and Valentine, 1967). The biomarkers can be used as early diagnostic assays to determine the effectiveness of dietary interventions to reduce the damage of free radicals and improve the internal antioxidant defense system of chickens.

Statistical analysis

The analysis of data was performed with SPSS software (version 25) with 6 treatments × 3 replicates based on the completely randomized design (CRD). The significant differences between the treatments were determined by ANOVA with one-way analysis and then multiple range test Duncan test was performed at the level of p 0.05. Varonic homogeneity and normality was checked and results were reported in terms of the mean and standard deviation. The aim of the analysis was to determine the dietary additive effects on meat quality and growth.

RESULTS AND DISCUSSION

Growth performance

Final feed intake and final body weight

The results of Table 2 show the effect of various treatments of cinnamic acid and magnetized water was demonstrated on the final feed intake (kg) and final body weight (kg) of broiler chickens revealed that there were no significant differences in the amount of feed consumed in the control group (T1) and group that was only applying magnetized water (T2). The feed consumption in T1 and T2 was 3.250 and 3.240 kg, respectively, meaning that the application of the magnetized water did not significantly affect feed consumption. On the same note, there were no noticeable differences on the final body weight between these two treatments with final body weight of 1.950 and 1.953 kg, respectively- a fact that would be expected considering that there were no significant changes in nutritional composition.

On the contrary, final body weight and feed intake indicated a statistically significant difference ($P \leq 0.05$) when cinnamic acid was applied individually or in conjunction with magnetized water. Combined supplementation (0.5% and 1% cinnamic acid, with magnetized water, treatment T5 and T6, respectively) performances showed significantly better results compared to the other treatments in both performance indicators. The highest final body weight was (2.350 kg) and feed intake (3.700 kg) in treatment T6 and the lowest final body weight was (2.310 kg) with a feed intake of (3.696 kg).

The capillary action of cinnamic acid which is a phenolic compound having antioxidant and antimicrobial effects coupled with magnetized water which is thought to confer water properties and to enhance nutrient uptake can explain this augmentation of final weight. This synergy manifested itself in the increase of the feed conversion efficiency and growth performance. T3 and T4 (0.5% and 1% cinnamic acid, respectively) treatments also had distinctly better final weight than controls, recording a body weight of 2.121 kg and 2.145 kg respectively, although not so high as in T5 and T6. This points to the fact that magnetized water increases the bioefficacy of cinnamic acid. This is probably because cinnamic acid has the properties of a natural phenolic antioxidant, which can help in the regulation of gut microbiota by decreasing the number of harmful bacteria and increasing the number of useful microbes, thus improving nutrient absorption (Bouarab-Chibane *et al*., 2019; Johnson *et al*., 2008; Yang *et al*., 2021). Its occurrence in the diet can also trigger the digestive enzymes and enhance the digestibility of both proteins and carbohydrates with a positive impact on growth rates.

Table 2: Effect of different treatments of cinnamic acid and magnetized water on final feed intake and final body weight of broiler chickens (Mean ± SD).

Treatment	Final feed intake (Kg)	Final body weight (Kg)
T1	3.250^{a} ± 0.06	1.950^{c} ± 0.14
T2	3.240^{a} ± 0.10	1.953^{c} ± 0.09
T3	3.460^{b} ± 0.22	2.121^{b} ± 0.04
T4	3.460^{b} ± 0.01	2.145^{b} ± 0.11
T5	3.696^{c} ± 0.14	2.310^{a} ± 0.16
T6	3.700^{c} ± 0.03	2.350^{a} ± 0.01
Sig.	0.05	0.05

* T1 was the control group that did not have additives; T2 was added with magnetized water as drinking source; T3 was added with 0.5% cinnamic acid drinking source; T4 was added with 1% cinnamic acid drinking source; T5 was added with a mixture of magnetized water and 0.5% cinnamic acid drinking source; T6 was added with a mixture of magnetized water and 1% cinnamic acid drinking source. Statistical significance of the differences between treatments was regarded as P 0.05.

In the case of magnetized water, it is believed to have an effect because it physically changes the surface tension and cell permeability due to the magnetic field and could be used to enhance the transportation of water and nutrients to animal cells enhancing physiological conditions and growth rates (El-Deeb *et al*., 2025). There are also other studies that revealed that broilers that consumed magnetized water exhibited better growth performance, fewer feed per pound ratio, and immune status than those that consumed regular water (El-Hanoun *et al*., 2017). The findings are consistent with the study by Usuf *et al*. (2022), who discovered that the addition of magnetized water to natural products of plant origin (phenols or essential oils) resulted in a cumulative positive effect on the performance indicators, especially with heat stress conditions when physiological support is the most important. Also, the treatment of higher feed consumption in the treatments that involved cinnamic acid either by itself or in combination with magnetized water might be an indication that the compound could be acting as a palatability inducer to feed- explicitly because of better gut environment conditions or direct effect of the compound on feeding. Jamroz *et al*. (2006) postulated that plant phenolic compounds can increase the feeding behavior of poultry by acting on appetite-linked sensory receptors.

Total weight gain and feed conversion rate

The data presented in Table 3 consists of the effects of the different treatments with cinnamic acid and magnetized water with regards to total weight gain and feed conversion ratio (FCR) of the broilers chicken within the course of the experiment. Treatments in both variables were statistically significant (P 0.05) indicating that the additives used produced a quantifiable impact on the growth performance and feed efficiency. The control group (T1) was the one that was not provided with any additives and had the lowest total weight gain (1.910 kg) and the lowest feed ratio (1.70 kg feed/kg weight gain). On the same note, T2, which received magnetized water alone, also had very similar outcomes (1.913 kg and 1.69, respectively), and therefore, it was evident that in the absence of feed additives, magnetized water alone significantly did not affect growth performance.

On the contrary, groups enriched with cinnamic acid T3 (0.5%), T4 (1%) showed a significant increase in both parameters. T3 and T4 gained weights of 2.081 kg and 2.105 kg, respectively and had FCR of 1.66 and 1.64, respectively. These results show that cinnamic acid has a beneficial impact on growth, which can probably be related to its biological functions like antioxidant effects, the ability to modify the gut microbiota, and the increase in nutrient digestibility (Qaid *et al*., 2024; Syed *et al*., 2021). T5 and T6 with the addition of magnetized water and cinnamic acid (0.5% and 1%, respectively) produced the best performance results. T6 had the best weight gain (2.310 kg) and FCR (1.60) with T5 right behind (2.270 kg and FCR of 1.62). This finding indicates a described synergistic effect of cinnamic acid and magnetized water, potentially because of their complementary action in enhancing metabolic activity, digestion, and nutrient assimilation (Ebrahim and Azab, 2017; Abd El-Ghany, 2022).

The increase in the feed conversion efficiency implies that the broilers could use the feed better when the combined additives were present. It could be explained by the fact that it enhanced the enzymatic activity, decreased oxidative stress in the gut, and maximized water metabolism due to the change in the physical characteristics of magnetized water (Abd El-Ghany, 2022). In general, the results prove that the use of natural growth promoters such as cinnamic acid and technological interventions such as magnetized water can result in the serious enhancement of weight growth and feed efficiency in broiler production systems. Such findings can be attributed to the overall tendency of substituting antibiotic growth promoters with safe, effective, and environmentally sustainable alternatives (Rahman *et al.*, 2022).

Table 3: Effect of different treatments of cinnamic acid and magnetized water on total weight gain and feed conversion rate of broiler chickens (Mean ± SD).

Treat-ment	Total weight gain (Kg)	Feed conversion rate (kg feed/kg Weight Gain)
T1	1.910^{c} ± 0.11	1.70^{c} ± 0.15
T2	1.913^{c} ± 0.19	1.69^{c} ± 0.06
T3	2.081^{b} ± 0.07	1.66^{b} ± 0.24
T4	2.105^{b} ± 0.10	1.64^{ab} ± 0.18
T5	2.270^{a} ± 0.12	1.62^{a} ± 0.17
T6	2.310^{a} ± 0.09	1.60^{a} ± 0.02
Sig.	0.05	0.05

T1 was the control group with no additives, T2 was supplemented with only a source of magnetized water, T3 was supplemented with 0.5% of cinnamic acid, T4 was supplemented with 1% cinnamic acid, T5 was a combination of water that was magnetized and 0.5% cinnamic acid, and T6 was a combination of water that was magnetized and 1% cinnamic acid. Significance in treatment differences was taken to be statistically significant, at P 0.05.

Meat quality

Dressing percentage, breast cut yield and thigh cut yield

Table 4 shows the impact of various treatments of cinnamic acid and magnetized water on the dressing percentage, the cut yield of the breast of broiler chickens, and the cut yield of the thigh of broiler chickens. The findings show significant differences ($P \leq 0.05$) between the experimental treatments on all the measured carcass traits which depicts the effect of the interventions applied to the carcass composition and the meat yield. The control group (T1), which did not receive any additives, had the lowest values of the dressing percentage (69.98%), breast yield (30.90%), and thigh yield (28.50%). These baseline values are the typical results of normal rearing conditions in the absence of any supplement and are used as a benchmark of the experiment treatments to assess their effectiveness. The T2-that treated only with magnetized water did not indicate significant changes in the breast yield (30.93%) but indicated a slight numerical fluctuation in thigh yield (29.23%), indicating potentially minimal yet possible effects of magnetized water on carrison characteristics, probably by enhancing nutrient uptake and water ratios (Abd El-Ghany, 2022).

Table 4: Effect of different treatments of cinnamic acid and magnetized water on dressing percentage, breast cut yield and thigh cut yield of broiler chickens (Mean ± SD).

Treat-ment	dressing percent-age (%)	Breast cut yield (%)	Thigh cut yield (%)
T1	69.98^{c} ± 2.24	30.90^{b} ± 0.25	28.50^{b} ± 0.01
T2	70.20^{c} ± 1.10	30.93^{b} ± 0.11	29.23^{ab} ± 0.15
T3	72.31^{b} ± 1.08	31.11^{b} ± 0.45	29.31^{ab} ± 0.74
T4	72.40^{b} ± 3.01	31.15^{b} ± 0.09	29.45^{ab} ± 0.10
T5	74.82^{a} ± 1.17	32.87^{a} ± 0.44	30.10^{ab} ± 0.12
T6	75.34^{a} ± 2.03	33.30^{a} ± 1.04	30.50^{a} ± 0.81
Sig.	0.05	0.05	0.05

*T1 was a control group that was not added with any additives, T2 was added with only magnetized water as a source of drinking, T3 was added with 0.5 percent cinnamic acid, T4 was added with 1 percent cinnamic acid, T5 was added with combination of magnetized water and 0.5 percent cinnamic acid, T6 was added with combination of magnetized water and 1 percent cinnamic acid. The difference between treatments was deemed significantly different at $P \leq 0.05$.

Statistically significant changes in dressing percentage (72.31% and 72.40, respectively) and less significant (though consistent) increases in breast and thigh yields were observed by adding cinnamic acid at 0.5% (T3) and 1% (T4) instead of the control. Such effects can be explained by biological actions of cinnamic acid, such as the boosting of protein metabolism, gut health, and alleviation of oxidative stress, which lead to improved nutrient partitioning in favor of lean tissue accretion (Qaid *et al.*, 2024). The best results were noted in T5 and T6 where a mixture of magnetized water and cinnamic acid with 0.5 and 1 percent was used respectively. These treatments recorded the largest values in all parameters with the dressing percentage of 75.34, breast yield of 33.30 and the thigh yield of 30.50. These findings indicate that cinnamic acid and magnetized water have a synergistic impact, in that their combined action increases the quality of the entire carcass than when used individually.

The increase in the dressing percentage in T5 and T6 could be attributed to an increase in the feed conversion efficiency and increased protein deposition in the muscle tissues as opposed to adipose tissues. In the meantime, there is an improvement in the breast and thigh yield, indicating a positive effect on the economically desirable cuts in the commercial broilers production systems, which leads to the augmentation of the productivity and profitability. The results are in line with the past studies that have shown the effectiveness of phytogenic feed additives and

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technological water treatment in enhancing the carcass characteristics. As an example, Syed *et al.* (2021) have added that phytogenic chemicals such as cinnamic acid enhance nutrient digestibility and decrease microbial burden in the gut that can boost muscle deposition. Also, Abd El-Ghany (2022) demonstrated that magnetized water modifies physical water characteristics where cellular hydration and nutrient uptake are enhanced, which eventually results in improved carcass composition.

Appearance, texture and tenderness, aroma and flavor

Table 5 highlights the effects of various treatments that use cinnamic acid and magnetized water on the most important sensory properties of broiler meat: appearance, texture and tenderness, aroma and flavor. These are critical parameters that make poultry products to be acceptable to consumers and marketable and are usually assessed using trained sensory panels. Appearance scores were found to be varying between 8.31 in T1 (control) and 8.75 in T6. The appearance scores of the control group (T1) and the magnetized water group (T2) were statistically the same and significantly lower than scores of the treated groups. T3 and T4 (0.5% and 1% cinnamic acid, respectively) showed a better appearance (8.40 and 8.43), whereas T5 (8.68) and T6 (8.75) were the ones that used cinnamic acid together with magnetized water. This means that they have a synergistic effect resulting in the enhancement of visual meat quality (probably through increase in carcass conformation, muscle hydration, and stability in colour) which are linked to improved physiological and oxidative conditions in the tissue (Qaid *et al.*, 2024; Abdel-Baky *et al.*, 2023).

Table 5: Effect of different treatments of cinnamic acid and magnetized water on appearance, texture and tenderness, aroma and flavor of broiler chickens (Mean ± SD).

Treatment	Appearance	Texture and tenderness	Aroma and flavor
T1	$8.31^{c} \pm 0.27$	$7.90^{c} \pm 0.41$	$7.34^{c} \pm 2.10$
T2	$8.32^{c} \pm 0.15$	$7.90^{c} \pm 0.09$	$7.39^{c} \pm 0.18$
T3	$8.40^{b} \pm 0.32$	$8.14^{b} \pm 0.34$	$7.52^{b} \pm 0.04$
T4	$8.43^{b} \pm 0.10$	$8.16^{b} \pm 0.19$	$7.54^{b} \pm 1.00$
T5	$8.68^{a} \pm 0.04$	$8.33^{a} \pm 0.11$	$7.81^{a} \pm 0.74$
T6	$8.75^{a} \pm 0.08$	$8.38^{a} \pm 0.24$	$7.85^{a} \pm 0.01$
Sig.	0.05	0.05	0.05

T1 was the control group that had no additives; T2 was supplemented with only the magnetized water as a source of drink; T3 was supplemented with only 0.5% cinnamic acid; T4 was supplemented with only 1% cinnamic acid; T5 received a combination of the magnetized water and 0.5% cinnamic acid; T6 received a combination of the magnetized water and 1% cinnamic acid. Treatment differences were deemed to be statistically significant at P 0.05.

The most important parameters to a consumer are texture and tenderness, which depend on the integrity of muscle fibers, the water holding capacity, and the distribution of fat. The lowest score was obtained in the control group (7.90), T5 and T6 had the largest tenderness scores (8.33 and 8.38, respectively), and the difference was statistically significant ($P \leq 0.05$). The observed improvement in the tenderness of groups in which cinnamic acid was used, particularly when mixed with magnetized water, could be explained by a decrease in oxidative damage and a better muscle network due to the antioxidant activity and increased use of nutrients (Guo, 2021). With regard to sensory perception, aroma and taste are the most important as far as the overall palatability of meat is concerned. The T1 and T2 groups had the lowest values (7.34 and 7.39) and the highest values were recorded in T5 (7.81) and T6 (7.85). The changes in flavour and aroma could be explained by the antimicrobial and antioxidative action of cinnamic acid, which weaken lipid oxidation, protect volatile aromatic compounds, and overall freshness (Syed *et al.*, 2021). In addition, better metabolism of the birds that were supplied with magnetized water could also help increase the quality of the meat products by reducing off flavors and maximizing the natural flavor profile.

The findings help to conclusively indicate that cinnamic acid and magnetized water (T5 and T6) have a significant positive effect on all the assessed sensory characteristics of broiler meat. This can be applied in practice due to the biological characteristics of cinnamic aids like anti-inflammatory and antioxidant effects- as well as physiological advantages of magnetized water in the process of facilitating cell hydration and nutrient absorption. These make the meat better biochemically and structurally. The obtained results are consistent with the findings of Abd El-Ghany (2022) and Qaid *et al.* (2024), who revealed that the addition of natural phytogenic compounds to physical water treatment technologies can significantly enhance the quality of functions of poultry meat and its acceptability to the consumers.

Oxidative stress

Table 6 shows the actions of dietary supplementation of cinnamic acid, magnetized water and combination of both on Glutathione Peroxidase (GSH-Px) and Superoxide Dismutase (SOD) in broilers chicken. These enzymes are key constituents of the cellular antioxidant defense mechanism and are used as biomarkers to oxidative stress and metabolic proficiency in poultry. The lowest value of GSH-Px activity was recorded with the control group (T1) and the group treated only with magnetized water (T2) (2.32 and 2.30 U/L, respectively), and there were no significant differences between them. Nevertheless, the GSH-Px activity due to the presence of cinnamic acid in T3 and T4 (2.65 and 2.66 U/L, respectively) was much higher and showed greater antioxidant capacity of enzymes. The maximum values were obtained in T5 (2.89 U/L) and T6 (3.04 U/L) which included cinnamic acid, and the magnetized water, and demonstrated statistically significant improvements compared to all other groups (P 0.05).

Table 6: Effect of different treatments of cinnamic acid and magnetized water on glutathione peroxidase (Gpx) and superoxide dismutase (SOD) of broiler chickens (Mean ± SD).

Treatment	Glutathione peroxidase (G-px) U/L	Superoxide dismutase (SOD) µm/mL
T1	2.32^{c} ± 0.06	2.53^{c} ± 0.14
T2	2.30^{c} ± 0.10	2.58^{c} ± 0.09
T3	2.65^{b} ± 0.22	2.71^{b} ± 0.04
T4	2.66^{b} ± 0.01	2.75^{b} ± 0.11
T5	2.89^{a} ± 0.14	2.96^{a} ± 0.16
T6	3.04^{a} ± 0.03	3.30^{a} ± 0.01
Sig.	0.05	0.05

* T1 is control group or no additives, T2 was only given drinking water that was magnetized, T3 was given drinking water with cinnamic acid that was 0.5 percent, T4 was given drinking water with cinnamic acid that was 1 percent and T5 was given drinking water with a combination of cinnamic acid that was 0.5 percent with the drinking water and T6 was given drinking water with a combination of cinnamic acid that was 1 percent. Statistical significance was taken to be P ≤ 0.05.

The antioxidant nature of cinnamic acid could be the reason why GSH-Px activity increased during the observed range as the compound has been reported to amplify glutathione-dependent enzyme systems by alleviating reactive oxygen species (ROS) and regulating the redox-sensitive pathways (Qaid *et al*., 2024). Also, magnetized water has been discussed to have a beneficial effect on the structure and availability of ions in water, which might positively change enzyme activity and metabolic performance (Abdel-Baky *et al*., 2023). The same was also the case with SOD activity. The least values were registered in T1 (2.53 µm/mL) and T2 (2.58 µm/mL). T3 and T4 increased significantly (2.71 and 2.75 mu/mL, respectively) but not significantly more, with the peaks of SOD 3 and 4 (2.96 and 3.30 0.mu/mL, respectively) observed once again. Synergistic effects seem to be observed in the combination treatments and the activities of antioxidant enzymes increase substantially.

SOD plays a vital role of catalyzing the dismutation of the superoxide radical to oxygen and hydrogen peroxide, which subsequently averts oxidative damage of tissues. The fact that it was upregulated in the presence of the Cinnamic Acid Supplementation indicates that the birds had reduced oxidative load, and they had better redox homeostasis. The improvement of the combination groups is in accordance with the results of the recent literature that demonstrates that synergistic approaches with the use of natural antioxidants and physical water treatment can be more effective in terms of protection (Abd El-Ghany, 2022; Syed *et al*., 2021).

Physiologically, high GSH-Px and SOD concentrations reflect an improved level of cell protection, less oxidative stress, and increased health condition of broiler chickens. This enzyme increase is linked to the gains in growth performance, feed efficiency and meat quality reported in the preceding (Tables 2-5) and the significance of oxidative balance to productive characteristics. Dietary techniques that enhance antioxidant defenses are becoming more useful in the context of contemporary poultry systems, in which high metabolic rate will predispose birds to oxidative stress. These discoveries justify the use of cinnamic acid a non-toxic natural phenolic and magnetized water as non-pharmaceutical interventions to enhance poultry health and productivity in the sustainable production systems.

CONCLUSIONS

The experiment established the effectiveness of cinnamic acid and magnetized water, especially when used together to improve growth performance, carcass traits and the quality of meat among broiler chickens. The combined treatments (T5 and T6) reached the highest final body weight, high feed ratio, and dressing percent, as well as, a tremendous improvement in sensory traits. GSH-Px and SOD increased their activity, which means that their metabolic health and oxidative stability were improved. These findings confirm the fact that the combination of natural compounds with technology is safe and effective and can be used as a viable alternative to conventional growth boosters. This is a way of supporting the use of antibiotic free production of chicken.

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NOVELTY STATEMENT

The animal care procedures and ethical approval were done in accordance with the guidelines provided by the local ethics committee of the Technical Institute, Kut, Middle Technical University.

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AUTHOR'S CONTRIBUTION

Data collection and organization was mainly done by the first author. The second author worked on the discussion of the laboratory work and results, the third author did the statistical analysis and review of the manuscript. Each of the authors took part in the general supervision.

Generative AI and AI-assisted technology statement

The author did not use generative AI or AI-assisted technologies in the preparation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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