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The influence of vitamin C and early-age thermal conditioning on the quality of meat and specific production characteristics of broilers during heat stress

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Abstract: Heat stress (HS) is one of the greatest problems in contemporary chicken production and it entails significant economic losses. The purpose of this paper is to examine the influence of early-age thermal conditioning (ETC), vitamin C (Vit C) supplementation, and their combination on the production characteristics and specific quality parameters of the meat of broilers which were exposed to chronic HS in the last two weeks of breeding. Four hundred broilers (Cobb 500) of both sexes were divided into 4 experimental groups. Group C was given Vit C (2 g/L) dissolved in water from day 22 until the end of production. Group T was exposed to ETC for a period of 24 h at the temperature of 38 ± 1 °C and 40%–60% relative humidity on the fifth day of breeding. Group TC was the combination of the groups T and C, while group K was the control group. The results indicate that ETC, independently or in combination with Vit C, improves the production characteristics in terms of feed conversion reduction ($P < 0.05$). The examined treatments increase the volume ($P < 0.05$) of certain parts of the body (carcass, legs and thighs, and back) with regards to total body weight, especially in group TC. Regarding meat quality determined according to pH value and meat color criteria (CIEL*), the best results were also observed in group TC, followed by groups T and C. These results justify the use of Vit C and ETC in summer conditions, when heat stress is expected; however, the best results can be achieved by combining these two methods, thus producing a synergistic effect.

Key words: Broiler production, heat stress, meat quality, thermal conditioning, vitamin C

1. Introduction

Heat stress (HS) is one of the greatest problems in contemporary chicken production, reinforced by current climate changes arising from global warming. It causes significant losses including reduced growth, decreased feed utilization, reduced immune response, changes in gut microflora, increased mortality, and meat quality reduction [1]. Genetic selection in poultry has led to an intensive expansion of broilers with high metabolic rates, which leads to large-scale heat production due to the increased feed consumption [2,3]. Birds are homeotherms and maintain their body temperature within a narrow range. However, birds have a reduced ability of releasing heat at high temperatures [4]. The facts that birds do not have any sweat glands and that their skin is covered in feathers are also aggravating factors [5]. In addition, a large number of broilers are raised in small areas, which makes achieving thermoneutral temperature in the production facility more difficult. All of these facts indicate that HS is an important factor that can cause significant economic losses in the chicken production process.

Different authors suggest different strategies of reducing the effects of HS. One of them involves manipulation of ambient factors, such as increasing ventilation, using cooling systems, implementing appropriate lighting schedules, early-age thermal conditioning (ETC), feed restrictions, and stocking density reduction [6,7]. The use of different nutrients such as probiotics, microelements, and vitamins has also proven to be beneficial in the reduction of HS [8,9]. Several of these strategies have adverse effects as well, i.e. feed restrictions will reduce the mortality of broilers, but it will also simultaneously result in lower production in the process of breeding [10]. For these reasons it is necessary to use easily implementable

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and available strategies which at the same time minimize the adverse effects on production results. A good example of this kind of strategy is the implementation of ETC and vitamin C (Vit C) supplementation.

Vit C (L-ascorbic acid) is one of the most important antioxidants regularly synthesized in birds [11]. It is included in the leukocyte production, thus boosting the bird's immune response. Its synthesis is insufficient during HS, and these kinds of stressful conditions also interfere with the absorption of Vit C in the digestive system, therefore increasing the necessity of this vitamin in stressful breeding conditions [12,13]. However, published studies lack information on the effects this vitamin has on the processes occurring in the muscles during HS. These studies describe exposure to high temperatures over the course of 24 h on the 5th day of age as ETC and propose it as a technique which aims to achieve thermotolerance in broilers exposed to HS in the later stages of production [14–18]. The mechanism of this effect is reflected in the fact that during the later phases this manner of thermal manipulation decreases the body temperature through thyroid hormones in blood, as well as by reducing the levels of corticosterone [19].

HS affects the quality of meat as a result of physiological changes occurring in the metabolic processes in muscles [20,21]. It has been proven that these kinds of ambient conditions during chicken production lead to oxidative stress in muscles, reduction of pH values, denaturation of muscle proteins, and increased fat accumulation in muscles [22]. These changes may result in pale meat [23,24] with limited water binding capacity, i.e. pale, soft, exudative meat (PSE), which is undesirable both for consumers and the meat industry, which requires good quality raw meat in order to obtain quality products with no economic losses [25]. The purpose of this paper was to investigate the effects of ETC, Vit C supplementation, and the combination of these two methods on certain meat quality parameters, as well as production characteristics of broilers exposed to chronic HS, which has not been done before.

2. Materials and methods

2.1. Animals and experimental design

The experiment involved 400 one-day-old Cobb 500 broilers. The broilers were divided into 4 groups in 4 repetitions, into divided boxes, all in the same production facility. Each group included equal numbers of male and female broilers (feather sexing). Group C received Vit C dissolved in water from day 22 until the end of the breeding (Veterinary Institute Subotica, Serbia) in the amount of 2 g/L (1 g of Vit C contains 100 mg of active substance). Group T on the 5th day of breeding was transferred to an environmentally controlled chamber and exposed to ETC for a period of 24 h at the temperature of 38 ± 1 °C and 40%–60% relative humidity (RH). Group TC was exposed to ETC in the same manner as group T, but this group also received Vit C dissolved in water in the same manner as group C, starting from the 22nd day of breeding. Group K was the control group, and the broilers in this group were neither exposed to ETC nor received Vit C supplementation.

Since this research was conducted in the summer of 2018, high temperatures were expected, and they did occur on the 29th day of breeding, continuing until the end of the production cycle. The summer of 2018 was determined to have been the warmest summer in Serbia according to the lowest air temperature since the temperature measurements started. On 74 days the subjective temperature experience was over 30°C[1]. Ambient temperature in the facility was measured from 08:00 to 20:00 in 2-h intervals. The Figure shows the average temperature in the facility for the trial period between the 29th and 42nd day of breeding. All groups (including K group) were subjected to the heat stress conditions. These temperatures correspond to chronic HS. RH remained between 40% and 70%. On the remaining days (except for day 5 for groups T and TC) the ambient conditions were within the recommended values for this chicken hybrid, and equal for all test groups. During the entire production cycle, the broilers received commercial broiler feed (Table 1) and water ad libitum.

2.2. Growth performances and carcass traits

During the production cycle the feed consumption was tracked, the broilers' weight were checked on the 21st and the 42nd day, and the feed conversion was calculated. Since the treatments of groups K and C and groups T and TC were not different until the 21st day of breeding, the body weight (BW), feed consumption, and feed conversion results were provided for the above mentioned groups collectively. The BW results achieved between the 22nd and 42nd day of breeding were obtained through calculations in which the average weight of the broilers from a particular group on the 21st day was subtracted from the weights of each broiler weighed at the end of the production.

On day 42 the broilers were sent to be slaughtered. All broilers were weighed alive, right before the slaughter, as well as after they had been exsanguinated. On the slaughter line, 24 broilers were selected from each group (total of 96), i.e. 6 broilers from each repetition, by random sampling, ensuring equal numbers of male and female broilers. After plucking and evisceration, the "grill" mass of the broilers, namely carcass (meat prepared for grilling), was checked,

[1] Seasonal Bulletin for Serbia, Sumer 2018. Hydrometeorological Service of Serbia [online]. Web: http://www.hidmet.gov.rs/podaci/meteorologija/eng/summer.pdf [accessed 27 May 2019].

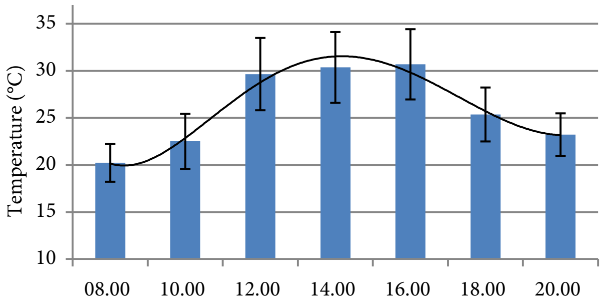

Figure. Average temperature in the facility between days 29 and 42 of breeding (°C).

and then cutting into body parts was performed in order to determine the yield and quality of the chicken carcasses. WEDA FD-121-7.5 scales (WEDA, the Netherlands) were used for measuring. Breast meat samples were taken from each broiler and kept at a temperature of 4 °C for 24 h, after which the color and pH values were determined.

2.3. Measuring of breast meat color

The color of breast meat was measured at 24 h postmortem (pm) (approximately the time necessary for fresh chicken meat to reach stores after slaughter) on the surface and inside each sample three times. Instrumental breast meat

Table 1. Content and chemical composition of the commercial diets.

Ingredients (g/kg)	Starter 1–21 days old	Grower 22–35 days old	Finisher 36–42 days old
Maize	488.3	525.1	577.3
Full fat soybean	169.9	228.0	220.3
Soybean meal	199.3	122.5	59.7
Wheat feed flour	90.0	49.9	40.7
Sunflower meal	0.0	30.0	60.0
Monocalcium phosphate	11.8	10.3	9.4
Limestone	15.9	12.6	12.0
Salt	2.1	2.7	2.7
Sodium bicarbonate	1.8	1.8	1.8
L-Threonine	1.2	0.2	-
L-Lysine	3.7	2.0	1.8
DL-Methionine	4.0	2.9	2.3
Mycotoxin binder	2.0	2.0	2.0
Vitamin and mineral premix	10	10	10
Chemical composition			
Crude protein (%)	22	19	17
Fat (%)	5	5	5
Crude fiber (%)	5	5	6
Metabolisable energy (MJ/kg)	13	13	13
Lysine (%)	1.15	0.90	0.84
Methionine-cysteine (%)	0.85	0.70	0.60
Calcium (%)	1.20	0.98	0.70
Phosphorus (%)	0.80	0.61	0.54
Sodium (%)	0.15	0.15	0.15
Vitamin A (IU/kg of feed)	12500	12500	12500
Vitamin D_3 (IU/kg of feed)	2000	2000	1500
Vitamin E (mg/kg of feed)	40	40	20
Vitamin C (mg/kg of feed)	30	30	30

color parameters were determined using the Minolta Chroma Meter CR-400 colorimeter (Minolta Co., Ltd., Japan) at d-65 lighting and standard viewing angle of 2°, with an 8 mm opening on the measuring head. The instrument had previously been heated in accordance with the manufacturer's instructions, as well as calibrated in accordance with the standard procedure. The measurement results are presented in the CIEL*a*b* system [26], where L* defines lightness, a* denotes the green-red component, and b* the blue-yellow component.

2.4. pH values of breast meat

The determination of pH values in the breast meat was performed at 24:00 in accordance with the reference method SRPS ISO 2917:2004 using the portable Testo 205 pH-meter (Testo AG, USA), equipped with a hardened combined glass electrode with a temperature probe, for direct determination of pH values in meat and meat products. Before and during the reading, the pH-meter was calibrated using standard phosphate buffers (pH 7.02 and 4.00 at 20 °C). The measurement was conducted three times per sample.

2.5. Statistical analysis

The results in the paper are presented in the form of arithmetic mean with standard deviation. The statistical processing of data was performed using R software implementing the analysis of variance (ANOVA) and Duncan's post hoc test where the statistical significance is presented at the $P < 0.05$ level.

This paper is a part of the research for a doctoral dissertation which received the approval of the Ethics Commission on the Protection of Animals Used for Scientific Purposes of the University of Novi Sad (EK: II-2018-02).

3. Results and discussion

3.1. Growth performances

Many published papers suggest that HS leads to a reduction of feed consumption and a reduction of the final BW, as well as to an increase of feed conversion in broilers [10,22,27]. In this research, the live broiler weights measured right before slaughter were not statistically different between the examined groups (Table 2). The greatest average weight was achieved in group C (2272.71 g), while group K had the least satisfactory results (2215.21 g). If we compare the average BW achieved in this study to the expected average weight defined by the breeder of this hybrid, which amounts to 2857 g[2] for the period of 42 days, it can be observed that HS caused a significant obstruction in growth in all examined groups. The reduced average body weight at the end of the production cycle could be explained by the fact that feed consumption in broilers exposed to HS was reduced in order to decrease the metabolic heat production and maintain homeothermy [28].

Statistical analysis did not reveal a significant difference between all groups in terms of average BW achieved by broilers in the period between days 22 and 42 of breeding. The average broiler BW on the 21st day of breeding was lower, with statistical significance in groups exposed to ETC when compared to groups not exposed to this treatment. This treatment had no negative consequences for the final BW, which may be due to better feed conversion in the period between days 22 and 42 of breeding in groups exposed to ETC. This could be seen as a type of compensatory growth. In their research, Yahav and McMurtry [29] reported that compensatory growth occurs immediately right after ETC, which is not in accordance with our results; in this research, this trend can be observed only in the second part of the production. Yahav and Plavnik [17] also concluded that ETC led to compensatory growth in the final stages of breeding; however, in their research, the broilers exposed to ETC had even greater BW than the control group at the end of the production cycle, which has not occurred in this study. When the average feed consumption per group is observed (Table 2), the largest feed consumption per broiler over the course of the entire production cycle was observed in group C (4111.22 g), while group T had the smallest feed consumption (3846.75 g). There was no statistically significant difference between groups T and TC in this period, while this was the case between other groups. A similar analogy was observed in the period between days 22 and 42 of breeding. In the period between days 1 and 21, no statistical difference of feed consumption per group was observed.

The most efficient conversion over the course of the entire production cycle was detected in group T (1.72), while group K had the least satisfactory conversion (1.82) with statistical significance. No statistically significant difference was observed between groups T and TC, or between groups K and C. A similar situation can also be observed in the period between days 22 and 42 of the production cycle, where the most efficient conversion was detected in group T and the least favorable in group K with statistical significance. In the first 21 days, there was no statistically significant difference in feed conversion. Taking into account the results of feed conversion during the entire production cycle, it can be determined that ETC caused better feed utilization when compared to groups not exposed to ETC, which is in accordance with the research results obtained by Oral Toplu et al. [22]. These

[2] Broiler Performance & Nutrition Supplement (2015). Cobb 500 [online]. Website: http://www.cobb-vantress.com/docs/default-source/cobb-500-guides/Cobb500_Broiler_Performance_And_Nutrition_Supplement.pdf [accessed 27 May 2019].

Table 2. Broiler chicken production results.

Traits	K	C	T	TC
Body weight (g)				
1–21 days	855.73 ± 11.81[a]		820.52 ± 17.24[b]	
22–42 days	1359.48 ± 108.02	1416.98 ± 30.24	1418.44 ± 18.85	1417.40 ± 44.04
1–42 days	2215.21 ± 108.02	2272.71 ± 30.24	2238.96 ± 18.85	2237.92 ± 44.04
Feed consumption (g/broiler)				
1–21 days	1131.28 ± 41.92		1078.69 ± 31.93	
22–42 days	2885.49 ± 43.51[b]	2979.94 ± 37.91[a]	2768.06 ± 34.59[c]	2825.17 ± 42.54[bc]
1–42 days	4016.77 ± 40.83[b]	4111.22 ± 72.07[a]	3846.75 ± 52.61[c]	3903.86 ± 71.83[c]
Feed conversion ratio (g feed/g gain)				
1–21 days	1.32 ± 0.04		1.31 ± 0.03	
22–42 days	2.13 ± 0.13[a]	2.10 ± 0.02[ab]	1.95 ± 0.01[c]	1.99 ± 0.04[bc]
1–42 days	1.82 ± 0.07[a]	1.81 ± 0.01[a]	1.72 ± 0.01[b]	1.74 ± 0.01[b]

[ab] Within columns means bearing different superscripts differ significantly at $P < 0.05$.

results confirm that ETC leads to a better feed usability, thus stimulating thermotolerance in HS conditions in the final phases of breeding. It is an interesting fact that the group which received Vit C achieved the highest average weight at the end of the production cycle, but with no statistical significance when compared to the other groups. In addition, this group had the greatest feed consumption in the period between days 22 and 42 of breeding, as well as during the entire production cycle (days 1–42). Statistical significance was observed compared to other groups, but without difference in feed conversion when compared to the control group in the end. These results are not compatible with the results obtained by Oral Toplu et al. [22], who concluded that Vit C stimulated feed conversion in broilers bred in HS conditions. Different results may be due to dosages of Vit C, which were different, as well as to the manner in which this supplement was administered.

3.2. Carcass traits

The results of individual slaughter characteristics expressed in percentages in relation to the total live chicken BW are provided in Table 3. The BW after exsanguination was highest for group TC (96.70%), but with no statistical significance when compared to other groups. A similar trend can be observed in slaughter characteristics of wings and necks, where it was observed that the highest values were present in group TC, but with no statistical significance. Group TC had the largest volume of carcass (grill chicken) (69.25%) when compared to other groups; when compared to group K specifically (66.43%), a statistical difference was obtained. Oral Toplu et al. [22] concluded that in HS conditions there were larger percentages of carcass (grill chicken) in broilers supplemented with Vit C or exposed to ETC when compared to a group which did not undergo this kind of treatment, which is in accordance with our results. This research did not include a combination of Vit C and ETC, which led to the best results in our case with statistical difference. Sahin et al. [30] also reached a conclusion that the implementation of Vit C in chicken production during HS increased the weight of carcass. The best results of the chicken leg and thigh weights, as well as back, were also achieved in group TC, while the lowest values for these parameters were observed in group K. In comparing groups C and T with group K, no statistical significance was observed, which is in accordance with the research conducted by Oral Toplu et al. [22]; however, the combination of these two treatments in our study led to a statistically significant difference when compared to the K group, which provides a justification for the implementation of the combination of these two treatments and their synergistic effect.

Based on the results of our research, it can be observed that Vit C, independently and in combination with ETC, reduces the gizzard weight with statistical significance when compared to the other two groups. In their research Oral Toplu et al. [22] reached the conclusion that ETC and Vit C equally reduced the gizzard weight in HS conditions, which is only partially in accordance with our results. On the other hand, Sahin et al. [30] reported that Vit C in HS conditions increased the gizzard weight with statistical significance when compared to a group which did not receive this type of treatment. No statistically significant difference was observed for other parameters of the carcass parts in our study, which is in accordance with the results obtained by Oral Toplu et al. [22]. It is important to mention that the broilers in experimental groups had larger breast weights with corresponding bones when compared to group K. Even though this difference is not statistically significant, the fact that groups T and TC had more successful conversion than the other two groups means that a larger weight of the "most expensive" part of the broiler (breast meat) is produced with smaller feed consumption, which justifies the use of these treatments in broilers in summer conditions.

3.3. pH values of breast meat

By examining the technological characteristics of the breast meat (Table 4), it has been determined that the breast meat in group TC had the highest average pH value of 5.69. The lowest average pH value in breast meat of 5.61 was detected in group K with statistical significance when compared to the other groups. There was no statistically significant difference for this investigated parameter between other groups exposed to ETC and Vit C. Based on the pH values, Barbut et al. [31] suggest that there are three different types of breast meat quality, and that the meat is PSE (pale, soft, exudative) when the pH values are under 5.7, DFD (dark, firm, dry) when the pH values are higher than 6.1, and of expected quality RFN (reddish-pink, firm, nonexudative) when the pH values are between 5.7 and 6.1. According to these meat quality determination criteria, all the groups in our study have a slightly lower quality (PSE meat), which may be due to the effects of HS to which the broilers were exposed. The presented breast meat pH value data indicate that the values in treated groups were very balanced and, with statistical significance, more satisfactory when compared to group K, which suggests that all treatments had a positive effect on the breast meat pH value and quality. It is worth mentioning that the breast muscle pH values in group TC were near the limit value between normal and lower quality if these criteria are taken into account in determining the meat quality. The PSE meat is tightly connected to low pH values of the muscles. In other words, when the animals are exposed to antemortem stress, the pm glycolysis in the muscles of those broilers is accelerated, resulting in abnormally low pH value levels, while the muscle temperature is still high [32]. This is the reason why HS triggers the development of PSE meat in this study, given the fact that it leads to higher muscle temperatures. The combination of high muscle temperatures and low pH values of water lead to the denaturation of muscle proteins which are responsible for

Table 3. Specific slaughter characteristics expressed in percentages in relation to the total BW (n = 96).

Traits	K	C	T	TC
Weight after bleeding	96.35 ± 0.63	96.29 ± 0.61	96.41 ± 0.99	96.70 ± 0.88
Carcass (grill chicken)	66.43 ± 6.62^{b}	68.52 ± 2.84^{ab}	68.48 ± 2.23^{ab}	69.25 ± 2.60^{a}
Breasts with bones	24.31 ± 2.77	25.24 ± 2.10	25.11 ± 1.68	25.10 ± 1.70
Legs and thighs	19.70 ± 2.17^{b}	19.83 ± 1.06^{b}	20.43 ± 0.99^{ab}	20.74 ± 0.97^{a}
Wings	8.24 ± 0.81	8.44 ± 0.62	8.37 ± 0.56	8.45 ± 0.40
Back	13.70 ± 2.19^{b}	14.60 ± 1.19^{ab}	14.36 ± 1.52^{ab}	14.77 ± 1.57^{a}
Neck	3.96 ± 0.46	3.76 ± 0.54	3.98 ± 0.58	4.04 ± 0.52
Liver	2.62 ± 0.54	2.58 ± 0.47	2.46 ± 0.48	2.37 ± 0.41
Heart	0.53 ± 0.13	0.49 ± 0.12	0.46 ± 0.13	0.48 ± 0.12
Gizzard	1.44 ± 0.30^{a}	1.26 ± 0.32^{b}	1.45 ± 0.28^{a}	1.25 ± 0.32^{b}

^{ab} Within columns means bearing different superscripts differ significantly at $P < 0.05$.

Table 4. pH value and color parameters observed inside the chicken breast meat (n = 96).

Traits	K	C	T	TC
pH	5.61 ± 0.11^{b}	5.67 ± 0.09^{a}	5.68 ± 0.11^{a}	5.69 ± 0.09^{a}
L*	58.71 ± 4.10^{a}	57.66 ± 2.84^{ab}	57.49 ± 3.78^{b}	57.08 ± 3.01^{b}
a*	1.80 ± 0.84	1.55 ± 0.81	1.69 ± 0.65	1.69 ± 0.86
b*	3.18 ± 1.27^{a}	2.62 ± 1.00^{b}	2.57 ± 1.08^{b}	2.40 ± 1.19^{b}

^{ab} Within columns means bearing different superscripts differ significantly at $P < 0.05$.

Table 5. Color parameters observed on the surface of breast meat (n = 96).

Traits	K	C	T	TC
L*	74.48 ± 2.65^{ab}	75.08 ± 2.48^{a}	73.78 ± 2.57^{b}	75.17 ± 2.28^{a}
a*	0.81 ± 0.79^{ab}	0.68 ± 0.77^{b}	0.99 ± 1.04^{a}	0.93 ± 0.77^{ab}
b*	5.13 ± 1.14	4.91 ± 1.24	5.00 ± 1.69	5.28 ± 1.34

^{ab} Within columns means bearing different superscripts differ significantly at P < 0.05.

the limited water binding capacity in this type of meat, as well as to an increased rate of oxyhemoglobin autoxidation, which has a significant effect on the meat color and the development of paleness [33].

3.4. Breast meat color

The color of meat is another important parameter determining the meat quality, and it is directly connected to pH value, water binding capacity, and the chemical composition of meat [34,35]. Examining the color indicators (CIEL*a*b*) inside the mm. pectoralis (Table 4), it can be observed that the muscles in group K have the lightest color with lightness (L*) of 58.71, while the darkest muscles are found in group TC with lightness (L*) of 57.08 with statistical significance when compared to the control group. The proportion of red color (a*) in the chicken breast meat measured inside was between 1.55 in group C and 1.80 in group K, with no statistical significance. The greatest proportion of yellow (b*) was detected in breast muscles in group K (3.18), while the smallest proportion of yellow was observed in group TC (2.40); all values were measured inside the breast muscles. Based on lightness L* as a parameter and the criterion for "normal" meat of 48 < L* < 52 [36], the chicken mm. pectoralis of breast meat, i.e. its inside, in all groups in our study is considered light-colored meat and can be placed in the PSE meat category. In this case, the best results were again observed in group TC (with statistical significance), followed by groups T, C, and finally group K with the lightest color. Oral Toplu et al. [22] obtained similar results suggesting that these types of treatments stimulate the development of meat color. A similar situation was observed when examining the proportion of yellow color inside the meat; the best results were detected in group TC, while the least satisfactory ones were in group K, with statistical significance.

Slightly different results were obtained when examining the surface of breast meat (Table 5). Group T had the darkest breast meat, with lightness L* of 73.78, while group TC had the lightest ones with lightness L* of 75.17, with statistical significance. The proportion of red color (a*) at the surface of breast meat was between 0.68 and 0.99. The proportion of yellow color (b*) was between 4.91 and 5.28, with no statistically significant difference between the groups. These results, which stand in contrast to the values measured inside the meat, may be due to the effects of exposure to high temperatures involved in the process of scalding, which is a part of slaughter, and the unequal durations of this process for each broiler. Therefore, the values measured inside the meat can be considered relevant and representative for interpretation.

4. Conclusion

A conclusion can be drawn that ETC, independently and in combination with Vit C, improves the production characteristics in HS conditions in terms of feed conversion reduction. In addition, the examined treatments contribute to increasing the volume of specific body parts (carcass – grill chicken, legs and thighs, and back) in relation to the total BW, predominantly in group TC, in which the synergistic effect of two independent treatments is stimulated. The gizzard weight is smaller in groups which received Vit C (C and TC), which suggests that this treatment reduces the gizzard weight. In terms of color and pH value, the best results were also achieved in group TC, followed by groups T and C. Such results justify the use of Vit C and ETC treatments in summer ambient conditions, when HS is to be expected, and simultaneously lead to a new conclusion that the best results can be achieved by combining these two methods, thus achieving a synergistic effect.

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Conflict of interest

The authors declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

References

1. Zaboli G, Huang X, Feng X, Dong A. How can heat stress affect chicken meat quality? – A review. Poultry Science 2018; 98 (3): 1-6. doi: 10.3382/ps/pey399
2. Havenstein GB, Ferket PR, Qureshi MA. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets 1. Poultry Science 2003; 82 (10): 1500-1508. doi: 10.1093/ps/82.10.1500
3. Syafwan S, Kwakkel RP, Verstegen MWA. Heat stress and feeding strategies in meat-type chickens. World's Poultry Science Journal 2011; 67 (4): 653-674. doi: 10.1017/S0043933911000742
4. Yahav S. Alleviating heat stress in domestic fowl: Different strategies. World's Poultry Science Journal 2009; 65 (4): 719-732. doi: 10.1017/S004393390900049X
5. Loyau T, Berri C, Bedrani L, Métayer-Coustard S, Praud C et al. Thermal manipulation of the embryo modifies the physiology and body composition of broiler chickens reared in floor pens without affecting breast meat processing quality. Journal of Animal Science 2013; 91 (8): 3674-3685. doi: 10.2527/jas.2013-6445
6. Khan RU, Naz S, Nikousefat Z, Selvaggi M, Laudadio V et al. Effect of ascorbic acid in heat-stressed poultry. World's Poultry Science Journal 2012; 68 (3): 477-490. doi: 10.1017/S004393391200058X
7. He SP, Arowolo MA, Medrano RF, Li S, Yu QF et al. Impact of heat stress and nutritional interventions on poultry production. World's Poultry Science Journal 2018; 74 (4): 1-18. doi: 10.1017/S0043933918000727
8. Lin H, Jiao HC, Buyse J, Decuypere E. Strategies for preventing heat stress in poultry. World's Poultry Science Journal 2006; 62 (1): 71-85. doi: 10.1079/WPS200585
9. Sahin K, Sahin N, Kucuk O, Hayirli A, Prasad A. Role of dietary zinc in heat-stressed poultry: a review. Poultry Science 2009; 88 (10): 2176-2183. doi: 10.3382/ps.2008-00560
10. Abu-Dieyeh ZHM. Effect of chronic heat stress and long-term feed restriction on broiler performance. International Journal of Poultry Science 2006; 5 (2): 185-190. doi: 10.3923/ijps.2006.185.190
11. Khan RU. Antioxidants and poultry semen quality. World's Poultry Science Journal 2011; 67 (2): 297-308. doi: 10.1017/S0043933911000316
12. Klasing KC. Nutritional modulation of resistance to infectious diseases. Poultry Science 1998; 77 (8): 1119-1125. doi: 10.1093/ps/77.8.1119
13. Şentürk D, Demirel R. A research on the effect of vitamin c on high temperature stress in broiler, III. In: Proceedings of the National Animal Nutrition Congress; Adana, Turkey; 2005. pp. 141-145.
14. Arjona AA, Denbow DM, Weaver WD Jr. Effect of heat stress early in life on mortality of broilers exposed to high environmental temperatures just prior to marketing. Poultry Science 1988; 67 (2): 226-231. doi: 10.3382/ps.0670226
15. Yahav S, Hurwitz S. Induction of thermotolerance in male broiler chickens by temperature conditioning at an early age. Poultry Science 1996; 75 (3): 402-406. doi: 10.3382/ps.0750402
16. Zhou WT, Fujita M, Ito T, Yamamoto S. Effects of early heat exposure on thermoregulatory responses and blood viscosity of broilers prior to marketing. British Poultry Science 1997; 38 (3): 301-306. doi: 10.1080/00071669708417991
17. Yahav S, Plavnik I. Effect of early-age thermal conditioning and food restriction on performance and thermotolerance of male broiler chickens. British Poultry Science 1999; 40 (1): 120-126. doi: 10.1080/00071669987944
18. Hassan AM, Reddy PG. Early age thermal conditioning improves broiler chick's response to acute heat stress at marketing age. American Journal of Animal and Veterinary Sciences 2012; 7 (1): 1-6. doi: 10.3844/ajavsp.2012.1.6
19. Piestun Y, Shinder D, Ruzal M, Halevy O, Yahav S. The effect of thermal manipulations during the development of the thyroid and adrenal axes on in-hatch and post-hatch thermoregulation. Journal of Thermal Biology 2008; 33 (7): 413-418. doi: 10.1016/j.jtherbio.2008.06.007
20. Northcutt JK, Foegeding EA, Edens FW. Waterholding properties of thermally preconditioned chickens breast and leg meat. Poultry Science 1994; 73 (2): 308-316. doi: 10.3382/ps.0730308
21. Kadim IT, Al-Quamshui BHA, Mahgoub O, Al-Marzooqi W, Johnson EH. Effects of ascorbic acid and seasonal temperatures on meat quality characteristics of broiler chickens maintained in opensided and closed houses. International Journal of Poultry Science 2009; 8 (8), 733-739. doi: 10.3923/ijps.2009.733.739
22. Toplu HDO, Nazligül A, Karaarslan S, Kaya M, Yagin O. Effects of heat conditioning and dietary ascorbic acid supplementation on growth performance, carcass and meat quality characteristics in heat-stressed broilers. Ankara Üniversitesi Veteriner Fakültesi Dergisi 2014; 61 (4): 295-302. doi: 10.1501/Vetfak_0000002645
23. Petracci M, Betti M, Bianchi M, Cavani C. Color variation and characterization of broiler breast meat during processing in Italy. Poultry Science 2004; 83 (12): 2086-2092. doi: 10.1093/ps/83.12.2086
24. Wang RH, Liang RR, Lin H, Zhu LX, Zhang YM et al. Effect of acute heat stress and slaughter processing on poultry meat quality and postmortem carbohydrate metabolism. Poultry Science 2017; 96 (3): 738-746. doi: 10.3382/ps/pew329
25. Barbut S. Pale, soft, and exudative poultry meat - Reviewing ways to manage at the processing plant. Poultry Science 2009; 88 (7): 1506-1512. doi: 10.3382/ps.2009-00118
26. CIE. Official recommendation on uniform colour spaces, colour difference, equations and metric colour terms. Suppl. 2 to CIE Publication N.15, Colourimetry. Paris, France: Commission Internationale de I'Eclairage Publ., 1976.
27. Lu Q, Wen J, Zhang H. Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. Poultry Science 2007; 88 (6): 1059-1064. doi: 10.1093/ps/86.6.1059

28. Ryder AA, Feddes JJR, Zuidhof MJ. Field study to relate heat stress index to broiler performance. Journal of Applied Poultry Research 2004; 13 (3): 493-499. doi: 10.1093/japr/13.3.493

29. Yahav S, Mcmurtry JP. Thermotolerance acquisition in broiler chickens by temperature conditioning early in life–the effect of timing and ambient temperature. Poultry Science 2002; 80 (12): 1662-1666. doi: 10.1093/ps/80.12.1662

30. Sahin K, Sahin N, Kucuk O. Effects of chromium, and ascorbic acid supplementation on growth, carcass traits, serum metabolites, and antioxidant status of broiler chickens reared at a high ambient temperature (32°C). Nutrition Research 2003; 23 (2): 225-238. doi: 10.1016/S0271-5317(02)00513-4

31. Barbut S, Zhang L, Marcone M. Effects of pale, normal, and dark chicken breast meat on microstructure, extractable proteins, and cooking of marinated fillets. Poultry Science 2005; 84 (5): 797-802. doi: 10.1093/ps/84.5.797

32. Owens CM, Alvarado CZ, Sams AR. Research developments in pale, soft, and exudative turkey meat in North America. Poultry Science 2009; 88 (7): 1513-1517. doi: 10.3382/ps.2009-00008

33. King NJ, Whyte R. Does it look cooked? A review of factors that influence cooked meat color. Journal of Food Science 2006; 71 (4): 31-40. doi: 10.1111/j.1750-3841.2006.00029.x

34. Allen CD, Fletcher DL, Northcutt JK, Russell S. The relationship of broiler breast colour to meat quality and shelf-life. Poultry Science 1998; 77 (2): 361-366. doi: 10.1093/ps/77.2.361

35. Qiao M, Fletcher DL, Northcutt JK, Smith DP. The relationship between raw broiler breast meat color and composition. Poultry Science 2002; 81 (3): 422-427. doi: 10.1093/ps/81.3.422

36. Džinić N, Sakač M, Okanović Đ. Uticaj upotrebe ekstrudirane hrane na kvalitet mesa brojlera. In: Filipović S, Sakač M (editors). Ekstrudiranje u proizvodnji hrane za životinje. Novi Sad, Serbia: Institut za prehrambene tehnologije; 2013. pp. 233-250 (in Serbian).