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Research Article

Meat quality analysis of naked neck chickens: Role of cabbage leaves and different production systems

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Abstract

This study evaluated the impact of cabbage leaves as a selenium source on carcass traits, quality, composition, and taste of meat from naked neck chickens raised in various housing systems. Experimental birds were managed at the ICGRC, UVAS, and divided into 2 production systems (Intensive and free range) and 4 feeding strategies (control feed, 0.3mg per kg selenium from cabbage leaves, 0.3mg per kg selenium from sodium selenite and 0.3mg per kg selenium from cabbage leaves+ sodium selenite). A total of 128 birds (4 per replicate) were slaughtered at 18 weeks of age and data were analyzed using the factorial ANOVA and DMR tests. Birds in the intensive system demonstrated superior carcass traits, higher shear force, and greater percentages of moisture, crude protein, and ash in the meat. In contrast, free-range birds exhibited more vibrant meat color, higher chroma, cooking loss, dry matter, and ether extract percentages but lower pH levels. Among feeding strategies, diets enriched with selenium from cabbage leaves improved carcass, breast, drumstick, ribs and back, wing, neck, and gizzard weights, while control-fed birds had higher live and thigh weights. A combined selenium diet increased shear force, whereas cabbage selenium alone enhanced the hue angle and crude protein percentage. Sodium selenite supplementation led to higher chroma, cooking loss, dry matter, ether extract, and ash percentages. Additionally, meat from cabbage-fed birds displayed better color, while the combination diet improved taste, flavor, and overall acceptability. Overall, significant interactions between feeding strategies and production systems were observed across all parameters. The findings highlight the potential of selenium-enriched cabbage leaves as a viable dietary supplement to improve meat quality and sensory attributes in naked neck chickens.

Key words: Carcass traits, meat quality, Chickens

Introduction

In Pakistan's cuisines, the most frequently consumed vegan is cabbage having low caloric contents and a high nutrient profile along with the presence of ample amounts of antioxidants. The cabbage (*Brassica oleracea* L.) has functional properties to control the negative impact of free radicals by enhancing non-enzymatic and enzymatic antioxidant defense systems hence maintaining the functions and structure of cells (Ji *et al.* 2015). Cabbage has considerable nutritive importance in terms of crude proteins and minerals (Rosa and Heaney, 1996; Mustafa and Baurhoo, 2017). Cabbage leaves contain 59% soluble selenium of which selen-o-methionine is the most abundant one (23%) (Mechora *et al.* 2012). Cabbage shows properties of higher phenolic compounds, therefore, nutritionists are focusing on designer food applications and exploring its nutraceuticals worth (Sultana and Anwar, 2008). It has been reported that its continuous supply is crucial for maintaining the well-being of both humans and animals (Zarczynska *et al.* 2013). Selenium is a component in over twenty selenoproteins, playing an important role in reproduction, DNA replication, thyroid hormone regulation, and defense against certain infections (Sunde, 2012), immunity (Reilly, 2006), and protection from oxidation of the cell components (Lee *et al.* 2014). Moreover, bio-preservatives are the cabbage powder or its extracts (Malav *et al.* 2015). Incorporating cabbage into meat-based products offers a diverse array of nutrients, including ascorbic acid, α-tocopherol, and phytoceutics including β-carotene therefore overcoming the unwise integration of artificial antioxidants to extend meat quality and protecting it from oxidative deterioration. Meat surface color was not affected by adding 8 ppm selenium or 100 IU of α-tocopherol (Ryu *et al.* 2005). Nevertheless, Batool *et al.* (2018) documented that the change in general nutritional strategies ultimately affects the color of chicken meat. Another study reported that the addition of organic selenium was found to enhance the quality and prolong the shelf life of meat (Sevcikova *et al.* 2006). Hoffman *et al.* (2010) also found that various factors, including the quality and quantity of nutrients, scavenging behavior, and the availability of additional feed resources, can impact the color of chicken meat. Similarly, other reported, selenium influences the carcass quality and growth performance in poultry (Boostani *et al.* 2015). Inorganic selenium form is involved in the structural improvement of carcass yield including the yield of neck, feet, thighs, and legs (Upton *et al.* 2008). In the study conducted by Mikulski *et al.* (2009), it was found that the breast tissues of birds with sodium selenite containing selenium supplementation have a much higher value of crude protein. However, the contradictory study also reported that sensory attributes of broiler meat did not differ among *ad-libitum*, feed-restricted, and different feeding regimes (Farghly *et al.* 2019).

A Naked Neck breed is highly recommended for backyard poultry due to its ideal characteristics (Sadaf *et al.* 2015). Moreover, the industry is reverting to slow-growing chicken (Tougan *et al.* 2013) so there is constant research in developing and utilizing the non-commercial chicken gene pool. Indigenous breeds are frequently selected for free-range farming due to their adaptive characteristics against harsh climatic nature and better adaptability (Mwacharo *et al.* 2007). Consumers often place a higher value on the meat characteristics of free-range and organic chickens; however, it is crucial to acknowledge that the overall quality of the meat can be impacted by various factors such as genetics, nutrition, housing system, and age of birds (Fanatico *et al.* 2013). Moreover, Hanyani (2012) documented that the consumers favored the meat obtained from poultry raised in a partially scavenging environment. Alternate rearing systems are available but which system is best for Naked Neck productivity needs to be explored. Moreover, efforts should be made to find alternate selenium sources because inorganic selenium like sodium selenite has a low efficacy at room temperature and is highly toxic if its ratio increases. In Pakistan, locally available cabbage and spinach have good potential to contribute selenium, especially the organic one that might also influence the bird performance; therefore, the present study aimed to capture the variation among carcass characteristics, meat quality, compositional and sensory properties of Naked Neck chickens across various selenium-based feeding strategies and production systems.

Material and methods

The present research aimed to evaluate how various feeding strategies affect the carcass characteristics, meat quality, compositional analysis, and sensory properties of Naked Neck chickens across various housing systems. The research was carried out at the Department of Poultry Production, University of Veterinary and Animal Sciences, Pakistan. Pattoki city experiences normally warm and moist weather conditions, with temperatures varying between 13℃ during the winter season and reaching up to + 45℃ in the summer months.

Birds' husbandry

800 Naked Neck (06 weeks old) chicks were utilized and housed at the Indigenous Chicken Genetic Resource Center (ICGRC) according to the directions of the Committee of Ethical Handling of Experimental Birds, UVAS, Lahore, Pakistan, under approval number DR/124. These experimental birds were divided into 2 production systems (a) intensive and (b) free range and 4 feeding strategies

i.e., (a) commercial feed, (b) commercial feed with 0.3mg per kg selenium from cabbage source, (c) commercial feed with 0.3mg per kg selenium from sodium selenite source and (d) commercial feed with 0.3mg per kg selenium from cabbage+ sodium selenite source. Treatments have been carried out in two × four factorial associations following a complete randomized design. For every treatment, there were four duplicates, each including twenty-five birds. In an intensive production system, birds were fed 100% commercial feed along with additives i.e., selenium supplements whereas, in free range production system 25% commercial feed along with supplementation, and 75% of birds were grazed with spinach (*Spinacia oleracea L.*) and lucerne (*Medicago sativa)*. Between 06:00 AM to 06:00 PM, free-range birds had access to vegetation and later were offered different dietary intervention-based rations in the evening while in the intensive production system, no outdoor access was allowed for experimental birds. Feed allowances of experimental birds were increased to the correlation for growing pattern every week; on the other hand, water was available at all times during the trial. In the indoor area, a nipple drinking system was utilized to provide drinking water, while supplementary drinkers were positioned in the outdoor area. At the start of the rearing period per bird was given 0.65 sq. ft space; later on, with an increase in age, the space was adjusted to 1.5 sq. ft. in an intensive production system. A pen measuring 15 by 10 square feet indoors and 25 by 10 square feet outdoors was made available to 25 birds. Ten square feet were allotted to each bird in this free-range setup.

Table 1. Chemical compositional available commercial rations

Ingredients	**%**	**Nutrients**	**%**
Corn	63.79	DM	88.87
Soybean meal (CP 45%)	20.30	CP	15.44
Limestone	9.06	CF	3.32
Rice polishings	5	EE	3.76
Vegetable oil	0.40	Phosphorus	0.36
MCP	0.36	Calcium	3.43
Salt	0.32	Lysine	0.67
DL-Methionine	0.15	Methionine	0.383
Sodium bicarbonate	0.13	ME (Kcal/Kg)	2784.20
Choline CL-60%	0.09		
Phytase (600 FTU)	0.01		
Vit/Min Premix	0.40		
Total	100		

Compositional analysis of vegetables

The vegetables (cabbage, spinach and lucerne*)* were grown within the university premises. Before being fed to the experimental bird, the proximate composition (moisture and ash content, crude protein, fat, and fiber) of the veggies was examined using the guidelines of AOAC, (2006). The phenolic compounds in vegetable extract, measurements were taken using the Folin-Ciocalteu method outlined by Mahboubi *et al.* (2015); moreover, flavonoids were measured using the method of Aluminum chloride colorimetric assay as demonstrated by Mohammed and Manan (2015). High-Performance Liquid Chromatography (HPLC) quantification of flavonoids and phenolics was carried out following the protocols outlined by Sultana *et al.* (2012) and Sultana and Anwar (2008), respectively. Vitamin E in vegetables was estimated with the methodology established by Siriamornpun *et al.* (2012). Minerals like Ca, K, and Na were detected via Flame Photometer-410 while Zn, Mg, Mn, Fe, Cu, and Co were through Atomic Absorption Spectrophotometer according to the instruction by AOAC, (2006). The determination of selenium contents was conducted using the method employed by Chatterjee *et al.* (2001) (Table 2).

Parameters evaluated

Carcass traits: After 18 weeks, 04 Naked Neck birds were chosen at random from each replicate, and they were slaughtered humanely by following the Halal slaughtering method (Khan *et al.* 2019). The electronic balance was used to weigh each bird individually. To ensure that there were no feed particles in their intestines or crops, the birds were fasted for five hours before slaughter. Following the slaughter of the birds, their feathers were manually plucked and subsequently eviscerated. The carcass yield was calculated using the weight of the heated carcass (devoid of skin and giblets) as follows:

$$\text{Carcass yield \%} = \frac{\text{Dressed weight(g)}}{\text{Live weight (g)}} \times 100$$

After that; the carcasses were cut into different cut-ups such as thighs, drumsticks, breasts, wings and ribs and back, and their % was computed using the Khan *et al.* (2019) formula concerning the live bird weight.

$$\text{Cut up part (\%)} = \frac{\text{weight of cut up parts (g)}}{\text{Live bird weight (g)}} \times 100$$

Table 2. Chemical composition of cabbage, spinach and Lucerne

Components	**Nutrients**	**Cabbage** (*Brassica oleracea var. capitata*)	**Spinach** (*Spinacia oleracea L*)	**Lucerne** (*Medicago sativa*)
Proximate (%)	Dry matter	8.06	6.79	18.15
	Ether extract	3.74	4.5	1.88
	Crude protein	24.05	32.61	25.20
	Ash	10.31	24.65	14.85
	Fiber	11.77	9.44	23.65
Vitamins (Cabbage and Spinach=Fresh Weight Basis; Lucerne=Dry Weight Basis)	Vitamin A	0.08 (mg/100g)	137.07 (mcg/100g)	26 (mg/kg)
	Vitamin E	0.21 (mg/100g)	0.54 (mg/100g)	21 (mg/kg)
Antioxidants (cabbage= mg/100g fresh weight; Spinach and lucerne =TPC (mg GAE/g), TF (mg QE/g)	Total Pheno Content	55.21	39.12	0.80
	Total Flavono Content	32.35	21.05	0.065
High Performance Liquid Chromatography (Phenolics and Flavonoid mg/g)	Gallic acid	0.187	0.148	0.175
	Chlorogenic acid	1.082	1.052	0.685
	Caffeic acid	0.165	--	0.537
	Sinapic acid	0.016	--	0.027
	Myricetin	1.056	0.816	--
	Quercetin	1.438	0.599	0.147
	Kaempferol	0.966	0.453	--
Minerals (cabbage and spinach=mg/100g fresh weight basis, lucerne=mg/kg dry weigh basis)	Potassium	52.22	152.22	1.58 (g/100g)
	Calcium	19.55	27.55	3.25 (g/100g)
	Magnesium	21.55	20.35	4.35
	Sodium	9.65	17.65	0.78 (g/100g)
	Iron	0.70	0.72	89.15
	Zinc	0.30	0.12	70.25
	Copper	0.05	0.03	2.05
	Manganese	0.11	0.18	17.88
	Selenium (mg/kg D.M)	0.095	0.082	0.065

Meat quality

A pH meter (Weilheim, WTW GmbH, model WTW-3210, Germany) was used to measure the pH of the breast meat at 15 minutes and 24 hours following slaughter. For meat color (L*= lightness, a*= redness, b*= yellowness), and hue angle (*h*) the breast samples were collected, and measurement was taken at 2 hours and 24 hours post slaughtering with the help of a chromameter (Konica Minolta Chroma Meter CR-410). During 24 hours of refrigerated storage, the weight lost by the breast meat samples was measured as drip loss, indicated as a percentage (%). The samples were first weighed and then covered with plastic bags before being hung at a temperature of 8-10ºC (Honikel, 1987).

$$\text{Drip loss\%} = \frac{\text{Before haning weight (g)} - \text{After hanging weight (g)}}{\text{Before hanging weight (g)}} \times 100$$

Each breast fillet was packed in a polythene zipper bag and was cooked to a core temperature of 72ºC. Using scalpel-handle blades, the muscle tissue was cut into cubes after being sliced parallel to the direction of the muscle fibers. The Warner-bratzler shear force (N/cm^2) was subsequently determined using a Texture analyser (Stadig *et al.* 2016). Cooking loss was evaluated in triplicate for whole breast fillet samples 24 hours after slaughter. The samples were weighed, put into plastic pouches, and heated to a boil in a water bath (82-85ºC) for 10 minutes. After that, they were left to cool on absorbent paper at room temperature (40ºC). Afterward, the samples were weighed again, and the variation between fresh breast fillets (initial weight) and cooked breast fillets (final weight) was defined as cooking loss (Honikel, 1987).

Compositional analysis

The Official Methods of the AOAC (2006) was used to analyze the composition of the breast samples.

Sensory analysis

Meat from experimental birds was subjected to boiling at 72°C without any salt and spices (Castellini *et al.* 2002). The panel consisted of 10 members. Before presenting the meat samples, the panelists were guided to fill out the performa. After that, samples of meat were subjected to a nine-point hedonic scale consumer acceptance rating (dislike extremely to like extremely), as illustrated by Wichchukit and O'Mahony, (2014). The following parameters were recorded in this regard: meat color, aroma, taste, flavor, juiciness, tenderness, and overall acceptability.

Statistical analysis

The data collected was analyzed by factorial ANOVA, using SAS software (version 9.1). The Duncan's Multiple Range (DMR) test (Duncan, 1955) was then used to compare the means, with a predetermined significance level of $P \leq 0.05$.

Results

There are significant differences ($P \leq 0.05$) in carcass traits of birds across various production systems and feeding strategies. In the intensive production system, higher carcass traits were noted compared to the free-range production system, including live (P=0.0034), carcass (P=0.0002), breast (P<.0001), thigh (P=0.0030), drumstick (P=0.0004), ribs and back (P=0.0010), wings (P<.0001), neck (P<.0001) and gizzard (P=0.0005) weight; however, heart, liver and intestinal weight and intestinal length did not differ significantly. Regarding feeding strategies, higher live (P=0.0798) and thigh (P=0.0647) weights were observed in those birds who were reared on control feeding treatment while higher intestinal (P=0.0987) weight was seen in those birds who were reared on 0.3 mg per kg selenium form cabbage source feeding treatment. Moreover, higher carcass (P=0.0012), breast (P<.0001), drumstick (P=0.0020), ribs and back (P=0.0081), wings (P<.0001), neck (P=0.0024) and gizzard (P=0.0049) weight were found in control and 0.3 mg per kg selenium form cabbage source feed treatment while heart and liver weight and intestinal length did not differ significantly.

The meat quality of birds raised using different production systems and feeding strategies varies significantly ($P \leq 0.05$). Regarding production systems, free-range birds exhibited lower initial (P=0.0145) and ultimate (P=0.0089) pH levels, along with higher chroma (P<.0001) and cooking loss (P=0.0029) compared to intensive birds whereas, higher shear force value (P<.0001) was seen in the intensive production system. While, meat colors such as L*, a*, b*, drip loss %, and hue angle did not differ across production systems. In terms of feeding strategies, a higher shear force value (P<.0001) was observed in those birds who were reared on 0.3 mg per kg selenium form cabbage+ sodium selenite source feeding treatment, moreover, a higher hue angle (P=0.0335) was seen in 0.3 mg per kg selenium from cabbage source feeding treatment. Whereas, higher chroma (P=0.0010) and cooking loss (P<.0001) were observed in the meat of those birds who were raised on 0.3 mg per kg selenium from sodium selenite source feeding treatment. Meat color, final and initial pH levels, and drip loss percentage did not change significantly between feeding strategies.

Compositional analysis of the meat of birds differed ($P \leq 0.05$) among production systems and feeding strategies. Regarding production systems, higher moisture (P<.0001), crude protein (P<.0001), and ash (P=0.0201) % were found in those birds who were raised in intensive production systems however, higher dry matter (P<.0001) and ether extract (P<.0001) % were observed in free-range birds. In terms of feeding strategies, higher moisture % (P<.0001) was observed in a sample of those birds who were reared on 0.3 mg per kg selenium from cabbage source and 0.3 mg per kg selenium from cabbage+ sodium selenite source feeding treatment. While higher dry matter (P<.0001), ether extract (P<.0001), and ash (P<.0001) % were observed in those birds who were raised on 0.3 mg per kg selenium form sodium selenite source feeding treatment moreover, higher crude Protein % (P<.0001) was observed in 0.3 mg per kg selenium from cabbage source feeding treatment.

Sensory attributes of the meat of birds differed ($P \leq 0.05$) among production systems and feeding strategies. In terms of the production system, birds raised on an intensive system showed less color than birds raised on the free range (P=0.0030). Whereas, aroma, taste, flavor, juiciness, tenderness, and overall acceptability did not vary significantly among production systems. In terms of feeding strategies, more color (P=0.0815) was observed in the meat of those birds who were reared on 0.3 mg per kg selenium from cabbage source feeding treatment whereas, more taste (P=0.0317), flavor (P=0.0072) and overall acceptability (P=0.0284) were observed in 0.3 mg per kg selenium form cabbage+ sodium selenite source feeding treatment. However, aroma, juiciness, and tenderness did not differ significantly among feeding strategies. Overall, there were notable distinctions ($P \leq 0.05$) observed in the interaction between production systems and feeding strategies.

Discussion

The objective of this research was to examine the effects of the feeding strategies and production system on carcass and meat characteristics, composition, and taste of naked neck chicken. Better carcass traits of Naked Neck chicken were observed in an intensive production system; this may be due to the availability of a controlled environment, birds performed well because of reduced threats of climate change and diseases. Similarly, with free-range treatment body weight and weight gain were lower than indoor floor treatment (Wang *et al.* 2009). However, another study on Aseel chicken, revealed that the weight of the body differs depending on the rearing system, whether it is semi-intensive, under-intensive, or extensive (Rehman *et al.* 2016). Moreover, Ying *et al.* (2011) found that various production systems can impact the yield of leg and breast muscles in eviscerated carcasses. On the other hand, an increase in breast yield was observed as the free-range days progressed, while a linear decline in yield was noted in the leg, thigh bone, thigh muscles, and foot (Tong *et al.* 2014). However, according to the research conducted by Połtowicz and Doktor (2011), it was found that the yield of carcasses remained natural by the different housing systems. In the present study, regarding feeding strategies, higher carcass, breast, drumstick, ribs and back, wing, and neck weight were observed in those birds who were reared on control feed and 0.3 mg per kg selenium from cabbage leaves. This may be due to the existence of organic selenium in cabbage improved the yield of carcasses and their cutup parts because it deposits in tissues that prevent oxidation. Contradictory finding, a dietary supplement of selenium did not affect carcass, thigh muscle yield, breast, and relative organs (Bakhshalinejad *et al.* 2018).

Some studies have shown the impact of selenium on poultry carcass quality (Boostani *et al.* 2015). Similarly, inorganic selenium is involved in structural improvement of carcass yield including the yield of neck, feet, thighs, and legs (Upton *et al.* 2008). The current investigation revealed that birds reared on control feed and treated with 0.3 mg per kg selenium from cabbage source feed exhibited an increase in gizzard weight compared to other groups. This is in line with research by De Verdal *et al.* (2010) who documented that a larger proportion of the forage in the diet increased the digestive activity of the bird resulting in a heavier gizzard. Similarly, Batkowska *et al.* (2015) observed that three distinct chicken genotypes experienced a rise in gizzard weight when provided with high-fiber diets and green fodders. However, a non-significant variation in the gizzard weight of commercial broilers under different feeding regimes, including ad-lib, feed-restricted, and alternating feeding (Farghly *et al.* 2019). Regarding the liver, weight did not differ among production systems. Contrarily, housing systems affected liver weight in naked neck chickens reported by Ahmad *et al.* (2019).

Regarding meat quality, the current research indicates that free-range birds have lower initial and ultimate pH in comparison to intensive birds. This may be due to the presence of higher glycogen in muscles; which develops proportionately lactic acid to achieve the ideal pH at 24 hours; moreover, meat pH depends on the bird's feeding habits. Similarly, Hanyani (2012) found that chickens raised in semi-scavenging environments exhibited improved meat ultimate pH levels as a result of consuming carotenoid rich forage. Moreover, Ying *et al.* (2011) documented that pH is not influenced by the different production systems. The present study showed no differences in meat color and drip loss among feeding strategies and production systems. This may be due to the availability of selenium which reduces the chance of oxidation in the cell membrane; it is a cofactor of the glutathione peroxidase enzyme. Ryu *et al.* (2005), have also documented comparable results, indicating that the addition of 8 ppm Se or 100 IU of α-tocopherol did not impact the surface meat color. Moreover, the change in nutrients ultimately affects the color of chicken meat (Batool *et al.* 2018). According to research by Sevcikova *et al.* (2006), adding organic selenium to meat has been shown to improve its quality and lengthen its shelf life. In broiler feed organic selenium has been increased to enhance and improve the physiochemical characteristics of the meat, increase the food shelf life, and have more bioavailability (Kieliszek and Blazejak, 2016).

In another study, Hoffman *et al.* (2010) also reported that several variables, including feed availability, scavenging behavior, and nutritional quality and quantity, might impact the color of the chicken meat. According to the studies conducted by Wattanachant (2008), it has been found that feeding different feeds to indigenous chickens has a major impact on the color of the meat. Additionally, da Silva *et al.* (2017) found that slow growing chickens raised in a free-range environment had more yellowness in their meat. Moreover, Stadig *et al.* (2016) reported, that water holding capacity was not influenced by different production systems. Regarding cooking loss, variation was observed in all treatment groups in the present research. This could potentially relate to the temperature experienced during the cooking process; or might be influenced by feeding strategies because antioxidants present in the feed may improve the structure of a cell, and reduce the denaturation of protein during heating. Water holding capacity during cooking may be influenced by cooking temperature documented by Heyman *et al.* (1990). Devatkal *et al.* (2018) found that meat quality might be affected within and between the birds; it's a complex trait that may influence genetics and non-genetics.

Regarding meat proximate higher crude Protein % was observed in those birds who were reared on 0.3 mg per kg selenium from cabbage source feeding treatment. This may be due to the presence of organic selenium in cabbage leaves, which may improve the deposition of protein among tissues due to overcoming the chance of disease and free radicals. Contrarily, breast tissues of birds who were fed sodium selenite supplemented feed have much higher crude protein reported by Mikulski *et al.* (2009).

The increased meat coloration noted in poultry raised in free-range systems may be attributed to the presence of natural color pigments found in plants. Similarly, Mikulski *et al.* (2011) noted that hens raised in indoor systems had breast muscles that were noticeably lighter in color than those grown in open house systems. Moreover, Hanyani (2012) documented that consumers exhibit a preference for meat derived from birds raised in a semi-scavenging system due to its superior qualities, including taste and texture. More taste, flavor, and overall acceptability were observed in those birds who were raised on 0.3 mg per kg selenium from cabbage+ sodium selenite source feed. This may happen due to the presence of selenium (organic, inorganic) because it reduces the chance of oxidation and increases the shelf life of meat. Contrarily, the taste of meat did not vary among ad-lib, feed-restricted, and different feeding regimes in broiler chicken (Farghly *et al.* 2019).

Conclusions

The results obtained from this study suggest that the naked neck chicken exhibited superior carcass and meat quality attributes as well as compositional and sensory attributes of meat showed better values under the intensive production systems. The naked neck breed exhibited superior performance in carcass traits (breast, drumstick, ribs and back, wings, neck, and gizzard), meat quality (*hue* angle), compositional (crude protein), and sensory attributes (color) when supplemented with 0.3mg per kg selenium from cabbage leaves.

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Table 3. Effect of feeding strategies on carcass characteristics of naked neck chicken among different production system.

Treatment \ Carcass traits		Live weight	Carcass weight	Breast weight	Thigh weight	Drumstick weight	Ribs and back weight	Wings weight
Production systems								
Intensive		1490.67^{a}	783.58^{a}	160.51^{a}	128.33^{a}	112.23^{a}	133.98^{a}	69.29^{a}
Free-range		1395.33^{b}	711.33^{b}	141.38^{b}	111.33^{b}	103.09^{b}	123.68^{b}	64.92^{b}
Feeding strategies								
Control feed		1504.00^{a}	781.17^{a}	159.82^{a}	128.87^{a}	111.90^{a}	134.28^{a}	68.97^{a}
Cabbage feed		1451.67^{ab}	786.82^{a}	166.12^{a}	124.75^{ab}	113.15^{a}	132.83^{a}	70.60^{a}
Sodium selenite feed		1403.67^{b}	693.00^{b}	133.28^{c}	111.08^{b}	101.27^{b}	120.95^{b}	63.00^{c}
Cabbage + sodium selenite feed		1412.67^{b}	728.83^{b}	144.57^{b}	114.62^{ab}	104.33^{b}	127.27^{ab}	65.85^{b}
Production systems X Feeding strategies								
Intensive	Control feed	1584.00^{a}	822.33^{a}	168.67^{a}	141.33^{a}	118.00^{a}	139.47^{a}	70.50^{a}
	Cabbage feed	1462.00^{abc}	797.63^{ab}	166.87^{ab}	126.20^{ab}	116.23^{a}	135.57^{ab}	70.70^{a}
	Sodium selenite feed	1428.67^{bc}	733.33^{bc}	146.00^{c}	120.97^{abc}	104.17^{bc}	126.13^{bcd}	65.63^{b}
	Cabbage + sodium selenite feed	1488.00^{ab}	781.00^{ab}	160.50^{abc}	124.83^{ab}	110.53^{ab}	134.77^{ab}	70.33^{a}
Free-range	Control feed	1424.00^{bc}	740.00^{bc}	150.97^{ab}	116.40^{bc}	105.80^{bc}	129.10^{abc}	67.43^{ab}
	Cabbage feed	1441.33^{bc}	776.00^{ab}	165.37^{ab}	123.30^{abc}	110.07^{ab}	130.10^{abc}	70.50^{a}
	Sodium selenite feed	1378.67^{bc}	652.67^{d}	120.57^{d}	101.20^{c}	98.37^{c}	115.77^{d}	60.37^{c}
	Cabbage + sodium selenite feed	1337.33^{c}	676.67^{cd}	128.63^{d}	104.40^{bc}	98.13^{c}	119.77^{cd}	61.37^{c}
ANOVA								
SEM		18.48	13.12	3.85	3.21	1.69	1.90	0.90
Housing systems		0.0034	0.0002	<.0001	0.0030	0.0004	0.0010	<.0001
Feeding strategies		0.0798	0.0012	<.0001	0.0647	0.0020	0.0081	<.0001
Housing systems × Feeding strategies		0.0173	0.0004	<.0001	0.0196	0.0010	0.0039	<.0001

Superscripts on different means within column differ significantly at $P \leq 0.05$

Table 4. Effect of feeding strategies on carcass characteristics of naked neck chicken among different production system

Treatment \ Carcass traits		Neck weight	Intestinal weight	Intestinal length	Gizzard weight	Heart weight	Liver weight
Production systems							
Intensive		41.01[a]	54.78	58.42	39.12[a]	5.95	24.87
Free-range		35.93[b]	51.78	57.83	32.86[b]	5.83	25.13
Feeding strategies							
Control feed		40.42[a]	52.98[ab]	58.00	38.90[a]	5.95	24.20
Cabbage feed		40.27[a]	56.48[a]	59.33	38.88[a]	5.87	25.77
Sodium selenite feed		36.43[b]	50.50[b]	57.00	31.35[b]	5.87	25.17
Cabbage + sodium selenite feed		36.77[b]	53.13[ab]	58.17	34.82[ab]	5.87	24.85
Production systems X Feeding strategies							
Intensive	Control feed	43.63[a]	54.67[ab]	58.33	44.47[a]	5.93[ab]	23.77
	Cabbage feed	42.80[a]	57.83[a]	60.00	38.97[ab]	6.17[a]	25.87
	Sodium selenite feed	39.00[b]	51.83[ab]	57.00	34.33[bc]	5.90[ab]	25.23
	Cabbage + sodium selenite feed	38.60[b]	54.77[ab]	58.33	38.70[ab]	5.80[ab]	24.60
Free-range	Control feed	37.20[bcd]	51.30[ab]	57.67	33.33[bc]	5.97[ab]	24.63
	Cabbage feed	37.73[bc]	55.13[ab]	58.67	38.80[ab]	5.57[b]	25.67
	Sodium selenite feed	33.87[d]	49.17[b]	57.00	28.37[c]	5.83[ab]	25.10
	Cabbage + sodium selenite feed	34.93[cd]	51.50[ab]	58.00	30.93[c]	5.93[ab]	25.10
ANOVA							
SEM		0.74	0.85	0.37	1.18	0.05	0.26
Housing systems		<.0001	0.0726	0.4508	0.0005	0.2246	0.6457
Feeding strategies		0.0024	0.0987	0.2274	0.0049	0.9102	0.2787
Housing systems × Feeding strategies		0.0001	0.2074	0.5745	0.0010	0.2452	0.6533

Superscripts on different means within column differ significantly at P ≤ 0.05

Table 5: Effect of feeding strategies on meat quality of naked neck chicken among different production system

Treatment \ Quality Attribute		Initial pH	Ultimate pH	Lightness (L*)	Redness (a*)	Yellowness (b*)
Production systems						
Intensive		6.41[a]	5.47[a]	47.61	12.56	13.93
Free-range		6.15[b]	5.16[b]	48.24	12.45	14.60
Feeding strategies						
Control feed		6.23	5.27	49.67	11.15	14.57
Cabbage feed		6.20	5.30	45.74	13.14	13.64
Sodium selenite feed		6.23	5.23	47.55	12.27	13.52
Cabbage + sodium selenite feed		6.46	5.46	48.74	13.44	15.32
Production systems X Feeding strategies						
Intensive	Control feed	6.33[ab]	5.40[ab]	50.05[a]	9.92[b]	13.66
	Cabbage feed	6.25[b]	5.35[ab]	43.84[b]	13.57[ab]	12.06
	Sodium selenite feed	6.37[ab]	5.40[ab]	49.20[ab]	11.69[ab]	14.06
	Cabbage + sodium selenite feed	6.68[a]	5.72[a]	47.36[ab]	15.03[a]	15.93
Free-range	Control feed	6.13[b]	5.14[b]	49.29[ab]	12.38[ab]	15.48
	Cabbage feed	6.16[b]	5.26[ab]	47.64[ab]	12.71[ab]	15.21
	Sodium selenite feed	6.09[b]	5.05[b]	45.90[ab]	12.85[ab]	12.99
	Cabbage + sodium selenite feed	6.24[b]	5.21[b]	50.13[a]	11.84[ab]	14.70
ANOVA						
SEM		0.05	0.06	0.67	0.52	0.48
Housing systems		0.0145	0.0089	0.6161	0.9178	0.5036
Feeding strategies		0.2104	0.3995	0.1666	0.4376	0.5375
Housing systems × Feeding regimens		0.1082	0.1160	0.1987	0.4638	0.5176

Superscripts on different means within column differ significantly at $P \leq 0.05$

Table 6: Effect of feeding strategies on meat quality of naked neck chicken among different production system

Treatment	Quality Attribute	Drip Loss (%)	Shear force (N)	Hue angle (*h*)	Chroma (*c*)	Cooking loss (%
Production systems						
Intensive		3.32	29.69^{a}	44.61	14.11^{b}	30.86^{b}
Free-range		3.00	23.53^{b}	47.04	18.65^{a}	31.90^{a}
Feeding strategies						
Control feed		3.36	29.58^{b}	43.39^{b}	14.30^{c}	31.21^{b}
Cabbage feed		2.80	16.14^{d}	53.82^{a}	16.26^{b}	29.32^{c}
Sodium selenite feed		3.30	23.73^{c}	44.52^{b}	18.13^{a}	33.39^{a}
Cabbage + sodium selenite feed		3.17	37.00^{a}	41.58^{b}	16.82^{ab}	31.59^{b}
Production systems X Feeding strategies						
Intensive	Control feed	3.72^{a}	35.91^{b}	42.04	13.09^{c}	30.68^{cd}
	Cabbage feed	2.89^{ab}	11.91^{f}	54.09	15.91^{b}	30.12^{d}
	Sodium selenite feed	3.61^{a}	24.02^{d}	40.52	14.21^{bc}	33.07^{ab}
	Cabbage + sodium selenite feed	3.06^{ab}	46.93^{a}	41.80	14.22^{c}	31.18^{cd}
Free-range	Control feed	3.00^{ab}	23.25^{d}	44.74	15.51^{bc}	31.75^{c}
	Cabbage feed	2.72^{b}	20.36^{e}	53.54	16.61^{b}	28.52^{e}
	Sodium selenite feed	3.00^{ab}	23.44^{d}	48.52	22.05^{a}	33.71^{a}
	Cabbage + sodium selenite feed	3.29^{ab}	27.07^{c}	41.36	20.42^{a}	32.01^{bc}
ANOVA						
SEM		0.10	2.06	1.60	0.68	0.35
Housing systems		0.0906	<.0001	0.4040	<.0001	0.0029
Feeding strategies		0.1520	<.0001	0.0335	0.0010	<.0001
Housing systems × Feeding regimens		0.1224	<.0001	0.6866	0.0004	0.6860

Superscripts on different means within column differ significantly at $P \leq 0.05$

Table 7. Effect of feeding strategies on meat compositional analysis of naked neck chicken among different production system

Treatment		Moisture %	Dry matter %	Crude protei %	Ether extrac %	Ash %
Production systems						
Intensive		72.46^{a}	27.53^{b}	73.81^{a}	19.51^{b}	6.13^{a}
Free-range		69.40^{b}	30.60^{a}	70.02^{b}	24.03^{a}	5.68^{b}
Feeding strategies						
Control feed		70.72^{b}	29.27^{b}	69.48^{c}	23.79^{b}	6.30^{b}
Cabbage feed		72.54^{a}	27.45^{c}	78.73^{a}	16.12^{d}	5.11^{c}
Sodium selenite feed		67.69^{c}	32.31^{a}	66.96^{d}	25.75^{a}	7.03^{a}
Cabbage + sodium selenite feed		72.77^{a}	27.23^{c}	72.50^{b}	21.43^{c}	5.18^{c}
Production systems X Feeding strategies						
Intensive	Control feed	73.39^{b}	26.61^{c}	71.00^{c}	21.84^{d}	6.69^{b}
	Cabbage feed	75.37^{a}	24.63^{d}	83.07^{a}	12.10^{f}	4.81^{e}
	Sodium selenite feed	67.68^{d}	32.32^{a}	67.68^{d}	24.43^{bc}	7.45^{a}
	Cabbage + sodium selenite feed	73.42^{b}	26.58^{c}	73.50^{b}	19.66^{e}	5.55^{de}
Free-range	Control feed	68.06^{d}	31.94^{a}	67.97^{d}	25.73^{ab}	5.91^{cd}
	Cabbage feed	69.72^{c}	30.27^{b}	74.38^{b}	20.14^{e}	5.40^{de}
	Sodium selenite feed	67.71^{d}	32.29^{a}	66.23^{d}	27.07^{a}	6.61^{bc}
	Cabbage + sodium selenite feed	72.12^{b}	27.88^{c}	71.51^{c}	23.19^{cd}	4.81^{e}
ANOVA						
SEM		0.61	0.61	1.05	0.92	0.20
Housing systems		<.0001	<.0001	<.0001	<.0001	0.0201
Feeding strategies		<.0001	<.0001	<.0001	<.0001	<.0001
Housing systems × Feeding strategies		<.0001	<.0001	<.0001	<.0001	<.0001

Superscripts on different means within column differ significantly at $P \leq 0.05$

Table 8. Effect of feeding strategies on meat sensory attributes of naked neck chicken among different production system

Treatment \ Organoleptic traits		Color	Aroma	Taste	Flavor	Juiciness	Tenderness	Overall acceptability
Production systems								
Intensive		6.60^{b}	7.10	7.00	7.00	6.73	6.67	7.08
Free-range		7.38^{a}	6.96	6.92	7.04	7.04	7.00	6.96
Feeding strategies								
Control feed		7.21^{ab}	7.17	7.17^{ab}	7.13^{ab}	6.71	6.92	6.75^{b}
Cabbage feed		7.42^{a}	7.08	6.75^{ab}	6.54^{b}	6.92	7.00	7.17^{ab}
Sodium selenite feed		6.71^{ab}	6.71	6.50^{b}	6.79^{b}	6.92	6.46	6.58^{b}
Cabbage + sodium selenite feed		6.63^{b}	7.17	7.42^{a}	7.63^{a}	7.00	6.96	7.58^{a}
Production systems X Feeding strategies								
Intensive	Control feed	6.42^{c}	7.25^{ab}	7.33^{ab}	7.25^{ab}	6.25^{b}	6.92^{ab}	7.25^{abc}
	Cabbage feed	6.92^{bc}	7.42^{a}	6.83^{ab}	6.25^{b}	6.58^{ab}	6.67^{ab}	7.00^{abc}
	Sodium selenite feed	6.58^{c}	6.33^{b}	6.33^{b}	6.50^{b}	6.67^{ab}	6.00^{b}	6.42^{bc}
	Cabbage + sodium selenite feed	6.50^{c}	7.42^{a}	7.50^{a}	8.00^{a}	7.42^{a}	7.08^{a}	7.67^{a}
Free-range	Control feed	8.00^{a}	7.08^{ab}	7.00^{ab}	7.00^{ab}	7.17^{ab}	6.92^{ab}	6.25^{c}
	Cabbage feed	7.92^{ab}	6.75^{ab}	6.67^{ab}	6.83^{b}	7.25^{ab}	7.33^{a}	7.33^{abc}
	Sodium selenite feed	6.83^{c}	7.08^{ab}	6.67^{ab}	7.08^{ab}	7.17^{ab}	6.92^{ab}	6.75^{abc}
	Cabbage + sodium selenite feed	6.75^{c}	6.92^{ab}	7.33^{ab}	7.25^{ab}	6.58^{ab}	6.83^{ab}	7.50^{ab}
ANOVA								
SEM		0.14	0.11	0.12	0.12	0.12	0.12	0.13
Housing systems		0.0030	0.5202	0.7230	0.8545	0.2063	0.1453	0.6210
Feeding strategies		0.0815	0.4256	0.0317	0.0072	0.8562	0.3011	0.0284
Housing systems × Feeding strategies		0.0067	0.2590	0.1780	0.0127	0.2029	0.1901	0.0563

Superscripts on different means within column differ significantly at $P \leq 0.05$