



Characteristics of Carcass Traits and Meat Quality of Broiler Chickens Reared under Conventional and Free-range Systems

Peymaneh Davoodi and Alireza Ehsani*

Department of Animal Science, Tarbiat Modares University, Tehran, PO Box 14115-336, Iran.

*Corresponding author's E-mail: alireza.ehsani@modares.ac.ir ; ORCID: 0000-0001-6933-3469

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ABSTRACT

Alternative chicken production systems have become popular in recent years due to animal welfare criteria and consumer's perceptions. General beliefs express that the meat quality of chicken reared under free-range systems is better than that of chickens under conventional production conditions. The aim of this study was to compare the meat quality and carcass traits of chickens raised in conventional and free-range systems. Either conventional or free-range systems used meat-type Hubbard JA57 birds with a slaughter age of approximately 78 days. For assessing carcass traits and meat quality, six male chickens were selected from each system. The meat quality parameters, pH at 45 minutes, ultimate pH, color coordinates, drip loss, cooking loss, and water-holding capacity were measured. Furthermore, proximate parameters, such as crude protein, total fat, and crude ash were determined. There were no significant differences in main carcass yield and breast muscles between chickens reared in two systems, however, color values dramatically were influenced by rearing systems. Breast muscle samples from birds reared under the conventional system had a smaller hue angle and saturation value than those from the free-range birds. Moreover, the drip loss parameter was significantly higher in free-range chickens. The ash and protein contents of breast muscles were similar although raw breast meat from free-range birds had significantly lower fat content. The results prove that a free-range rearing system can modify the appearance, color values, and fat content of chicken meat and it can be a part of the interests of meat production consumers.

Keywords: Broiler chickens, Free-range, Hubbard JA57, Intensive rearing system, Meat quality

INTRODUCTION

Chickens were primarily raised on family farms outdoor until around the 1950s (Alvarado et al., 2005). Since then the remarkable growth of chicken meat production commenced when the modern poultry industry began. This has led to developing intensive rearing systems, ensuring highest effectiveness and profitability of production (Bogosavljevi-Boskovic et al., 2012). However, intensive systems and rapid growth can cause animal stress, resulting in undesirable physiological and behavioral responses which lead to poor performance and meat quality (Xing et al., 2019) and occurrence of idiopathic myopathies, white striping, wooden breast, as well as pale, soft and exudative (PSE)-like meat (Ishamri and Seon-Tea, 2017). In contrast, free-range system can decrease stress conditions and allow better chicken welfare without causing any environmental confinement on broilers (Santos et al., 2005; da Silva et al., 2017). The poultry meat quality, in general, is an extremely complex concept that can be evaluated from different aspects because it is

dependent on numerous factors, including genotype, sex, age, diet, density, environment and also rearing system (Berg, 2001; Brown et al., 2008; Miele, 2011; da Silva et al., 2017). In this respect, over the last decades, poultry meat production has paid particular attention to animal welfare, high-quality food safety standards, and different rearing systems. So, the competitiveness in this market has been radically changed into equally both price and quality competitiveness (Berg, 2001; Yeung and Morris, 2001; Bogosavljevic-Boskovic et al., 2010; Saleh et al., 2015).

From the prevailing viewpoint, broilers should have not only high slaughter yields and desirable carcass conformation scores, but also proper aesthetic, nutritional, and healthy characteristics. Hereupon, the chemical composition of chicken meat is another essential factor of broiler meat quality (Berg, 2001; Yeung and Morris, 2001; Castellini et al., 2008; Wang et al., 2009; Miele, 2011; Saleh et al., 2015; Srednicka-Tober et al., 2016). According to previous studies, broilers that had outdoor access showed better meat quality considering chemical

composition and healthy characteristics of produced meat (Berg, 2001; Castellini et al., 2008; Miele, 2011; Saleh et al., 2015; Srednicka-Tober et al., 2016). Castellini et al. (2002) and Lin et al. (2014) also claimed that chemical contents in the chicken meat produced in free-range were better than those from other conventional systems, also meat sensory scores and overall acceptability in the free-range group were higher than those in other systems. In addition, high protein content, and low fat in meat of free-range chickens offers a healthier diet choice (Lin et al., 2014). Given that the consequence of rearing systems can differ by fattening length, the density of the flock, time to access free range, climatic factors, seasons and breeds, the results reported in previous studies are often quite variable (Bogosavljevi-Boskovic et al., 2012; Srednicka-Tober et al., 2016). Some authors have reported no significant effect of rearing system on carcass yields and meat quality traits but others have obtained statistically significant differences (Wang et al., 2009). Therefore, the objective of the current study was to evaluate the growth performance, carcass characteristics, and meat quality of Hubbard JA57 strain (known for free-range rearing) in both conventional and free-range systems in Iran condition.

MATERIALS AND METHODS

Ethics approval

The Ethics Committee on the Use of Animals of Tarbiat Modares University, Iran approved all the experiments and protocols used in this study (14-67626). All experimental protocols were applied in accordance with relevant legislation and recommendations by this committee.

Experimental schedule and sample collection

This trial was carried out at the Poultry Experimental Farm in Tarbiat Modares University, Iran from September to November 2017. The test material used in this study included a total of 82 fertile eggs of slow-growing Hubbard JA57 strain imported from Denmark. The eggs were placed in an incubator (Victoria Como, Italy) with the broad end pointing upwards and proper temperature and humidity. At the end of 18 days of incubation, the eggs were transferred into individual pedigree hatch bags sewn with a net fabric in order that chicks could be traced back to their initial egg weights. The hatch was pulled at day 21.5 with hatchability of 91%, then all 74 day-old chicks generated were identified with left leg tags using plastic cable ties and housed in a standard conventional system until the end of week 5 and then divided randomly

into two groups each with 36 birds, one was reared in the same house and the other was transferred to the free-range system until the end of the rearing period of 11 weeks. Birds were provided with the same starter and finisher diets (Table 1), formulated based on the chemical composition of ingredients and broiler nutritional requirements according to NRC (NRC, 1994). The summary of the rearing systems conditions is given in Table 2. At the end of the rearing period of 11 weeks, 12 male broilers (6 from each rearing system) with a target weight range of 3.2 to 3.5 kg were randomly chosen to provide materials for analysis and sent to the chicken slaughterhouse related to the Department of Animal Sciences of Tarbiat Modares University, Iran to assess carcass characteristics and meat quality. After fasting for 12 hours before slaughter, all birds were weighed individually, slaughtered, and processed using standard commercial practices. All of them were used for physical, chemical, raw and cooked product analyses. The organ weights (liver, spleen, gizzard, heart, bursa of Fabricius) were recorded.

Table 1. Ingredients of starter and finisher diets and Dry matter based proximate chemical composition of diets.

Item	Starter (1-4 weeks)	Finisher (5-11 weeks)
Ingredient		
Maize	59.78	66.00
Soybean meal	28.52	22.00
Soybean oil	4.50	3.80
Wheat bran	4.56	5.92
Dicalcium phosphate	1.05	0.60
Limestone powder	0.90	1.05
Mineral and Vitamin Mix	0.34	0.34
Salt	0.10	0.10
Lysine	0.10	0.13
Methionine	0.15	0.06
Threonine	0.00	0.06
Chemical composition		
Metabolizable energy (kcal/kg)	3100	3150
Crude protein (%)	23.00	20.00
Crude fiber (%)	2.44	2.60
Ether extract (%)	7.16	6.20
Lysine (%)	1.12	1.00
Methionine (%)	0.50	0.39
Calcium (%)	1.00	0.90

Table 2. Summary of rearing conditions for chickens raised under two different systems.

Items	Conventional rearing system	Free-range rearing system
Outdoor access	No access	Access after week 5
Diet	<i>Ad libitum</i> regular diet with no animal ingredient	<i>Ad libitum</i> regular diet with no animal ingredient + access to pasture
Water	<i>Ad libitum</i>	<i>Ad libitum</i>
Vaccine program	Regular vaccination against Newcastle	Regular vaccination against Newcastle
Antibiotic	No antibiotic	No antibiotic
Slaughter age (day)	78	78

Measurements and evaluations

The meat quality variables, carcass component yield, initial and ultimate pH, color coordinates (Lightness, L*; redness, a*; yellowness, b*), Hue angle, saturation, drip loss, and water-holding capacity were measured. Also, cooked breast samples were evaluated for cooking yield (Mikulski et al., 2011).

Carcass component yield

The carcass weight was obtained after removing the head, neck, and shanks. Then, the main commercial segments (e.g., warm carcass, breast, and leg) and marginal parts (e.g., wings, abdominal fat, spleen, testicles, heart, and gallbladder) were weighed. Finally, the values were expressed as a percentage of carcass weight (Santos et al., 2005; Comert et al., 2016).

pH

The initial pH (45 min after slaughtering) and ultimate pH (pH in 24 h after slaughtering) were measured on raw homogenized breast muscles of six chickens from each group with three replications, in the same procedure. Approximately 2.5 g of meat was removed from the center of each pectoral major muscle, minced by mortar and pestle, and suspended in 25 mL distilled water then centrifuged for 5 min at 6000 rpm. Measurement of pH was performed using a digital pH meter equipped with a sensitive electrode, the device was calibrated before measurement at pH 4.0 and 7.0 buffer solutions (Choo et al., 2014).

Cooking loss

Cooking loss was determined by weighing meat before and after cooking. Meats were enveloped in an aluminum foil and cooked in an electric oven at 100 °C for 15 min, then samples were removed from the oven and left to cool at room temperature (Lin et al., 2014).

Drip loss

Drip loss was measured by keeping samples suspended in covered plastic bags on plastic racks for 48 h at 2 °C and calculated as a percentage of weight loss during storage (Funaro et al., 2014).

Water-holding capacity

Water-holding capacity was determined by the filter paper press method to obtain expressible meat juice. A 1000 mg raw meat sample was placed between several pieces of filter paper with 11 cm diameter and pressed for 5 min. Expressed juice of meat was defined as the loss in weight after pressing and expressed as a percentage of the initial weight of the raw meat sample (Wierbicki and Deatherage, 1958; Lee, 1995).

Color

The color profile of lightness, L*; redness, a*; yellowness, b* was measured by a reflectance colorimeter (ColorFlex EZ Spectrophotometer, USA) in triplicate on raw breast meat. The device was calibrated with black and white standards before meat color determination. Hue angle and saturation index were measured using formulas $h_{ab} = \arctan(b^*/a^*)$ and $S = ([a^{*2} + b^{*2}]^{1/2}) / L^*$, respectively (da Silva et al., 2017).

Proximate analysis

Protein, fat, and ash content of raw breast were each independently measured with three replications from each of 6 broilers from free-range and 6 broilers from standard rearing system. Samples for proximate analysis were frozen until analyzed at the laboratory of the Animal Science Faculty of Tarbiat Modares University. Protein, fat, and ash content was measured following the AOAC methodology (Lee, 1995).

Statistical analysis

The R 4.0.2 software was used for statistical analysis. Pairwise treatment differences between carcass traits obtained from two different rearing system were determined with the Student t-test and any differences were considered significant at $p < 0.05$, for this reason, data were summarized as mean \pm standard deviation and analyzed by one-way analysis of variance taking the rearing system as the main effect.

RESULTS

The comparison of carcass traits between the two rearing systems is reported in Table 3. There were no significant effects of rearing systems on the main carcass parameters measured. The results of physical and chemical meat characteristics comparison between conventional and the

free-range system are presented in Table 4. The initial pH of the breast meat from free-range broilers was slightly lower than conventional even though the ultimate pH of the breast meat became higher in free-range than

conventional birds. These differences were not statistically significant but the difference of initial and ultimate pH values in free-range birds showed significant change ($p = 0.004$).

Table 3. Carcass characteristics of chickens reared under conventional and free-range systems.

Trait	Conventional system	Free-range system	t statistics	p-value
Live Weight (g)	3548.33	3371.67	-1.279	0.229
Carcass Weight (g)	2770.83	2560.00	-1.722	0.115
Drop Carcass (g)	777.50	811.67	0.758	0.465
Tight (%)	25.56	25.31	-0.424	0.680
Breast (%)	26.87	27.29	0.509	0.621
Wings (%)	11.63	10.97	-1.353	0.205
Legs (%)	4.57	4.74	1.197	0.258
Liver (%)	2.10	2.22	0.899	0.389
Abdominal fat (%)	2.50	2.53	0.114	0.911
Gizzard (%)	1.46	2.45	2.002	0.096
Testicle (%)	0.15	0.07	-2.314	0.061
Burse (%)	0.13	0.18	1.299	0.222
Gallbladder (%)	0.15	0.10	-1.908	0.085
Spleen (%)	0.19	0.22	1.360	0.203
Heart (%)	0.63	0.60	-1.244	0.241

Each group contained 36 chickens. *Statistically significant at $p < 0.05$

Table 4. Chicken carcass quality traits in conventional and free-range rearing systems.

Meat quality traits	Conventional system	Free-range system	t-statistics	p-value
pH measures				
Initial pH	5.81 ± 0.11	5.78 ± 0.15	-0.379	0.713
Ultimate pH	5.77 ± 0.14	5.83 ± 0.09	1.450	0.178
pH difference	-0.04 ± 0.10	0.05 ± 0.10	3.727	0.004*
Meat quality metrics				
Cooking loss	29.33 ± 2.45	28.10 ± 1.70	-1.259	0.237
Drip loss	3.24 ± 1.22	3.70 ± 1.60	2.384	0.038*
Water holding capacity	53.03 ± 2.32	55.26 ± 1.80	1.92	0.08
Color parameters				
Lightness	59.92 ± 0.33	52.00 ± 2.70	-7.008	0.000*
Redness	7.29 ± 1.79	3.40 ± 1.30	-4.309	0.002*
Yellowness	11.01 ± 2.04	13.20 ± 0.90	2.461	0.034*
Hue angle	56.40 ± 10.03	75.60 ± 4.80	4.233	0.002*
Saturation	13.40 ± 1.29	13.70 ± 1.00	4.902	0.001*

Data are expressed as mean ± standard deviation. Each group contained six chickens. *Statistically significant at $p < 0.05$.

Table 5. Proximate analysis of raw breast meat from conventional and free-range broilers.

Proximate analysis	Conventional system	Free-range system	t-statistics	p-value
Protein, %	23.85 ± 0.41	24.20 ± 0.54	1.23	0.24
Fat, %	4.01 ± 0.40	3.18 ± 0.40	-3.57	0.005*
Ash, %	3.03 ± 0.21	3.05 ± 0.28	-0.12	0.90

Data are expressed as mean ± standard deviation. Each group contained six chickens. *Statistically significant at $p < 0.05$

The effect of the two rearing systems on meat quality did not represent a significant difference in terms of the cooking loss and water holding capacity parameters, however, the drip loss parameter was affected by rearing systems significantly ($p = 0.038$). All the color coordinates L^* , a^* , b^* , hue angle, and saturation value also showed extremely significant differences between the rearing systems. Breast muscle from free-range birds revealed significantly lower L^* and a^* values making it paler in comparison to conventional breast muscle. The smallest difference was seen in the b^* coordinate with the breast muscle from the free-range birds which was significantly higher than conventionally reared birds, so breast meat in free-range was more yellow ($p = 0.03$) than conventional.

The result of the proximate analysis of the raw breast meat produced from chickens reared under conventional and the free-range system is reported in Table 5. Raw breast meat from free-range birds had significantly ($p = 0.005$) lower fat content in comparison to broilers reared conventional system, however, no significant differences ($p > 0.05$) was observed for protein and ash content of the raw breast meat.

DISCUSSION

A growing knowledge of human health, food safety, and animal welfare interests have led to the great transformation in animal rearing systems and particularly free-range product markets all over the world. Chicken meat produced in alternative systems, such as free-range or organic, are part of this orientation. It is specified that slaughtering age, genetic breeds (fast and slow-growing), physical activity, and pasture intake are key factors in chicken meat quality.

In this research, no significant differences were observed in yield of carcass parts. The result has no consistency with the findings of Mikulski et al. (2011) who reported the significant influence of rearing system on carcass yields. Several studies also reported that body weight, body weight gain, and the proportion of breast meat of birds from the free-range system were

significantly lower than of those reared in indoor floor system (Grashorn and Serini, 2006; Dou et al., 2009; Wang et al., 2009). Conversely, some other researchers have found that free-range chickens had the higher live weight, breast, and thigh-drumstick weights compared to the conventional system (Alvarado et al., 2005; Santos et al., 2005; Połtowicz and Doktor, 2011; Lin et al., 2014; Comert et al., 2016) and also there are some other results reported by different researchers that were consistent with findings of the current study as they claimed that most of the carcass yield, especially body weight, did not show significant changes (Cheng et al., 2008; Chen et al., 2013; Fu et al., 2015).

The meat quality attributes including color values, pH measures, and water holding capacity were evaluated in this experiment because these parameters can have important effects on the characteristics of fresh chicken meat at the point of sale (Kim et al., 2020).

In the present study, the initial and ultimate pH of breast meat were slightly affected by two rearing systems but the changes were not significant and this finding was consistent with the results of many studies (Cheng et al., 2008; Husak et al., 2008; Ponte et al., 2008; Wang et al., 2009; Mikulski et al., 2011; Li et al., 2017). Although the initial and ultimate pH values were not significantly different between the two rearing systems, their variation obviously showed a different pattern that could be deduced why some studies have concluded that meat from broilers reared in the free-range system had lower shelf-life stability compared with conventionally reared broiler meat (Alvarado et al., 2005; Husak et al., 2008; Funaro et al., 2014). Because pH, microorganism content, and oxidation are intra-dependent factors and pH alteration during storage can be resulted by proteolytic degradation or fat oxidation which is decreases shelf-life of meat (Kim et al., 2020). This notable different pattern in pH change in breast meat of free-range birds might be the result of intensive physical activity and more pre-slaughter stress in comparison to the conventional broilers (da Silva et al., 2017; Kim et al., 2020). Pre-slaughter stress and physical activity in free-range chicken may lead to the range of

chemical changes based on the conversion of ATP to ADP and also anaerobic glycolysis of glycogen storage in muscles decreases pH due to lactic and pyruvic acid production so finally it can change the meat acidity during the rigor mortis.

The influence of the two studied rearing systems on meat quality did not reveal a significant difference in the cooking loss and water holding capacity parameters, although, drip loss parameter was affected by rearing systems significantly. The result of water holding capacity concurs with similar studies in comparing breeding methods (Castellini et al., 2002; Cheng et al., 2008; Dou et al., 2009; Wang et al., 2009; Stadig et al., 2016; Li et al., 2017). Water holding capacity is an important attribute of meat quality, if water holding capacity is poor, meat and meat products will lack juiciness. As slow-growing chickens are better suited to the free-range system (Castellini et al., 2008; Kingori et al., 2010; Bogosavljevi-Boskovic et al., 2012), but Fanatico et al. (2007) claimed that slow-growing birds had weaker water-holding capacity but their meat is more tender than the fast-growing birds.

The absence of significant differences in the carcass yield and other studied traits between two different systems are may be due to short rearing period with outdoor access. An experiment was conducted to evaluate the effect of free-range days on growth performance, carcass yield, and meat quality; and it was reported that increasing free-range length advantageously affects breast yield, but decreases thigh, and foot yields as well as the water-holding capacity of the thigh. No evidence was found that free-range days can change growth performance and meat quality (except water holding capacity) (Tong et al., 2014).

It can be demonstrated that free-range rearing system can modify the color values in chicken meat as the findings showed the breast meat from free-range broilers had higher yellow color and much lower red color than another rearing system (Brown et al., 2008; Poltowicz and Doktor, 2011; Funaro et al., 2014; da Silva et al., 2017). Of course, it should not be ignored that there were some peculiarities in results reported by authors about meat color values in comparing two standard and free-range meat yield.

According to the present result, raw breast meat from free-range birds had significantly lower fat content in comparison to conventional broilers, which could be important to consumers concerned with fat intake. The obtained results in previous studies suggested that the free-range rearing system was more favorable than the

conventional system, as it resulted in significantly higher protein content and a lower fat content of chicken meat (Bogosavljevi-Boskovic et al., 2012) however, no significant differences were observed for protein and ash content of the raw breast in the present study.

CONCLUSION

Although the quantitative carcass traits showed less significant differences between the two groups, some main qualitative traits including apparent characteristics such as all color coordinates and drip loss were significantly affected by the free-range system. Moreover, fat percentage of raw breast meat was significantly lower in the free-range production system, therefore, it could be healthier. Accordingly, no significant differences in the amount of meat produced in two rearing systems showed that the conventional production system in the poultry industry can be successfully replaced by alternative systems such as free-range without production loss. Also, the different chemical composition of meat in the free-range system may become more attractive in terms of increasing healthy food demand in the world industry. Ultimately, further studies are suggested to investigate consumer preferences, especially in terms of sensory evaluation of meat from the two production systems.

DECLARATIONS

Competing interests

We certify that there is no conflict of interest with any financial organization regarding the aspects discussed in the manuscript.

Authors' contributions

Alireza Ehsani designed the experiments, guided the research team, and edited the final draft of the manuscript. Peymaneh Davoodi performed field and lab researches, analyzed the data, and wrote the paper. Finally, all authors read and approved the final manuscript.

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