Meat quality traits of European quails reared under different conditions of temperature and air velocity

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ABSTRACT This study's objective was to evaluate the influence of thermal environment and air velocity during the rearing phase on European quail meat quality traits. A total of 1,152 one-day-old European quail chicks were placed inside floor pens within environmental chambers. Each experimental period was approximately 5 wks, with birds slaughtered at 37 d of age. The experimental design consisted of a 2×4 factorial arrangement of treatments in completely randomized design with 2 air velocities (0 and 2 m/s) $\times$ 4 air temperatures (severe cold [**SC**], moderate cold, thermal comfort, and moderate heat [**MH**]). ANOVA, with air velocity and thermal environment as fixed effects, was performed to evaluate the effect of main factors and their interaction on meat quality traits, using the GLM procedure (SAS 9.4). Least square means of treatments effects were compared using Tukey's test ($\alpha = 0.05$). Lightness (L*), redness (a*), and yellowness (b*), of quail meat were affected by thermal environment and air velocity ($P < 0.05$). Initial and final L* values were greater for MH ($P < 0.05$). Meat from birds subjected to 2 m/s air velocity had lower final L*, but no velocity effect was noted for initial L*. Quail meat from SC presented higher initial and final a* values compared with the other thermal environment groups ($P \leq 0.001$). Final a* was affected by air velocity ($P < 0.05$). Initial and final b* values for meat from MH were greater, 13.8 and 15.2, respectively, differing from the other treatment environments ($P < 0.05$). However, air velocity did not influence b* values ($P > 0.05$). Interactions were not significant for pHu ($P = 0.993$). Thawing loss and shear force were affected by treatments ($P < 0.05$) but not ultimate pH, drip loss, or sarcomere length. This study demonstrates that thermal environments and air velocity affect quail meat quality traits. Further investigation is recommended to explore effects of air velocity and thermal environment on muscle proteolysis of quail meat quality.

Key words: cold stress, heat stress, quail production, sarcomere length, shear force

INTRODUCTION

Meat quality is a major concern, especially for more demanding consumers (Melo et al., 2016). Meat quality can be defined as the set of parameters, attributes, and characteristics that determine the suitability for consumption of fresh or stored meat without any deterioration over a certain time interval (Elmasry et al., 2012). Quails are valuable for the high nutritional content of both their eggs and meat (Wen et al., 2017). The European quail strain (*Coturnix coturnix coturnix*) is used predominantly for meat production (Grieser et al., 2017) and is commonly seen in Asia, Africa, and Europe (Rajput et al., 2016). According to Barbieri et al. (2015), quail meat production has been growing and gaining popularity in recent years due mainly to a search for new sources of quality animal protein.

The use of quail meat, although still limited, is increasing because of the introduction of a European variety that meets the requirements of meat production (Farrapo et al., 2017). Furthermore, quail production facilities do not require large capital investments, and the short production cycle (35–37 D) allows for a fast capital return, particularly for smaller producers (Pastore et al.,

2012; Raji et al., 2015; Sakamoto et al., 2018). Quail production barns in Brazil are typically open sided, exposed to prevailing winds and with relatively poor environment control. The effect of these temperature and velocity conditions on meat quality is not understood.

Poultry meat quality is determined by 2 important traits: appearance (color) and meat tenderness (texture) (Fletcher, 2002). These attributes are the criteria consumers use to judge meat quality and acceptability (Fletcher et al., 2000; Karthika et al., 2016).

The effects of environmental temperature on meat tenderness vary depending on temperature deviation from thermal comfort (**TC**) and duration of exposure during grow out (Holm and Fletcher, 1997). Heat stress decreases meat quality, and the level of stress experienced by the bird is one of the factors affecting meat quality (Song and King, 2015; Castellini et al., 2016). According to Kim et al. (2017), cyclic heat stress had little impact on color, water-holding capacity (**WHC**), protein functionality, and lipid/protein oxidation stability of ground chicken leg meat. Heat stress also reduces the muscle pH, which in turn affects all physicochemical attributes such as cooking loss (**CL**), WHC, meat color, and shear force (**SF**) (Gregory, 2010).

Heat stress is a recognized concern for producers and scientists, but cold stress also causes economic loss worldwide (Nguyen et al., 2016). According to Schneider et al. (2012), effects of cold temperatures during growth on broiler meat quality are less understood than those of heat stress. A cold environment during grow out imposes acute demands on energy metabolism and increases glycogenolysis and may also result in changes in meat quality in broilers, which may result in meat with dark, firm, and dry (**DFD**) characteristics (Chan et al., 2011; Dadgar et al., 2010, 2012). With hypothermia, the birds' core body temperature drops below the lower critical temperature as a result of exposure to cold ambient temperatures, especially at high wind speeds (Nicol and Scott, 1990). The effect of air temperature (**AT**) on quail meat quality has not been well established yet. May et al. (2000), Santos et al. (2017), and Santos et al. (2019) observed that the effects of air velocity can be beneficial and alleviate heat stress in moderate to hot environments but can be detrimental under cold stress by excess convective cooling.

The objective of this study was to evaluate the influence of thermal environment, air velocity, and their interactions imposed during the rearing phase on European quail (*Coturnix coturnix coturnix*) meat quality traits.

MATERIALS AND METHODS

Animal Management and Experimental Design

All bird management procedures for the experiment were approved by the Animal Welfare Committee, which regulates ethical animal usage at the Federal University of Viçosa (Protocol No. 29/2017), Minas Gerais State, Brazil.

A total of 1,152 one-day-old European quail chicks were used in 2 replicate trials. Quails were randomly placed into one of four environmental chambers at the Research Center of Environment and Agroindustry System Engineering (**AMBIAGRO**), Department of Agricultural Engineering. Each environmental chamber measured 3.20 m × 2.44 m × 2.38 m (L × W × H). Quails were placed inside floor pens measuring 0.50 m × 0.50 m × 0.60 m (L × W × H), with 18 quails placed in each pen at a density of 140 cm^2/quail and with 8 pens (144 quails) per environmental chamber. Each experimental period was approximately 5 wks in duration, with birds harvested at 37 D of age. Pen floors were covered with 7–10 cm of medium-grade pine shavings, mixed weekly, and replaced with new pine shavings as needed. All quails were provided feed and water ad libitum. Feed was provided in starter (1 to 21 D) and grower (21 to 37 D) phases. Basal diets were formulated following the Brazilian tables for poultry and swine by Rostagno et al. (2017) in order to meet the nutritional requirements of the quail; the chemical compositions of the basal diets are shown in Table 1. The light:dark (**L:D**) schedule was 24L:0D and 23L:1D for days 0–14 and 15–37, respectively, based on that used in commercial farms.

The air velocity treatments (0 and 2 m/s) were applied to the front of each pen, with the velocity decreasing from the front to the back of the pen, with each air velocity treatment applied to 4 pens in each environmental chamber. Further details of the air velocity arrangement are provided fully in Santos et al., 2019. The AT treatments were based on estimated TC temperature for European quails, which varies with age (Table 2). One of four thermal environments was applied to each environmental chamber during the day period (6:00 am to 6:00 pm). All birds received TC temperature during the night period (6:00 pm to 6:00 am).

The experimental design consisted of a 2 × 4 factorial arrangement of treatments in completely randomized design (pen within chambers) with fixed air velocity of 0 and 2 m/s, and the AT to each chamber for each week was severe cold (**SC**), moderate cold (**MC**), TC, and moderate heat (**MH**), as described in Table 2. Temperature treatments differed by 3°C. The experimental unit was defined as a pen, totaling 8 replicates. Adjacent pens shared one air velocity controller. The average values of AT and relative humidity inside the chambers were close to those desired for each thermal environment (Table 3).

Slaughter and Meat Sampling

A total of 320 birds, 5 males and 5 females from each replicate pen, were randomly selected from each pen for meat quality evaluation at the end of each trial. Quails were randomly slaughtered, stunned by cervical dislocation and decapitated 6 h after feed withdrawal by

Table 1. Composition and nutrient levels of the basal diet.

Ingredients (%)	Starter diet (1-21 D)	Grower diet (21-37 D)
Corn, ground (7.86% CP)	48.10	55.11
Soybean meal (45% CP)	45.94	38.65
Soy oil	2.50	3.56
Dicalcium phosphate	1.10	0.88
Limestone	1.10	0.90
Salt	0.39	0.35
DL-methionine	0.39	0.21
L-lysine HCl	0.14	-
Vitamin and mineral premix[1]	0.17	0.17
Choline chloride	0.10	0.10
Anticoccidial	0.05	0.05
Antioxidant	0.01	0.01
Growth promoter	0.01	0.01
Total	100.00	100.00
Calculated nutritive values, %		
CP	25.00	22.00
ME (kcal/kg)	2,900	3,050
Calcium	0.85	0.70
Available phosphorus	0.32	0.27
Digestible lysine	1.37	1.09
Digestible methionine	0.71	0.50
Met + Cys	1.04	0.80
Sodium	0.17	0.15

[1]Premix provided per kilogram of diet: vitamin A (min), 1,200,000 IU; vitamin D3 (min), 2,250,000 IU; vitamin E (min), 25,000 IU; vitamin K3 (min), 3,000 mg; thiamin, 2,400 mg; riboflavin, 12 mg; pyridoxine HCl, 2,000 mg; vitamin B12 (min), 24,000 mcg; calcium pantothenate (min), 15 g; niacin (min), 42 g; biotin (min), 180 mg; folic acid (min), 1,800 mg; BHT, 50 g; Se (min), 180 mg; Fe (min), 50 mg; Cu (min), 8,500 mg; Co (min), 1,000 mg; I (min), 1,000 mg; Mn (min) 70 mg; and Zn (min), 60 mg.

cutting between the occipital and atlas bones using scissors. The birds were bled out for 2 min, scalded (53°C–55°C, 1 min), manually defeathered, and eviscerated, and the abdominal fat pad (from the proventriculus surrounding the gizzard down to the cloaca) was removed.

Carcasses were individually placed in plastic bags and stored at 4°C overnight. All measurements of meat quality traits were performed on breast meat samples. The pectoralis minor and pectoralis major muscles were excised from the carcasses 24 h postmortem, packaged in plastic bags, and stored at 4°C for subsequent analyses. Measured meat quality traits consisted of ultimate pH (pH_u); initial and final color lightness (L*), redness (a*), and yellowness (b*); WHC by the drip loss (**DL**) method; thawing loss (**TL**); CL; SF; sarcomere length (**SL**); and myofibrillar fragmentation index (**MFI**).

pH

At 24 h postmortem, the final pH, referred to herein as ultimate pH (pH_u), was measured with a previously calibrated portable pH meter (InLab Solids PRO, Mettler-Toledo AG, Schwerzenbach, Switzerland). The pH_u of each sample was measured in the pectoralis major muscle at about 1-cm depth.

Instrumental Color Measurement

Meat color was obtained from an average of 3 readings across the surface of the pectoralis minor and pectoralis major previously exposed to air ambient for 30 min. Immediately before data collection, a Hunter MiniScan EZ (4,500L; Hunter Associates Laboratory, Inc., Reston,

VA) was calibrated and used to scan meat color. The spectrophotometer was set to read using illuminant D65, with a port size of 31.8 mm and a 10° standard observer. Values of L*, a*, and b* were obtained according to the CIE (**International Commission on Illumination**) L*a*b* color system (Mancini and Hunt, 2005).

Drip Loss

Water-holding capacity was measured using DL applying no external force. To evaluate DL, each sample was weighed and then suspended inside an inflated plastic pot for 48 h at 4°C, ensuring that the sample did not make contact with the bag, after which they were reweighed (Honikel, 1998). DL was calculated as the percentage of weight loss: [(initial weight–final weight)/ initial weight] × 100% (Honikel, 1998).

Thawing Loss

Breast samples were stored in a plastic bag and frozen for 24 h for TL measurement. Subsequently, the frozen

Table 2. Thermal environments established in air temperature treatment for each week.

Thermal environments	Air temperature (°C) (6:00 am to 6:00 pm)				
	1°wk	2°wk	3°wk	4°wk	5°wk
Severe cold (**SC**)	30	24	20	18	17
Moderate cold (**MC**)	33	27	23	21	20
Thermal comfort (**TC**)[1]	36	30	26	25	23
Moderate heat (**MH**)	39	33	29	27	26

Night temperature was TC from 18:00 to 6:00.
[1](Sousa et al., 2014 ab; Albino and Barreto, 2012).

Table 3. Mean and standard deviation of air temperature (AT) and relative humidity (RH) in each treatment.

		Thermal environments							
		Severe cold (SC)		Moderate cold (MC)		Thermal comfort (TC)		Moderate heat (MH)	
Wk	Period (h)	AT ($^{\circ}$C)	RH (%)	AT ($^{\circ}$C)	RH (%)	AT ($^{\circ}$C)	RH (%)	AT ($^{\circ}$C)	RH (%)
1°Wk	6 am to 6 pm	30.8 ± 0.8	67.3 ± 2.9	33.6 ± 1.2	68.8 ± 4.9	36.3 ± 0.5	67.6 ± 5.1	39.0 ± 0.8	63.8 ± 5.4
	6 pm to 6 am	35.5 ± 0.6	61.2 ± 5.6	36.0 ± 1.43	64.0 ± 8.3	36.4 ± 0.4	65.2 ± 7.9	36.2 ± 0.7	66.3 ± 6.4
2°Wk	6 am to 6 pm	24.2 ± 0.9	62.7 ± 6.0	27.6 ± 0.5	67.3 ± 7.6	30.5 ± 0.9	70.7 ± 7.4	33.0 ± 0.6	74.6 ± 4.8
	6 pm to 6 am	29.9 ± 0.5	68.3 ± 3.1	30.0 ± 0.4	65.4 ± 8.3	30.1 ± 0.8	67.9 ± 7.2	30.4 ± 0.6	71.2 ± 6.4
3°Wk	6 am to 6 pm	20.5 ± 0.8	67.7 ± 4.3	23.5 ± 0.4	66.3 ± 4.1	26.2 ± 8.8	75.4 ± 0.5	29.1 ± 0.5	73.4 ± 6.9
	6 pm to 6 am	26.5 ± 0.7	67.8 ± 9.9	26.3 ± 0.5	75.47 ± 8.9	26.3 ± 0.4	72.2 ± 0.9	26.4 ± 0.3	76.3 ± 6.5
4°Wk	6 am to 6 pm	18.4 ± 0.7	64.9 ± 5.1	21.3 ± 0.5	66.2 ± 3.4	25.4 ± 0.4	74.8 ± 4.5	27.3 ± 0.5	77.1 ± 5.8
	6 pm to 6 am	24.7 ± 0.8	57.2 ± 5.1	25.1 ± 0.7	70.0 ± 9.1	25.1 ± 0.3	75.0 ± 5.3	25.7 ± 0.5	81.5 ± 5.0
5°Wk	6 am to 6 pm	17.7 ± 0.9	68.4 ± 3.2	20.5 ± 0.6	68.3 ± 3.1	23.3 ± 0.6	72.9 ± 3.6	26.4 ± 0.7	79.3 ± 6.2
	6 pm to 6 am	22.7 ± 0.7	68.7 ± 4.1	22.9 ± 0.8	71.0 ± 5.0	23.2 ± 0.6	72.8 ± 6.5	24.2 ± 0.8	81.9 ± 5.5

samples were weighed and kept refrigerated for 12 h at 4°C to thaw. Thawing loss was determined by weighing the samples on an analytical scale before and after thawing. Total loss was calculated as the weight difference between frozen and thawed, expressed in percentage.

Cooking Loss

To evaluate the CL, breast meat samples (pectoralis major) were weighed, individually vacuum sealed in a plastic bag, and cooked in water bath at 74°C for 40 min. Quail sample bags were then cooled in ice water for 15 min. The cooled samples were taken from the bag, blotted dry, and reweighed (Honikel, 1998). Cooking loss was calculated as a percent of initial uncooked weight (Honikel, 1998).

Shear Force

After measuring CL, the samples were stored overnight at 4°C and SF values were determined using a Warner–Bratzler shear attachment on a texture analyzer (Wheeler et al., 2005). Five rectangular core samples measuring approximately 1 × 1 × 2 cm (height × width × length) were removed from each sample parallel to the longitudinal orientation of the muscle fibers from each cooked breast after cooling.

Cores were sheared once, perpendicular to the longitudinal orientation of the muscle fibers by a Warner-Bratzler shear machine (G-R Electrical Manufacturing Company, Manhattan, KS) coupled with a 1.016-mm-thick V-shaped blade at a constant speed of 2 mm/s. The SF for each sample was recorded as average of the maximum force (N) obtained from the 5 cores.

Sarcomere Length

The sheared cores used for SF were kept for SL measurement (Wheeler et al., 2002). Five fiber bundles were taken from each core using a fine-tip tweezer and then placed on a microscope slide with a drop of fresh buffer solution containing 0.2 M sucrose in 0.1 M NaHPO4 buffered at pH 7.2. The sarcomere length was measured using a helium–neon laser diffraction unit (05-LHR-021; Melles Griot, Carlsbad, CA) and calculated as described by Cross et al. (1981).

Myofibrillar Fragmentation Index

Myofibrillar fragmentation index was evaluated by measuring the turbidity of homogenized samples at standardized protein concentration (Olson et al., 1976). Some modifications including the use of a shaft-type homogenizer were applied for better results

Table 4. Ultimate pH (pH$_u$) and color main effects of European quail meat harvested at 37 D of age in 4 different thermal environments and 2 air velocities.

	Thermal environment				Air velocity (m/s)		P-value		
Item	SC	MC	TC	MH	0	2	T	V	T*V
pH$_u$	5.65	5.57	5.49	5.60	5.61	5.54	0.128	0.144	0.933
L*$_{Initial}$	52.41[a]	53.01[a]	52.24[a]	54.49[b]	53.23	52.84	<0.001	0.254	0.254
a*$_{Initial}$	9.82[a]	9.17[b]	9.18[b]	8.89[b]	9.27	9.25	0.023	0.955	0.678
b*$_{Initial}$	13.17[a,b]	13.52[a,c]	12.93[b]	13.83[c]	13.52	13.21	0.002	0.087	0.747
L*$_{Final}$	49.94[a]	50.41[a,b]	51.06[b]	52.22[c]	51.29[A]	50.52[B]	<0.001	0.009	0.263
a*$_{Final}$	12.31[a]	11.79[b]	11.37[b,c]	11.22[c]	11.43[A]	11.92[B]	<0.001	0.003	0.170
b*$_{Final}$	14.38[a,b]	14.69[a,c]	13.98[b]	15.15[c]	14.54	14.55	0.003	0.946	0.081

[a,b,c]Least significant means within a row with a different superscript differ significantly ($P < 0.05$) by Tukey's test for thermal environment.

[A,B]Least significant means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test for air velocity.

Abbreviations: MC, moderate cold; MH, moderate heat; SC, severe cold; T, temperature; TC, thermal comfort; T*V, air temperature by air velocity interaction; V, velocity.

Table 5. Meat exudate losses (drip, thawing, and cooking) for European quail meat harvested at 37 D of age in 4 different thermal environments and 2 air velocities.

Air velocity (m/s)	Thermal environment				Mean by velocity[1]	P-value		
	SC	MC	TC	MH		T	V	T*V
Drip loss (%)						0.867	0.98	0.826
0	1.08	1.17	1.06	1.07	1.10			
2	1.05	1.10	1.23	1.02	1.10			
Mean by temperature[1]	1.07	1.14	1.15	1.04				
Thawing loss (%)						0.046	0.038	0.002
0	2.80[a]	3.60[A,b]	3.15[a,b]	3.11[Aa,b]	3.16[A]			
2	2.87[a]	2.46[B,a]	3.55[b]	2.47B[a]	2.84[B]			
Mean by temperature[1]	2.83	3.03	3.35	2.79				
Cooking loss (%)						<0.001	0.0008	0.4282
0	10.27	10.61	10.89	9.73	10.37[A]			
2	11.10	11.19	12.47	10.23	11.25[B]			
Mean by temperature[1]	10.69[b]	10.90[b]	11.68[c]	9.98[a]				

[A,B]Least significant means within a column with different superscript differ significantly ($P < 0.05$) by Tukey's test.

[a,b,c]Least significant means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test.

Abbreviations: MC, moderate cold; MH, moderate heat; SC, severe cold; T, temperature; TC, thermal comfort; T*V, air temperature by air velocity interaction; V, velocity.

[1]Main effects means (velocity or temperature) that followed the same uppercase letter do not differ by the Tukey test ($P < 0.05$).

(Hopkins et al., 2004). Duplicate myofibrils were extracted from the frozen pectoralis samples of each treatment; for more details, see the study by Silva et al. (2017). Afterward, protein concentration was determined by the biuret method (Gornall et al., 1949). Aliquots were then diluted in ice-cold buffer to achieve 0.5 mg of protein per mL of solution. A final reading was performed at 540 nm, and absorbance was multiplied by 150 to obtain the MFI value.

Statistical Analysis

ANOVA with fixed effects of air velocity and thermal environment was performed to evaluate the effect of main factors and their interaction on meat quality traits, using the GLM procedure of SAS 9.4 (Statistical Analysis System Institute, Inc., Cary, NC, SAS Institute, Inc 2013). All data were analyzed as a 2 × 4 factorial arrangement of treatments in completely randomized design, with factors being 2 air velocities (0 and 2 m/s) × 4 ATs (SC, MC, TC, and MH). Least square means of treatment effects ($P < 0.05$) were compared using Tukey's test with a significance level of 0.05.

RESULTS AND DISCUSSION

Main effect and interactions for ultimate pH (pH_u) were not significant ($P = 0.993$), and the overall mean value pH_u was 5.58, as noted in Table 4. The lack of treatment effect on pH_u indicates that glycogen reserves of quails submitted to cold stress can be similar to those submitted to TC or heat stress at different air velocities ($P > 0.05$). Similar pH_u values (5.7–5.8) for quail meat were found by Tavaniello et al. (2014), although Rouhalamini et al. (2014) observed a lower pH value (4.94) for quails under heat stress conditions. Singh and Verma (1995) reported that the pH of the quail meat breast muscle declined rapidly within the first 2 h

of slaughter and leveled off after 4 h of aging to 5.8 to 5.9. According to Napper et al. (2015), cold stress caused a significant increase in pH_u of broiler chicken meat ($P = 0.0003$); similarly, no difference between control and heat stress treatment was noted. In a study with broiler breast meat, the pH_u in a cold treatment was highest, with no differences observed between the heat and thermoneutral groups (5.97 vs. 5.87 and 5.90, respectively) (Schneider et al., 2012). Bressan and Beraquet (2002) reported that broiler chickens maintained at higher temperatures responded with higher glycolysis postmortem and that the pH of their meat was significantly higher than that in the meat of chickens maintained at TC. However, these results are different from those presented in this work. According to Terlouw et al. (2008), normal pH stabilizes after 24 h postmortem, usually between 5.4 and 6.0. The pH_u in our study was on average of 5.6, which can be characterized as normal pH. However, pale, soft and exudative (**PSE**) can be detected by combining pH values (below 5.8) and color (an L* value above 52), measured 24 h after slaughter (Barbut, 1993; Olivo et al., 2001). Tang et al. (2013) found a significant effect ($P < 0.05$) on pH_u of broiler chickens subjected to heat stress (5.57) compared with those subjected to no heat stress (5.93). According to Wang et al. (2017), heat stress accelerated the pH decrease in commercial conditions, and they found $pH_u = 5.87$ and 6.04 in heat stress and TC, respectively. Dadgar et al. (2012) showed that the breast meat pH_u of cold-stressed broilers (6.44) was significantly higher ($P \leq 0.0001$) than those subjected to control treatment (6.09).

The color characteristics L*, a*, and b* of quail meat were affected by thermal environments and air velocity ($P < 0.05$). Initial and final L* values were greater ($P < 0.05$) for MH (54.5 and 52.2, respectively, Table 4). Quail meat of birds subjected to 2 m/s air velocity had a lower final L* value, but there was no

Table 6. Meat quality characteristics of European quail harvested at 37 D of age in 4 different thermal environments and 2 air velocities.

Air velocity (m/s)	Thermal environment				Mean by velocity[1]	P-value		
	SC	MC	TC	MH		T	V	T*V
Warner Bratzler shear force (N)						0.0002	0.839	0.0008
0	8.708[a]	8.888[A,a]	8.888[a]	7.257[A,b]	8.434			
2	9.042[a]	7.512[B,b]	9.042[a]	8.306[B,a]	8.473			
Mean by temperature[1]	8.875	8.198	8.963	7.777				
Sarcomere length (µm)						0.744	0.459	0.149
0	1.67	1.62	1.66	1.69	1.66			
2	1.66	1.69	1.68	1.67	1.67			
Mean by temperature[1]	1.66	1.66	1.67	1.68				
Myofibrillar fragmentation index						<0.001	0.499	0.899
0	119.31	100.11	93.51	104.25	104.30			
2	116.43	100.86	93.02	100.68	102.75			
Mean by temperature[1]	117.87[d]	100.48[b]	93.27[a]	102.46[c]				

[a,b,c]Least significant means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test.
[A,B]Least significant means within a column with different superscript differ significantly ($P < 0.05$) by Tukey's test.
Abbreviations: MC, moderate cold; MH, moderate heat; SC, severe cold; T, temperature; TC, thermal comfort; T*V, air temperature by air velocity interaction; V, velocity.
[1]Main effects means (velocity or temperature) that followed the same uppercase letter do not differ by the Tukey test ($P < 0.05$).

velocity effect on initial L* ($P > 0.05$). Similarly, Napper et al. (2015) found heat stress to cause a significant increase in L* (lightness) of broiler chicken meat ($P < 0.0001$) compared with a cold stress treatment. Schneider et al. (2012) reported that meat from the hot and thermoneutral treatments was lighter in color than that from the cold group (53.22 and 54.13 vs. 53.22, respectively). Narinc et al. (2013) and Nasr et al. (2017) reported that the average L*, a*, and b* values of quail breast meat were 43.09, 19.24, and 7.74, and 44.23, 9.31 and 12.10, respectively. According to Barbut (1997) and Zhang and Barbut (2005), for broiler chicken meat, the ideal L* value should be between 46 and 53, and the L* values found in this work are within the ideal. The apparent pale color in poultry meat is also associated with lower pH (Wang et al., 2017).

Quails kept under SC presented higher initial and final a* values compared with the other 3 thermal environment groups ($P \leq 0.001$), and the final a* value was affected by air velocity ($P < 0.05$). The initial and final b* for quails subjected to MH had higher mean values, 13.8 and 15.2, respectively, differing from the other treatment environments ($P < 0.05$), but air velocity did not influence b* values ($P > 0.05$). Similarly, Tang et al. (2013) observed a significant increase in L* and b* and a reduction in a* for broiler meat from heat-stressed birds compared with a control treatment. The quail meat presents a higher percentage of oxidative muscle fibers (red fibers rich in myoglobin) that affects positively the redness (a*), yellowness (b*), and lightness (L*) (Genchev et al., 2010).

Table 5 summarizes the effects of thermal environments and air velocities in European quail meat on DL, TL, and CL. Meat exudate losses (DL and CL) were unaffected ($P > 0.05$) by any thermal environment and air velocity treatments.

The most serious defect of PSE meat is DL (Çelen et al., 2016). Offer (1984) suggested that higher DL in chicken meat can be characterized by PSE meat and reduced DL by DFD. According to Barbut et al. (2005), DL values for PSE, normal, and DFD meat were 1.65, 1.00, and 0.69%, respectively, in chicken meat. The authors suggest that light PSE meat showed a significantly higher DL and lower WHC, compared with normal and DFD meat. The ability to retain water, one of the main contributors to the yield during product processing, was lower in heat-stressed birds, which reduces meat juiciness (Fletcher, 2002). Zhu et al. (2011) and Hashem et al. (2013) found that muscles in a heat-stressed group had higher DL compared to non–heat-stressed controls ($P < 0.05$). By contrast, there was no difference for DL in this study ($P > 0.05$), which may indicate that meat from all treatments presented a similar degree of protein denaturation and pH_u. According to Wang et al. (2017), heat stress did not increase the DL. Moisture loss in meat is inevitable postmortem due to the decrease in pH (closer to the isoelectric pH of meat proteins) and steric effects due to shrinkage of the myofibrils as a result of rigor mortis (Huff-Lonergan and Lonergan, 2005).

Interactions between air velocity and AT affected TL (Table 5, $P = 0.002$). For the still air treatment (0 m/s), there was higher TL in MC (3.6%) and similar for TC and MH (3.2% and 3.1%, respectively, $P > 0.05$). For the 2 m/s treatment, quails kept under TC had higher TL (3.6%) ($P < 0.05$), but quails kept under SC, MC, and MH were similar ($P > 0.05$). In contrast with this study, greater TL (9.01%) was found by Narinc et al. (2013).

Freezing and thawing are known to affect the amount of exudate (TL or DL) (Leygonie et al., 2012). This is attributed to melting of ice in the extracellular spaces which causes an increase in water activity, resulting in a net flow of water into the intracellular spaces and its subsequent reabsorption by the dehydrated fibers (Leygonie et al., 2012). Gonzalez-Sanguinetti et al. (1985) suggested that at increased rates of thawing,

the rate at which water becomes available exceeds the rate at which the fibers can reabsorb water, and the excess water is excreted as exudate.

Although the interaction of CL was similar ($P > 0.05$) among the treatments, CL main effects were affected by both thermal environment and air velocity ($P \leq 0.001$ and $P = 0.0008$, respectively). CL was greatest at TC (11.68%) thermal environment and was the highest for the 2 m/s air velocity (11.25%), differing from the other treatments ($P < 0.05$). The CL in this study (approximately 10–12%) is lower than the range of 19.9 to 21.5% reported by Zerehdaran et al. (2012) for white quails; ranges of 13.7 to 34.2% and 27.3 to 31.1% were reported by Narinc et al. (2013) and Kaye (2014), respectively.

Low meat pH values decrease WHC and tenderness and increase CL percentage (Northcutt et al., 1994; Barbut, 1997; Van Laak et al., 2000). It is acknowledged that only 10-15% of muscle water is chemically bound to proteins. The remainder is "free water" that can be lost during cooking as a result of protein denaturation (Valkova-Yorgova et al., 2000). Dunn et al., (1993) indicated that CL was affected only by the ultimate pH value. Wang et al. (2017) reported that the change in CL caused by heat stress on poultry meat was not significant ($P > 0.05$). Nasr et al., (2017) subjected Japanese quails to similar conditions of MC as this work and obtained CL of 20.6%, higher than that found in this study.

The SF, SL, and MFI values of different treatments are presented in Table 6. There was an interaction effect by thermal environments and air velocity on SF ($P = 0.008$). Values of SF in the meat samples ranged between 7.257 and 9.042 N; the breast meat samples for the treatment combination of MH at 0 m/s had the lowest SF and differed from those for SC, MC, and TC ($P < 0.005$). Different results found by Vaz et al. (2016) show that the meat of broilers grown with high temperatures was stiffer than that from a thermoneutral treatment ($P < 0.05$), resulting in decreased meat quality. However, higher rates of SF indicate reduced postmortem proteolytic potential, leading to a decrease in tenderness. By contrast, both Zhang et al. (2012) and Tang et al. (2013) reported that breast meat from broilers in heat stress had higher ($P < 0.05$) SF value than those in the standard temperature group.

Regarding both meat quality traits SL and MFI, the environments that quail were subjected to had no influence ($P > 0.05$). An SL value of 1.32 ± 0.12 from broilers was found by Wattanachant et al. (2005). Sarcomere is the contractile unit of myofibrils, and SLs shorten during muscle contraction (Honikel et al., 1986). The SL had no relationship with SF. Weaver et al. (2008) found that samples containing long sarcomeres had lower SF values than samples with short sarcomeres. Dunn et al. (1993) reported that as pH_u decreased, SLs tended to decrease and SF increase.

The MFI has been used to determine the degree of myofibrillar protein degradation and is an indirect indicator of protease activity and the proteolytic potential (Olson et al., 1976; Yu et al., 2005; Wilhelm et al., 2010). In the current study, the MFI was affected only by thermal environment main effect ($P < 0.05$) and not by air velocity. The mechanism of meat tenderization is related to the destruction of myofibrils (Uytterhaegen et al., 1994; Shin et al., 2008), and in this work, MFI and SF were affected by proteolysis. The thermal environments tested suggest that proteolysis in the muscle can be affected by thermal stress.

CONCLUSION

Thermal environment and air velocity affected quail meat quality traits. It is noteworthy that the pH_u, DL, and SL values were not affected by any thermal environment, air velocity treatments, or their interaction. Nonetheless, CL and MFI were highest at TC (11.68) and SC (117.87) environments and differed from the other treatments. Heat stress decreased the SF and increased the MFI compared with samples from the TC treatment. Thawing loss was greater for TC samples at 2 m/s air velocity. Further investigation is recommended to explore the effect of air velocity and thermal environments on muscle proteolysis of quail meat quality.

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