

TATIANY CARVALHO DOS SANTOS

**EVALUATION OF DIFFERENT AIR TEMPERATURE AND AIR VELOCITY
CONDITIONS ON PERFORMANCE, CARCASS CHARACTERISTICS AND MEAT
QUALITY OF EUROPEAN QUAIL**

Thesis submitted to the Agricultural Engineering
Graduate Program of the Universidade Federal de
Viçosa in partial fulfillment of the requirements
for the degree of *Doctor Scientiae*.

Adviser: Richard Stephen Gates

Co-advisers: Mário Luiz Chizzotti
Sérgio Zolnier
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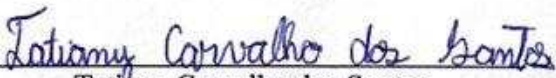
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Assent:



Tatiány Carvalho dos Santos
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Richard Stephen Gates
Advisor

*To God for allowing me to be here finishing another important step in my life;
To my beloved mother, **Clemência**, for teachings of honesty and faith.*

I dedicate!!!

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Thank you, God, for allowing me to be here, always by my side and giving me strength so that I could finish this walk.

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BIOGRAPHY

TATIANY CARVALHO DOS SANTOS, daughter of Landy Carvalho de Souza (in memoriam) and Clemência dos Santos Souza, was born in Janaúba, Minas Gerais state – Brazil, on July 28th of 1990.

In July of 2009, she started to pursue a degree in Animal Science at the Montes Claros State University (Janaúba, Minas Gerais state, Brazil), graduating in July of 2014. In August of 2014, started the Master's degree in Agricultural Engineering, in the area of Rural Buildings and Animal Environment at the Federal University of Viçosa (Viçosa, Minas Gerais State, Brazil) and defended her dissertation in July of 2016.

In August of 2016, she became a doctoral student in the Graduate Program of Agricultural Engineering, conducting part of her research study at the University of Illinois at Urbana-Champaign (Urbana, Illinois state, United States of America). In January of 2020, she applied to defend her Doctoral Thesis.

ABSTRACT

SANTOS, Tatianny Carvalho dos, D.Sc., Universidade Federal de Viçosa, January, 2020. **Evaluation of different air temperature and air velocity conditions on performance, carcass characteristics and meat quality of European quail.** Adviser: Richard Stephen Gates. Co-advisers: Mário Luiz Chizzotti, Sérgio Zolnier and Ilda de Fátima Ferreira Tinôco.

Brazilian quail production is still small compared to the billions of broiler chickens raised every year in Brazil, but in the last years it has been developing rapidly. Mixed type quail farming is practiced worldwide because quails are suitable for commercial rearing for both egg and meat production under intensive management. These features are noteworthy, considering the increase in world consumption of meat and the increase number of consumers demanding quality products. Quail are sensitive to changes in their environment, and the indoor environment is designed and managed for optimal control of the temperature, ventilation, light, humidity, and external noise so that the birds can reach their maximum performance. The temperature and air velocity in quail production barns are the main environmental factors to manipulate for better production results. 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. In view of the need to clarify the above, it is necessary to evaluate the effects of the thermal environment in which the birds are reared, thus establishing ideal standards for the production environment based on their production performance. This thesis documents a literature review on the effects of stress on meat quality, performance and quail meat quality. Also, an experimental evaluation was conducted in climatic chambers located in AMBIAGRO - DEA/UFV, using quails raised from 1 to 37 days of age. The thesis chapters are entitled as: Chapter I: "Meat quality parameters and the effects of stress: A review". Chapter II: "Effects of temperature and air velocity on European quail performance and carcass traits". Chapter III: "Meat quality traits of European quails reared under different conditions of temperature and air velocity" and Chapter IV: Final Summary. The objective of the research in (Chapter II and II) was to evaluate the effect of different air velocities in different temperature ranges on the productive performance, carcass traits and meat quality of European quail (*Coturnix coturnix coturnix*) during the rearing phase. Producing and processing high-quality meat is a challenge since it is necessary to apply methods that promote comfort in a complete sense, in a way that minimizes significant stress. Thermal environment and air velocity both affected quail performance. There was a tendency for temperature and air speed to influence body weight and cumulative body weight gain in the first weeks of bird life.

The thermal environment and air velocity also affected quail meat quality traits. Thawing loss was greater for thermal comfort samples at 2 m/s air velocity.

Keywords: European quail. Meat quality. Poultry. Tenderness. Thermal environment.

RESUMO

SANTOS, Tatiany Carvalho dos, D.Sc., Universidade Federal de Viçosa, janeiro de 2020. **Avaliação de diferentes condições de temperatura e velocidade do ar sobre desempenho, características de carcaça e qualidade da carne de codornas europeias.** Orientador: Richard Stephen Gates. Coorientadores: Mário Luiz Chizzotti e Sérgio Zolnier e Ilda de Fátima Ferreira Tinôco.

A produção brasileira de codornas ainda é pequena em comparação aos bilhões de frangos de corte criados anualmente no Brasil, mas nos últimos anos vem apresentando um desenvolvimento muito expressivo. A criação de codornas de tipo misto é praticada em todo o mundo, pois codornas são adequadas para criação comercial para produção de ovos e carne sob manejo intensivo. Considerando o aumento do consumo mundial de carne, aumenta o número de consumidores com perfis exigentes, buscando produtos de qualidade. As codornas são sensíveis a mudanças em seu ambiente, e o ambiente interno é projetado para otimizar o controle de temperatura, ventilação, luz, umidade e ruído externo, para que as aves possam atingir seu máximo desempenho. A temperatura e a velocidade do ar nos galpões de produção de codornas são os principais fatores ambientais a serem manipulados para obter melhores resultados de produção. Os galpões de produção de codornas no Brasil são tipicamente abertos, expostos aos ventos predominantes e com controle ambiental relativamente pobre. O efeito dessas condições de temperatura e velocidade na qualidade da carne não é compreendido. Tendo em vista a necessidade de esclarecer o exposto, é necessário avaliar os efeitos do ambiente térmico no qual as aves são criadas, assim, estabelecendo padrões ideais do ambiente de produção baseados no desempenho produtivo das aves. A tese foi escrita em capítulos de uma revisão da literatura sobre os efeitos do estresse na qualidade de carne, desempenho e qualidade da carne de codornas. A coleta de dados foi realizada durante a avaliação experimental realizada em câmaras climáticas localizadas na AMBIAGRO - DEA/UFV, utilizando codornas de corte de 1 a 37 dias de idade. Os capítulos têm os títulos: Capítulo I: “Parâmetros de qualidade da carne e os efeitos do estresse: Uma revisão”. Capítulo II: “Efeitos da temperatura e velocidade do ar no desempenho e características de carcaça de codornas europeias”. Capítulo III: “Características da qualidade da carne de codornas europeias criadas em diferentes condições de temperatura e velocidade do ar” e Capítulo IV: Resumo final. O objetivo deste estudo foi avaliar o efeito de diferentes velocidades do ar em diferentes faixas de temperatura sobre o desempenho produtivo, características da carcaça e qualidade da carne de codornas europeias (*Coturnix coturnix coturnix*) durante a fase de criação. Produzir e processar carne de alta qualidade é um desafio, pois é necessário aplicar métodos que promovam conforto

em um sentido completo, de maneira a minimizar um significativo estresse. O ambiente térmico e a velocidade do ar afetaram o desempenho das codornas. Houve uma tendência para a temperatura e a velocidade do ar influenciarem o peso corporal e o ganho cumulativo de peso corporal nas primeiras semanas de vida das aves. O ambiente térmico e a velocidade do ar afetaram as características da qualidade da carne de codorna. A perda de descongelamento foi maior nas amostras de conforto térmico à velocidade do ar de 2 m/s.

Palavras-chave: Ambiente térmico. Avicultura. Codorna Europeia. Qualidade de carne.

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GENERAL INTRODUCTION

Brazilian quail production is still small compared to the billions of broiler chickens raised every year in Brazil, but in the last years it has been growing rapidly. In Brazil, quail were introduced for egg production (*Coturnix japonica*), which were, at the end of the laying cycle, intended for slaughter (Vasconcelos et al., 2014). However, the quail breed predominantly used for meat is the European quail (*Coturnix coturnix coturnix*) (Grieser et al., 2017).

According to the Brazilian Institute of Geography and Statistics (IBGE, 2018), the number of quail, regardless of the purpose of rearing (meat or eggs) has grown. In 2017 the activity started to grow again, and in 2018 the number of quail totaled 16.8 million birds, a 3.9% increase compared to 2017 (IBGE, 2018). Mixed type quail farming is practiced worldwide because quails are suited for commercial rearing for egg and meat production under intensive management (Egbeyale et al., 2013). This was only possible with improvements in the breeding system, as more suitable installations were developed to optimize the production space, improve environment control to favor improved thermal comfort, and especially balanced nutrition to meet the nutritional requirements in each phase of production. According to Rodrigues et al. (2016), to maximize yield, production and product quality, quail must be well fed and raised in an appropriate, equipped installation, such as in automated facilities, allowing strains to have achieve greater production.

Recently, quail meat has begun to attract consumers (Baylan, 2017). Quail meat is similar to broiler meat. It is one of the most desired alternative poultry meats among consumers, as it has the lowest fat content and contains good levels of phospholipids, and hence there has been a gradual increase in the farmed quail population, especially in developing countries such as south India (Santhi and Kalaikannan, 2017). Quail meat is tender, tasty, nutritious, and gaining popularity as a table delicacy among the consumers (Tunsaringkarn et al., 2013). Considering the increase in world consumption of meat and increased number of consumers with demanding profiles, seeking quality products (Pinheiro et al., 2015), not only meat weight and yield are relevant but other characteristics of meat quality are important, including pH, softness, water holding capacity, color and sensorial characteristics (Rodrigues et al., 2008).

Quail are sensitive to changes in their environment, and the indoor environment should be designed and managed for optimal control of temperature, ventilation, light, humidity, and external noise so that the birds can reach their maximum performance (Shanaway, 1994; Bertechini, 2012). The thermal conditions inside quail barn should be as close of thermal

comfort zone for each age group of the birds, to provide the best productive performance. In quail, the comfortable ambient temperature ranges between 18 to 30°C with the optimal temperature between 21 to 27°C, and cooling is needed when temperatures exceed 30°C (Shanaway, 1984). Among the environmental factors, the temperature, humidity and air movement are those that directly affect the birds, as they compromise the maintenance of homeothermy (Tinôco, 2001). High environmental temperatures lead to a wide range of deleterious impacts on physiological and performance traits in poultry (El-Kholy et al., 2017), such as higher water consumption and lower feed intake, affecting feed conversion, growth rate, carcass yield and meat quality for organoleptic properties (Rosa et al., 2011).

According to Berto (2012) the ambient temperature and air movement are environmental factors that directly affect the birds, becoming stressors if they are not kept within optimal ranges. Santos et al. (2017) reported that the ideal air velocity for Japanese quail in the laying phase is around 2 m.s⁻¹, and in high air temperature the increase in air velocity may have a beneficial effect in contrast to low values. According to Medeiros (2001) and Cobb (2008) the air velocity for broilers is between 1.5 and 2.5 m.s⁻¹. Bottcher et al. (1995), suggested that air velocity equal to 2.0 m.s⁻¹ is enough to reduce the temperature of birds in hot environments and provide greater comfort. Providing adequate ventilation is important since any damage to carcass quality will lower meat yield and the price received.

Most Brazilian quail barns are open and naturally ventilated, which can vary throughout the day and year, making it necessary to study the extent to which air speed can compromise the performance of quail. The consequences of stress (heat and cold) in chicken and turkey production has been extensively evaluated, however studies on quail are scarce and to date there are few studies correlating stress with temperature and relative humidity (Rosa et al., 2011). Considering that most quail meat research is focused on nutrition, meat quality data for quail are scarce, and few studies have evaluated the effects of ambient temperature and air velocity on the production performance of quail. In this sense, research on quail meat quality should consider the evaluation of carcass yield and cuts, softness, pH, water holding capacity, weight loss by cooking, color and luminosity, which has a close relationship with their acceptance by customers and consumers (Genchev et al., 2005).

With the potential of quail production, new studies related to the environment are necessary, to evaluate the effect of different air velocities in different temperature ranges on the productive performance, carcass traits and meat quality of European quail (*Coturnix coturnix coturnix*) during the rearing phase (from 1 to 37 days of age). From the results found, these may

help in the management of the ventilation systems, thus adapting to the physiological needs of the birds in the breeding environment.

This thesis has been prepared in journal manuscript format and includes three manuscripts that together help to answer the questions raised above. The chapters were written from a literature review on the effects of stress on meat quality, performance and meat quality data collection during experimental evaluation in the Center for Research in Ambience and Agroindustrial Engineering - AMBIAGRO, at Department of Agricultural Engineering, Federal University of Viçosa, and is presented in three chapters entitled:

- Chapter I: “Meat quality parameters and the effects of stress: A review”. Published in the Journal of Agricultural Science and Technology B 9 (2019) 305-315. DOI: 10.17265/2161-6264/2019.05.001.
- Chapter II: “Effects of temperature and air velocity on European quail performance and carcass traits”. To be submitted in Poultry Science.
- Chapter III: “Meat quality traits of European quails reared under different conditions of temperature and air velocity”. Published in Poultry Science (2019). DOI: <https://doi.org/10.1016/j.psj.2019.10.037>
- Chapter IV: Final Summary.

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CHAPTER 1

MEAT QUALITY PARAMETERS AND THE EFFECTS OF STRESS: A REVIEW

T. C. Santos¹, R. S. Gates², C. F. Souza¹, I. F. F. Tinôco¹, M. G. L. Cândido¹ and L. C. S. R. Freitas¹

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ABSTRACT: The objective of this review was to address the stress effects on meat quality considering the main attributes that involve meat quality. Animal protein production has been increasing with global demand for meat with meat quality a major concern, especially for more demanding consumers who are looking for quality products to meet their needs. The quality of the meat is the result of what happened to the animal throughout the production chain, that is, good rearing conditions result in a better meat quality. Different types of stress can be harmful to animals due to inadequate or improper animal handling on farms, inadequate transport conditions, poorly maintained trucks and roads, and conditions that agitate animals can lead to bruising, thermal stress. The stress in animals occurs when they are in adverse conditions and can significantly compromise meat quality loss. As an example, stress can significantly affect meat quality parameters as drip loss (DL), meat color, change ultimate pH and cause meat anomalies. Among the main parameters of evaluation used for meat quality are color, characterized by luminosity (L^* , a^* , b^*), lipid and protein oxidation, pH, water holding capacity (WHC) and softness. Producing and processing high-quality meat is a challenge since it is necessary to apply methods that promote comfort in a complete sense, in a way that minimizes inducing significant stress. Based on the results presented it is remarkable that stress alters the meat quality, compromising the main attributes that involve it, like color, pH, WHC, Warner-Bratzler shear force (WBSF), lipid oxidation, among others and is necessary to avoid or reduce stress caused during the production of the animals to ensure a high-quality meat, resulting in greater profitability for the producer.

Key words: Animal stress, drip loss, farm buildings, meat quality, tenderness.

INTRODUCTION

Animal protein production has been increasing with global demand for meat [1, 2] with meat quality a major concern, especially for more demanding consumers who are looking for quality products to meet their needs [3, 4]. Meat quality can be perceived by its sensory attributes (color, texture, juiciness, taste, odor, softness), nutritional composition (fat content, fatty acid profile, protein percentage, minerals and vitamins), technical parameters (pH, water holding capacity (WHC) and thawing loss), absence of chemical and microbial residues (antibiotics, hormones, dioxins, *Salmonella*, *Listeria* or other contaminants), ethical considerations (animal husbandry, animal welfare) and, in addition, by the sustainable production aspects [4, 5].

Carcass traits and meat quality, such as tenderness and color, are critical for consumer acceptance [6]. Some aspects of meat quality such as color and amount of fat can be perceived visually, but others such as nutritional value and the absence of residues are only ensured by means adequate analysis and labeling and certification.

The level of stress experienced by the animal is one of the factors affecting the meat quality [7]. When subjected to stressful conditions, the meat of slow-growing chickens could be different from that of fast-growing [8]. Meat (and meat products) can deteriorate due to microbial growth and subsequent chemical deterioration, with the most common form of chemical deterioration being lipid and protein oxidation [9]. Deterioration may be caused when the animal is subjected to adverse conditions that lead to stress, directly influencing the meat quality. Karaca et al. [10] reported that fasting had a negative effect on some meat quality parameters, with significant increases in some physiological stress indicators after fasting periods of 24 h or longer on traits of lambs.

Some specific processes during the production cycle result in stress for the animal. In the process of transferring animals from farm to slaughter, stress is an inevitable consequence [11]. Pre-slaughter stress is both an animal welfare and a meat quality issue [12]. There is a direct association of meat quality with pre-slaughter management, whether on the property or while transporting animals to a slaughterhouse [12-16]. Incorrect pre-slaughter handling may cause carcasses to develop meat abnormalities such as pale, soft, exudative (PSE) or dark, firm, dry (DFD) [15].

The effects of environmental temperature on meat tenderness vary depending on temperature and duration of exposure [17]. Heat stress also decreases meat quality [6]. According to Kim et al. [18] cyclic heat stress had little impact on color, WHC, protein

functionality and lipid/protein oxidation stability of ground chicken leg meat. Increased levels of stress hormones in the muscle could lead to post-mortem metabolic/structural modifications that could be reflected on meat quality [19]. The objective of this review was to address the stress effects on meat quality considering the main attributes that involve meat quality.

STRESS FACTORS THAT AFFECT MEAT QUALITY

The concept of stress was introduced by Selye [20] in 1936, but is still a controversial subject among people involved with animal production, from workers to the scientific community, perhaps because of the commonly established relationship between stress and animal welfare [21]. Cortisol is one of the most common stress indicators measured [22] and cortisol response to stress has been shown to vary between individuals as well as fluctuate during pre-slaughter handling [23].

Livestock meat and carcass quality characteristics are governed by several intrinsic and extrinsic factors [24]. The intrinsic factors that affect meat quality in ruminants include species, breed, age, weight at slaughter and gender (male, female, castrated). Similarly, extrinsic factors affecting the meat quality include stress (environmental effects, transportation and handling), diet and weaning [5]. Animals respond to the stressors faced during transport by making behavioral, immunological, hematological and metabolic changes [25], which may impair slaughter performance, and carcass and meat quality [26].

Many authors have investigated the effects of different factors, such as journey, transport and lairage duration [14, 27, 28], environmental conditions [29], welfare [30] and stocking density [31]. The results found by Toldrá [32] show that when an animal is stressed before slaughter, the resultant meat quality often suffers as a result. Pre-slaughter stress may result in the development of dark-cutting beef because of depletion of antemortem muscle glycogen stores and less post-mortem lactic acid accumulation [33]. Pre-slaughter stress can be roughly divided into two types: (1) long-term (chronic), from the collection, boarding and transportation stages; (2) short-term (acute), regarding management stages at the slaughterhouse (selection, waiting and driving at slaughter) [34, 35]. Pre-slaughter heat stress must be minimized to the greatest degree which is possible to minimize PSE defects in broiler breast meat, the most valuable animal cut [36]. Trocino et al. [28] showed increased meat pH and WHC in rabbits subjected to long journeys. Holinger et al. [37] point out that carcasses of stress-exposed pigs had thicker backfat, lower lean meat percentage and different fatty acid composition of the adipose tissue.

It is important to highlight that thermal stress directly affects the development of animals, since it compromises the maintenance of homeothermy. Due to this, a physiological imbalance occurs that is caused by adverse temperatures and air relative humidity, either during rearing or at the time of slaughter, affecting the muscle glycogen reserves that are responsible for the development of post-mortem biochemical reactions that determine the meat quality and its functional properties.

Dokmanović et al. [38] correlated different categories of animal stresses, meat quality, and carcass quality characteristics in pigs and found that cortisol affected the carcass quality. High cortisol values in beef cattle resulted in high pH but cooking loss values were still within the normal range [39]. After arrival at the slaughterhouse, two important factors that may affect the level of stress in pigs and consequently pork quality, are lairage time and handling procedure immediately prior to slaughter [40]. Also, long lairage time proved to be a more stressful procedure and had a detrimental effect on carcass quality of pigs [40].

Heat is one of the most important environmental stressors for the poultry industry in the world [41]. Impacts of stress induced by high temperatures lead to a series of consequences for productivity, with higher water consumption and lower feed consumption, which directly affects feed conversion, growth rate, carcass yield and meat quality for organoleptic properties [6].

According to Wang et al. [36] heat stress increased the production of lactate in muscle, which in turn increased the rate of pH decline and subsequently decreased the quality of breast meat and increased the proportion of PSE meat of broiler chickens. Heat stress also reduces the muscle pH which in turn affects all the physicochemical attributes such as cooking loss, WHC, meat color and shear force [42].

Due to the changes that occur during the process of transformation of the live tissue muscle in consumable meat, it should be stressed that inadequate conditions of general environment offered to the animal, which can result in its stress, may lead to the formation of low quality products and rejection by the consumer.

Stress can significantly compromise meat quality, and among the main meat quality evaluation parameters that stand out are color-luminosity (L^* , a^* , b^*) [43], pH [44], WHC [45], tenderness (shear force) [46] and lipid and protein oxidation [47]. Table 1 shows different stressor agents can affect meat quality in the species.

Table 1 Stress factors that affect meat quality of poultry, pigs, cattle, sheep, calves and lamb.

Stressor agent	Species	Effects observed on meat quality	Reference
Heat stress	Poultry	Higher incidence of pale, soft, exudative (PSE) meat and decrease in the a* value of meat;	Tankson et al. [48]; Dai et al. [49]; Vaz et al. [50]
		Increased the rate of pH decline and incidence of PSE meat; Higher L* value; Developed PSE or dark, firm, dry (DFD) breasts; Higher lipid oxidation.	Wang et al. [36] Zhang et al. [46] Gotardo et al. [51] Vaz et al. [50]
Cold stress	Poultry	Acute demands on energy metabolism and increases glycogenolysis, which may result in meat with DFD characteristics; Increase of pH and decrease of L* value.	Dadgar et al. [52, 53] Napper et al. [43]
Acute stress	Cattle	Tougher Warner-Bratzler shear force (WBSF).	Zhao et al. [54]
Fighting	Pigs	Increased plasma levels of cortisol, adrenaline and metabolites, and meat ultimate pH increases proportionally to fighting levels.	Fernandez et al. [55]; Terlouw et al. [56]
Transport and lairage	Cattle	Lairage decreased ultimate pH; bulls subjected to 24 h lairage had the lowest L*, b* and H* values; lairage time had no effects on water holding capacity (WHC), cooking loss and shear force values. Greater WBSF.	Teke et al. [57] Gruber et al. [58]
	Pigs	A stronger increase in salivary cortisol and their meat had more drip loss (DL); Transport time significantly affected DL, pH and meat color; Highest WBSF.	Teke et al. [57]; Geverink et al. [59] Chai et al. [60] Lukić et al. [61]
Slaughter and Pre-slaughter	Poultry	Altered ultimate pH of thigh meat;	Debut et al. [62]; Berri et al. [63]
	Pigs	Higher ultimate pH;	Terlouw et al. [56]
	Calves and Cattle	Higher ultimate pH;	Lensink et al. [64]; Mounier et al. [65]
	Lambs	Increased the rate of pH decline and ultimate pH, as well as the ability of muscle to hold water;	Simmons et al. [66]; Bond and Warner [67]
	Lambs	Increases in DL.	Bond and Warner [67]
Higher noise	Pigs	Significant negative effect on meat pH _i	Van de Perre et al. [68]
Food/water deprivation/fasting	Poultry	Increased muscle pH and increased sarcomere at post-mortem 0 h, while decreased at post-mortem 10 h;	Wang et al. [69]
	Lambs	Tenderness scores varied significantly between the 0 h and 48 h groups.	Karaca et al. [10]
Stunning	Poultry	Affected breast meat color by decreasing a* and 9 d, 150 V, 60 Hz stunning reduced lipid oxidation in breast meat.	Xu et al. [70]

THE STRESS INFLUENCE ON MEAT QUALITY PARAMETERS

Color

Color is one of the most important sensory attributes used to evaluate the quality of products and first criterion consumers use to judge meat quality and acceptability [71]. The main pigment responsible for meat color is myoglobin, a protein present in the sarcoplasm of the muscle fiber [35].

According to Mir et al. [72], light scattering affects meat lightness (L^*) in a fashion inverse to that caused by heme pigment concentration, having a minimal effect on meat redness (a^*) and yellowness (b^*). It could be argued that appearance is the most important quality attribute of cooked or raw poultry meat because consumers associate it with the product's freshness, and they may decide whether or not to buy the product based solely on their opinion of its attractiveness [72]. In general, meat with a higher proportion of red fibers has a higher concentration of myoglobin, which is related to the predominance of aerobic (oxidative) metabolism, and a red color (greater than L^*) and darker (lower L^*) [35]. According to Zhang et al. [46], high ambient temperature had a significant influence on broiler meat quality. The meat color data showed that the meat of the breast and thigh of broilers subjected to constant high temperature presented higher L^* . A significant increase in the red content (a^*) was observed by Vaz et al. [50] in the breast of birds that remained in the warm environment for 48 h and 72 h, compared with birds that were not exposed to such stress. These authors suggest that a lower incidence of pale breast meat was found in birds raised under the heat stress conditions.

Extreme anomalous conditions include PSE and DFD meat, which are responsible for considerable economic losses in the industry [35]. The DFD meat, of dark color (dark), firm texture (firm) and extremely non-exudative (dry), is observed with some frequency in cattle, and can also be found in swine and birds. On the other hand, PSE is reported as the main anomalies in swine and birds [35]. The difference between "PSE" and "DFD" is that the former is associated with stress during a short time, just before slaughter, while DFD is closely linked to long-term stress before slaughter without the occurrence of adequate carbohydrate replacement in the body [73].

In a study conducted by Gotardo et al. [51], these inequalities indicate that, under a heat stress period of 1 h/d, broiler chickens at different stages of management will develop PSE or DFD breasts. Soares et al. [74] have proposed the following criteria for the classification of

breast meat into quality categories: $L^* \geq 53$ means a PSE meat, $L^* \leq 44$ means a DFD and $44 < L^* < 53$ means a normal meat.

PSE meat is the result of accelerated post-mortem glycolysis, which results in a rapid post-mortem decline in pH while carcass temperatures are still high. Among the environmental factors to induce occurrence of PSE meat, ante-mortem stress, heat stress at the end of the growth or pre-slaughter phase and methods of stunning in the slaughterhouse seem to play the main role [72, 73]. Van de Perre et al. [68] reported that in the summer, the risk of PSE in pigs is almost double the risk in winter, as these animals are sensitive to high temperatures. The apparent pale color in poultry meat is associated with lower pH [36]. PSE can be detected by combining pH values (below 5.8) and color (L^* value above 52) measured 24 h post-slaughter [75, 76].

It is known that DFD meat is a problem caused by chronic stress before slaughter, which depletes glycogen levels. The incidence of DFD meat is observed when the pH remains above normal, since the water retention capacity of the muscle proteins is very high, neither fibers are swollen by filling with sarcoplasmic fluids and their dispersed surface is less light [73]. Poor handling of cattle prior to slaughter might lead to a high incidence of DFD meat (6.22 ± 0.10) and a low mean value of percent cooking loss (22.5 ± 3.25) [16]. This type of change in meat is also observed in swine [77], broiler [76], sheep [78] and especially in cattle [79].

pH

Stress has a direct effect on the quality and physical-chemical characteristics of the meat as it changes the pH drop pattern due to the rapid use of glucose when the animal is subjected to conditions that modify its well-being. The main critical points that contribute to this are events related to pre-slaughter handlings, such as transport [80].

According to Boudjellal et al. [81], the rate of pH drops, as well as the final pH of the meat after 24-48 h, is quite variable. The pH drop is faster in pigs, intermediate in sheep and slower in cattle [82]. For cattle, glycolysis usually develops slowly; the initial pH at one-hour post-slaughter is around 7.0, drops to 6.4-6.8 after 5 h, and to 5.5-5.9 after 24 h. In pigs, the rate of dropping is higher, reaching values of 5.6-5.7 after 6-8 post-mortem hours and 5.3-5.7 after 24 h [82]. For DFD meat, pH drops gradually by only a few tenths during the first hour after slaughter, the meat with final pH value (after 24 h) remains between 6.5 and 6.8. For RFN (Reddish Pink, Firm and Non-Exudative) meat, pH drops approximately 7.0 in live muscle to ~5.6 after 6-8 h post-mortem, reaching a final pH between 5.5 and 5.7 (normal). For PSE meat,

pH drops rapidly in the first post-mortem hour, for values lower than 5.8 in 45 min, presenting a final pH between 5.4 and 5.6, or even lower values. For acidic meat, pH drops gradually, but with very low final value, close to 5.0. Dotted curves illustrate intermediate quality categories such as slightly dark meat and PSE (Fig. 1) [35].

Karunanayaka et al. [84] found a correlation between pH and L* values, the L* value increased as muscle pH decreased. Desai et al. [85] subjected broilers to short-term heat stress (38 °C for 2 h) and found lower values of pH for breast meat at 15 min after death (for PSE meat than normal meat).

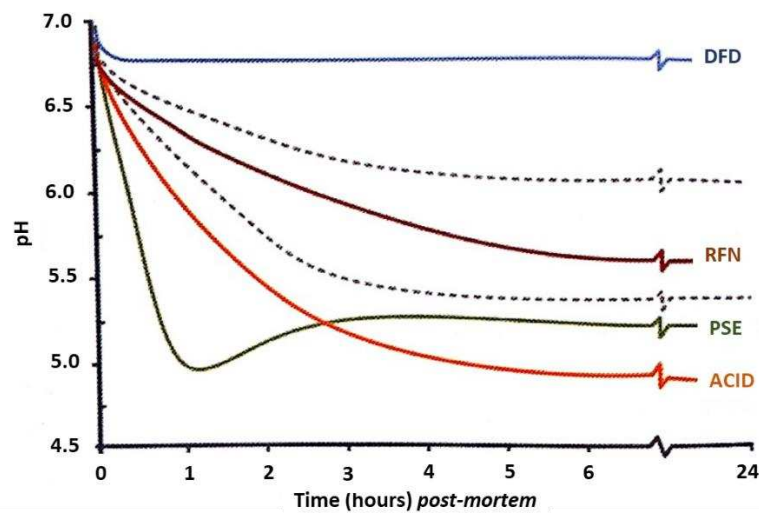


Fig. 1 Typical curves of post-mortem pH drops in pigs.

DFD: dark, firm, dry; PSE: pale, soft, exudative; RFN: reddish pink, firm and non-exudative
Source: Briskey [83]. Adapted by Ramos and Gomide [35].

WHC

WHC is one of the important sensory qualities of meat [6]. It is defined as the ability of meat to hold its own or added water during the application of external forces such as cutting, heating, grinding and pressing, and is implicated in numerous technological processes in which water retention plays a major role [60, 61].

WHC is directly related to muscle fiber density and according to Huff-Lonergan and Lonergan [86], the muscular structure is composed of several “compartments” from which drip could originate. These could include the space within the myofibril, the intracellular space outside the myofibril and the extracellular space, including the space between the muscle bundles.

Drip loss (DL) can be used to determine WHC under no applied external force. To evaluate DL each sample is weighed then placed and suspended in an inflated plastic pot for 48 h at 4 °C, after which they are reweighed [87]. DL is calculated as the percentage of weight loss: $[(\text{initial weight} - \text{final weight})/\text{initial weight}] \times 100\%$ [87]. WHC is $100\% - \text{DL} (\%)$.

According to Mir et al. [72], WHC has a direct bearing on the color and tenderness of meat, and is among the most important functional properties of raw meat. A study showed that cyclic heat stress (32.0, 21.0 and 32 °C, for 10 h/d) had little impact on WHC of ground chicken leg meat [18]. Zhang et al. [45] evaluated the relationship of heat shock protein levels in swine muscles and meat quality and they observed a correlation between heat shock proteins and the WHC of the meat. DFD meat has a high WHC due to the pH being far from the isoelectric point of muscle proteins; in addition, with higher pH, there is more incidence of deteriorating microorganisms [77].

Evaluating the effect of different periods (0, 24, 48 and 72 h) of thermal stress on the physical and chemical quality of the meat of broilers, Vaz et al. [50] concluded that thermal stress affected the qualitative properties of the meat, especially lipid oxidation, WHC and shear force. Confirming the findings of some authors, Woelfel et al. [88] showed a tendency in reduction of WHC in meat from animals stressed prior to slaughter.

Tenderness (Shear Force)

Tenderness is probably the most important quality factor associated with consumer satisfaction of eating quality of poultry [72]. Tenderness is regarded as the most important sensory attribute affecting the meat acceptability [71].

Warner-Bratzler shear force (WBSF) is a direct indicator of the meat tenderness quality [13]. According to Gomide [34], the shear force or softness is an attribute of the texture and the coarser the texture, the lower the softness. It is closely related to the amount of intramuscular water, and hence, WHC of the meat, so that the higher the water content in muscle, the greater the meat tenderness [89].

Previous research in beef has indicated that stress prior to slaughter is linked with a reduction in tenderness. Some studies have established a relationship between heat shock proteins and meat quality, including small heat shock proteins and their role in meat tenderness [90]. In a study with Angus cattle, Zhao et al. [54] subjected the animals to acute stress and the WBSF results showed that the stress group was much tougher than the control (nonstress) group. They also identified 137 differently expressed genes related to variations on stress status and beef quality. Physiological reactions of animals to transportation stress resulted in greater

WBSF [58]. On the other hand, Vaz et al. [50] studying different conditions of thermal stress in broiler chickens at 42 d showed that the different temperatures (thermoneutral and stress conditions) and duration of stress influenced the meat tenderness, and that the meat of the birds that remained in thermal stress was more rigid; however, there was a lower post-mortem proteolytic potential, leading to a decrease in softness. Also, Lukić et al. [61] reported that pigs were affected by different durations of lairage time and WBSF was the highest in the group with 24 h lairage time.

Lipid and Protein Oxidation

Lipid oxidation is described as a deterioration of the oxygen-dependent meat quality of saturated and unsaturated fatty acids, contributing to flavor degradation and reduced product shelf life due to initiation of peroxidation [91]. Another characteristic of the lipid oxidation is to be an important quality indicator of fats, meat and meat products. Oxidized lipids not only change the color, aroma, flavor and texture of meat [92], they also result in rancid odor, unpleasant taste, loss of nutritional value, shortened shelf life and accumulation of toxic compounds which may be detrimental to the health of consumers [90, 91].

According to Reitznerová et al. [92], lipid oxidation in meat can be monitored through the value of thiobarbituric acid reactive substances (TBARS). Many studies have reported that broilers raised at high temperatures increased TBARS in plasma, organs and carcass [70, 72]. For this reason, these authors can conclude that the presented modified TBARS spectrophotometric method is suitable for monitoring the lipid oxidation processes in meat samples [92]. Higher lipid oxidation was observed in the meat of broilers that underwent thermal stress during periods of 24, 48 and 72 h compared to those without thermal stress [50]. In this way the quality of this meat will be inferior, since the lipid oxidation is one of the major causes of deterioration, contributing to the reduction of the useful life of the products [91].

Protein oxidation is described as the covalent modification of a protein, induced by reactive oxygen species or reaction with secondary byproducts of oxidative stress, which occurs through a free radical chain reaction, as well as oxidation of lipids in the muscles [47]. Oxidation of oxymyoglobin to metmyoglobin results in meat discoloration, while lipid oxidation leads to the production of off-flavor and decreases nutritional values of meat and meat products [47].

CONCLUSIONS

It is necessary to consider animal welfare in the *ante-mortem* period and during slaughter, in order to obtain a higher yield and use of carcass, and *post-mortem* processes to guarantee better quality of the produced meat.

Producing and processing high-quality meat is a challenge since it is necessary to apply methods that promote comfort in a complete sense, in a way that minimizes inducing significant stress. Based on the results presented it is remarkable that stress alters the meat quality, compromising the main attributes that involve it, like color, pH, WHC, WBSF, lipid oxidation, among others. It is necessary to avoid or reduce stress caused during the production of the animals to ensure a high-quality meat, resulting in greater profitability for the producer.

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CHAPTER 2

**EFFECTS OF TEMPERATURE AND AIR VELOCITY ON EUROPEAN QUAIL
PERFORMANCE AND CARCASS TRAITS**

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ABSTRACT The purpose of the present experiment was to examine possible interactions and influence of thermal environment and air velocity on European quail (*Coturnix coturnix coturnix*) performance and carcass traits. 1152 one-day-old European quail chicks were placed inside floor pens within environmental 43 chambers. Each experimental period was approximately 5 wks with birds harvested at 37 d of age. The experimental design consisted as a 2 x 4 factorial arrangement in randomized blocks with 2 air velocities (0 and 2 m/s) x 4 air temperatures (severe cold (SC), moderate cold (MC), thermal comfort (TC) and moderate heat (MH)). ANOVA with fixed effects of air velocity and thermal environment was performed to evaluate performance and carcass traits main effects and their interaction, using the GLM procedure (SAS 9.4). LS means of treatments effects were compared using Tukey's test ($\alpha = 0.05$). Interactions for cumulative performance parameters was not significant, except for cumulative feed intake (CFI) at wk 5 ($P = 0.0421$). Quails subjected to SC treatment in wk 1-4 tended to gain more weight ($P < 0.05$) as compared with quail subjected to MC, TC and MH. At wk 2 and 4 body weight and cumulative body weight for SC treatment had highest weight (131.37 and 273.24 g/bird, respectively). Air velocity influenced CFI for all wks ($P < 0.05$), with higher values of CFI at 2 m/s. Cumulative feed conversion ratio was improved significantly up to a MH treatment, with lowest values (3.13 g:g), differing from other treatments ($P < 0.05$). Thermal environments and air velocities interactions had no effect ($P > 0.05$) on weekly body weight gain (WBWG) ($P = 0.300$) wk 2, weekly feed intake (WFI) ($P = 0.0179$) wk 3 and weekly feed conversion ratio (WFCR) ($P = 0.0154$) wk 3. Significant differences in WFI were observed between thermal environments and air velocities main effects ($P < 0.05$). WFCR worsened as quails got older, 1 from 5 wk of age. Daily body weight gain

(DBWG) was not influenced by the thermal environments, air velocity and interaction ($P > 0.05$). Lowest daily feed intake (DFI) was observed in MH at 0 m/s (26.1 g/bird/day) and temperature main effect (26.46 g/bird/day) ($P < 0.05$). There was no significant effect of interactions for all carcass traits ($P > 0.05$). Carcass yield main effect was higher in SC, MC and TC, differing from MH treatment ($P < 0.05$).

Key words: body weight, cold stress, European quail, feed intake, heat stress, poultry

INTRODUCTION

Quail raising (coturniculture) is prominent within the poultry industry and has been growing recently in Brazil. The most common specie of quail found in Brazil include European quail (*Coturnix coturnix coturnix*), used predominantly for meat production (Grieser et al., 2017) and is commonly seen in Asia, Africa and Europe (Rajput et al., 2016). Broiler quail meat production has been gaining popularity among consumers and many people are interested to rear quail on commercial basis due to lower initial investment and risk rather than commercial broiler farming (Pastore et al., 2012; Islam et al., 2014; Raji et al., 2015).

According to Farrapo et al. (2017) quail meat production although still limited compared to broilers, is increasing because of the introduction of the European variety that meets the requirements of meat production. Broiler quail meat have higher growth rates and market weight than laying quails, allowing them to reach adequate slaughter weight at early age (Grieser et al., 2015). The European strain is well known for its rapid body growth until 21 days of age and thereafter, weight gain starts to decrease since protein and water deposition rates decline, followed by an increase in fat content in carcass and organs (Grieser et al., 2017).

Thermal stress (cold or heat) is one of the main limiting factors of quail production. The temperature and air velocity in quail production barns are the main environmental factors to manipulate for better production results (Gasparino et al., 2015). High house temperature is the main cause of heat stress and is especially problematic in tropical regions, particularly when its interactions with radiation, relative humidity, and air velocity are considered (Lima et al., 2014; Silva et al., 2015). The amount of heat produced by birds surpasses the animal's capacity to dissipate metabolic heat to its surrounding environment, resulting in increased body temperature, reduced feed intake, live weight and growth rate and consequently growth performance (Ozbey and Ozelik, 2004; Akbarian et al., 2016; Borges et al., 2017). When the temperature and relative humidity exceed the comfort level of birds, they lose the ability to efficiently dissipate heat (Song and King, 2015).

Besides high temperatures, cold stress is a common problem in the quail industry (Çiftçi et al., 2016). Low ambient temperatures stimulate an increase in feed intake, and can result in reduced growth, nutrient digestibility, and feed conversion efficiency (Spinu and Degen, 1993; Kucuk et al., 2003).

According to Sousa et al. (2014b) the thermal comfort temperature ranges for quail meat are: 36 to 39°C, 27 to 30°C and 24°C for first, second and third week respectively. For the growing final phase, during the fourth and fifth week, the ideal temperature for European quail

is accepted as 26°C and 25°C, respectively. To obtain the best performance of a given production system, it is necessary that it operates within the zone of thermal comfort for the animals (Ribeiro et al., 2016). The limited literature is somewhat conflicting. A reasonable estimate of quail meat thermal comfort is 36, 30, 26, 25 and 23°C for the first five-week of life.

Air velocity is a key environmental factors for thermoregulation (Al-Dawood and Büscher, 2014). Effects of air velocity may alleviate heat stress in moderate to hot conditions, but can exacerbate cold stress by excess convective cooling (Santos et al., 2017). Berto (2012) reported that ambient temperature and air movement directly affect the birds, becoming stressors if they are not kept within optimal ranges. Santos (2016) and Santos et al. (2017) reported that feeding and drinking behavior was greater for Japanese quails subjected to air velocity around 2 m/s at the feeder, and at higher air temperature the air velocity increase can provide a beneficial effect. In addition, heat loss by convection and radiation can increase considerably increasing air velocity. Elevated air velocity can also expose more skin and thus may increase radiant losses (Syafwan et al., 2011).

The objective of this study was to evaluate the influence of thermal environment and air velocity on European quail (*Coturnix coturnix coturnix*) performance and carcass traits during the rearing phase.

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.

The experiment was carried out using a total of 1152 one-day-old European quail chicks, breed UFV 1 and UFV 2, divided equally in two replicate trials. Quail 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 x 2.44 m x 2.38 m (LxWxH). Quails were placed inside floor pens measuring 0.50 m x 0.50 m x 0.60 m (LxWxH) with 18 quails placed in each pen at a density of 140 cm²/quail, and eight pens (144 quails) per environmental chamber. Each experimental period was approximately 5 wks duration and the birds were harvested at 37 d of age. Pens were provided with 7–10 cm of medium-grade pine shavings, mixed weekly and replaced with new pine shavings as needed.

Each chamber was equipped with a 2-kW electric resistance heater (Model AB Split 1, Britania Eletrodomesticos S.A. Pirabeiraba, SC, Brazil) and an air conditioner (Model ABS 12FC 2LX, Komeco, Manaus, AM, Brazil). Air temperature (AT) and relative humidity (RH) were maintained by an electronic microcontroller (Model MT-531R plus, Full Gauge Controls, Canoas RS, BR) for heating and humidification; normally, the air conditioner operated continuously, and the heater provided supplemental heat for precise temperature control. An ultrasonic air humidifier with a water volume of 4.5 L and a humidification potential of 300 mL per hour was automatically activated by the microcontroller to maintain RH in the range of 50–70%. Fresh air ventilation in each chamber was provided by two continuously running axial exhaust fans (Model FD08025S1M AMB, Ambition Technology Company, Guangdong, CH), providing approximately four air changes per hour.

Chamber AT and RH were recorded every 10 minutes with a datalogger (Model U14-001, Onset Computer Corp, Bourne MA, USA). The Light:Dark (L:D) hourly schedule was 24L:0D, 23L:1D for Days 0–14 and 15–37, respectively, based on that applied 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 four pens in each environmental chamber. An air velocity control system was developed to supply the 2 m/s treatment by using 2 axial fans (Model MC20B, Elgin, São Paulo SP, BR) installed in the ends of a PVC tube (25 cm diameter), with a slot cut along its length for air discharge. Fan speed was altered to adjust the desired velocity directed towards the birds. The air velocity system was operated daily from 6:00 a.m. to 6:00 p.m.. Further details of the air velocity arrangement are described fully in (Santos et al., 2019).

The air temperature treatments were based on estimated the thermal comfort (TC) temperature for European quails, which vary with age (Table 1). One of four thermal environment was applied to environmental chamber during the day period (6:00 am to 6:00 pm). All birds received the thermal comfort (TC) temperature during the night period (6:00 pm to 6:00 am).

The experimental design consisted as a 2 x 4 factorial arrangement in randomized blocks with replication (pen within chambers) with two air velocities (fixed air velocity: 0 and 2 m/s) and randomly assigned air temperature to each chamber for each week with: severe cold (**SC**), moderate cold (**MC**), thermal comfort (**TC**) and moderate heat (**MH**), as described in Table 1. The average values of AT and RH inside the chambers were close to those desired for each

thermal environment (Table 2). Temperature treatments differed by 3°C. The experimental unit was defined as a pen, totaling eight replicates. Adjacent pens shared on air velocity controller.

Table 1. Thermal environments established in air temperature treatment for each week.

Thermal environments	Air temperature (°C) 6:00 am to 6:00 pm				
	1° Week	2° Week	3° Week	4° Week	5° Week
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

¹Sousa et al., (2014); Albino e Barreto (2012)

Quail chicks were randomly placed in to pens in order to have similar initial mean body weights between pens (10 g/quail average). All quail were provided feed and water *ad libitum*. A trough feeder was situated at the pen front, and one automatic nipple waterer with a cup was placed midway between front and back next to a partition, which were always kept supplied. From 1 to 21 d of age, quail were fed with a starter ration and from 22 to 37 d a growth/fattening ration. 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 3. Mortality was recorded daily during the experimental period.

Performance

All quail were individually weighed at the end of each wk on days 7, 14, 21, 28 and 37. Body weight (**BW**) (g/bird) was measured as the weight at the end of each week. Cumulative body weight gain (**CBWG**) (g/bird) was calculated as the difference between body weight at the end of each week and the starting weight. Cumulative feed intake (**CFI**) (g/bird) was measured weekly as the difference between feed provided and what was leftover in the feeders and added to the total of the previous week. Cumulative feed conversion ratio (**CFCR**) (g feed: g gain) was calculated using CFI divided by CBWG. Weekly body weight gain (**WBWG**) (g/bird) was calculated as the difference between BW at the end of each week and weight at the week before.

Table 2. Mean and standard deviation of air temperature (AT) and relative humidity (RH) in each treatment.

Week	Period (h)	Thermal environments							
		Severe cold (SC)		Moderate Cold (MC)		Thermal comfort (TC)		Moderate heat (MH)	
		AT (°C)	RH (%)	AT (°C)	RH (%)	AT (°C)	RH (%)	AT (°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

Table 3. 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	-
Vit & Min. 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, %		
Crude Protein	25.00	22.00
Metabolizable energy (kcal/kg)	2900	3050
Calcium	0.85	0.70
Available phosphorus	0.32	0.27
Digestible lysine	1.37	1.09
Digestible methionine	0.71	0.50
Dig. Met + Cys ²	1.04	0.80
Sodium	0.17	0.15

¹Premix provided per kilogram of diet: vitamin A (min), 1200000 IU; vitamin D3 (min), 2250000 IU; vitamin E (min), 25000 IU; vitamin K3 (min), 3000 mg; thiamin, 2400 mg; riboflavin, 12 mg; pyridoxine HCl, 2000 mg; vitamin B12 (min), 24000 mcg; calcium pantothenate (min), 15 g; niacin (min), 42 g; biotin (min), 180 mg; folic acid (min), 1800 mg; BHT, 50 g; Se (min), 180 mg; Fe (min), 50 mg; Cu (min), 8500 mg; Co (min), 1000 mg; I (min), 1000 mg; Mn (min) 70 mg; Zn (min), 60 mg.

²Methionine + Cystine.

Weekly feed intake (**WFI**) (g/bird) was measured weekly, as the difference between feed provided and what leftover in the feeders. Weekly feed conversion ratio (**WFCR**) (g feed: g gain) was calculated weekly using WFI divided by WBWG. Mortality was recorded daily.

Five males and 5 females were randomly selected from each pen for carcass evaluation at the end of experiment. Quail were decapitated at 37 d of age, 6 h after feed withdrawal, by cutting between the occipital and atlas bones, using scissors. The birds were bled for 2 minutes and scalded (53-55 °C, 1 min), manually defeathered and eviscerated, and the abdominal fat pad (from the proventriculus surrounding the gizzard down to the cloaca) was removed. To reduce variation in the cutting procedure, all dissections were carried out by two operators with the same level of experience.

To obtain the carcass weight (**CW**) (g) carcasses were weighed (without feet, head and neck, abdominal fat and internal organs). Breasts and legs were separated, with skin, and weighed to obtain the breasts and legs (thigh and drumstick) weight (**BW**) and (**LW**) (g), respectively. Carcass yield (**CY**) (%) was obtained by the relation between CW and fasting weight. Breast (**BY**) (%) and legs (thigh and drumstick) yield (**LY**) (%), with skin, were obtained by the relation between the weight of these parts (BW and LW) and the CW. All weights were obtained using an electronic digital balance with a sensitivity of 0.01 g.

Statistical Analysis

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

RESULTS AND DISCUSSION

There was no significant mortality during the experimental period. Performance of European quails are summarized in Table 4. Interactions for all performance parameters was not significant, except for cumulative feed intake (CFI) at wk 5 ($P = 0.0421$). Temperature main effect was significant ($P < 0.05$) for body weight (BW) and cumulative body weight gain (CBWG) at wk 1-4, however at wk 5 thermal environment was not able to influence these parameters.

At wk 2 and 4 BW and CBWG for SC treatment had highest weight (131.37 and 273.24 g/bird, respectively), differing among the treatments ($P < 0.05$). For wk 1 it is noted that SC was similar to MC and at wk 3 SC, MC and TC were similar ($P > 0.05$). Weight gains at wk 5 was not influenced by thermal environment ($P > 0.05$). Air velocity treatment was not significant for BW and CBWG.

Different results BW and CBWG were reported by Sousa et al. (2014b), in which after 1 week no differences were observed in quail meat subjected to different thermal environments ($P > 0.05$). In their study quails presented lower mean values of BW (32.5 g/bird) and CBWG (23.3 g/bird) during the first week for similar temperatures. However, in this work, at wk 1, quails had higher mean values of BW (55,10 g/bird) and CBWG (45,11 g/bird) for the low air velocity treatment (0 m/s).

Table 4. Performance cumulative of European quail subjected to four thermal environments and two air velocities.

Item	Week	Thermal environment				Air velocity (m/s)		P-value ¹		
		SC	MC	TC	MH	0	2	T	V	T*V
BW (g/bird)	1	56.62 ^b	56.06 ^b	54.57 ^a	53.79 ^a	55.10	55.42	<.0001	0.4514	0.8900
	2	131.37 ^b	126.14 ^a	125.94 ^a	123.98 ^a	127.7	126.02	0.0002	0.1424	0.1068
	3	205.42 ^b	204.23 ^b	204.24 ^b	200.35 ^a	203.5	203.62	0.0301	0.9227	0.4759
	4	273.24 ^b	266.30 ^a	267.36 ^a	263.45 ^a	267.71	267.47	0.0006	0.8834	0.4802
	5	320.85	319.78	324.5	323.79	320.17	324.19	0.6056	0.1596	0.7455
CBWG (g/bird)	1	46.57 ^b	46.11 ^b	44.52 ^a	44.52 ^a	45.11	45.36	<.0001	0.5274	0.9271
	2	121.32 ^b	116.20 ^a	115.89 ^a	115.89 ^a	117.71	115.96	0.0001	0.122	0.0923
	3	195.37 ^b	194.28 ^b	194.19 ^b	190.30 ^a	193.51	193.56	0.0261	0.9625	0.4542
	4	263.40 ^b	256.35 ^a	257.31 ^a	257.31 ^a	257.71	257.42	0.0006	0.8516	0.4401
	5	310.8	309.83	314.45	314.45	310.18	314.24	0.6176	0.1658	0.7578
CFI (g/bird)	1	67.81	67.72	70.23	66.66	65.84 ^A	70.37 ^B	0.1102	<.0001	0.4801
	2	222.15 ^{ab}	218.15 ^a	224.82 ^b	216.68 ^a	216.79 ^A	224.11 ^B	0.0265	0.0007	0.6065
	3	426.42 ^{bc}	421.37 ^{ab}	436.4 ^c	413.85 ^a	418.86 ^A	430.19 ^B	0.0019	0.0063	0.0849
	4	670.26 ^b	665.54 ^b	678.38 ^b	647.57 ^a	657.19 ^A	673.68 ^B	0.0004	0.0014	0.1068
	5	1032.20 ^b	1021.68 ^b	1031.78 ^b	979.07 ^a	1001.49 ^A	1030.87 ^B	<.0001	<.0001	0.0421
CFCR (g/feed: g gain)	1	1.46 ^b	1.47 ^{ab}	1.58 ^c	1.53 ^{ac}	1.46 ^A	1.55 ^B	0.0036	0.0004	0.4942
	2	1.83 ^a	1.88 ^{ab}	1.94 ^b	1.90 ^b	1.84 ^A	1.93 ^B	0.0176	0.0003	0.7150
	3	2.18 ^{ab}	2.17 ^a	2.25 ^b	2.18 ^a	2.16 ^A	2.22 ^B	0.1022	0.0178	0.0799
	4	2.55 ^a	2.60 ^{ab}	2.64 ^b	2.56 ^a	2.55 ^A	2.62 ^B	0.0161	0.0023	0.0668
	5	3.33 ^b	3.30 ^b	3.28 ^b	3.13 ^a	3.23	3.28	0.0007	0.1707	0.1629

¹T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly (P < 0.05) by Tukey's test for Thermal Environment.

^{AB}LS means within a row with different superscript differ significantly (P < 0.05) by Tukey's test for Air Velocity.

BW: body weight; CBWG: cumulative body weight gain; CFI: cumulative feed intake; CFCR: cumulative feed conversion ratio.

Differently, Dozier et al. (2005a) reported that increasing air velocity from 2 to 3 m/s improved growth of broilers during 5 wk under high cyclic temperatures compared with control treatment (still air). Broilers had higher FI in higher air velocities (2 and 3 m/s). Broilers receiving any air velocity had improved BWG, FI and FCR compared with broilers grown in still air (Dozier et al., 2005b). Fujikura (2016) reported performance standards for European quails as the body weight of 25-35 g, 75-85 g, 125-155g, 200-225 g and 230-260 g for wk 1, 2, 3, 4 and 5 respectively. Thus, given the results found in this work, it appears that they were superior to the report by Fujikura (2016).

According to Simmons et al. (2003), air velocity did not affect broiler BWG between 3 to 4 wk. The authors reported that with air velocities of 2 and 3 m/s, significant improvements were noted in body weight gain and feed:gains in broilers from 4 to 5 and 5 to 6 wk of age. And during the last week (6 to 7), an air velocity of 3 m/s significantly improved BWG and feed:gain, as compared with the 2 m/s or the still air. Studying air velocity in broiler chickens, Hamrita and Conway (2016) found that at 3 to 4 wk of age, elevated air velocities had no significant effects in weight gain, however, significant improvements were observed during 5 wk. In this study, no improvement was observed in BW and CBWG in all weeks of development. The different treatments were not significant ($P > 0.05$) on the final BW and CLBW (5 wk). Moreover, higher growth performance in TC (324.5 g/bird) and (314.45 g/bird), respectively.

Cumulative feed intake (CFI) was not affected by thermal environment at wk 1; but was impacted from wk 2 with lower CFI values at MH and MC in relation to the TC treatment ($P < 0.05$) and at wk 5, quails subjected to MH exhibited lowest FI (979.07 g/bird) ($P < 0.001$). Air velocity influenced CFI for all wks ($P < 0.05$), with higher values of CFI at 2 m/s. These results are consistent with those of Yahav et al. (2001), who evaluated the effect of air velocity on the performance of broilers subjected to high temperature. The authors observed significantly higher FI of birds subjected to air velocities of 1.5 and 2 m/s, and significantly lower values at 0.5 and 1 m/s. It can be deduced that the heat load was higher, leading to the suppression of feed intake when birds were subjected to low levels of air velocity. Ruzal et al. (2011) observed higher FI at 2 m/s for laying hens exposed to high air temperature values, however in this study, not observed high FI in high temperatures. Olfati et al. (2018) observed that broiler chickens exposed to heat stress exhibited lower FI, BW and higher FCR in comparison to the birds reared under TC condition.

CFCR was improved significantly up to a MH treatment, with lowest values (3.13 g:g), differing from other treatments ($P < 0.05$). Yahav et al. (2008) reported that body weight at 6 wk of age was significantly lower in turkeys exposed to 0.8 m/s than in those in 1.5, 2.0 and

2.5 m/s, all of which were similar to one another. These differences paralleled similar differences in feed intake, and feed efficiency was not affected. According to Yahav et al. (2004), air velocity significantly affected BW and FI of broiler chickens exposed to high ambient temperature. Bonfim et al. (2016) reported that quails' BW (g) was affected ($P < 0.05$) by the environment at 42 days of age, however, in this study, no effect of the environment was observed at 37 days.

Griep Júnior et al. (2017) found mean values of meat quail performance of 704.1 g/bird, 211.1 g/bird and 3.2, from 1 to 35 days of age, and 908.1 g/bird, 233.8 g/bird and 3.9, from 1 to 42 days of age for FI, BWG and FCR, respectively. The performance of the 42-day old quail obtained by Grieser et al. (2015) for BW, BWG, CFI and FCR was 258.53 g/bird, 249.79 g/bird, 848.7 g/bird and 3.4. It was verified that BW at 42 days of age and the CBWG were lower and the FCR was similar to the values of this work (Table 4). According to Fujikura (2016) quail at wk 6 present FCR of 2.6, lowest than the results cited here.

Also, differently from this work, Souza et al. (2014a) obtained the lowest weight gain for meat quails at 35 days of age created in different thermal environments. The highest weight gain observed in the treatment of TC (254.8 g/bird). Abreu et al. (2014) observed body weight (g/bird) 212.44 at 35 days and 240.42 at 42 in quail meat. Quail slaughtered at 42 days of age had higher body weight than the quails slaughtered at 35 days of age. According to Cavalcante et al. (2010) quail meat (*Coturnix coturnix coturnix*) are earlier compared to Japanese quail and on the 42nd day of life they reach an average weight of 280 g/bird.

The average weights obtained in this experiment were higher, in all evaluated treatments, than those found in the literature for European quail (Drumond et al., 2013; Grieser et al., 2015; Dumont et al., 2017) and Japanese quail (Móri et al., 2005; Bagh et al., 2016; Inci et al., 2016; Santos et al., 2016; Farrapo et al., 2017; Grieser et al., 2017). Çiftçi et al. (2016) reared Japanese quails under low ambient conditions had live body weight at 36 d of 148.06 g/bird and at day 43 d of 170.84 g/bird. Aljumaily (2011) studying the effect of high environmental temperature on growth performance in two lines of Japanese quail at 5 wk of age found mean values for BW of 195.42 and 186.14 g/bird. Hussein et al. (2018) found that the live body weight of Japanese quail at 6 wk was 199.60 g/bird. Through what has been reported we can say that European quail perform better than Japanese quail, this result may be related to be a different quail strain.

Weekly body weight gain, feed intake and feed conversion of European quails are presented in Table 5. Thermal environments and air velocities interactions had no effect ($P > 0.05$) on WBWG ($P = 0.300$) wk 2, WFI ($P = 0.0179$) wk 3 and WFCR ($P = 0.0154$) wk 3.

Table 5. Performance weekly of European quail subjected to four thermal environments and two air velocities.

Item	Week	Thermal environment				Air velocity (m/s)		P-value ³		
		SC	MC	TC	MH	0	2	T	V	T*V
WBWG (g/bird)	1	46.57 ^a	46.12 ^a	44.52 ^b	43.75 ^b	45.11	45.36	<.0001	0.5274	0.9271
	2	74.75 ^b	70.09 ^a	71.37 ^a	70.19 ^a	72.60 ^A	70.6 ^B	0.0039	0.0461	0.0300
	3	74.05 ^b	78.08 ^a	78.30 ^a	76.36 ^a	75.8	77.6	0.0344	0.1139	0.3024
	4	67.82 ^b	62.07 ^a	63.12 ^a	63.10 ^a	64.21	63.85	0.0027	0.7515	0.1850
	5	47.61 ^b	53.47 ^{ab}	57.14 ^a	60.34 ^a	52.46	56.82	0.0138	0.1223	0.3818
WFI (g/bird)	1	67.81 ^{ab}	67.72 ^{ab}	70.23 ^b	66.66 ^a	65.84 ^A	70.37 ^B	0.1102	<.0001	0.4801
	2	154.34 ^b	150.43 ^a	154.59 ^b	150.02 ^a	150.98 ^A	153.74 ^B	0.0399	0.0557	0.8506
	3	204.26 ^{ab}	203.22 ^a	211.64 ^b	197.16 ^a	202.06	206.08	0.0113	0.1782	0.0179
	4	243.84 ^a	244.17 ^a	241.92 ^a	233.72 ^b	238.34 ^A	243.49 ^B	0.0031	0.0198	0.707
	5	361.94 ^a	356.13 ^a	353.40 ^a	331.50 ^b	344.29 ^A	357.19 ^B	<.0001	0.0024	0.2401
WFCR (g/bird)	1	1.46 ^b	1.47 ^{ab}	1.58 ^c	1.53 ^{ac}	1.46 ^A	1.55 ^B	0.0036	0.0004	0.4942
	2	2.08 ^a	2.15 ^{ab}	2.17 ^b	2.14 ^{ab}	2.09 ^A	2.18 ^B	0.2545	0.0074	0.2829
	3	2.71 ^b	2.61 ^a	2.71 ^{ab}	2.60 ^a	2.68	2.66	0.0963	0.8053	0.0154
	4	3.62 ^c	3.95 ^a	3.84 ^{ab}	3.72 ^b	3.73	3.83	0.0044	0.0993	0.2151
	5	8.45 ^b	6.83 ^a	6.26 ^a	5.80 ^a	7.21	6.46	0.0011	0.1155	0.2117

¹T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly (P < 0.05) by Tukey's test for Thermal Environment.

^{AB}LS means within a row with different superscript differ significantly (P < 0.05) by Tukey's test for Air Velocity.

WBWG: weekly body weight gain; WFI: weekly feed intake; WFCR: weekly feed conversion ratio.

All interactions among others wks were not influenced by treatments ($P > 0.05$). Higher WBWG was observed in SC treatment at 1, 2 and 4 wk of age. However, MC, TC and MH was similar at wk 3 and 5 with higher values in these treatments ($P < 0.05$), but at wk 5 no significant difference was observed between SC and MC ($P > 0.05$).

Hamrita and Conway (2016) monitored body weight gain of broiler chickens on a weekly basis and seemed to agree that, in most cases, elevated air velocity leads to higher weight gain. The authors further reported that, overall, heat stressed birds exposed to tunnel ventilation gained more weight on average than birds that were not. However, it was observed that the air velocity only was influenced the WBWG at 2 wk ($P = 0.0461$). Although no significant difference was observed in the other weeks, there is a trend of higher BWG values at 2 m/s.

Quails had the best results for WBWG in SC (74.75 g/bird), MC, TC and MH (78.08, 78.30, 76.36 g/bird), SC (67.82 g/bird) and MC, TC and MH (53.47, 57.14, 60.34 g/bird) for wk 2, 3, 4 e 5, respectively, differing from other temperatures ($P < 0.05$). The weekly results found by Grieser et al. (2015) and Sousa et al. (2014b) were similar, however, they were lower than those found in this study. In the last weeks of life, it can be observed that quails presented a reduction in BWG, which was also observed by Sousa et al. (2014a) and Grieser et al. (2015).

Air velocity was able to influence WBWG only at wk 2, we can see lower value at 2 m/s ($P < 0.05$). Yahav et al. (2001) reported that weight gain for male broilers exposed to a constant high temperature was significantly higher at air velocities of 1.5 to 2 m/s compared to those exposed to air velocities of 0.5 and 1.0 m/s. Lott et al. (1998) demonstrated improvements in weight gain with an air velocity of 2 m/s compared to still air.

Significant differences in WFI were observed between thermal environments and air velocities main effects ($P < 0.05$). As we can see WFI increased when quails reach breeding age and was higher at wk 5. TC was higher and similar to SC and MC at wk 1 ($P > 0.05$). Lower WFI was observed at wk 5 (331.50 g/bird) in MH, differing among thermal environments ($P < 0.05$). Higher WFI for SC, MC and TC (361.94, 356.13 and 353.40 g/bird), respectively, at wk 5 ($P > 0.05$). It is also noted that WFI was higher at 2 m/s condition at wk 1, 2, 4, and 5 ($P < 0.05$). According to Dauda et al. (2014) feed intake increase with advancement in age and body weight, as observed in this study. Sousa et al. (2014a) subjected quails to different thermal environments (temperatures of 26 °C, 30 °C and 33 °C for wk 4 and 5). Although they were not significant, it was verified that most of the thermal environments in the which quails were kept at comfort temperatures, provided higher FI during the week 4.

WFCR worsened as quails got older, 1 from 5 wk of age. Significant difference was observed in all the weeks between the thermal environment treatments ($P < 0.05$). WFCR was lowest at 0 m/s for wk 1 and 2 ($P < 0.05$). In the other weeks air velocity had no effect on WFCR ($P > 0.05$). In agreement with our results, Grieser et al. (2015) reported the best means of feed conversion occurred in the initial (1 to 14 days of age) of quail growth, worsening over time. Thus, FCR increases with the animal age. Generally, broiler quails are slaughtered at about 5 to 6 wk of age for economic reasons (Genchev et al., 2008). Walita et al. (2017) has reported that quails should be slaughtered around 5-6 weeks of age so as to obtain higher carcass yields. The slaughtering of birds at this age is due to the fact that feed conversion worsens considerably as observed in this work.

Daily performance of European quail on 37d are presented in Table 6. Considering the whole rearing period (1 to 37 days of age) the DBWG was not influenced by the thermal environments, air velocity and interaction ($P > 0.05$). When considering feed intake values recorded, it can be noticed that DFI varied with the thermal environments, with significative effect on temperature, air velocity and interaction ($P < 0.05$). The lowest DFI was observed in MH at 0 m/s (26.1 g/bird/day) and temperature main effect (26.46 g/bird/day) ($P < 0.05$). At 2 m/s there was no significant interaction between the MH and MC, DFI were statistically the same ($P > 0.05$), and also MC did not differ from SC and TC ($P > 0.05$). The velocity main effect to DFI was higher at 2 m/s ($P < 0.05$). Indeed, quails average DFI ranged from 26.06 to 28.73 g/bird/day. At the same age, these values were higher than the average feed intake Albino e Barreto (2012).

Interaction for DFCR was not significant ($P > 0.05$). The application of air velocity did not improve feed conversion ($P > 0.05$). It is probably related to the adjustment in feed intake according to different thermal conditions. Significant effect was observed for the main effects of temperature, showing better performance of quails in MH treatment ($P < 0.05$).

Carcass traits of European quail from 1 to 37 days subjected to four thermal environments and two air velocities are presented in Table 7. There was no significative effect of interactions for all carcass traits ($P > 0.05$). Was observed influence of treatments on the main effects of thermal environment and air velocity ($P < 0.05$). Higher CW was found in SC, MC and TC with similar values, differing from MH treatment ($P < 0.05$). It can also be observed that in MH the CW was lower (226.63 g) than the other environments. Quails had higher BW in TC treatment, followed by MC and SC, differing only from MH ($P < 0.05$), however no significant difference was observed between TC, MC e SC ($P > 0.05$).

Table 6. Performance daily of European quail from 1 to 37 days subjected to four thermal environments and two air velocities.

Air velocity (m/s)	Thermal environment				Mean by velocity ¹	<i>P</i> -value ²		
	SC	MC	TC	MH		T	V	T*V
<i>Daily Body Weight Gain (g/bird/day)</i>						0.6176	0.1658	0.7578
0	8.32	8.28	8.44	8.5	8.38			
2	8.48	8.47	8.56	8.46	8.49			
Mean by temperature ¹	8.4	8.37	8.5	8.48				
<i>Daily Feed Intake (g/bird/day)</i>						<.0001	<.0001	0.0421
0	27.71 ^a	27.46 ^a	27.04 ^{Aa}	26.06 ^{Ab}	27.07 ^A			
2	28.09 ^{ab}	27.77 ^a	28.73 ^{Bb}	26.87 ^{Bc}	27.86 ^B			
Mean by temperature ¹	27.90 ^a	27.61 ^a	27.89 ^a	26.46 ^b				
<i>Daily Feed Conversion Ratio (g feed:g gain)</i>						0.0007	0.1707	0.1629
0	3.34	3.32	3.21	3.08	3.23			
2	3.31	3.28	3.36	3.18	3.28			
Mean by temperature ¹	3.33 ^a	3.30 ^a	3.28 ^a	3.13 ^b				

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

²T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test.

^{AB}LS means within a column with different superscript differ significantly ($P < 0.05$) by Tukey's test.

Table 7. Carcass traits of European quail from 1 to 37 days subjected to four thermal environments and two air velocities.

Item	Thermal environment				Air velocity (m/s)		<i>P</i> -value ³		
	SC	MC	TC	MH	0	2	T	V	T*V
<i>Carcass weight (g)</i>	237.56 ^a	236.06 ^a	234.07 ^a	226.63 ^b	231.59 ^A	235.56 ^B	0.0004	0.0336	0.2707
<i>Breast weight (g)</i>	99.79 ^a	102.45 ^{ac}	103.63 ^c	96.81 ^b	98.70 ^A	102.64 ^B	0.0006	0.0016	0.2048
<i>Legs weight (thigh and drumstick) (g)</i>	51.78 ^a	53.04 ^{ab}	55.17 ^b	52.11 ^a	53.63	52.42	0.0529	0.1962	0.3415
<i>Carcass yield (%)</i>	75.69 ^a	75.36 ^a	74.06 ^a	71.22 ^b	74.11	74.06	<.0001	0.9384	0.3059
<i>Breast yield (%)</i>	42.00 ^b	43.82 ^{ac}	44.27 ^c	42.72 ^{ab}	42.61 ^A	43.58 ^B	0.0018	0.0189	0.1179
<i>Legs yield (thigh and drumstick) (%)</i>	21.89 ^b	22.54 ^{ab}	23.58 ^c	22.30 ^{ac}	23.17 ^A	22.28 ^B	0.0089	0.0167	0.1007

¹T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test for Thermal Environment.

^{AB}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test for Air Velocity.

Air velocity had a positive effect on CW and BW at 2 m/s, differing from 0 m/s ($P < 0.05$). Reis et al., 2012 studied cutting quails at 35 days and obtained the weight of 169.6 g for CW. Was observed greater LW in quails subjected to thermal environments TC and SC with 55.17 g and 53.04 g, respectively. Quail LW was not influenced by air velocity ($P > 0.05$). Santos et al. (2016) evaluating the performance of meat quails at 42 days, obtained BRW of 59.75 g and LW of 36.01 g.

Carcass yield main effect was higher in SC, MC and TC, differing from MH treatment ($P < 0.05$). Air velocity did not influence the CY ($P > 0.05$). In thermal environments SC and MC the BY was higher not differing from each other ($P > 0.05$), however MC was similar to MH ($P > 0.05$). As showed in table 5, air velocity had significant effect in BY with higher value at 2 m/s (48.58 %) ($P < 0.05$). Legs yield was affected by the thermal environment and air velocity treatments ($P < 0.05$). TC (23.58%) and MH (23.30%) treatment presented higher LY not differing from each other ($P > 0.05$). In an experiment with Japanese quail was observed at 42 days of age, the carcass yield for males and females was 68.32% (Kirmizibayrak and Altinel, 2001), showing to be lower than those obtained in this work (Table 7). The same can be observed by Pasquetti et al. (2014) and Grieser et al. (2015), when they evaluated the CY (59.94%) of meat quails at 35 days of age, however similar results BY and LY were found 44.57% and 24.95%, respectively. Bonfim et al. (2016) reported that quails' CY (%), BY (%) and LY (%) was not affected ($P > 0.05$) by the environment at 42 days of age. Mori et al., 2005 had similar results for meat quails at 42 days in thermal comfort. The authors observed CW (174.53 g), CY (71.22%), LY (24.22%) and BRY (72.74%).

CONCLUSION

Thermal environment and air velocity affected quail performance. There was a tendency for temperature and air speed to influence body weight and cumulative body weight gain in the first weeks of bird life. In this work, quails gained more weight in the severe cold, suggesting that temperature ranges be adjusted. It is also concluded that, after the 4th week, the thermal environment has no influence on weight gain. Moderate heat negatively affects the performance of the birds, with the worst CFCR values in the first 2 weeks. It is noteworthy that the air velocity does not influence CBWG and BW in the first weeks and better results for CFI, CFCR, WBWG, WFI and WFCR were found in birds kept in still air. The thermal environment does not influence DBWG, DFCR and carcass traits.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

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CHAPTER 3

MEAT QUALITY TRAITS OF EUROPEAN QUAIL 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 x 4 factorial arrangement of treatments in completely randomized design with 2 air velocities (0 and 2 m/s) x 4 air temperatures (severe cold, moderate cold, thermal comfort, and moderate heat). 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 pH_u ($P = 0.993$). 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). Further, quail production facilities do not require large capital investments, and the short production cycle (35-37 days) 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 first 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, dry (DFD) characteristics (Chan et al., 2011; Dadgar et al., 2010, 2012). With hypothermia, the birds's 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 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*) 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.

1152 one-day-old European quail chicks were used in two replicate trials. Quail 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 x 2.44 m x 2.38 m (LxWxH). Quail were placed inside floor pens measuring 0.50 m x 0.50 m x 0.60 (LxWxH) with 18 quails placed in each pen at a density of 140 cm²/quail, and with eight pens (144 quails) per environmental chamber. Each experimental period was approximately 5 wks in duration with birds harvested at 37 d of age. Pens floors were covered with 7–10 cm of medium-grade pine shavings, mixed weekly and replaced with new pine shavings as needed. All quail 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) hourly schedule was 24L:0D, 23L:1D for Days 0–14 and 15–37, respectively, based on that applied in commercial farms.

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	-
Vit & Min. 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, %		
Crude Protein	25.00	22.00
Metabolizable energy (kcal/kg)	2900	3050
Cálcium	0,85	0.70
Available phosphorus	0.32	0.27
Digestible lysine	1.37	1.09
Digestible methionine	0.71	0.50
Met + Cys ²	1.04	0.80
Sodium	0.17	0.15

¹Premix provided per kilogram of diet: vitamin A (min), 1200000 IU; vitamin D3 (min), 2250000 IU; vitamin E (min), 25000 IU; vitamin K3 (min), 3000 mg; thiamin, 2400 mg; riboflavin, 12 mg; pyridoxine HCl, 2000 mg; vitamin B12 (min), 24000 mcg; calcium pantothenate (min), 15 g; niacin (min), 42 g; biotin (min), 180 mg; folic acid (min), 1800 mg; BHT, 50 g; Se (min), 180 mg; Fe (min), 50 mg; Cu (min), 8500 mg; Co (min), 1000 mg; I (min), 1000 mg; Mn (min) 70 mg; Zn (min), 60 mg.

²Methionine + Cystine.

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 four pens in each environmental chamber. Further details of the air velocity arrangement are described fully in (Santos et al., 2019). The air temperature treatments were based on estimated thermal comfort (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 as a 2 x 4 factorial arrangement of treatments in completely randomized design (pen within chambers) with fixed air velocity with: 0 and 2 m/s and air temperature to each chamber for each week with: severe cold (SC), moderate cold (MC), thermal comfort (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 eight replicates. Adjacent pens shared one air velocity controller. The average values of AT and RH inside the chambers were close to those desired for each thermal environment (Table 3).

Table 2. Thermal environments established in air temperature treatment for each week. Night temperature was Thermal comfort (TC) from 18:00 to 6:00.

Thermal environments	Air temperature (°C) (6:00 am to 6:00 pm)				
	1° Week	2° Week	3° Week	4° Week	5° Week
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

¹(Sousa et al., 2014ab; Albino and Barreto, 2012).

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

Week	Period (h)	Thermal environments							
		Severe cold (SC)		Moderate Cold (MC)		Thermal comfort (TC)		Moderate heat (MH)	
		AT (°C)	RH (%)	AT (°C)	RH (%)	AT (°C)	RH (%)	AT (°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

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. Quail were randomly slaughtered, stunned by cervical dislocation and decapitated 6 h after feed withdrawal by cutting between the occipital and atlas bones using scissors. The birds were bled out for 2 minutes and scalded (53-55 °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 *post-mortem*, packaged in plastic bag 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*), water holding capacity (WHC) by drip loss method (DL), thawing loss (TL), cooking loss (CL), shear Force (SF), sarcomere length (SL) and myofibrillar fragmentation index (MFI).

pH

At 24 h *post-mortem* 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 three reading across the surface of the *Pectoralis minor* and *Pectoralis major* previously exposed to air ambient for 30 min. Immediately prior to data collection, a Hunter MiniScan EZ (4500L, Hunter Associates Laboratory, Inc., Reston, Virginia, USA) was calibrated and used to scan meat color. The spectrophotometer was set to read using illuminant D65, port size of 31.8 mm and a 10° standard observer. Values of L*, a* and b* were obtained according to CIE (International Commission on Illumination) L*a*b* color system (Mancini and Hunt, 2005).

Drip loss

Water holding capacity was measured using drip loss (DL) applying no external force. To evaluate DL, each sample was weighed 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] x 100%, (Honikel, 1998).

Thawing loss

Breast samples were stored in a plastic bag and frozen for 24 h for thawing loss (**TL**) measurement. Subsequently, the frozen samples were weighed and kept refrigerated for 12 hours 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 cooking loss (**CL**) breast meat samples (*Pectoralis major*) were weighed, individually vacuum sealed in a plastic bag and cooked in a water bath at 74 °C for 40 min. Quail samples 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 cooking loss the samples were stored overnight at 4 °C and shear force (**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, USA) 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 five cores.

Sarcomere length

The sheared cores used for SF were kept for sarcomere length (**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. Sarcomere length was measured using a helium neon laser diffraction unit (05-LHR-021, Melles Griot, Carlsbad, CA, USA) and calculated as described by Cross et al. (1981).

Myofibrillar fragmentation index

Myofibrillar fragmentation index (**MFI**) was evaluated by measuring the turbidity of homogenized samples at standardized protein concentration (Olson et al., 1976). Some modifications were applied for better results including the use of a shaft type homogenizer (Hopkins et al., 2004). Duplicate myofibrils were extracted from the frozen pectoralis samples

of each treatment, for more details see Silva et al. (2017). Afterwards, 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

Analysis of variance (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, USA). All data were analyzed as a 2 x 4 factorial arrangement of treatments in completely randomized design with factors being 2 air velocities (0 and 2 m/s) x 4 air temperatures (SC, MC, TC, MH). Least square means of treatments effects ($P < 0.05$) were compared using Tukey's test with significance level 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.

Table 4. Ultimate pH (pH_u) and color main effects of European quail meat harvested at 37d of age in four different thermal environments and two air velocities.

Item	Thermal environment				Air velocity (m/s)		P -value ¹		
	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^* <i>Initial</i>	52.41 ^a	53.01 ^a	52.24 ^a	54.49 ^b	53.23	52.84	<.001	0.254	0.254
a^* <i>Initial</i>	9.82 ^a	9.17 ^b	9.18 ^b	8.89 ^b	9.27	9.25	0.023	0.955	0.678
b^* <i>Initial</i>	13.17 ^{ab}	13.52 ^{ac}	12.93 ^b	13.83 ^c	13.52	13.21	0.002	0.087	0.747
L^* <i>Final</i>	49.94 ^a	50.41 ^{ab}	51.06 ^b	52.22 ^c	51.29 ^A	50.52 ^B	<.001	0.009	0.263
a^* <i>Final</i>	12.31 ^a	11.79 ^b	11.37 ^{bc}	11.22 ^c	11.43 ^A	11.92 ^B	<.001	0.003	0.170
b^* <i>Final</i>	14.38 ^{ab}	14.69 ^{ac}	13.98 ^b	15.15 ^c	14.54	14.55	0.003	0.946	0.081

¹T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test for Thermal Environment.

^{AB}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test for Air Velocity.

The lack of treatment effect on pH_u indicates that glycogen reserves of quail submitted to cold stress can be similar to those submitted to thermal comfort 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 lower pH value (4.94) for quails under heat stress conditions. Singh and Verma (1995) reported that the pH of quail meat breast muscle declined rapidly within the first 2 h following 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, 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 *post-mortem* and that the pH of their meat was significantly higher than in the meat of chickens maintained at thermal comfort. However, these results are different from those presented in this work. According to Terlouw et al. (2008), normal pH stabilizes after 24 hours *post-mortem*, 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, PSE (Pale, Soft and Exudative) can be detected by combining pH values (below 5.8) and color (L^* value above 52), measured 24 hours 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 to no heat stress (5.93). According to Wang et al. (2017), heat stress accelerated the pH decrease in commercial conditions and they found $\text{pH}_u = 5.87$ and 6.04 in heat stress and comfort, respectively. Dadgar et al. (2012) showed that the breast meat pH_u of cold-stressed broilers (6.44) was significantly higher ($P = < 0.0001$) than those subjected to control treatment (6.09).

The color characteristics L^* , a^* , b^* of quail meat were affected by thermal environments and air velocity ($P < 0.05$). Initial and final L^* 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 lower final L^* , but there was no 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 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 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 ideal L^* 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).

Quail kept under SC presented higher initial and final a^* values compared with the other 3 thermal environments groups ($P < 0.001$), and final a^* 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 environment treatments ($P < 0.05$) but air velocity did not influence b^* values ($P > 0.05$). Similarly, Tang et al. (2013) observed a significative increase of L^* and b^* , and a reduction in a^* for broiler meat from heat stressed birds compared to 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) unaffected ($P > 0.05$) by any thermal environment and air velocity treatments.

Table 5. Meat exudate losses (Drip, Thawing, and Cooking) for European quail meat harvested at 37d of age in four different thermal environments and two air velocities.

Air velocity (m/s)	Thermal environment				Mean by velocity ¹	P-value ²		
	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 ^{Ab}	3.15 ^{ab}	3.11 ^{Aab}	3.16 ^A			
2	2.87 ^a	2.46 ^{Ba}	3.55 ^b	2.47 ^{Ba}	2.84 ^B			
Mean by temperature ¹	2.83	3.03	3.35	2.79				
	Cooking Loss (%)					<.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				

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

²T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test.

^{AB}LS means within a column with different superscript differ significantly ($P < 0.05$) by Tukey's test.

The most serious defect of PSE meat is drip loss (Çelen et al., 2016). Offer (1984) suggested that higher drip loss in chicken meat can be characterized by PSE meat and reduced drip loss by DFD. According to Barbut et al. (2005), drip loss values for PSE, Normal and DFD were 1.65, 1.00 and 0.69% respectively in chicken meat. The authors suggest that light PSE meat showed a significantly higher drip loss 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 drip loss compared to non-HS controls ($P < 0.05$). By contrast, there was no difference for drip loss 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 *post-mortem* 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 air temperature 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, quail kept under TC had higher TL (3.6%) ($P < 0.05$), but 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, ($P = < 0.001$) and ($P = 0.0008$), respectively. CL was greatest at TC (11.68%) thermal environment and was the highest for the 2 m/s (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 quail; 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 quail to similar conditions of moderate cold 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 ($P = 0.0008$). 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 SC, MC and TC ($P < 0.005$). Different results were 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 *post-mortem* 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 standard temperature group.

Regarding both meat quality traits SL and MFI, the environments that quail were subjected had no influence ($P > 0.05$). SL value of 1.32 ± 0.12 from broilers was found by Wattanachant et al. (2005). Sarcomere is the contractile unit of myofibrils, and sarcomere lengths 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 shear force values than samples with short sarcomeres. Dunn et al. (1993) reported that as pH_u decreased, sarcomere length tended to decrease and shear force increase.

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, MFI was affected only by thermal environment main effect ($P < 0.05$) and not 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.

Table 6. Meat quality characteristics of European quail harvested at 37d of age in four different thermal environments and two air velocities.

Air velocity (m/s)	Thermal environment				Mean by velocity ¹	P-value ²		
	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 ^{Aa}	8.888 ^a	7.257 ^{Ab}	8.434			
2	9.042 ^a	7.512 ^{Bb}	9.042 ^a	8.306 ^{Ba}	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					<.0001	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				

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

²T = Temperature. V = Velocity. T*V = Air temperature by air velocity interaction.

^{abc}LS means within a row with different superscript differ significantly ($P < 0.05$) by Tukey's test.

^{AB}LS means within a column with different superscript differ significantly ($P < 0.05$) by Tukey's test.

CONCLUSION

Thermal environment and air velocity affected quail meat quality traits. It is noteworthy that the pH_u , drip loss and sarcomere length values were not affected by any thermal environment, air velocity treatments or their interaction. Nonetheless, cooking loss and myofibrillar fragmentation index were highest at thermal comfort (11.68) and severe cold (117.87) environments and differed from the other treatments. Heat stress decreased the shear force and increased the myofibrillar fragmentation index compared to samples from the thermal comfort treatment. Thawing loss was greater for thermal comfort 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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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

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CHAPTER 4

FINAL SUMMARY

As highlighted in this study, the environmental conditions in which the production animals are raised directly linked to their production performance and to the meat quality. Given the above, it was possible to know and show how thermal stress from temperature and air velocity affects performance, carcass traits and degrades the meat quality by changing the main parameters important to consumers.

With respect to quail performance, the study of thermal stress and evaluation of different air temperature and air velocity was found to affect quail performance, showing a tendency for better results for birds kept in environments of severe cold, moderate cold and thermal control and still air. It can be concluded that, after the 4th week, the thermal environment tested had no influence on weight gain. The temperature and air velocity were seen to affect quail meat quality traits. Further investigation is recommended to explore the effect of air velocity and thermal environments.

Knowing the ideal thermal environment, including air temperature and velocity and ideal nutrition, for each week of the birds' life is important so that good results are obtained in production. This study demonstrated that the quail development can be affected when they are maintained at a high air speed and that it is of great importance to know the ideal temperature ranges for each week of bird life.