Analysis of the physical meat quality in partridge (*Alectoris chukar*) and its relationship with intramuscular fat

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ABSTRACT This study was undertaken to assess the effect of various levels of intramuscular fat (**IMF**: <0.5%, 0.5–0.99%, 1.0–1.49%, 1.5–1.99%, 2.0–2.49%, and >2.5%) on the physical meat quality of partridge. Physical characteristics such as moisture, pH, shear force, water-holding capacity (**WHC**), and color, along with IMF, were measured on 414 partridges (pectoral muscle). In this study, partridge meat was described as a kind of tender and moderately juicy meat with a nice color. Additionally, tenderness was significantly different between IMF < 0.5% and IMF > 0.5% levels ($P < 0.01$). IMF >0.5% also obtained higher value of WHC than IMF <0.5% although the difference was statistically nonsignificant. IMF levels did not affect pH or color. The results showed that IMF content was not significantly correlated with physical meat quality. However, in terms of eating experience, the minimum IMF level for better meat quality for consumer was 0.5%.

Pearson correlation coefficients indicated that IMF content had significant negative correlations with moisture content but not with pH ($r = -0.066$), shear force ($r = -0.072$), WHC ($r = 0.085$), or color (L*($r = -0.049$), a*($r = -0.028$) and b*($r = 0.045$)). Besides, meat pH had significant negative correlations with WHC ($r = -0.036$; $P < 0.01$) and lightness (L*) ($r = -0.292$; $P < 0.01$). Consequently, we consider pH to be one of the most important factors in evaluating meat quality of partridge.

Key words: partridge, meat quality, IMF, shear force, WHC

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INTRODUCTION

Partridges, characterized by medicinal and health-promoting values, delicious taste, and superior meat quality, are becoming increasingly popular. In China, the common partridges in the market, originally imported from the United States, have been raised for meat production in most areas for many years. Although partridges have been raised domestically for many years, research studies on meat quality of partridges are limited compared with other avian species. For the partridge industry to be successful, it requires meat products to satisfy the consumer (Fortin et al., 2005). However, the literature includes rare information on the meat quality of partridge. Consequently, a basic study of partridge meat quality is essential to commercial production. It also could provide an important reference for studying meat quality in partridge.

Many factors could affect meat quality, including age, nutrition, genotype, type of muscle, feeding regime, and handling and slaughtering conditions. The pH was a major indicator of meat quality as it could influence meat color, water-holding capacity (**WHC**), flavor, tenderness, and shelf life (Jensen et al., 2004). In general, shear force, an important indicator reflecting the tenderness of the meat, is dependent not only on the structural and metabolic characteristics of a muscle at slaughter but also muscle metabolism during rigor mortis and aging (Andújar et al., 2003; Girolami et al., 2003). WHC is a significant parameter in whole meat and further processed meat products. WHC may vary based on the intramuscular fat (**IMF**) content and the ratio of the different types of fibers present in the muscle and can also result in an increase in pH (Andújar et al., 2003). Meat color, associated with freshness and wholesomeness, is an important quality factor influencing consumer's selection of fresh meat at the time of consumption. Because of its importance to meat quality, factors affecting poultry meat color have been extensively examined.

In addition to the above physical characteristics, IMF also contributes to the meat quality. IMF content was affected by genotype and production system. It could alter muscular structure, allow for the retention of

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higher levels of water, and give physical protection against muscle dehydration (Lopes et al., 2014). Aaslyng et al. (2003) suggested that juiciness experienced later in the chewing process was determined by a combination of the water content, IMF content, and the saliva production during chewing of the meat. In addition, some studies have indicated that there was a relationship between IMF content and the sensory traits of "juiciness" and "tenderness" in meat (Devol et al., 1988; Fernandez.et al., 1999; Rincker et al., 2008; Font-i-Furnols., 2012). It is generally accepted that a higher level of IMF had a positive influence on the sensory experience associated with eating (Wood, et al., 2004). Given these preferences and to evaluate the quality of partridge meat, we compared the differences in physical characteristics of meat quality with different IMF content.

As described earlier, physical characteristics such as moisture, pH, shear force, WHC, and color, along with IMF, were important traits affecting the quality of meat, and relationships between physical characteristics of meat quality and IMF had been extensively studied in other livestock (Fiems et al., 2003; Fortin et al., 2005; Wang.et al., 2009; Utama et al., 2018). However, there was no information about the relationship between IMF content and physical characteristics of meat quality in partridge obtained. To evaluate the quality of partridge meat and extend current knowledge, the purpose of this study was to evaluate physical characteristics of partridge systematically and determine the relationship between each of the physical factors affecting meat quality in partridge.

MATERIALS AND METHODS

Samples

We studied 414 partridges (*Alectoris chukar*), which were hatched and raised for 18 wk in the breeding facility of Wenzhou Yongzheng Agricultural cooperation company (Wenzhou, China). Ten chicks were housed in cages (55 × 65 cm) fitted with 1 bell waterer and hanging tube feeder, providing with water and feed for ad libitum consumption (Raji et al.,2014). The feed for partridges contained 23% CP and 3,000 kcal of ME/kg for the first 6 wk and contained 18% CP and 2,800 kcal of ME/kg between 6 and 18 wk (NRC, 1994). On the first day, the ambient temperature was controlled at around 34°C and was lowered by 3°C per week until reaching 20°C (Ozek et al., 2003; Arslan, 2004; Yildiz et al., 2005). A constant photoperiod of 24 h was provided during the first 3 D and then exposed to natural lighting the rest of the experiment. All procedures were based on the guiding principles for the care and use of research animals (Cetin et al., 2007). Experiments were performed on samples of pectoral muscle obtained from the right carcass side after euthanasia. Carcass weight was 395 to 450 g, with an average of 426 g. Pectoral muscle samples were prepared at each meat plant, and then a number of parameters were studied in meat. All analyses were performed at 24 h after partridges were slaughtered.

Intermuscular Fat and Moisture

Samples were prepared from the pectoral muscle. Intramuscular fat was extracted and examined according to the procedures of AOAC (1990), and moisture content was measured by drying the samples at 105°C for 24 h (Utama et al., 2018). IMF and moisture content were analyzed by the Zhejiang Academy of Agricultural Sciences Laboratories (Hangzhou, China). Intramuscular fat and moisture content were recorded as the average of 3 samples.

pH

The pH of meat was measured by pH-Star (Matthaus, Germany) calibrated with buffer solutions at pH 4.01 to 7.00 with an automatic temperature compensation program, 3 replicates from each muscle were analyzed, and the average value was recorded as the pH for each sample after slaughter (Bernad et al., 2018).

Shear Force

Shear force value was determined on each core perpendicular to the fiber grain using an Instron 4,301 Material Testing System equipped with a Warner-Bratzler cell and Series 9 Software (Fortin et al., 2005). Samples were cut through the slit of the table against the grain as the blade moved down with a constant speed of 200 mm/min (Silva et al., 2017). The final value, recorded in Newtonian force (N), was an average of 3 measurements per sample.

Water-Holding Capacity

WHC was defined as the proportion of free water in the meat. It was estimated according to filter-paper fluid uptake as described by Kauffman et al. (1986). A raw meat sample was placed between 18 pieces of 11-cm-diameter filter paper and pressed at 25 kg for 5 min. Expressed juice was defined as the loss in weight after pressing and presented as a percentage of the initial weight of the original sample (Bouton et al., 1971). Water-holding capacity was measured in 3 replicate samples from each pectoral muscle, with the average value recorded as the final value for each sample.

Color

The value of meat color was evaluated using a reflectance spectrophotometer (X-Rite SP64, USA) to determine L* (lightness), a* (redness), and b* (yellowness) values. Each assay was repeated 3 times for each sample.

Table 1. Summary of partridge meat quality in 6 IMF groups.

	Intramuscular group[1]					
Measurements	1	2	3	4	5	6
Number	28	130	88	94	50	24
Intramuscular fat (g/100 g)						
Mean	0.414	0.737	1.193	1.735	2.209	2.929
SD	0.088	0.146	0.139	0.130	0.165	0.678
Moisture (%)						
Mean	71.363[a]	71.168[a]	70.484[b]	70.093[b]	69.329[c]	69.114[c]
SD	0.011	0.015	0.009	0.008	0.012	0.008
pH						
Mean	5.99	5.87	5.84	5.93	5.88	6.04
SD	0.032	0.025	0.046	0.035	0.029	0.058
Shear force						
Mean	18.99[a]	16.62[b]	16.35[b]	16.48[b]	16.81[b]	16.34[b]
SD	3.639	4.065	4.775	5.492	3.841	3.523
WHC(%)						
Mean	4.310	5.644	5.896	6.116	5.863	5.846
SD	0.023	0.035	0.054	0.045	0.029	0.050
Color						
L						
Mean	48.13	47.77	47.87	47.94	47.53	47.41
SD	3.083	3.192	3.304	3.055	3.510	2.823
a						
Mean	6.52	6.48	7.01	7.47	6.92	6.91
SD	1.720	2.685	2.235	3.604	2.052	1.364
b						
Mean	8.46	8.75	8.66	8.91	9.61	8.74
SD	2.563	2.508	2.207	1.903	2.493	1.937

[a,b,c]Within IMF groups, means with different letters are significantly different ($P < 0.05$).

Abbreviations: IMF, intermuscular fat; SD, standard deviation; WHC, water-holding capacity.

[1]IMF groups. 1: <0.5%; 2: 0.5–0.99%; 3: 1.0–1.49%; 4: 1.5–1.99%; 5: 2.0–2.49%; and 6: >2.5% intramuscular fat.

Statistical Analysis

The meat was grouped by different IMF content (<0.5%, 0.5–0.99%, 1.0–1.49%, 1.5–1.99%, 2.0–2.49%, and >2.5%); all results were calculated and summarized as mean (x) and standard deviation (s). Moreover, relationships between the traits were determined by linear correlation using the CORR procedure. Pearson values were statistically evaluated by the significance of differences to $P < 0.05$.

RESULTS AND DISCUSSION

The meat was divided into 6 groups according to the following IMF levels: <0.5%, 0.5–0.99%, 1.0–1.49%, 1.5–1.99%, 2.0–2.49%, and >2.5%. Table 1 showed the number of samples, means, and standard deviation, for each IMF group. Intramuscular fat means for IMF group 1–6 were: 0.414, 0.737, 1.193, 1.735, 2.209, and 2.929%, respectively. In this study, the range in IMF content was 0.21 to 4.81%, with an average of 1.21%. Intramuscular fat content in the range of 1.5-1.99% is the most (75.36%) in our study of the relationship analysis between IMF content and meat quality traits of 414 partridges. There were no data reported concerning IMF in partridge so far. Intramuscular fat content was affected by genotype and production system. Poultry meat was known for being low in fat because unlike other meat animals, fat is mainly deposited subcutaneously or in the abdomen rather than in the meat (Fanatico et al., 2007).

Consistent with the nature of the relationships with IMF previously described for moisture, moisture were found statistically significant results vary from IMF <1.0, 1.0% < IMF <2.0%, and IMF >2.0% ($P < 0.001$) (Table 1). There was a strong negative correlation between IMF content and moisture. With the increasing of IMF content, the moisture content became lower and lower. It was consistent with the result in pigs reported by Watanabe et al. (2018).

Meat pH was important in terms of meat quality, indicating the preservation and stability of meat. It was known that muscle with higher pH means shorter shelf life stability because of the more favorable environment for microbial growth and muscle with lower pH means poor WHC and poor functionality (Owens et al., 2000; Woelfel et al., 2002; Wang et al., 2009). Postmortem pH decline was one of the most important events in the conversion of muscle to meat, especially as its effect on meat tenderness, color, and WHC (Aberle et al., 2001). The rate of pH decline was dependent on the activity of glycolytic enzymes just after death; the ultimate pH was determined by the initial glycogen reserves of the muscle (Bendall, 1973). Muscles might be classified based on their functionality into oxidative muscles ("red" fibers, rich in mitochondria and myoglobin—high pH) and glycolytic muscles ("white" fibers, low level of mitochondria, and rich in glycogen—low pH) (Listrat et al., 2016).

Differences in meat pH were not observed between different groups in this study. As shown in Table 1, the range in meat pH was 5.84 to 6.04, with an average of 5.89. The value of meat pH in partridge was slightly lower than the value reported in partridge by Yamak et al. (2016) and higher than those reported in chickens (Fanatico et al., 2007; Wang et al., 2009) and greater rhea (Bernad et al., 2018). Changes could be due to the fact that the slow-growing birds such as partridges may be more stress susceptible than chickens that grow faster (Debut et al., 2005). The exercise was another cause of muscle metabolism (Farmer et al., 1997). Partridges were more active and more prone to shackling stress than large-scale farmed poultry because of the state of semi-dominant and semi-wild, which led to rapid breast muscle acidification. All these factors were known to influence the quality characteristics of meat. Considering the general range of pH values obtained in this study and the aforementioned citations for the species, partridge meat could be classified as an intermediate meat-type between normal (pH $<$ 5.80) to extreme dark, firm, and dry meat (pH $>$ 6.20) (Morris et al., 1995; Sales, 1996a; Sales and Mellett, 1996b; Sales and Horba˜nczuk, 1998a; Sales, 1998b; Hoffman et al., 2008).

Among the organoleptic characteristics, the texture was a crucial consumer attribute, particularly tenderness, which could be defined as how easy the meat could be chewed or cut. Shear force was an important indicator reflecting the tenderness of meat. As shown in Table 1, the range in shear force was 16.34 N to 18.99 N, with an average of 16.69 N. The value of shear force in partridge was significantly lower than those reported in chickens (Wang et al., 2009) and greater rhea (Bernad et al., 2018) in the same age. The differences in tenderness might be endogenous. Dransfield and Sosnicki (1999) found that birds with large muscle mass accrete protein through reduced protein catabolism. Because they had reduced proteolytic potential, there was less postmortem proteolysis and, therefore, reduced tenderization in the meat. Schreurs et al. (1995) also had a conclusion that slow-growing birds show higher proteolytic activity. Therefore, lower shear force in partridge meat may be caused by more tender muscle fibers as well as by lower content of insoluble elastin (Veisethkent et al., 2010). Partridge meat that had less than 0.5% IMF showed higher value for shear force than meat with more than 0.5% IMF ($P < 0.05$); this parameter have affirmed the conclusions of Fortin et al. (2005) that the IMF influences shear force in pork. Le Bihan-Duval (2003) made an observation and proved that the birds with more IMF in breast meat are usually associated with higher tenderness. Besides, Fernandez et al. (1999) also reported that a low correlation between sensory tenderness and IMF levels, although the effect of IMF level on tenderness is factual, is nevertheless not systematic.

Water-holding capacity is a significant parameter in whole meat and further processed meat products. Poor WHC means poor juiciness, as well as poor sensory characteristics. As shown in Table 1, the range in WHC was 4.310 to 6.116, with an average of 5.689. The value of WHC in partridge is significantly higher than that in the previous study in chickens (Wang et al., 2009) using the same method. Some authors indicate that high WHC is related to proteases, which promote disintegrating of the Z lines and change in the permeability of the membranes, with a certain diffusion and ionic redistribution that gives as a result the replacement of some divalent ions and the weakening of forces that approximate the protein chains (Hamm, 1986). Water-holding capacity in the group with high IMF more favorable results were obtained than the group with low IMF although the results were statistically nonsignificant. There were no studies concerning WHC% of poultry at different IMF content.

Color was one of the first characteristics noticed by consumers when buying meat products; it is regarded as an indicator of freshness and wholesomeness at the point of sale (Mancini and Hunt, 2005). In natural and organic markets, where carcasses were often marketed whole, color and uniformity of poultry skin and meat and consistency of color play a particularly important role (Qiao et al., 2002). Skin color was dependent on the genetic ability of the bird to produce melanin pigments in the dermis and epidermis, as well as to absorb and deposit carotenoid pigments in the epidermis (Fletcher, 1999). Myoglobin content was a major factor responsible for meat color and is dependent on species, muscle, and age of the bird; other heme proteins such as hemoglobin and cytochrome C might also play a role in beef, lamb, pork, and poultry color (Mancini and Hunt, 2005). Besides, other intrinsic factors such as pH could also influence meat color (Fletcher, 2002).

The L* value, which is associated with poor meat quality, indicates the degree of paleness; pale, soft, and exudative meat was an increasing problem in the poultry industry (Baeza et al., 2002). There was no difference in lightness (L*) between different groups in this study (Table 1). The lightness (L*) value, between 47.41 and 48.18, was slightly lower than previously reported in partridge (Yamak et al., 2016) and significantly lower than reported in chicken (Fanatico et al., 2007) at same age, but were similar to those reported by Fletcher et al. (2000) in chicken. According to breast meat lightness (L*) values as follows: lighter than normal (light, $L^* > 53$), normal ($48 < L^* < 53$), and darker than normal (dark, $L^* < 46$), partridge meat could be classified as a normal meat type (Qiao et al., 2001). As shown in Table 1, the range in redness (a*) was 6.52 to 7.47, with an average of 6.90. The value of redness (a*) in partridge was higher than the value reported in partridge by Yamak et al. (2016). Compared with the values of other poultry, the value of redness (a*) was significantly higher than in previous studies in chickens (Qiao et al.,

Table 2. Pearson correlation coefficients between IMF, moisture, pH, shear force, WHC, and color of partridge.

Item	IMF	Moisture	pH	Shear force	WHC	Color L	Color a	Color b
IMF	1	−0.512**	−0.066	−0.072	0.085	−0.049	−0.028	0.045
Moisture	-	1	−0.058	−0.072	0.009	0.101	0.078	−0.039
pH	-	-	1	0.053	−0.036**	−0.292**	−0.029	0.064
Shear force	-	-	-	1	0.678	0.071	0.097	−0.042
WHC	-	-	-	-	1	0.113	0.006	−0.071
Color								
L	-	-	-	-	-	1	0.283**	0.419**
a	-	-	-	-	-	-	1	0.547**
b	-	-	-	-	-	-	-	1

i* $P < 0.05$, ** $P < 0.01$.
Abbreviations: IMF, intermuscular fat; WHC, water-holding capacity.

2001; Fanatico et al., 2007) and lower than in greater rhea reported by Bernad et al. (2018) at similar age. The intense red color, which was mainly due to a high concentration of myoglobin pigment, may be explained in part by its high final pH (Berge et al., 1997; Lawrie, 1998). The yellowness (b*) value, between 8.46 and 9.61, was much higher than the value reported in partridge by Yamak et al. (2016). Meanwhile, the yellowness (b*) value was also much higher than previously reported in chicken (Fanatico et al., 2007) and greater rhea (Bernad et al., 2018) at same age, but are similar to those reported by Fletcher et al. (2000) in chicken. In terms of color, there was no difference between 6 IMF groups ($P > 0.05$).

Pearson correlation coefficients were shown in Table 2. IMF content had significant negative correlations with moisture content (r = -0.512; $P < 0.01$). It was generally accepted that moisture content of beef and pork correlates negatively with fat content (Savell et al., 1986; Ueda et al., 2007; Watanabe et al., 2018). Likewise, moisture was replaced by fat in partridge as well.

As shown in Table 2, IMF content was not significantly correlated with pH ($r = -0.066$), shear force ($r = -0.072$), WHC ($r = 0.085$), or color (L*($r = -0.049$), a*($r = -0.028$) and b*($r = 0.045$)). As for shear force, Wood et al. (2004) reported a weak association between tenderness (shear force) and IMF in pork. Laack et al. (2001) also reported that IMF and ultimate pH influence tenderness, but their roles had not been conclusively determined. In terms of WHC, Cannata et al. (2010) reported a significant negative correlation between IMF content of meat and cooking loss. However, Watanabe et al. (2018) found no significant correlation between the IMF and WHC. Here, in this study, IMF content was not significantly correlated with shear force and WHC.

In our study, WHC was significantly and negatively correlated with pH, a finding similar to the results of previous studies in other livestock (Huff-Lonergan et al., 2002; Geesink et al., 2003; Prevolnik et al., 2009). It stands to reason as pH fall of postmortem induced myosin denaturation and an increase in extracellular spaces, which then increase WHC (Penny. 1969; Offer. 1991; Guignot et al., 1993). Therefore, it could be suggested that the effect of pH on WHC was greater than the effect of IMF content on WHC. In terms of meat quality, pH control was more important for improving WHC than IMF content. On the other hand, other factors such as a slaughter stress, postmortem temperatures, and nutritional factors might have effects on WHC. Changes in these physical factors contribute to WHC, and it was suggested to improve them respectively by the management of factors such as a slaughter stress, postmortem temperatures, and nutritional factors (Watanabe et al., 2018).

As shown in Table 2, meat pH had significant negative correlations with lightness (L*) ($r = -0.292$; $P < 0.01$). This finding agreed with the result of Fletcher et al. (2000) reported in chicken. However, unlike the earlier study, meat pH had no significant correlation with redness (a*) or yellowness (b*). There was also a significant difference, or interaction, among the 3 color groups. These results indicated that factors affecting variation in meat pH and color should be better identified and controlled to help getting a better meat quality, especially in the darker than normal color ranges, which might have adverse effects on meat quality.

CONCLUSION

This is the first research evaluating physical characteristics of partridge systematically and describing the relationship between IMF content and physical characteristics of meat quality in partridge. In our study, partridge meat was described as a tender, moderately juicy meat with a nice color. Considering that the lack of juiciness severely restricts the appeal of consumer, caution should be taken into account when elaborating processed meat and developing new by-products because it will directly affect its quality. Additionally, we found that tenderness was significantly different between IMF <0.5% and IMF >0.5% ($P < 0.01$), and IMF > 0.5% also obtained higher value of WHC than IMF < 0.5% although the results were statistically nonsignificant. Intramuscular fat levels had no effect on pH or color. Therefore, it would then appear that IMF content was not significantly correlated with meat quality. However, it is generally accepted that a higher level of IMF has a positive influence on the sensory experience associated with eating. In terms of eating experience, it was suggested that the minimum level of IMF that will ensure a better meat quality for consumers is 0.5% IMF.

Pearson correlation coefficients indicates that IMF content had significant negative correlations with moisture content but not with pH ($r = -0.066$), shear force ($r = -0.072$), WHC ($r = 0.085$), or color (L*($r = -0.049$), a*($r = -0.028$) and b*($r = 0.045$)). Besides, we had found that meat pH had significant negative correlations with WHC ($r = -0.036$; $P < 0.01$) and lightness (L*) ($r = -0.292$; $P < 0.01$). So ultimately, we considered pH to be one of the most important factors for meat quality.

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