PRODUCTION, MODELING, AND EDUCATION

Cholesterol content and intramuscular collagen properties of pectoralis superficialis muscle of quail from different genetic groups

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ABSTRACT To study growth performance and meat quality traits (cholesterol content and intramuscular collagen properties) of quail, 3 trials were carried out. Trial 1 used males of generation 19 of the egg type Japanese quail (*Coturnix japonica*) selected previously (until generation 17) for low (n = 8) or high (n = 7) yolk cholesterol content as well as an unselected control (n = 11). Trial 2 used males of meat Pharaoh quail selected earlier (generations 1 to 6 and 9 to 11) on the basis of BW decrease after periodic deprivation of food (high decrease of weight, n = 10; low decrease of weight, n = 8) and unselected control (n = 10). Trial 3 compared males of English White quail, Manchurian Golden quail, and British Range quail. The birds were raised to 35 d of age. Quail were fed ad libitum commercial diets according to age and had free access to water. At slaughter, all birds were individually weighed (after a fasting period of 12 h), stunned, and decapitated. After the refrigeration period (24 h at 4°C), the left pectoralis superficialis muscle was removed from the carcasses, weighed, vacuum packaged, and stored frozen (−40°C) for analyses of cholesterol and intramuscular collagen (IMC; collagen and crosslink concentration). In trial 1, divergent selection for yolk cholesterol content did not significantly influence pectoralis superficialis muscle weight and IMC crosslinking of Japanese quail, whereas it significantly reduced growth and IMC amount. In addition, it had greater effect on the amount of cholesterol in meat; in fact, the meat of quail with low yolk cholesterol content contained lower cholesterol (−36.6%) than that of birds with high yolk cholesterol content. In trial 2, divergent selection on the basis of Pharaoh quail BW decrease altered IMC crosslinking, leading to variability in meat tenderness of Pharaoh quail. In trial 3, English White quail were significantly heavier than the other breeds.

Key words: quail, genetic selection, growth, meat quality

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INTRODUCTION

In recent years, quail meat has gained popularity among consumers. In fact, nowadays quail are found on all continents (Genchev et al., 2005). Several lines, breeds, and varieties have been developed for different production purposes. The largest number of birds is found in southeast and east Asia, and they are most often used for egg production (Minvielle, 2004). The largest quail meat producers are Europe and the United States (Minvielle, 2004).

Avian meat is one of the main products consumed by humans and allows the development of products with reduced cholesterol content, which is an urgent need in industrialized societies. In the poultry world, quail meat production is negligible when compared with that of broilers, but nevertheless occupies a relevant place in poultry breeding and contributes to the variety in poultry meat production. The valuable taste and dietary properties of quail meat are pivotal in determining the growing interest of consumers in this product (Genchev et al., 2008). In addition, when it comes to composition, quail meat has interesting technological properties because of the lower loss of moisture, which might aid in its marketing (Genchev et al., 2005, 2010). In terms of its basic composition, it is quite similar to broiler meat.

Poultry meat quality is determined by 2 extremely important traits: appearance and meat tenderness (Fletcher, 2002). Appearance (e.g., color of skin and meat) is critical for both consumers' initial selection of the product and final product satisfaction. Meat tenderness sensation is affected by the presence of several factors, such as fiber resistance, sarcomere length, pH,

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and collagen morphology (Lepetit, 2007). Collagen is an important parameter in the meat industry because an increased amount of this component may affect toughness and meat quality (Karunaratne et al., 2005). Collagen contribution to meat toughness was recently reviewed by Purslow (2005), with emphasis placed on structural and morphological aspects of connective tissue and their relationship to meat tenderness. It has been established that collagen covalent crosslinking, particularly pyridinoline [the main intramuscular collagen (**IMC**) mature crosslink], is a reasonable predictor of tenderness (Lepetit, 2008). Knowledge on collagen crosslinks in quail intramuscular connective tissue is scarce (Maiorano et al., 2009).

The quality and composition of meat are influenced by numerous factors such as genotype of birds (Genchev et al., 2005; Alkan et al., 2010), divergent selection (Maiorano et al., 2009), feeding (Gardzielewska et al., 2005), sex (Genchev et al., 2008), age (Tserveni-Gousi and Yannakopoulos, 1986), and stress (González et al., 2007). According to available information, no research has yet been conducted to study the effect of divergent selection on the basis of BW decrease after periodic deprivation of feed on meat quality traits, and few studies have been conducted to compare meat quality traits of different lines (Genchev et al., 2005) or breeds (Alkan et al., 2010) of quail. Additional research is needed (Maiorano et al., 2009) to increase knowledge regarding the effect of divergent selection for a low or a high yolk cholesterol on meat quality of quail. Therefore, 3 trials were conducted to evaluate the consequences of quail selection for 1) a low or a high yolk cholesterol content, 2) a low or a high BW decrease after periodic deprivation of food, and 3) the effect of breed on growth performance and meat quality traits (IMC properties and cholesterol content).

MATERIALS AND METHODS

Birds

Trial 1. The quail used in this research were of the egg type (Baumgartner, 1994). Male birds of generation 19 of Japanese quail (*Coturnix japonica*), selected previously (until generation 17) for low (**LCH**; n = 8) or for high (**HCH**; n = 7) yolk cholesterol content, as well as an unselected control (n = 11), were used for this experiment. The LCH and HCH lines were developed from a control egg type, wild color plumage stock 07, from the Poultry Breeding Station in Ivanka at Danube (Slovakia) that was maintained without conscious selection. The lowering of yolk cholesterol content in the low cholesterol line was 313 mg/100 g of yolk, and the increase in yolk cholesterol content in the high cholesterol line was 116 mg/100 g of yolk (i.e., −17.25 and +6.39%, respectively, compared with the parental egg type line; Maciuszonek et al., 2006).

Trial 2. Meat quail (Pharaoh) that have been previously divergently selected on the basis of BW decrease after periodic deprivation of feed (Witkowski, 1984), as well as an unselected control line, were used. The selection lasted to generation 6, then was suspended for generations 7 and 8, restarted for generations 9 to 11, and was suspended again beginning from generation 12. The selection was finally ended in 1986 and since then the lines have not been checked for the trait selected. The result of selection (A. Witkowski, University of Life Sciences, Lublin, Poland; personal communication) was a partition of the population (S12 generation) into subpopulation lines: high reacting (**HR**) and low reacting (**LR**). The HR line had higher reduction of BW than the LR line and unselected control (**UC**) birds (Witkowski, 1986). The HR (n = 10) and LR (n = 8) decrease lines were compared with UC (n = 10). The current study was performed on males from the last of the 33 generations mated randomly within lines. The difference among these subpopulations was confirmed at molecular level based on random amplified polymorphic DNA fingerprint analysis (A. Witkowski, personal communication).

Trial 3. Males of 3 distinct quail breeds, English White (n = 10), Manchurian Golden (n = 10), and British Range (n = 10), were used. The Manchurian Golden quail, according to Genchev and Mihaylov (2008), used over the last years for industrial poultry meat production, have good fattening performance and excellent meat quality. The English White quail is good for meat and egg production (Genchev et al., 2005). The British Range (also known as American Range or Range quail) originates after the English White and Dark British Range and has good egg production (Vali, 2007).

Bird handling followed the recommendations of European Communities (1986). The quail chicks of the 3 trials were wing banded at hatch and placed in the conventional poultry house of the Didactic Experimental Station of the University of Life Sciences in Lublin. The birds were raised to 35 d of age in collective cages under continuous lighting (natural and artificial). The rearing temperature was gradually decreased, 38 to 34°C in the first week, 33 to 28°C in the second week, and 27 to 22°C in the third week. Afterward it was maintained at 18 to 20°C. Quail were fed ad libitum commercial diets (Table 1) according to age. Birds had free access to water during the experiment.

Slaughter Surveys

At slaughter (35 d of age), all birds were individually weighed (after a fasting period of 12 h), stunned, and decapitated. Stunning was performed by a percussive blow to the back part of the head (occiput) and decapitation was performed with scissors between the cervical vertebrae and the base of the skull according to the EU regulations on the protection of animals at the time of killing (European Communities, 2009). After the refrigeration period (24 h at 4°C), the left pectoralis superficialis (**PS**) muscle was removed, weighed, vacuum packaged, and stored frozen (−40°C) for analyses of cholesterol and IMC.

Measurement of Muscle Cholesterol

Cholesterol was extracted using the method of Maraschiello et al. (1996) and then quantified by HPLC. A Kontron HPLC (model 535, Kontron Instruments, Milan, Italy) equipped with a C18 reverse-phase column (250 mm × 4.6 mm × 5 μm; Phenomenex, Torrance, CA) was used. The mobile phase was acetonitrile:2-propanol (55:45 vol/vol) at a flow rate of 1.2 mL/min. The detection wavelength was 210 nm and retention time was 13.89 min.

Collagen Analysis

At analysis, muscle samples were thawed, trimmed of fat and epimysium, lyophilized for 48 h, weighed, and hydrolyzed in Duran tubes in 6 *N* HCl at 110°C for 18 to 20 h (Etherington and Sims, 1981) for determination of hydroxyproline (Woessner, 1961) and crosslinking. All analyses were carried out in duplicate. Intramuscular collagen concentration was calculated, assuming that collagen weighed 7.25 times the measured hydroxyproline weight (Eastoe and Leach, 1958), and expressed as micrograms of hydroxyproline per milligrams of lyophilized tissue. Hydroxylysylpyridinoline (**HLP**) concentration, the principal nonreducible crosslink of muscle collagen (McCormick, 1999), highly correlated with the thermal stability of collagen (Horgan, 1991), was determined using a modification (Maiorano et al., 1999) of the HPLC procedure developed by Eyre et al. (1984); it was expressed as moles of HLP per mole of collagen and also as micrograms of HLP per milligram of lyophilized tissue (Maiorano et al., 2007).

Statistical Analyses

Data were evaluated by ANOVA (SPSS Inc., 2008). Differences among groups of the trials 1 and 2 were determined by contrasts (trial 1, contrast 1: $2 \times \mu_{CE} - \mu_{HCH} - \mu_{LCH} = 0$; trial 1, contrast 2: $\mu_{HCH} - \mu_{LCH} = 0$; trial 2, contrast 1: $2 \times \mu_{UC} - \mu_{LR} - \mu_{HR} = 0$; trial 2, contrast 2: $\mu_{LR} - \mu_{HR} = 0$; μ = overall mean). In trial 3 a Scheffé's battery of pairwise tests was used.

RESULTS AND DISCUSSION

Trial 1

Slaughter traits, cholesterol, and IMC properties of PS muscle from Japanese quail are presented in Table 2. Control quail had higher ($P < 0.05$) final BW than those selected for yolk cholesterol content (LCH and HCH); in addition, the final weight was found to be different ($P < 0.05$) between the quail of selected lines (HCH > LCH). These findings are partially in contrast with those obtained by Maiorano et al. (2009) in Japanese quail and Washburn and Marks (1977) in Cornell Leghorn quail. These authors did not find significant differences between control quail (egg type) and quail (egg type) selected for low or high yolk cholesterol, nor between selected lines. However, Washburn and Marks (1977) reported also that the meat type of the Athens-Canadian population selected for low or high yolk cholesterol, after 4 generations, showed significant differences in growth performance between the 2 selected lines: the line selected for low yolk cholesterol weighed 80% of the line selected for high yolk cholesterol levels. The weight of PS muscle was found to be similar among experimental groups. The meat of the quail selected for low cholesterol in the egg yolk (LCH) had lower ($P < 0.05$) cholesterol (−36.6%) than that of the birds characterized by high cholesterol in the egg yolk (HCH). Moreover, compared with control birds, the LCH quail had slightly lower cholesterol content (−24.3%) and

Table 1. Composition and nutritional value of the diets

Item (% unless noted)	Period: 1 to 7 d	8 to 28 d	29 to 35 d
Component			
Maize	37.0	54.2	61.6
Soybean meal	41.5	31.9	16.8
Rapeseed meal	—[1]	—	8.0
Fish meal	10.0	8.0	5.0
Milk powder, skimmed	3.0	2.0	2.0
Alfalfa dehydrated	—	—	4.0
Rapeseed oil	6.2	1.8	0.3
Dicalcium phosphate	0.5	0.4	0.8
L-Lysine	—	—	0.2
DL-methionine	0.5	0.4	—
NaCl	0.3	0.3	0.3
Premix IB-1[2]	0.5	0.5	—
Premix IB-2[3]	0.5	0.5	—
Premix IB-3[4]	—	—	1.0
Calculated nutritional value			
ME[5] (kcal/kg)	3,001.7	2,898.3	2,797.9
CP	28.0	24.0	20.0
Crude fiber	3.84	3.70	4.76

[1]Dash indicates not detectable.

[2]Provided the following per kilogram: vitamin A, 650,000 IU; vitamin D_3, 200 mg; vitamin E, 3,000 mg; vitamin B_1, 250 mg; vitamin B_2, 600 mg; biotin, 20,000 μg; vitamin B_6, 350 mg; vitamin B_{12}, 2,500 μg; vitamin K, 175 mg; Ca pantothenate, 1,200 mg; niacin, 5,000 mg; folic acid, 150 mg; choline, 35,000 mg; lysine, 8,5%; methionine, 12%; threonine, 1%; Ca, 19.0%; P available, 4.0%; Na, 7.2%; Mn, 7,000 mg; Zn, 6,000 mg; Co, 35 mg; Se, 25 mg; Cu, 1,200 mg; Fe, 3,500 mg; I, 75 mg; Mg, 3,500 mg.

[3]Provided the following per kilogram: vitamin A, 620,000 IU; vitamin D_3, 170 mg; vitamin E, 2,200 mg; vitamin B_1, 150 mg; vitamin B_2, 550 mg; biotin, 17,000 μg; vitamin B_6, 300 mg; vitamin B_{12}, 1,800 μg; vitamin K, 150 mg; Ca pantothenate, 950 mg; niacin, 4,500 mg; folic acid, 120 mg; choline, 32,000 mg; lysine, 11,5%; methionine, 11%; threonine, 1%; Ca, 17.8%; P available, 4.0%; Na, 7.2%; Mn, 6,000 mg; Zn, 5,500 mg; Co, 25 mg; Se, 25 mg; Cu, 1,200 mg; Fe, 3,000 mg; I, 60 mg; Mg, 3,500 mg.

[4]Provided the following per kilogram: vitamin A, 600,000 IU; vitamin D_3, 150 mg; vitamin E, 2,000 mg; vitamin B_1, 120 mg; vitamin B_2, 500 mg; biotin, 15,000 μg; vitamin B_6, 200 mg; vitamin B_{12}, 1,500 μg; vitamin K, 120 mg; Ca pantothenate, 850 mg; niacin, 3,500 mg; folic acid, 100 mg; choline, 30,000 mg; lysine, 11.0%; methionine, 11%; threonine, 1%; Ca, 25.5%; P available, 4.0%; Na, 7.2%; Mn, 5,500 mg; Zn, 4,500 mg; Co, 20 mg; Se, 25 mg; Cu, 1,200 mg; Fe, 3,000 mg; I, 60 mg; Mg, 4,500 mg.

[5]ME (MJ/kg) = 1 to 7 d: 12.57; 8 to 28 d: 12.14; 29 to 35 d: 11.72.

Table 2. Least squares means and SE for slaughter traits, cholesterol content, and intramuscular collagen properties of pectoralis superficialis muscle from Japanese quails

Item[1]	Group[2]		
	LCH	HCH	CE
n	8	7	11
Final BW (g)	105.35 ± 2.86[c]	115.26 ± 3.30[b]	119.80 ± 2.00[a]
Pectoralis superficialis muscle (g)	9.22 ± 0.40	10.00 ± 0.65	9.71 ± 0.24
Cholesterol (mg/100 g)	23.57 ± 2.38[b]	37.20 ± 3.66[a]	31.13 ± 1.75[ab]
IMC (μg/mg of lyophilized muscular tissue)	19.38 ± 0.79[b]	21.28 ± 0.74[b]	24.84 ± 1.62[a]
HLP (μg/mg of lyophilized muscular tissue)	4.03 ± 0.79	5.05 ± 0.34	5.17 ± 0.21
HLP (mol/mol of collagen)	0.146 ± 0.003	0.168 ± 0.001	0.153 ± 0.001

[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]IMC = intramuscular collagen; HLP = hydroxylysylpyridinoline.

[2]LCH = low yolk cholesterol; HCH = high yolk cholesterol; CE = control egg.

HCH quail had slightly higher cholesterol (+16.3%), but these differences were not statistically significant. The cholesterol level of PS muscle in quail in our study (ranging from 23.57 to 37.20 mg/100 g) is lower than the cholesterol level found by Maiorano et al. (2009) in breast muscle of 35-d-old Japanese quail (ranging from 27.83 to 43.38 mg/100 g).

The human diet nowadays usually includes excessive levels of cholesterol and saturated fat (Wang et al., 2006). Various international institutions (e.g., World Health Organization) have drawn up nutritional recommendations that include limitations that refer not only to the amount of fat and the fatty acid composition but also the cholesterol levels in foods, of which meat and meat products constitute a major part (WHO, 2003). The cholesterol content obtained in our study was similar to results from breast pigeon muscle (ranging from 23.6 to 44.4 mg/100 g; Pomianowski et al., 2009). It should be emphasized that cholesterol content of quail meat determined in this study is lower than that reported for chicken breast muscle (47.1 mg/100 g; see Ponte et al., 2004) or ostrich meat (ranging from 63.0 to 68.4 mg/100 g; see Horbanczuk et al., 2004).

The effect of divergent selection for yolk cholesterol content had a partial influence on IMC properties. The IMC concentration was higher ($P < 0.05$) for unselected control quail compared with LCH and HCH, whereas selected lines did not differ ($P > 0.05$). Muscle HLP concentration (μg/mg) and collagen maturation (mol of HLP/mol of collagen) did not differ significantly among experimental groups. Similar collagen content and crosslinks values (HLP concentration and mol of HLP/mol of collagen) of PS muscle were reported by Maiorano et al. (2009) in Japanese quail; however, our results were partially supported by these authors, who did not observe any significant effect of divergent selection for yolk cholesterol in IMC properties (collagen amount and HLP crosslinks).

Higher amount of collagen was probably related to the growth rate of the birds; in fact, the literature documents growth rate-dependent shifts in muscle collagen amount or crosslinking or both (McCormick, 1994; Harper, 1999; Maiorano et al., 2007). It has been reported, also, that a specific interdependence between muscle collagen phenotypes (types 1 and 3) and collagen crosslinking exists (McCormick, 2009).

Trial 2

Feed restriction experiments in poultry, especially chickens and quail, have been described (Hassan et al., 2003; see reviews by Gebhardt-Henrich and Marks, 1995). These studies have focused on the effects of feed restriction on both growth and reproduction traits. Because stressors can only be reduced rather than completely avoided, an alternative or complementary approach is to select birds that are less susceptible to environmental stressors. From this point of view, lines of meat Pharaoh quail have been previously divergently selected on the basis of BW decrease after periodic deprivation of food (Witkowski, 1984). The result was a partition of the population into subpopulations of low reacting line and high reacting line. The low line had smaller reduction of BW compared with high line and control birds (Witkowski, 1986). However, the lines differed also in several correlated unselected traits. Selection toward LR has resulted in diminished BW (females) and egg production, delayed sexual maturity (Witkowski, 1986; Witkowski and Zięba, 1991), lower ovary weight (Witkowski and Wójcik, 1993), lower egg and yolk weight (A. Witkowski, personal communication), increased plasma total protein level and total cholesterol level (Witkowski and Zięba, 1990), and decreased blood serum T4 level (Witkowski and Zięba, 1991). However, according to available information, no research has yet been conducted to study the effect of divergent selection on the basis of the BW decrease after periodic deprivation of food on meat quality traits of quail selected for higher or lower reduction of BW.

Results on slaughter traits, cholesterol, and IMC properties on PS muscle from Pharaoh quail are presented in Table 3. Final BW and the weight of PS muscle and its cholesterol content were found to be similar among experimental groups.

The IMC amount was similar among experimental groups. Compared with the birds of HR and LR of

Table 3. Least squares means and SE for slaughter traits, cholesterol content, and intramuscular collagen properties of pectoralis superficialis muscle from Pharaoh quails

	Group[2]		
Item[1]	HR	LR	UC
n	10	8	10
Final BW (g)	146.44 ± 1.09	140.75 ± 3.38	138.16 ± 2.21
Pectoralis superficialis muscle (g)	13.36 ± 0.27	12.82 ± 0.58	12.40 ± 0.30
Cholesterol (mg/100 g)	29.94 ± 2.59	33.63 ± 3.28	32.97 ± 3.53
IMC (μg/mg of lyophilized muscular tissue)	20.89 ± 0.92	22.31 ± 1.27	21.12 ± 1.34
HLP (μg/mg of lyophilized muscular tissue)	4.83 ± 0.33[b]	6.22 ± 0.17[a]	3.72 ± 0.29[c]
HLP (mol/mol of collagen)	0.162 ± 0.009[b]	0.200 ± 0.013[a]	0.135 ± 0.014[c]

[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]IMC = intramuscular collagen; HLP = hydroxylysylpyridinoline.

[2]HR = high decrease of weight; LR = low decrease of weight; UC = unselected control.

weight, the quail of the UC group had lower ($P < 0.05$) muscle HLP concentration (μg/mg) and a slower ($P < 0.05$) collagen maturation (HLP/collagen). In addition, quail of HR had a slower (−19.0%) collagen maturation (HLP/collagen) and a lower (−22.35%) muscle HLP concentration (μg/mg) than those of LR ($P < 0.05$).

According to available information, no research has yet been conducted to study the effect of divergent selection on the basis of BW decrease after periodic deprivation of food on meat quality traits of quail selected for higher or lower reduction of BW. This selection was performed in HR and LR lines around 25 yr ago; about 20 generations of random (within lines) mating have been performed during this period. In this situation, it is not clear whether the demonstrated differences in phenotypical traits among these lines should be assigned to the earlier divergent selection itself or whether the differences are the effect of genetic drift, for example, as a result of random mating within these small populations of the lines. However, according to the molecular analysis based on the panel of random amplified polymorphic DNA markers, the genetic distance between the lines is still apparent, reaching 0.0831, 0.0559, and 0.0623 between HR–LR, HR–UC, and LR–UC lines, respectively (A. Witkowski, personal communication).

Meat is a complex, composite substance. It consists of myofibers, connective tissue, and lipids. It has been established that collagen, the major component of the intramuscular connective tissue (Light et al., 1985), plays a key role in determining meat toughness (McCormick, 1999; Purslow, 2005) of different domestic animals including birds (Baeza et al., 1998). However, very little is known about IMC in quail of different genetic groups.

Some researchers reported that shear force of raw meat is highly correlated with collagen content. However, the correlation between collagen content and cooked meat toughness is usually lower (reviewed in Lepetit, 2008). The quality of collagen gives toughness to the meat (Coró et al., 2003). Lepetit (2007) analyzed 10 studies in which collagen crosslinks in muscle tissue were measured. He concluded that measurements of crosslinks (pyridinoline) is a reasonable predictor of tenderness. Studies found little or no correlation between crosslinks levels and tenderness (Young et al., 1994; Avery et al., 1996); whether this is attributable to a lack of proportionality between HP and EC (Ehrlich chromogen) or other factors is not clear (McCormick, 2009). On the other hand, McCormick (1999) reported that mature crosslinks and collagen concentration have an additive effect on the toughening of meat. In other words, the role of collagen on meat tenderness depends not only on the crosslinks but also on the amount of collagen. Maiorano et al. (2001) gives a tenderness index, which is the amount in HLP crosslinks per gram of lyophilized muscular tissue in different muscles in goat meat. In agreement with the suggestions of McCormick (1999) and Maiorano et al. (2001), the results of HLP crosslinks concentration (μg/mg) indicate that meat from divergent selection birds could be tougher than that of the control quail and, moreover, the meat from quail of line HR could be more tender than that of the birds of line LR. This result may be related to the idea that the meat of control group could have greater fraction of both type 3 collagen and heat-soluble collagen, which are indicative of more youthful, labile, less crosslinked collagen (McCormick, 2009). With maturation, type 3 collagen is replaced by both type 1 collagen and greater complement of mature crosslinks (Kovanen and Souminen, 1989).

Trial 3

Results on slaughter traits, cholesterol, and IMC properties on PS muscle from English White, Manchurian Golden, and British Range quail are presented in Table 4. English White quail were heavier ($P < 0.05$) than Manchurian Golden and British Range quail. The weights of Manchurian Golden and British Range birds were similar ($P > 0.05$). Pectoralis superficialis muscle weight, cholesterol content, and IMC properties were found to be similar among the breeds studied.

It is difficult to assess and compare the results of this trial because of the limited information available in the literature. We expected that the Manchurian Gold-

Table 4. Least squares means and SE for slaughter traits, cholesterol content, and intramuscular collagen properties of pectoralis superficialis muscle from different quail breeds

Item[1]	Group		
	English White	Manchurian Golden	British Range
n	10	10	10
Final BW (g)	156.89 ± 1.14[a]	146.36 ± 1.85[b]	146.19 ± 2.03[b]
Pectoralis superficialis muscle (g)	13.00 ± 0.53	13.52 ± 0.31	13.37 ± 0.71
Cholesterol (mg/100 g)	26.63 ± 1.69	25.33 ± 3.34	32.20 ± 2.72
IMC (μg/mg of lyophilized muscular tissue)	19.29 ± 1.43	18.62 ± 1.04	19.19 ± 0.83
HLP (μg/mg of lyophilized muscular tissue)	5.10 ± 0.70	4.63 ± 0.25	3.80 ± 0.21
HLP (mol/mol of collagen)	0.182 ± 0.020	0.177 ± 0.012	0.140 ± 0.009

[a,b]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]IMC = intramuscular collagen; HLP = hydroxylysylpyridinoline.

en quail, as a breed for meat production, should have shown a better live BW; however, Genchev et al. (2005) recommended the English White breed as suitable for the production of quail eggs and meat. These authors reported that the BW of 31-d-old English White quail (male and female) was 171.6 ± 1.72 g with a considerable amount of breast meat (19.1%); the latter is comparable with the value (16.6%) observed in the breast of our 35-d-old English White quail.

Particularly interesting are the overall low levels of cholesterol found in the PS muscle of English White and Manchurian Golden (26.63 and 25.33 mg/100 g, respectively). These values are comparable with the levels of cholesterol observed in the meat of the quail (trial 1) selected for low cholesterol in the egg yolk (23.57 mg/100 g).

In conclusion, divergent selection for yolk cholesterol content did not significantly influence PS muscle weight and IMC crosslinking of Japanese quail, whereas it significantly reduced growth and IMC amount. In addition, it had greater effect on the amount of cholesterol in meat; in fact, the meat of the quail selected (during generation 17) for low cholesterol in the egg yolk contained lower cholesterol (−36.6%) than that of the birds selected for high cholesterol in the egg yolk. Therefore, this study confirms our previous suggestion (Maiorano et al., 2009) that the quail selected for low yolk cholesterol content could be recommended to reduce cholesterol in the meat, with advantages from the human nutritional point of view. Divergent selection on the basis of BW decrease after periodic deprivation of food did not significantly affect final weight, PS muscle weight, meat cholesterol, and IMC content of Pharaoh quail, whereas it can alter IMC crosslinking, leading to variability in meat tenderness. In particular, the results of HLP crosslink concentration indicate that meat from selected quail (HR and LR lines) could be tougher than that of the control birds; however, the meat from quail of HR of weight could be more tender than that of the birds of LR of weight. English White quail were significantly heavier than Manchurian Golden and British Range quail. No differences were found in meat quality among these breeds. Further research is warranted to increase knowledge regarding the effect of divergent selection (for yolk cholesterol content or BW decrease after periodic deprivation of food) on performance and meat quality of quail.

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