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**ANIMAL SCIENCE**

# Growth of breast muscles in European and Japanese quail raised in meat production system: a morphological analysis

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**Abstract:** Growth curves have been described in the quail but with no attention to the muscle composing of the breast. The description of the characteristics of growth curves to body weight and to breast muscle was the aim of this study. Morphological development of *Musculus supracoracoideus* and *Musculus pectoralis* in European and Japanese quail was assessed from the final incubation of to 35 days. Gompertz models were adjusted with maximum growth rates to body weight, breast weight, and *Musculus pectoralis* and *supracoracoideus* weight at 17.6; 22.2; 23.5, and 21.4 days. The European quail had a higher body and breast weight at maturity. *Musculus supracoracoideus* developed faster in both subspecies but with larger *Musculus pectoralis*. Both musculus had a greater number of fibers type IIA and largest fibers IIB, with quadratically increasing in fiber diameter with age in both subspecies and muscles. At 35 days, results of meat quality indicated similarity between genders and subspecies, with darker and redness breast meat in Japanese quail. In conclusion, breast weight gain was a result of type IIA and IIB fiber hypertrophy in both muscles and, despite the difference in size and aptitude, Japanese and European quail showed similar body and muscle growth patterns.

**Key words:** *Coturnix*, growth, Gompertz, muscle, NADH-TR.

## INTRODUCTION

Quail production has become an important economic activity in recent years for egg and meat production. The meat quail market can be considered a niche and a young productive sector compared with other poultry species. This market has important growth potential, because quail meat is a high-quality product (Santhi & Kalaikannan 2017). Two commercial breeds have been used: Japanese quail (*Coturnix coturnix japonica*), generally used for egg production, and European quail (*Coturnix coturnix coturnix*), generally used for meat and egg production (Bertechini 2012). Although European and Japanese quail have different aptitudes, they are not used only for meat or laying. European quail in many places is also used for laying because of their larger eggs.

In many Asian countries, Japanese quail are raised for both meat and eggs (Narinc et al. 2010). Likewise, in Brazil, companies supply the meat market with European and Japanese quail. This occurs because the Japanese quail is the most common species on farms. At the end of the laying period, females are used for meat production and males that were incorrectly sexed (Oliveira & Escocard 2010).

Quail meat is considered a healthy food with a high nutritive value. The composition varies with the diet ingredients and slaughtering age; however, in general, the meat is rich in essential amino acids, low in cholesterol, and high in polyunsaturated fatty acid content (Genchev et al. 2008, Maiorano et al. 2011). These characteristics associated to odor, flavor, and softness of quail meat become highly accepted by the general population.

The breast is considered by most markets as the avian cut with the highest added value, and it is correlated with the weight at slaughter (Sakomura et al. 2011). In quail, breast represents 22 to 36% of the carcass relative weight, depending on the genotype and age of the birds (Móri et al. 2005, Genchev et al. 2008, 2010). The quail breast is composed of *Musculus supracoracoideus* (MS) and *Musculus pectoralis* (MP), which are composed of type IIA and IIB muscle fibers. In birds, as in mammals, three basic types of fibers are found in muscles, classified according to their metabolic and contractile characteristics: type I fiber (slow contraction, oxidative metabolism), type IIA fiber (fast contraction, oxidative and glycolytic metabolism), and type IIB fibers (fast contraction and glycolytic metabolism) (Choi & Kim 2009, Choi et al. 2013). The glycolytic/oxidative profile of muscles is responsible for differences in meat characteristics, such as pH, color, and water-holding capacity (WHC) (Dransfield & Sosnicki 1999).

In animal production, commercial poultry breeders are selected for high egg and meat yields. But in quail, genetic improvement is not consolidated yet such as in chickens and layer hens. In this sense, information on body and muscle growth is the basis for nutritional investigations, and knowledge of the growth profile of both European and Japanese quail can be useful to create better strains for meat and laying.

Growth curves are important tools for determining the optimal time to modify diets for enhanced productivity. The literature describes European and Japanese quail with different body weights at maturity, growth rate, body composition, and nutrient deposition rates. European quails show the highest growth rate at 27 days; thus, at 35 days, the weight of European quails is approximately 25 times the initial weight (Silva et al. 2012).

Recent studies have determined the growth curves of quail (Grieser et al. 2015, 2018), but no specific attention has been given to the morphological characteristics of muscle fibers during growth. Therefore, the aim of this study was to describe the growth curves of the body, MP, and MS, and the size and density of muscle fibers from the last stages of the embryonic period to 35 days in European and Japanese quail.

## MATERIALS AND METHODS

This study was approved by the Animal Ethics Committee of the State University of Maringá, Paraná, Brazil (protocol no. 1237250914). The experiment was conducted at the poultry farm (Iguatemi Experimental Farm) of the State University of Maringá.

### Animals and experimental design

Fertile eggs of European (11.80 g ± 5%) and Japanese (9.79 g ± 5%) quail were incubated in an automatic vertical incubator (Petersime®, model Labo 13, capacity of 3,978 quail eggs) at 60% relative humidity and 37.6°C with open ventilation. After 348 h of incubation, the eggs were transferred to a hatcher (Petersime®, model Labo 9) at 70% relative humidity and 37.0°C.

After hatching, chicks were randomly housed in six pens (2.80 × 1.40 m) of 50 birds (n= 3 European, n=3 Japanese). Diets based on corn and soybean meal were formulated to meet the nutrient requirements of birds during the starter and grower phases (Silva & Costa 2009, Rostagno et al. 2011). The starter diet (1 to 21 days of age) contained 25% crude protein and provided 2,900 kcal/kg of metabolizable energy. The grower diet (22 to 35 days of age) contained 21% crude protein and provided 3,050 kcal/kg of metabolizable energy. Birds had *ad libitum* access to feed and water. Infrared lamps were used inside each box to provide heating for the chicks during the first 15 days to increase the temperature. The chick´s behavior (crowding or dispersing) and thermohydrometers were used to control the temperature, adjusting the distance between the lamps and litter accordingly. We started at 36°C and reduced it in the next days until room temperature (25 ºC) when the lamps were turned out. All quails in this experiment were destined for meat production, and the management was similar among all boxes. The light program used was 23 h light/1 h darkness (Shanaway 1994).

## Body and breast weight

Growth was monitored from day 13 of incubation to day 35 post-hatch. Live body and breast weight analyzes were performed at 13 (312 h) and 15 (360 h) days of incubation, at hatch (420 h), and at 4, 7, 10, 14, 21, 28, and 35 days of age. Six eggs per subspecies were analyzed at each incubation period. Eggs were broken, embryos were euthanized by cervical dislocation and weighed, and total breast muscles were dissected and weighed. Chicks were weighed, anesthetized intraperitoneally with sodium thiopental (10 mg/kg body weight) + lidocaine (10 mg/kg body weight), and sacrificed by cervical dislocation. For birds aged 14 days or older, it was possible to analyze MP and MS separately. Muscles were dissected and weighed. Relative weight was calculated as muscle weight divided by body weight and multiplied by 100.

## Analysis of muscle fiber type

At 14, 21, 28, and 35 days, muscle samples were collected for histological analysis. Sections (1 cm in length) were obtained from the middle portion of the MP and MS, both longitudinally and transversely in the fiber direction (Scheuermann et al. 2004). Muscle samples were immediately placed in n-hexane and stored at –80°C. Frozen samples were cut transversally to the muscle fibers to 10 µm thickness using a cryostat microtome at –26°C and mounted on microscope slides. Histochemistry reaction to reduced nicotinamide adenine dinucleotide-tetrazolium reductase (NADH-TR) was performed, according to Dubowitz, Sewry, and Olford (2020). Muscle fibers were classified as type IIA (fast oxidative-glycolytic) or IIB (fast glycolytic). Type IIA fibers were identified by their characteristic darker color, resulting from higher concentrations of NADH-TR (oxidative/glycolytic metabolism and a moderate number of mitochondria), whereas type IIB fibers were distinguished by their lighter color resulted from a moderate reaction to NADH-TR (glycolytic metabolism and a lower number of mitochondria). Muscle samples were also stained with hematoxylin and eosin for identification of muscle fibers and measurement.

Digital images ($n$ = 10 per bird) were obtained using a digital camera (Motican® 5 megapixels) coupled to an optical microscope. The fiber density (number of fibers/0.59 mm$^2$) and diameter (µm) were calculated using Motic Image Plus 2.0 (China Group Co. Ltd., Xiamen, China). Cells touching the right-hand side and bottom of the image were excluded, whereas cells touching the left-hand side and top were included in the count.

## Meat quality

Meat quality was analyzed in 30 birds (15 males and 15 females) per subspecies at 35 days of age. Birds were fasted for 6 h, sacrificed by cervical dislocation, and bled. The MP was dissected and analyzed for color and water-holding capacity (WHC). pH measurements (TESTO®, Testo do Brazil, Campinas, São Paulo, Brazil) were performed 20 min and 24 h post-mortem in the middle portion of MP. The WHC was determined according to Nakamura & Katok (1985). Shortly after slaughter, a 1-g fragment of MP was wrapped in filter paper and centrifuged at 1500 rpm for 4 min. Samples were weighed, oven-dried at 70°C for 12 h, and reweighed. WHC was calculated using the formula WHC = (weight after centrifugation – weight after dying)/initial weight × 100.

Breast meat color was analyzed using a colorimeter (CR300, Konica Minolta, Japan) according to the method of Honikel (1998). Three replicates per point were performed in the upper, middle, and lower portions of the MP at 15 min post-mortem. Color readings were expressed as lightness (L*), redness (a*), and yellowness (b*).

## Statistical analysis

To describe the quail body and breast variables, the Gompertz nonlinear regression model was adjusted (Fialho 1999) to body weight and breast weight from day 13 of incubation to 35 days and MP and MS weight from day 7 to 35 of age data as follows:

$$W = A \exp^{-\exp^{-B(t-C)}} \quad (1)$$

where *W* = is weight (g) estimate at age t; *A* = asymptotic weight (g) when t tends to infinity it can be interpreted as weight to adult age; *B* = relative growth at the inflection point (g/day per gram) or the maturity rate; *C* = age at the inflection point (days) or the time at which the growth rate is maximum; t = age (days); exp = 2.718281828459.

Growth rates (g/day) were calculated from the derivative of equation (1) as suggested by Fialho (1999):

$$\frac{dM}{dt} = AB \exp^{-B(t-C) - \exp^{-B(t-C)}} \quad (2)$$

Eight growth models ($M_1$ to $M_8$) were tested to analyze differences in growth curve parameters between European and Japanese quail. The first model ($M_1$) was complete without curves parameter alteration. Models $M_2$, $M_3$, and $M_4$ differed only in one parameter. $M_2$ differ in parameter *C*, $M_3$ differ on parameter while *B* and $M_4$ differ on parameter *A*. Models $M_5$, $M_6$, and $M_7$ differed in two parameters, *A* and *B*, *A* and *C*, and *B* e *C*, respectively. In $M_8$, all parameters were the same. The best model was chosen on the basis of the likelihood ratio test with a chi-square approximation, as proposed by Regazzi & Silva (2004).

Growth curves parameters were estimated using the Gauss-Newton methods modified from using the NLIN procedure of SAS (SAS Institute Inc., Cary, NC, USA). For statistical analysis of variables evaluated during the incubation period, day of hatching was considered as day 18 and day 35 was considered as day 52. For all other variables, day of hatching was considered as day 0.

Linear regression equations of growth parameters as a function of time (day) were fitted to experimental data. The interaction effect of age and subspecies on MP and MS data (relative weight and type IIA and IIB fiber diameter) was investigated. Main and interaction effects of subspecies and gender on muscle histology and meat quality parameters at 35 days post-hatch were determined by analyses of variance (ANOVA) and Tukey's test. All statistical analyses were performed using the GLM procedure of SAS (SAS Institute Inc., Cary, NC, USA).

## RESULTS

Body weight, breast weight, and MP and MS growth rates were best fitted to the $M_7$ model. $W_m$ values were higher in European quail than in Japanese quail, and *B* and *C* values did not differ between subspecies (Table I). Both quail subspecies reached maximum growth rates at 17.6 days of age (6.93 g/day in European quail and 3.87 g/day in Japanese quail). From 17.6 to 35 days of age, growth rates decreased 39% and Japanese quail had 2.34 g/day body weight and European quail had 4.19 g/day (Table I, Figure 1).

The maximum growth rate to the total breast weight was reached at 22.2 days, with 22.4 g for Europeans and 10.4 g for Japanese quail. The growth rate to breast weight at 22.2 days was 1.74 g/day to European quail and 0.83 g/day to Japanese quail. At the slaughter age of 35 days, breast weight had 44.5 g in European quail and 20.7 g in Japanese quail, representing 22.1% and 18.4% of body weight, respectively.

The growth rate of MS was higher that of MP in both subspecies. The MS growth rate was highest at 21.4 days of age in both subspecies, with a rate of 0.44 g/day in European quail and 0.22 g/day in Japanese quail. This rate reduced to 0.30 g/day and 0.15 g/day with 35 days, with a decline of 32.3% in a few days (Table I, Figure 2). Likewise, the greatest MP growth rates in European and Japanese quail were achieved at 23.5 days of age, after which the growth rate reduced by 19.1 % at 35 days of age in both quail lineages. The growth rate of MP at maturity was 35% (European) and 38% (Japanese) lower than that of MS; that is, MP maturity was reached two days later than MS maturity (Table I, Figure 2). At slaughter age, MP and MS represented 33.4 g (75.1 %) and 8.7 g (19.5 %), and 15.8 g (76.3 %) and 4.37 g (21.1 %), respectively, of the breast weight for European and Japanese quail (Table I).

Type IIA and IIB fibers were marked by NADH-TR staining of histological cross-sections of the muscles. Type IIA fibers, of smaller diameter and higher oxidative capacity, were located at the center of muscle bundles, and type IIB fibers, of larger diameter and lower oxidative capacity, at the periphery. These characteristics were observed in samples from both quail subspecies (Figure 3).

Morphometric analyzes showed that the MP type IIB fiber diameter increased linearly with age. The relative weights of MP and MS quadratically increased with age and were higher in European quail than in Japanese quail, as was MP type IIB fiber diameter (Figure 3).

The interaction effect between age and subspecies was significant ($p < 0.05$) for type IIA fiber diameter in both muscles and type IIB fiber

**Table I. Gompertz parameters for body, breast, *M. pectoralis*, and *M. supracoracoideus* weights in European (Eur) and Japanese (Jap) quail. Data expressed as mean ± stander error.**

| | ***Wm* (g)** | | ***B* (g/g day)** | | ***C* (days)** | |
|---|---|---|---|---|---|---|
| | **Eur** | **Jap** | **Eur** | **Jap** | **Eur** | **Jap** |
| Body weight (g) | 272.6 ± 7.44 | 152.3 ± 4.33 | 0.069 ± 0.002 | 0.069 ± 0.002 | 34.62 ± 0.49 (17.6)† | 34.62 ± 0.49 (17.6)† |
| Breast weight (g) | 66.73 ± 4.33 | 32.13 ± 2.16 | 0.071 ± 0.005 | 0.071 ± 0.005 | 39.24 ± 1.08 (22.2)† | 39.24 ± 1.08 (22.2)† |
| *M. pectoralis* weight (g) | 54.14 ± 5.91 | 25.66 ± 2.87 | 0.064 ± 0.007 | 0.064 ± 0.007 | 23.55 ± 1.95 | 23.55 ± 1.95 |
| *M. supracoracoideus* weight (g) | 15.92 ± 1.07 | 8.02 ± 0.56 | 0.076 ± 0.006 | 0.076 ± 0.006 | 21.44 ± 1.05 | 21.44 ± 1.05 |

**$W_m$, weight at maturity; *B*, maturity rate; *C*, time of maximum growth rate. † The number for body and breast weight represents incubation days + post-hatch days and in parentheses, time is converted to days post-hatch (reducing 17 days of incubation). Parameters were calculated using the $M_7$ growth model.**

diameter in MS. MP type IIA fiber diameter showed cubic behavior and MS types IIA and IIB fiber diameters showed quadratic behavior. Linear regression coefficients of equations modeling the growth parameters of European quail were four times higher than those of Japanese quail (Figure 3). MP type IIA fiber diameter increased 2.05-fold in European quail and 1.73-fold in Japanese quail from day 14 to day 35 (Figure 3), whereas MS type IIA fiber diameter increased 1.69- and 1.59-fold in European and Japanese quail, respectively. For European quail, there was an expressive increase in fiber diameter from day 21 post-hatch (Figure 4). In Japanese quail, fiber diameter increased markedly between days 14 and 28 post-hatch; at days 28 and 35, fiber

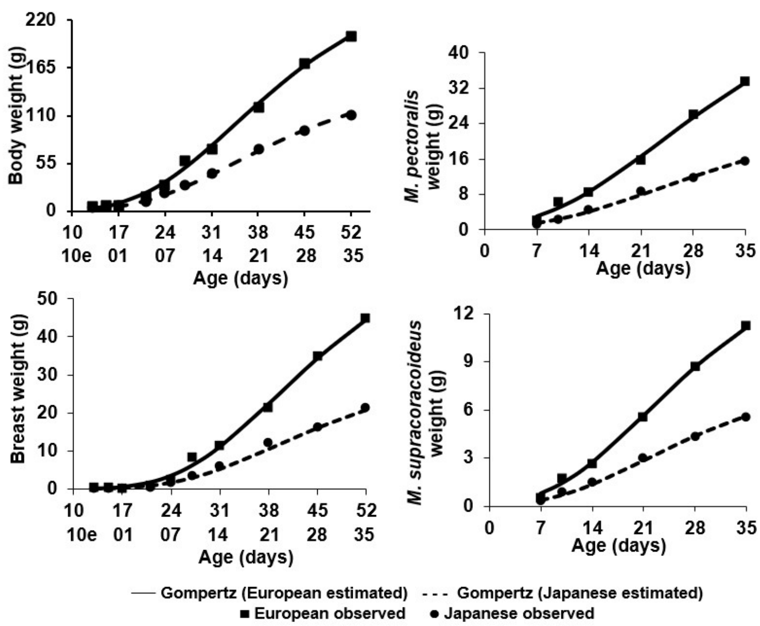


**Figure 1.** Adjusted growth curves of the body, total breast, *M. pectoralis*, and *M. supracoracoideus* in European and Japanese quail obtained using the Gompertz model.

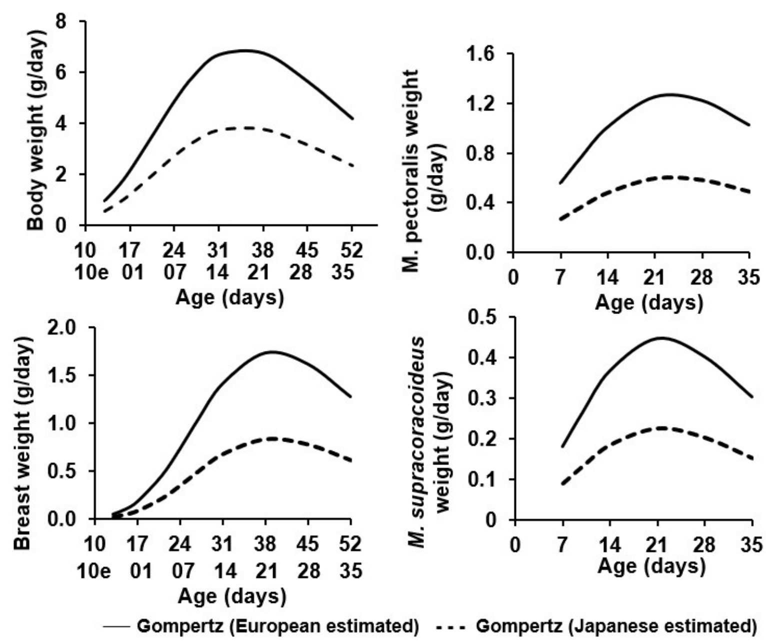


**Figure 2.** Growth rate curves of the body, breast, *M. pectoralis*, and *M. supracoracoideus* data in European and Japanese quail.

diameters were respectively 20.01 µm and 21.86 µm. The type IIB fiber diameter increased 1.66 and 1.47 times from day 14 to day 35 in European and Japanese quail, respectively (Figures 3-4).

### Morphological characteristics at 35 days post--hatch

The effects of quail subspecies, gender, and their interaction on morphometric parameters of breast muscles were evaluated on day 35 post-hatch. The interaction effect between quail subspecies and gender was significant ($p < 0.05$) for MP type IIB fiber diameter and density as well as for MS type IIB fiber diameter (Table II, Figure 5). Male European quail had thicker MP type IIB fibers than male Japanese quail and female European quail, but no significant differences were found between females of both species. MS type IIB fibers were thicker in male European quail than in male Japanese quail. Type IIB fiber density was lowest in male European quail.

Subspecies had a significant effect ($p < 0.05$) on MP and MS weight and type IIA fiber diameter. In European quail, MP and MS weights were almost twice those observed in Japanese quail. The type IIA fiber diameter of Japanese quail was 80% that of European quail. Gender influenced muscle weight, with males having

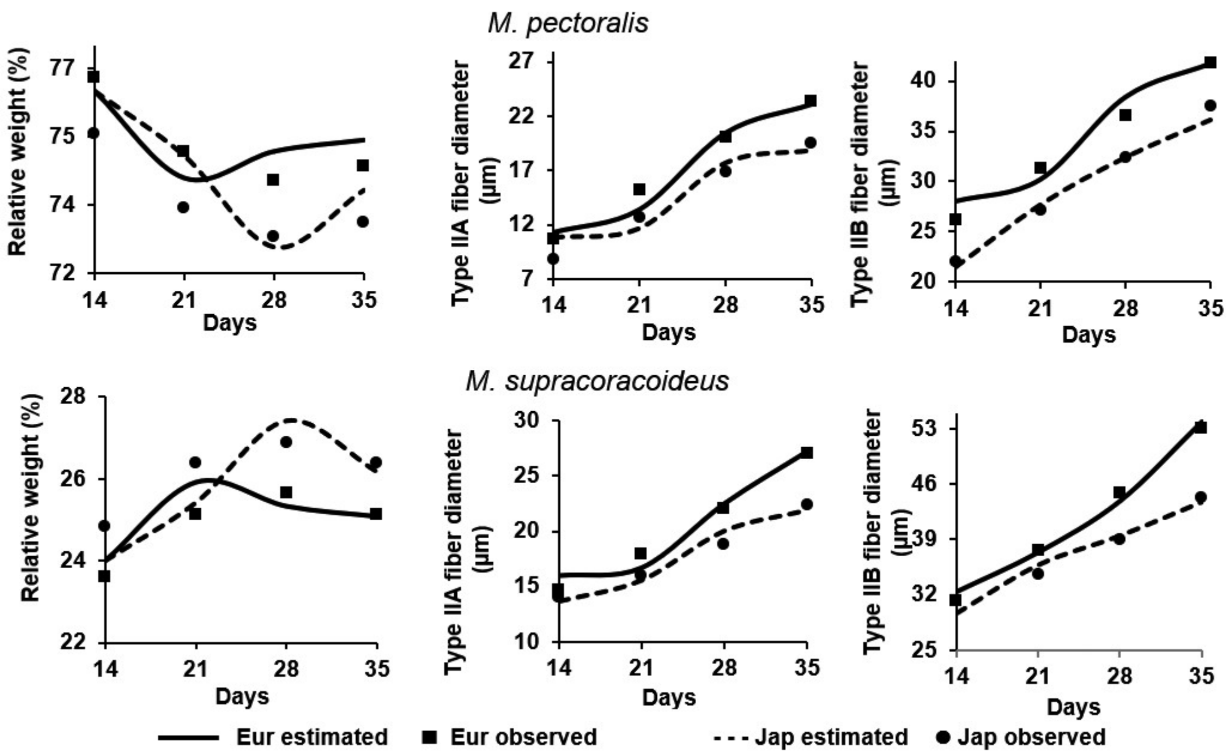


**Figure 3.** Morphometric parameters of *M. pectoralis* and *M. supracoracoideus* in European (Eur) and Japanese (Jap) quail ($n$ = 6). *M. pectoralis:*
**Relative weight** (%): Eur, $y = 82.5061 - 0.5825x + 0.010x^2$; Jap, $y = 81.2654 - 0.5825x + 0.010x^2$ ($R^2 = 0.46$)
**Type IIA** fiber diameter (µm): Eur, $y = 10.155 - 0.6407x + 0.0613x^2 - 0.00092x^3$; Jap, $y = 9.6613 - 0.7361x + 0.0613x^2 - 0.00092x^3$ ($R^2 = 0.90$)
**Type IIB** fiber diameter (µm): Eur, $y = 15.7347 + 0.7435x$; Jap, $y = 11.5232 + 0.7435x$ ($R^2 = 0.80$)
*M. supracoracoideus:*
**Relative weight** (%): Eur, $y = 17.4938 + 0.5825x - 0.0104x^2$; Jap, $y = 18.7345 + 0.5825x - 0.0104x^2$ ($R^2 = 0.46$);
**Type IIA** fiber diameter (µm): Eur, $y = 10.8843 + 0.1529x + 0.0088x^2$; Jap, $y = 12.8222 - 0.0337x + 0.0088x^2$ ($R^2 = 0.74$)
**Type IIB** fiber diameter (µm): Eur, $y = 21.5732 + 0.5572x + 0.0098x^2$; Jap, $y = 27.3900 + 0.1385x + 0.0098x^2$ ($R^2 = 0.74$)

16% and 12% higher MP and MS weights than females, respectively (Table II, Figure 5).

The density of MP type IIB fibers was lower in male European quail than in male Japanese quail. However, this parameter did not vary ($p < 0.05$) between male and female Japanese quail (Figure 5).

There was no significant interaction effect between the quail subspecies and gender on meat quality parameters. Subspecies had a significant ($p < 0.05$) effect on body weight, relative breast weight, breast weight, lightness (L*), and redness (a*). European quail had higher breast weight, relative breast weight, and lightness (Table III). Japanese quail had a higher redness value, that is, the meat was darker than that of the European quail. Males presented higher relative breast weight and lower yellowness (b*) values than females (Table III). No significant differences in pH at 20 min post-mortem and 24 h *post-mortem* were observed.

## DISCUSSION

Body weight, breast weight, and MP and MS growth rates were fitted to the Gompertz growth equation. The parameter $W_m$, $B$, and $C$ have important physiological implications. With these parameters, it is possible to estimate the growth curves of different quail subspecies. Weight at maturity is related to the final (adult) or asymptotic weight of birds. In studies by Raji et al. (2014), Grieser et al. (2015, 2018), and Narinc et al. (2010), Japanese quail were reported to weigh 143.71–233.11 g at maturity. Meat-type male and female quail weighed 275 and 369 g, respectively, at maturity (Grieser 2018). Although size is an inherited characteristic, it can be influenced by environmental factors, motor activities, age, gender, health, and muscle type (Rehfeldt et al. 2010), all of which affect weight at maturity. The results of this research on body weight, breast weight, and MP and MS growth rates were higher in European quail, indicating that they have a higher precocity for slaughter than Japanese quail. Despite their lower weight,

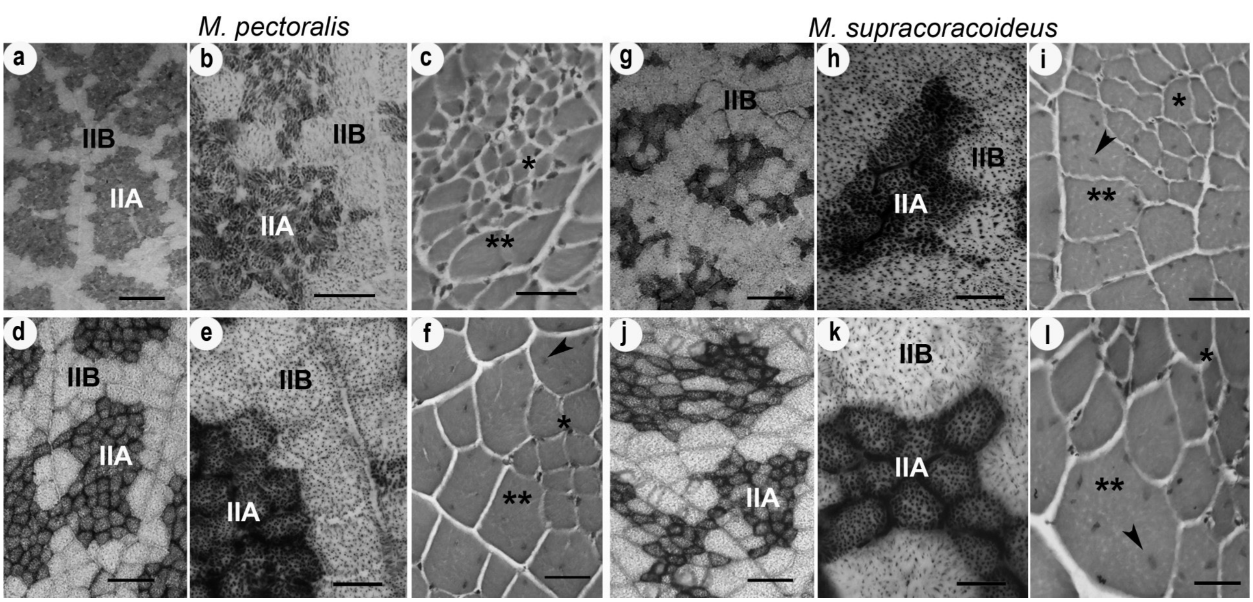


**Figure 4. Transverse histological sections of *M. pectoralis* and *M. supracoracoideus* fibers in Japanese quail at 7 (a–c), 14 (g–i), and 35 days of age (d–f and j–l). Note the difference in diameter of centrally located type IIA fibers and peripherally located type IIB fibers. Stain: NADH- tetrazolium reductase (a, b, d, e, g, h, j, and k) and hematoxylin and eosin (c, f, i, and l). Scale bar: 90 (a, d, g, and j) and 30 µm (b, c, e, f, h, i, k, and l).**

Japanese male and female quails can be an alternative for meat production, and specific selection for meat production could lead to lineage with better production rates. Bonafé et al. (2011) described higher weight at maturity, final weight, and growth rate in quails selected for meat production.

In this study, the *B* (maturity rate) values of European and Japanese quail were the same (0.07). A similar growth rate (0.075) was reported for Japanese quail by Narinc et al. (2013), while

**Table II.** ***M. pectoralis*** **and** ***M. supracoracoideus*** **weight, fiber diameter, and fiber density in European (*****n*** **= 15) and Japanese (*****n*** **= 15) quail at 35 days post-hatch.**

| | Weight | | Fiber diameter (μm) | | Fiber density¶ | |
|---|---|---|---|---|---|---|
| | (g) | (%) | Type IIA | Type IIB | Type IIA | Type IIB |
| *M. pectoralis* | | | | | | |
| Subspecies | | | | | | |
| European quail | 33.44[a] | 74.91 | 23.17[a] | 41.12 | 299[b] | 92 |
| Japanese quail | 15.63[b] | 73.83 | 18.87[b] | 36.13 | 453[a] | 128 |
| Sex | | | | | | |
| Male | 26.38[a] | 74.83 | 20.65 | 40.92 | 386 | 108 |
| Female | 22.70[b] | 73.91 | 21.40 | 36.33 | 383 | 116 |
| SEM† | 1.96 | 0.29 | 0.68 | 1.44 | 30.76 | 8.40 |
| CV (%)‡ | 10.55 | 1.81 | 9.92 | 10.63 | 29.38 | 24.64 |
| *p*-value for main and interaction effects | | | | | | |
| Subspecies | <0.0001 | 0.063 | 0.001 | 0.578 | 0.010 | 0.038 |
| Sex | 0.002 | 0.112 | 0.427 | 0.015 | 0.649 | 0.553 |
| Interaction | 0.094 | 0.458 | 0.656 | 0.006 | 0.685 | 0.021 |
| *M. supracoracoideus* | | | | | | |
| Subspecies | | | | | | |
| European quail | 11.19[a] | 25.08 | 27.21[a] | 53.86 | 126[b] | 72[b] |
| Japanese quail | 5.53[b] | 26.16 | 21.86[b] | 43.72 | 213[a] | 119[a] |
| Sex | | | | | | |
| Male | 8.84[a] | 25.16 | 24.43 | 49.69 | 160 | 97 |
| Female | 7.88[b] | 26.08 | 24.65 | 48.12 | 180 | 95 |
| SEM† | 0.62 | 0.29 | 0.80 | 1.45 | 13.02 | 6.55 |
| CV (%)‡ | 10.47 | 5.27 | 12.33 | 9.61 | 29.05 | 21.02 |
| *p*-value for main and interaction effects | | | | | | |
| Subspecies | <0.0001 | 0.063 | 0.003 | <0.0001 | 0.004 | <0.0001 |
| Sex | 0.014 | 0.112 | 0.861 | 0.493 | 0.327 | 0.803 |
| Interaction | 0.072 | 0.458 | 0.621 | 0.042 | 0.951 | 0.099 |

**[a,b] Means within a column and variable followed by different letters differ significantly by Tukey's test (*****p*** **< 0.05). † Standard error of the mean. ‡ Coefficient of variation. ¶ Fibers/0.59mm$^2$.**

Grieser (2018) observed that male European quail had a growth rate of 0.079 and females of 0.061, with a mean of 0.07 for both genders. The author also observed that Japanese quail had growth rates of 0.083 and 0.057 for males and females, respectively, with a mean of 0.07. The results were not separated by gender because sexual dimorphism was evident in feather differentiation only after 21 days. After the establishment of sexual dimorphism, both genders were included in the sampling process for growth curve analysis.

The time to the maximum growth rate (*C*) represents the growth curve inflection point, i.e., where the growth rate is highest. From this point on, the curve changes from a concave to a convex shape (Kessler et al. 2000). The growth rates of body and muscle parameters did not vary between quail subspecies.

Analysis of morphological parameters is essential for meat-type birds. The breast represents 27% and 25% of the weight of European and Japanese quail, respectively, which directly influences fattening and time to slaughter. At 18 days post-hatch, the maximum growth rate was 6.85 g/day for European quail and 3.66 g/day for Japanese quail. In this aspect, Narinc et al. (2013) reported a similar maximum growth rate for Japanese quail at 17 days of age. Du Preez & Sales (1997) also determined the growth rate of European quail using Gompertz equations and observed a rapid growth rate until 21 days of age, followed by a decreasing rate. In this sense, Grieser (2018) observed that the growth rate was highest at 14 and 21 days for meat-type males and egg-laying females. In contrast, Silva & Costa (2009) found that the highest growth rate of Japanese and European quail was achieved at 27 days of age.

Breast weight at maturity was higher in European than in Japanese quail; however, the same curve inflection point was observed for both subspecies. These results support those of Grieser et al. (2015), who observed that European quail weighed more at maturity than Japanese quail. In the current study, the time to the maximum growth rate of the breast was reached five days after that of the body weight.

Histochemical results of in breast muscle corroborate that European and Japanese quail are characterized as flying birds, as shown by their glycolytic profile and proportion of type IIA fibers (Welch & Altshuler 2009). The location of fibers (type IIA at the center of muscle bundles

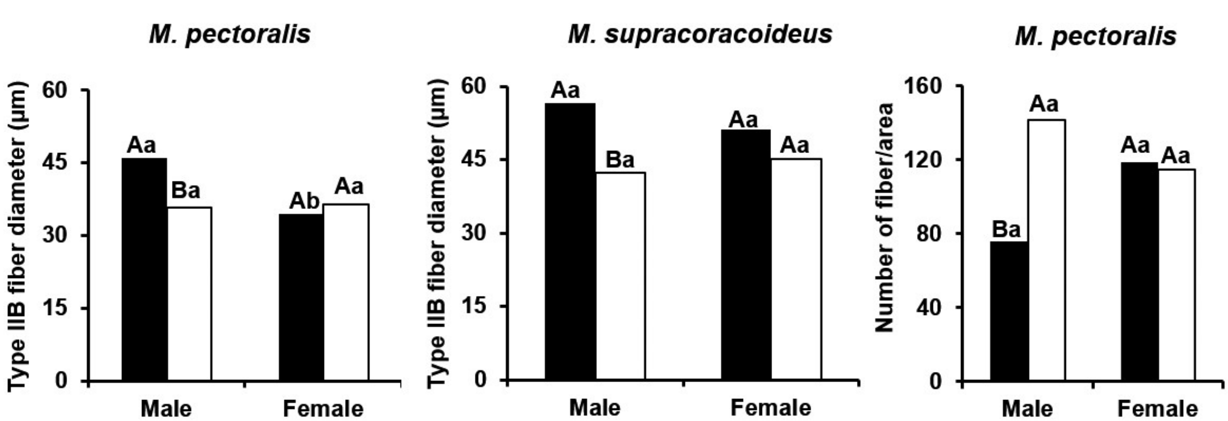


**Figure 5.** Main and interaction effects of subspecies and sex on *M. pectoralis* and *M. supracoracoideus* type IIB fiber diameter and fiber density in European and Japanese quail. Different uppercase letters indicate significant differences between subspecies, and different lowercase letters indicate significant differences between sexes (Tukey's test, $p < 0.05$).

and type IIB at the periphery) was the same as that described for quail by Choi & Kim (2009) and pigeons by Rosser et al. (1998).

In Japanese quail selected for body weight, type IIA and IIB fibers were present in MP at 43.6% and 56.6%, respectively; in unselected Japanese quail, the proportions were 79.7% and 20.0%, respectively (Choi et al. 2013). In ducks, MP was composed of 73.3% type IIB and 26.7% IIA fibers, whereas broiler MP comprises entirely of type IIB fibers (Musfiroh et al. 2013).

After hatching, muscle growth is accompanied by transverse and longitudinal growth of muscle fibers, also known as hypertrophy (Gosnak et al. 2010). Hyperplasia occurs in the embryonic stage when the number of muscle fibers is determined (Christ & Brand-Saberi 2002). In general, birds selected for meat production present fibers with larger diameters than those selected for egg production (Dransfield & Sosnicki 1999), implying differences in breast weight at maturity. Such differences were observed in the present study: European and Japanese quail differed in breast weight because of the larger diameters of type IIA and IIB fibers in European quail. In particular, type IIA fibers contributed more to breast weight than type IIB fibers in the European quail. However, meat-type quail are selected for their higher number and diameter of type IIB fibers compared with type IIA (Choi et al. 2013). These criteria suggest that type IIB fibers contribute more to the MP volume.

The differences between breeders in meat or laying aptitude are cited in other birds. Oshima et al. (2007) described in silky that male breeders with meat aptitude have higher MP weights at 7 and 35 days but do not differ in type IIB fiber diameter compared with males with laying aptitude. The authors concluded that because MP comprises type IIB fibers, the high breast weight in meat-type Silky chickens is attributed to numerous fibers with a small diameter.

According to Móri et al. (2005), female quail have a higher body weight than males at weeks 3 and 4, when they reach sexual

**Table III. Body weight, breast weight, relative breast weight, pH at 20 min ($pH_{20min}$) and 24 h post-mortem ($pH_{24h}$), water-holding capacity (WHC), and muscle color (L*, a*, and b*) in European (*n* = 15) and Japanese (*n* = 15) quail at 35 days post-hatch.**

| | Body weight (g) | Breast weight (g) | Relative breast weight (%) | pH 20min | pH 24h | WHC (%) | Muscle color | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lightness (L*) | Redness (a*) | Yellowness (b*) |
| Subspecies | | | | | | | | | |
| European | 202.03[a] | 55.22[a] | 27.30[a] | 6.04 | 5.89 | 27.85 | 38.78[a] | 13.74[b] | −1.28 |
| Japanese | 115.48[b] | 29.14[b] | 25.15[b] | 5.98 | 5.84 | 26.94 | 36.74[b] | 16.41[a] | −1.21 |
| Sex | | | | | | | | | |
| Male | 159.45 | 43.19 | 26.73[a] | 6.02 | 5.86 | 27.14 | 37.30 | 15.40 | −1.48[a] |
| Female | 158.06 | 41.17 | 25.72[b] | 6.00 | 5.88 | 27.65 | 38.23 | 14.75 | −1.02[b] |
| SEM† | 6.231 | 1.896 | 0.235 | 0.028 | 0.014 | 0.280 | 0.298 | 0.296 | 0.101 |
| CV%‡ | 13.35 | 15.52 | 5.25 | 1.72 | 1.52 | 7.13 | 5.49 | 12.56 | −6.08 |
| *p*-value | | | | | | | | | |
| Subspecies | <.0001 | <.0001 | <0.0001 | 0.131 | 0.105 | 0.114 | 0.001 | <.0001 | 0.736 |
| Sex | 0.801 | 0.237 | 0.006 | 0.486 | 0.562 | 0.368 | 0.089 | 0.189 | 0.023 |
| Interaction | 0.672 | 0.523 | 0.891 | 0.693 | 0.600 | 0.266 | 0.615 | 0.271 | 0.183 |

**[a,b] Means within a column and variable followed by different letters differ significantly by Tukey's test ($p < 0.05$). † Standard error of the mean. ‡ Coefficient of variation.**

maturity. Regarding this aspect, Abreu et al. (2014), evaluating the influence of gender and age on carcass yield and carcass quality in quail, reported that gender influenced breast yield and quality parameters, with males performing better than females.

Meat quality analysis revealed that European quail meat was lighter than Japanese quail meat. The lightness (L*) is the main determinant of color quality in poultry filets (Van Laack et al. 2000). Japanese quail breast meat had a reddish (a*) color compared with European quail breast meat because of the higher presence of type IIA fibers, which are characterized by a greater amount of myoglobin. The meat of male quail had higher redness (b*) values than that of female quail, regardless of subspecies, as also reported by Abreu et al. (2014). In broilers, pectoral muscles are whiter because of the predominant presence of type IIB fibers, whereas thighs and drumsticks are darker because they are formed by type IIB, IIA, and I fibers (Gonzales & Sartori 2002).

Meat color is an important functional property and is closely related to other properties such as pH and WHC. Poultry processing industries commonly use color as an indication of meat quality because it can be determined by a fast-nondestructive method (Harford et al. 2014). In the present study, the density of type IIA and IIB fibers in MP of European and Japanese quail at 35 days of age did not promote differences in pH at 24 h post-mortem or WHC. Genchev et al. (2010) described that the WHC of female Japanese quail meat decreased with lower MP pH values. The authors also observed that *Biceps femoris* had higher WHC than the MP. This difference can be explained by the metabolic profile of the fibers in each muscle. Muscles with a high oxidative profile have high WHC, which can also be correlated with light color.

In this study, both studied quails were management for meat production, and a further investigation could observe the differences in muscle growth under different management conditions. The results of breast muscle growth obtained can be used to determine adjustments in quail diets for meat production purposes and associate the requirements with muscle growth.

## CONCLUSIONS

Japanese and European quail showed similar body and muscle growth patterns with maximum growth rate to body weight, breast weight, and MP and MS weight at 17.6; 22.2; 23.5, and 21.4 days of age, respectively. The breast weight gain was due to hypertrophy of type IIA and IIB fibers in both MP and MS.

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