Animal Science Papers and Reports vol. 43 (2025) no. 3, 335-346
DOI: 10.2478/aspr-2025-0023
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The influence of age and sex on carcass composition, digestive system morphometry and leg bone dimensions in Japanese quail

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(Accepted June 6,2025)

Japanese quails are birds that are mainly reared for meat and egg production. Early sexual maturity and a high reproduction rate have contributed to the development of this poultry sector. This study investigated the effects of age, sex, and their interactions on the carcass composition, digestive system morphometry, and leg bone dimensions. The research was conducted on 40 Japanese quails: 20 birds at 6 weeks of age (10 males and 10 females) and 20 birds at 52 weeks of age, at the end of the egg production period (10 males and 10 females). Post-slaughter, body weight and the relative proportions of carcass components were recorded. Additionally, the lengths and diameters of intestinal segments, their proportions relative to total intestinal length, and morphometric measurements of the femur and tibia were assessed. The results showed that age significantly affected body weight, with older quails weighing more (174.30±23.59 g) than younger ones (166.94±10.25 g; *p*<0.05). Also, age significantly influenced the percentage of leg muscles, as well as the relative weights of the gizzard and spleen, and several morphometric parameters of the tibia and femur. Sex had a significant effect, too. Females exhibited higher body weights than males (177.49±26.95 g vs. 163.75±8.41 g) along with changes in selected osteometric dimensions of the tibia and femur. Some traits showed interaction effect. Overall, both age and sex significantly

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influence carcass composition and selected morphometric characteristics of the femur and tibia, while body weight increases with age and the relative proportion of leg muscles decreases.

KEY WORDS: Japanese quail/ carcass composition/ intestine/ leg bones

Japanese quail (*Coturnix japonica*) is a bird that was first domesticated in the 11th century in China as a songbird and then, in the 19th century, in Japan for egg production [Lukanov *et al*. 2018, Wilkinson *et al*. 2018]. Early sexual maturity (6-8 weeks), high reproductive rate and disease resistance have contributed to the development of this poultry sector mainly in Asian, African but also Latin American countries [Kismiati *et al*. 2023]. There are more than 70 breeds and varieties, used mostly for meat and egg production [Volkova *et al*., 2023, Kokoszyński *et al.* 2024]. Worldwide quail egg production equals 1.2-1.3 million tons, while meat production ranges between 0.2-0.24 million tons [Lukanov *et al*. 2023]. The body weight of an adult bird is largely determined by breed and variety, with large discrepancy from 120-140 to 400-450 g [Lukanov *et al*. 2018].

The development of the digestive tract largely depends on poultry species, specifically the growth rate, as it progresses more rapidly in faster-growing birds [Wasilewski *et al*. 2015]. The small intestine grows most rapidly early in the bird's life, with growth slowing as the bird ages [Wasilewski *et al*. 2015]. The small intestine includes the duodenum, jejunum and ileum [Wilkinson *et al*. 2018]. In the duodenum, where the chyme enters from the stomach, the initial phases of digestion occur. This is followed by the jejunum, where the primary absorption of nutrients takes place, continuing into the ileum. Fermentation processes occur in the ceca, which consist of two caudally positioned sections. [Wilkinson *et al.* 2018].

Importantly, the digestive tract, where feed nutrients are digested and absorbed, is also one of the most important parts of the birds' defense system [Chen *et al*. 2021]. The parameters of the intestine are subject to various influences. Strack and Rahmaan [2003] showed that a diet enriched in fiber affected the elongation of the small and large intestine. Other studies have shown that bird genotype, sex and age influenced gastrointestinal weight and the ratio of gastrointestinal length to body length [Wilkanowska *et al*. 2013, Kirella *et al*. 2023].

Bone development is primarily influenced by bird nutrition, but also genotype, sex and age of birds are the determinants of growth [Wilkanowska *et al*. 2013, Kirella *et al*. 2023, Lee *et al*. 2023, Włodarczyk *et al*. 2023]. As birds grow, the ratio of muscle to bone tissue changes. The percentage of meat and skin with subcutaneous fat increases, while the percentage of bone decreases [Włodarczyk *et al*. 2023]. Birds that grow rapidly may develop deformities and bone fragility due to excessive loading [Douglas *et al.* 2023]. In a study by Williams *et al*. [2004], the growth rate in fast-growing meat birds was largely responsible for lower bone stiffness. Bone growth should be synchronous with the development of muscle tissue and adipose tissue, as they are interrelated and affect normal growth in birds [Douglas *et al.* 2023].

Given that age and sex influence carcass traits, gastrointestinal morphometry, and leg bone dimensions, this study aimed to evaluate the effects of these factors on carcass composition, digestive tract morphology, and osteometric parameters in Japanese quail (*Coturnix japonica*). It was hypothesized that both age and sex exert a significant effect on carcass characteristics, as well as on the length and weight of the digestive tract and the development of leg bones, with older birds and males exhibiting larger dimensions of the analyzed structures.

Material and methods

Ethical permission and animals

The experiment was conducted in accordance with applicable regulations governing the use of animals for scientific and educational purposes. The study was approved by the Departmental Animal Welfare Team and the Experimental Unit of Bydgoszcz University of Science and Technology (Approval No. 17/2010). All procedures and protocols were reviewed and approved by the University's Ethics Committee (Approval No. 17/2010).

The birds came from the Quail Farm in Dziewoklucz near Budzyń, (Poland (52°54'050.0"N 17°04'022.4"E). The study was conducted on 40 Japanese quail, comprising 20 birds at 6 weeks of age (10 males and 10 females) and 20 birds at 52 weeks of age, i.e. at the end of egg production period (10 males and 10 females).

Experimental Design

Environment and feeding. The birds were reared indoors in 100x300 cm cages with a stocking density of 250 cm^2/bird. They were fed a balanced mixture depending on the needs and age of the birds. During the first week of life (1-7 days), birds were fed a diet containing 3000 kcal of metabolizable energy (ME), 28% crude protein (CP), and up to 3% crude fiber. In the following three weeks (8-28 days), they received a mixture with 2900 kcal ME, 24% CP, and up to 3.5% crude fiber. In the final period (29-42 or 29-364 days), the feed contained 2800 kcal ME, 20% CP, and up to 4% crude fiber. Water was provided ad libitum. At the start of rearing, the temperature was set at 34°C and gradually reduced to 21°C by the third week of the birds' life. The relative humidity was approximately 65%. From the 1st to the 14th day of the birds' life, a light program lasting 24 hours was applied, then 2 hours were deducted every 7 days, ultimately achieving 16 hours of light and 8 hours of darkness. Cold color LED lighting (6000K) with an intensity of 20 Lx was used.

Carcass analysis

The birds were slaughtered by severing the continuity of the spinal cord, cutting blood vessels, and bleeding out in accordance with the application submitted to the Ethics Commission and Polish law (Dz.U. 2004, No. 70, item 643, §14.6). No measures were used before euthanasia. The disemboweled carcasses and entrails were then transported to the University Laboratory, where they were cooled for 18 hours in a refrigerated cabinet (Hendi, Gadki, Poland) at 2°C. After cooling, dissection was performed using the simplified method described by Ziołecki and Doruchowski [1989], during which leg muscles, pectoral muscles and abdominal fat were collected. The obtained carcass parts were weighed individually on a (PS 1000.R2) balance (Radwag, Radom, Poland).

Anatomical analysis

The weights of the giblets (proventriculus, liver, heart, spleen, and gizzard) were measured to the nearest 0.01 g using a WPS 210/C electronic balance (Radwag, Radom, Poland). The lengths of the small intestinal segments (duodenum, jejunum, and ileum), as well as the ceca and colon, were measured with a tape measure accurate to 1 mm. The diameters of each intestinal segment were measured at three points (proximal, middle, and distal) using electronic calipers with a precision of 0.01 mm. Additionally, following dissection, osteometric measurements of the leg bones (femur and tibia) were taken using electronic calipers with the same level of accuracy.

The following measurements were taken on the femur: GL – greatest length; ML – medial length; GB – greatest width of the proximal end; GD – greatest depth of the proximal end; SM – smallest width of the diaphysis (shaft); GC – greatest width of the distal end; and GE – greatest depth of the distal end. For the tibia, the measured parameters included: GL – greatest length; AL – axial length; GD – greatest diagonal of the proximal end; SB – smallest bone width; SD – greatest width of the distal end; and DD – greatest depth of the distal end. All osteometric measurements were conducted in accordance with the methodology described by Włodarczyk *et al.* [2023]

Statistical analysis

Statistical analysis of the numerical data collected in this study was conducted using widely accepted methods. For each tested trait, arithmetic means were calculated for both factors (age and sex) and the standard error of the mean (SEM) for both assessment terms combined. The Shapiro-Wilk test was used to assess the empirical compliance of the feature distributions with the normal distribution. A parametric test in the form of a two-factor analysis of variance was used for the statistical assessment of the influence of age and sex on the tested trait. The following linear model was used:

$$Y_{ijk} = \mu + a_i + b_j + (a \times b)_{ij} + e_{ijk}$$

where:

Y_{ijk} – the value of the trait;

μ – the overall mean of the trait;

a_i – the effect of the i-age;

b_j – the effect of j-sex;

$(a \times b)_{ij}$ – the age of birds by sex interaction;

e_{ijk} – the error;

k – the kth observation for the target trait in the group.

SAS software (SAS Institute, Cary, NC, USA) version 9.4.23 was used to perform statistical calculations. The significance of differences at $p<0.05$ was verified between ages and between males and females using Tukey's post hoc test.

Results and discussion

We found significant ($p<0.05$) differences between age and sex in the body weight and percentage of some carcass components in the Japanese quail (Tab. 1). The body weight of the birds was significantly higher at 52 weeks of age (p = 0.004). It was also shown that females, regardless of age (6 weeks and 52 weeks), had significantly (p = 0.015) higher body weight compared to males. The percentage of gizzard was significantly higher in birds at 6 weeks of age (p = 0.018), while a higher percentage of spleen was found in Japanese quails at 52 weeks of age (p = 0.002). The age of the birds had no effect on the remaining analyzed features (percentage of breast muscle, heart, liver, proventriculus) (p = 0.128-0.934). The sex of the birds did not have a significant impact (p = 0.074-0.643) on the analyzed features (percentage of breast muscles, leg, stomach, liver, spleen, heart, proventriculus). However, there was an interaction between age and gender in body weight and the percentage of leg muscle and liver (p<0.001-0.003).

Table 1. Body weight, proportion of pectoral and leg muscles, and selected internal organs in body weight of Japanese quails in the 6 and 52 weeks

Trait	Young quail (6 weeks)		Aged quail (52 weeks)		SEM	*p*-values		
	male	female	male	female		A	S	A x S
Body weight (g)	162.60	171.28^{b*}	164.90	183.70^{a*}	2.832	0.004	0.015	<0.001
Pectoral muscles (%)	23.52	23.68	23.38	22.62	0.196	0.128	0.447	0.246
Leg muscles (%)	13.97	14.75^{a}	13.95	12.90^{b}	0.174	0.003	0.643	0.003
Heart (%)	0.80	0.72	0.82	0.76	0.017	0.436	0.074	0.750
Liver (%)	2.91	2.49	2.15	2.94	0.099	0.387	0.308	0.002
Proventriculus (%)	0.54	0.52	0.49	0.56	0.011	0.934	0.284	0.067
Gizzard (%)	2.40^{a}	2.54^{a}	2.14^{b}	2.19^{b}	0.064	0.018	0.442	0.710
Spleen (%)	0.07^{b}	0.06^{b}	0.10^{a}	0.13^{a}	0.008	0.002	0.476	0.184

^{ab}Means bearing different superscripts differ significantly between young and aged quail within the same sex at $p<0.05$.
*Statistical differences between males and females ($p < 0.05$) within a given age.
A – age; S – sex; A × S – interaction between age and sex; SEM – standard error of the mean.
n=10 for male or female within a given age.

The analysis of the length and diameter of individual intestinal sections (Tab. 2) showed no significant effect (p = 0.131-0.762) of age on the analyzed features (duodenum, jejunum + ileum, caeca, colon, total intestine). There was also no influence of gender on the above features (p = 0.059-0.999). However, an interaction

Table 2. Length and diameter of intestinal segments of Japanese quails in the age of 6 and 52 weeks

Trait	Young quail (6 weeks)		Aged quail (52 weeks)		SEM	*p*-values		
	male	female	male	female		A	S	A x S
				Length (cm)				
Total intestine	102.10	92.00	94.60	102.40	2.167	0.762	0.815	0.039
Duodenum	13.10	11.30	11.80	13.60	0.449	0.575	0.999	0.049
Jejunum + Ileum	56.10	53.00	54.80	56.70	1.256	0.644	0.817	0.338
Caeca	23.30	20.20	20.30	21.90	0.721	0.655	0.606	0.112
Colon	9.60	7.50	7.70	10.20	0.414	0.608	0.797	0.005
				Diameter (mm)				
Duodenum	6.10	5.72	5.98	6.83	0.340	0.176	0.500	0.080
Jejunum + Ileum	4.14	4.12	4.11	4.37	0.676	0.131	0.648	0.607
Caeca	4.06	5.63	4.77	4.52	0.634	0.187	0.063	0.012
Colon	3.12	4.14	3.62	3.64	0.448	0.139	0.059	0.067

A – age; S – sex; A × S – interaction between age and sex; SEM – standard error of the mean.
n=10 for male or female within a given age.

Table 3. Share (%) length of intestinal segments of Japanese quails in the age of 6 and 52 weeks

Trait	Young quail (6 weeks)		Aged quail (52 weeks)		SEM	*p*-values		
	male	female	male	female		A	S	A x S
Duodenum (%)	12.83	12.28	12.47	13.28	0.340	0.579	0.686	0.333
Jejunum+ileum (%)	54.95	57.61	57.93	55.37	0.676	0.639	0.877	0.189
Total small intestine (%)	67.78	69.89	70.40	68.65	0.634	0.688	0.716	0.204
Caeca (%)	22.82	21.96	21.46	21.39	0.448	0.160	0.603	0.677
Colon (%)	9.40	8.15	8.14	9.96	0.407	0.632	0.770	0.087

A – age; S – sex; A × S – interaction between age and sex; SEM – standard error of the mean.
n=10 for male or female within a given age.

of age and sex affected the length of the entire intestine, duodenum and colon, and the diameter of the cecum (p = 0.005-0.049).

The analysis of the percentages of individual intestinal segments in Japanese quails according to age and sex (Tab. 3) showed no significant differences (p = 0.160-0.877) in the analyzed traits.

Size wise, except for SB measurements, age had no effect on the analyzed tibial features in relation to age and gender influences (Tab. 4). Older birds (52 weeks) had a wider SB compared to Japanese quails at 6 weeks of age (p = 0.031). The gender of the birds also had some influence on the measurement of GD. Females had lower tibial GD measurements compared to males (p = 0.010). The age and sex of the birds had no effect on the remaining analyzed parameters (p = 0.052-0.987).

Analysis of femur dimensions (Tab. 5) showed significant differences ($p<0.05$) in the analyzed traits of GD, SM and GC. The quails at 52 weeks of age had higher values of GD, SM and GC compared to the birds from the 6 weeks of age group (p = 0.020-0.042). It was also shown that females had higher values of the femoral GD parameter relative to males (p = 0.019). Also, we observed an interaction between age and sex in the measurement of GD (p = 0.018).

Table 4. Dimensions of the tibia bone of Japanese quails in the age of 6 and 52 weeks

Trait	Young quail (6 weeks)		Aged quail (52 weeks)		SEM	*p*-values		
	male	female	male	female		A	S	A x S
GL (mm)	52.51	51.07	51.65	51.36	0.255	0.646	0.115	0.307
AL (mm)	50.41	49.58	49.69	50.10	0.272	0.860	0.707	0.274
GD (mm)	7.68	7.93	7.99	7.31*	0.135	0.139	0.010	0.725
SB (mm)	2.69	2.67[b]	2.72	3.04[a]	0.049	0.031	0.107	0.068
SD (mm)	5.01	5.27	4.96	5.20	0.064	0.633	0.052	0.936
DD (mm)	4.69	4.86	4.89	4.66	0.373	0.987	0.814	0.094

[ab]Means bearing different superscripts differ significantly between young and aged quail within the same sex at p<0.05).
*statistical differences between males and females ($p < 0.05$) within a given age.
GL – greatest length; AL – axial length; GD – greatest diagonal of the proximal end; SB – smallest breadth of the corpus; SD – greatest breadth of the distal end; DD – greatest depth of the distal end.
A – age; S – sex; A × S – interaction between age and sex; SEM – standard error of the mean.
n=10 for male or female within a given age.

Table 5. Dimensions of the femur bone of Japanese quails in the age of 6 and 52 weeks

Trait	Young quail (6 weeks)		Aged quail (52 weeks)		SEM	*p*-values		
	male	female	male	female		A	S	A x S
GL (mm)	41.67	40.69	41.31	41.90	1.300	0.300	0.629	0.058
ML (mm)	40.50	39.61	40.22	40.18	1.179	0.695	0.220	0.261
GB (mm)	6.79	6.59	7.00	7.02	0.506	0.054	0.513	0.533
GD (mm)	3.24[b]	3.77*	3.76[a]	3.77	0.406	0.020	0.019	0.018
SM (mm)	2.85[b]	2.94	3.07[a]	3.07	0.183	0.023	0.369	0.370
GC (mm)	5.44[b]	5.47[b]	5.73[a]	5.72[a]	0.412	0.042	0.923	0.862
GE (mm)	4.26	4.40	4.66	4.62	0.514	0.062	0.750	0.572

[ab]Means bearing different superscripts differ significantly between young and aged quail within the same sex at p<0.05).
*statistical differences between males and females ($p < 0.05$) within a given age.
GL – greatest length; ML – medial length; GB – greatest breadth of proximal end; GD – greatest depth of proximal end; SM – smallest breadth of the corpus; GC – greatest breadth of the distal end; GE – greatest depth of distal end.
A – age; S – sex; A × S – interaction between age and sex; SEM – standard error of the mean.
n=10 for male or female within a given age.

In recent years, studies on Japanese quails have shown that body weight and the proportions of breast and leg muscles are influenced by factors such as age, nutrition, sex, genotype, and housing system. [Akdemir *et al*. 2018, Abou-Kassem *et al*. 2019, Cullere *et al*. 2023, Mutter and Abbas, 2023].

Abou-Kassem *et al*. [2019] showed differences in the body weight of Japanese quails between 5, 6 and 7 weeks of age increased significantly with age. The same relationship was also demonstrated in another study [Wilkanowska *et al*. 2013], in which the body weight of Pharaoh quails at the age of 35 days was observed to be significantly lower compared to the body weight of birds at the age of 45 days. Our study confirmed this relationship. The body weight of Japanese quails at 6 weeks (166.94±10,25 g) was lower compared to birds at 52 weeks of age (197.30 g). Other reports were similar but recorded a higher final body weights in Japanese quails - 255.0 g at 5 and 267.6 g at 6 weeks of age -compared to our research [Cullere *et al.* 2023, Kirrella *et al*. 2023]. The higher results obtained in the above studies were most likely influenced by the birds' genotype and nutrition. Additionally, Kirrell *et al*. [2023] showed that the final body weight was also affected by the sex of the birds. Females were characterized by a higher body weight compared to males. This relationship was confirmed in our study.

Our results also showed that the proportion of leg muscles relative to body weight declined as the birds aged. Contrastingly, Abou-Kassem *et al.* [2019] observed that the proportion of leg muscles in the carcass increased with age (5-6 weeks), which was also reported by Wilkanowska and Kokoszyński [2011] in Pharaon quails. Similarly, Kaye *et al*. [2016] demonstrated that age influences leg and pectoral muscle development in Japanese quails. Birds at 35 days of age had lower leg muscle mass and a smaller proportion of pectoral muscles compared to those at 56 days.

In our study, we also observed that age affected the percentage of the stomach and spleen. The percentage of the stomach in body mass decreased, while the percentage of the spleen increased with the age of the Japanese quail. Kaye *et al*. [2016] and Abou-Kassem *et al*. [2019] noted the same relationship. The percentage of stomach in Japanese quails at week 5 (2.76%) decreased to 1.95% at week 7 [Abou-Kassem *et al*. 2019]. In contrast, other authors Zarandi *et al*. [2023] showed that gizzard percentage was influenced by RFI (residual feed intake) breeding value. Japanese quails with low RFI had a lower percentage of stomach compared to the group with high RFI breeding value.

In our study, age and sex of Japanese quails had no significant effect on the lengths or diameters of individual intestinal segments. Similarly, Wilkanowska *et al*. [2013] found no age-related differences in the lengths of the cecum, terminal intestine, or entire small intestine when comparing Pharaon quails at 35 and 45 days of age. Although not statistically significant, our results showed that 52-week-old females had the longest whole intestine length. This finding is physiologically relevant, as a longer digestive tract may enhance nutrient absorption from feed.

Interestingly, the cecum measurements in our 6-week-old quails were higher than those reported for Pharaon quails at 45 days of age by Wilkanowska *et al.* [2013]. The proportion of individual intestinal segments relative to the total digestive tract was also unaffected by age or sex. Across all groups, the jejunum + ileum accounted for the largest (non-significant) percentage of the total intestine, while the colon accounted for the smallest. Notably, the jejunum comprised more than twice the proportion of the colon within the entire intestine. In contrast, Kirrell *et al*. [2023] reported that digestive tract weight was influenced by both genotype and sex. Quails with white plumage had heavier digestive tracts than those with brown plumage. Additionally, females at 6 weeks of age had a heavier digestive tract compared to males.

Bone growth in birds is dynamic and changes depending on internal and external factors with physiological, nutritional and physical backgrounds [Douglas *et al*. 2023].

The structural and anatomical parameters of bone are genetically determined [Banks, 1992]. Wei *et al*. [2019] thinks that bone is a dynamic structure that can modify itself to different sizes, shapes and biology depending on external mechanical requirements. As a result, the analysis of the mechanical performance of bird bones may decrease depending on adaptation to the environment [Wei *et al*. 2019].

In our study of individual tibial features in Japanese quail, age had no significant effect on the analyzed parameters, except for the SB measurement. It was observed that with the age of the birds, the analyzed trait (SB) of the tibia was higher. It was also shown that the sex of the birds affected the value of GD. Males were characterized by higher tibial GD measurements compared to females. The authors of Kirrell *et al*. [2023], on the other hand, observed that tibia length was influenced by the birds' genotype and sex. Female Japanese quails with white plumage were characterized by a longer tibia bone compared to the analyzed trait in males with brown plumage. Our previous research also showed that some parameters of the tibia were influenced by the genotype of quails [Wegner *et al*. 2024]. Pharaoh quails were characterized by larger GD, SB, SD and DD dimensions and smaller GL and AL of the tibia compared to Japanese quails. Other authors Ardiningsasi *et al*. [1992] showed that the length of the tibia varied according to the quail lines studied (LL, RR and SS) selected for body size at 6 weeks of age, while measured at 2 to 12 weeks of age. LL (large body size) quails regardless of their age from 4 to 12 weeks were characterized by longer tibia compared to SS (small body size).

In our research, the age of quails had an impact on the analyzed dimensions (GM, SM, GC) of the femur, which were higher in birds aged 52 weeks. The gender of the birds also influenced the value of the GD parameter. In previous studies, we also observed that the analyzed features of the femur were influenced by the sex of ducks [Włodarczyk *et al*. 2023]. After laying, male ducks were characterized by higher GL, ML and GC values of the femur compared to females. In quails, however, gender had no effect on the above features, except for the GD measurement, which was higher in females.

Conclusion

Japanese quails exhibit well-developed musculature, particularly in the pectoral region. With age, body weight and spleen proportion increase, while the proportions of leg muscles and gizzard decrease. Age also affected certain skeletal traits, including increases in the smallest breadth of the tibial corpus and both the smallest breadth of the corpus and the greatest breadth of the distal end of the femur. Sex influenced body weight and the greatest diagonal of the proximal tibia, which was larger in males. Age and sex had no significant effect on gastrointestinal morphometry. Overall, both age and sex impact carcass composition and select tibial and femoral measurements, with some traits showing interaction effects.

Author contributions: All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that they have no conflict of interest.

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