Carcass traits and fat quality of breeding emu (*Dromaius novaehollandiae*) in Northern Japan

Yuichi Koshiishi,* Michiko Murata-Okubo,[*,†] Hinami Nakajyo,[†] Rikimaru Machida,[†] Taiga Yamamoto,[†] Takao Myoda,[*,†] Yuichi Kameyama,[*,†] Hiroki Hirayama,[*,†] Kousaku Souma,[*,†] Michinari Yokohama,[‡] and Kenta Wada ®[*,†,1]

Graduate School of Bioindustry, Tokyo University of Agriculture, Abashiri, Hokkaido, 099-2493, Japan; †Faculty of Bioindustry, Tokyo University of Agriculture, Abashiri, Hokkaido, 099-2493, Japan; and ‡Tokyo University of Agriculture, Abashiri, Hokkaido, 099-2493, Japan

ABSTRACT Characterization of carcass traits and fat quality is important to effectively produce and genetically improve emus. We investigated carcass traits in 309 emus. The meat production of female emus showed a significantly higher value than that of males ($P < 0.01$). The fat weight of male (9.232 ± 3.156 kg) was larger than that of the female (7.772 ± 2.697 kg). The fat yield (fat weight per kg of body weight) was strongly correlated to body weight ($r = 0.79$ and $r = 0.75$ in male and female, respectively). The fat melting points of females and males were 19.19 ± 3.39°C and 19.39 ± 3.39°C, respectively, without significant difference. Since the fat melting point did not correlate to body and fat weights, we predicted that it was an independent trait from body growth and was highly influenced by genetic elements. Percentages of palmitic, stearic, oleic, linoleic, and α-linolenic acids were $22.27 \pm 3.50\%$, $9.37 \pm 1.90\%$, $54.11 \pm 5.17\%$, $13.54 \pm 7.80\%$ and $0.71 \pm 0.59\%$, respectively. Among them, linoleic acid contents showed a wide individual difference (range $0.3-19.9\%$). The oleic/stearic acid ratio showed a negative correlation to the fat melting point. These results suggest that the fat melting point is a good indicator of C18:1/C18:0 ratio in emu fat.

Key words: emu, carcass traits, fatty acid composition

INTRODUCTION

The emu (*Dromaius novaehollandiae*) is a ratite bird native to Australia. In the 1970s, the domestication of emus began in Australia (Sales et al., 1999); subsequently, its industrial utilization was extended to other countries such as America, China, and Japan. Over the past several decades, emus have become a novel poultry species producing low-fat red meats, low allergenic eggs, and oils containing rich unsaturated fatty acids (**USFAs**). In particular, emu oil exhibits anti-inflammatory effects (Snowden and Whitehouse, 1997; Miyashita et al., 2018) and reduces melanin production in melanoma cells (Ito et al., 2016). Emu oil also has high economic value as a skincare product (Politis and Dmytrowich, 1998; Zanardo et al., 2017).

In Japan, almost all farms for production and exhibition are composed of a small population of fewer than 500 individuals. Among Japanese emu farms, the Okhotsk Emu Farm (**OEF**) established in Abashiri City, the island of Hokkaido, located in the northernmost part of Japan, is the largest farm with more than 1,400 birds. Thus, the OEF is one of the centers of the Japanese emu industry. To date, several effective methods for rearing management and reproduction of emu in northern Japan with cold climates have been established in our previous studies (Yokohama, 2014, 2016; Yokohama and Ide, 2014). In addition, we have investigated the genetic structure of emu populations bred in Japan and developed methods for sexing and parentage tests based on DNA markers (Koshiishi and Wada, 2018; Koshiishi et al., 2020a,b, 2021). However, according to an extensive literature search, no genetic improvement of emu productive traits has been carried out due to their short history of domestication compared to other livestock species (Yokohama, 2014; Yokohama et al., 2014). Traits of emu carcass and their major products need to be characterized to extend the values of the emu industry through effective production based on genetic improvement. In particular, the characterization

of the emu oil quality, which is predicted to be affected by fatty acid composition, is an important issue for the future emu industry.

Previous studies reported that adult emus have approximately 40 to 44 kg in body weight and approximately 10 kg in subcutaneous and abdominal fat (Sales et al., 1999; Naveena et al., 2013; Menon et al., 2014, Yokohama, 2014). At 4 to 6 yr of age, female emus exhibited larger body weight than males, while fat accumulation in males was greater than that in females (Blache and Martin, 1999; Menon et al., 2014; Yokohama, 2014). In addition, emus at 3 to 4 yr of breeding in Japan abundantly accumulated more fat from July to December than from January to June (Yokohama, 2014). Fat accumulation is known to increase during the pre-breeding period in late autumn (Blache et al., 2001; Menon et al., 2013). In Japan, the breeding period of emus starts in November and continues until April or May (Yokohama et al., 2014).

Emus mature at approximately 1.5 yr of age. Early slaughter of emu has advantages for cost-effective management owing to the sparing of forages and spaces. Therefore, almost all of the birds living in the OEF were slaughtered at approximately 2 yr of age in the period from summer (July) to winter (December) during pre-breeding and initial breeding seasons to obtain both meat and oil. However, there are few reports describing carcass characters of 2-yr-old emus by large-scale sampling. In addition, even though the rate of fat accumulation changes seasonally, there are no reports comparing carcass traits between egg-laying and non-egg-laying periods. Although the fatty acid composition of the adipose tissue as a material for oils, the major product of emu, has been reported by several studies (Minnaar, 1998; Wang et al., 2000; Beckerbauer et al., 2001; Bucław et al., 2020), no information is available on its differences and relationships with the fat melting point.

This study aims to provide information on carcass characters and oil quality to decide the slaughter season and breeding objectives for emus through large-scale sampling. For a few years, no production farms for slaughtering a large number of emus existed in Japan besides OEF. Therefore, OEF was the most proper population for characterization of carcass traits and products among Japanese farms. In this study, we characterized carcass traits in 2-yr-old emus using data obtained from more than 300 slaughtered individuals and revealed significant gender differences in oil productivity in egg-laying seasons. In addition, the fat melting point may be a trait that is independent of the other traits. Moreover, we found that individuals produce fat with remarkably low linoleic acid content.

MATERIALS AND METHODS
Ethics Statement

All procedures involving animals met the guidelines described in "The Proper Conduct of Animal Experiments," proposed by the Science Council of Japan and approved by the Ethical Care and Use of Animals Committee at the Tokyo University of Agriculture (approval number: 270049, 280002, 290096, 300126, and 2019109). The study was carried out in compliance with the ARRIVE guidelines.

Characterization of Carcass Traits of emu

A total of 309 two-year-old emus derived from the OEF (Hokkaido Abashiri in Japan, northern latitude of 44°) were randomly slaughtered from 2014 to 2018. Birds used for analysis were separately bred according to their age until they were slaughtered. They were kept in pens with free-access to the outdoors, and feed and water were provided ad libitum. The birds were not fed for 10 to 12 h before slaughter. The chemical components of the feed were analyzed according to the procedures of our previous studies (Souma et al., 2011; Hayashida et al., 2015) and are listed in Supplementary Table 1. We measured the slaughtered body weight, subcutaneous and abdominal fat weight, lean body weight (weight of removed fat from body weight), thigh meat production (with bone), and cut meat production (without bone) in 309 slaughtered birds (176 males and 133 females). We defined fat and meat yields as the proportion of fat and meat weight calculated by per 1 kg of body weight, respectively. We divided the data of each trait into 6 conditions: male, female, and slaughtered 17 periods: July to August (summer, no egg-laying), September to October (autumn, pre-egg-laying), and November to December (winter, initial egg-laying).

Fat Melting Point and Fatty Acid Composition

We randomly selected 74 subcutaneous fat samples from slaughtered individuals in 2016 and measured their melting points. The fat melting point was measured according to the slip point method described by the National Livestock Breeding Center, Nishigo-mura, Fukushima, Japan (http://www.nlbc.go.jp/). Furthermore, fat tissues measuring the fat melting point were divided into high-, medium-, and low-temperature groups (high and low were distinguished from 95% confidence intervals, 18.63−20.37°C; $P < 0.01$). A total of 12 samples composed of 4 individuals containing equal numbers of males and females in each group were used for the investigation of fatty acid composition by gas chromatography-mass spectrometry (Agilent J&W DB-23 Columns, 7890A GC System, Agilent Technologies, Santa Clara, CA), according to the conditions of previously reported methods (Ichihara et al., 1996). A 1 μL aliquot of the esterified samples was injected into a splitless injection port of an Agilent 7890A gas chromatograph equipped with a flame ionization detector (Agilent Technologies, Santa Clara, CA). A DB-23 column (60 m × 0.25 mm i.d., 0.15 m film thickness, J&W Agilent Technologies, Santa Clara, CA) was used. The column temperature was held at 50°C for 1 min,

increased at a rate of 25°C /min to 175°C, and then raised at 4°C /min to 230°C, which was held for 5 min. Reference mixtures (37-component FAME mix, Sigma-Aldrich, St. Louis, MO) were used to identify each component.

Statistical Analysis

The data were statistically analyzed by calculating the arithmetic mean, standard deviation (**SD**), and CV. Normal distribution of all data was confirmed using the Shapiro−Wilk test ($P < 0.05$). Gender differences in carcass traits were estimated using Welch's t test. Differences in traits among slaughtered emus, according to years and seasons, were estimated by one-way analysis of variance with Tukey's post hoc multiple comparison test. Relationships between traits were estimated using Pearson's coefficient of correlation (r). All statistical analyses were performed using EZR software version 2.5-1 (Kanda, 2013).

RESULTS AND DISCUSSION
Characteristics of Carcass Traits of emu

The mean body weight and lean body weight were 38.824 ± 5.870 kg and 30.333 ± 3.545 kg, respectively (Table 1). Meat production and cut meat production were 6.328 ± 1.192 kg and 2.743 ± 0.363 kg, respectively. Meat yield (meat production per kg body weight) was 0.164 ± 0.022 kg. In 2-yr-old birds, approximately 16% of the total body weight could be utilized as meat in the OEF. Fat weight and fat yield (fat weight per kg of body weight) were 8.659 ± 3.049 kg and 0.216 ± 0.055 kg, respectively, indicating that emus accumulated more fat than 20% of body weight at 2 yr of age.

Subsequently, we separately analyzed slaughter data in each year from 2014 to 2018 (Table S2). Significant differences were observed in all measured traits for slaughtered years ($P < 0.001$). The best and worst performances were observed in individuals slaughtered in 2018 and 2015, respectively. In 2015, body weight, meat weight, and fat weight (male/female) were 33.96 ± 6.59 kg/35.78 ± 6.94 kg, 5.66 ± 0.92 kg/6.12 ± 0.98 kg

Table 1. The carcass traits of slaughtered 309 emus at 2-yr-old.

Traits	Mean ± SD	Unit	CV
Body weight	38.82 ± 5.87	kg	0.15
Lean body weight	30.33 ± 3.55	kg	0.12
Meat	6.328 ± 1.19	kg	0.19
Cut meat	2.743 ± 0.36	kg	0.13
Meat rate	0.164 ± 0.02	kg	0.13
Fat weight	8.659 ± 3.05	kg	0.35
Fat rate	0.216 ± 0.06	kg	0.26

n = 309 (from OEF).
Slaughter seasons: July to December.
Meat rate and fat rate were calculated as fat weight/1 kg of body weight and meat yeild/1 kg of body weight, respectively.

and 7.26 ± 3.17 kg/6.50 ± 2.71 kg, respectively, while in 2018, the values were 42.74 ± 4.93 kg/44.17 ± 4.88 kg, 6.18 ± 0.63 kg/6.48 ± 0.73 kg, and 11.87 ± 3.36 kg/10.69 ± 2.99 kg, respectively. Significant differences in these traits were observed between genders for all investigated years; body weight and meat weight of females were higher than those of males ($P < 0.01$ and $P < 0.001$, respectively), and fat weight of males was higher than that of females ($P < 0.001$). These results suggest that characterization of carcass traits should be performed using integrated data with multiple slaughter periods and separately analyzed by gender.

We collected carcass data for 5 yr from 2014 to 2018 and analyzed the data based on gender. The mean body weight (lean body weight) in females and males was 39.500 ± 6.053 kg (32.080 ± 3.505 kg) and 38.088 ± 5.780 kg (29.013 ± 2.975 kg), respectively (Table 2). Female emus showed significantly higher body weight ($P < 0.05$) and lean body weight ($P < 0.001$) values than males did, consistent with a previous report (Yokohama, 2014). Meat production (meat weight) was 6.411 ± 0.843 kg (0.164 ± 0.016 kg) and 6.130 ± 1.349 kg (0.162 ± 0.025 kg) in females and males, respectively, and there was a significant difference between them ($P < 0.001$). Therefore, we confirmed that 2-yr-old female emus have higher meat productivity than males of the same age in the OEF. The fat weights of males and females were 9.232 ± 3.156 kg (0.235 ± 0.055 kg) and 7.772 ± 2.697 kg (0.190 ± 0.045 kg), respectively. Thus, the fat weight and fat yield of males were significantly higher than those of females ($P < 0.01$) in the 2-yr-old emus, consistent with data obtained from other ages (Menon

Table 2. The average carcass traits and melting point of male and female emus.

Traits	Female (n = 133)			Male (n = 176)			
	Mean ± SD	Unit	CV	Mean ± SD	Unit	CV	P
Body weight	39.500 ± 6.053	kg	0.15	38.088 ± 5.780	kg	0.15	*
Lean body weight	32.080 ± 3.505	kg	0.11	29.013 ± 2.975	kg	0.10	***
Meat	6.411 ± 0.843	kg	0.13	6.13 ± 1.349	kg	0.22	***
Cut meat	2.850 ± 0.350	kg	0.12	2.66 ± 0.350	kg	0.13	***
Meat rate	0.164 ± 0.016	kg	0.1	0.162 ± 0.025	kg	0.15	*
Fat weight	7.772 ± 2.697	kg	0.35	9.232 ± 3.156	kg	0.34	**
Fat rate	0.190 ± 0.045	kg	0.24	0.235 ± 0.055	kg	0.23	***
Fat melting point	19.187 ± 3.391	°C	0.18	19.39 ± 3.387	°C	0.17	n.s.

n = 309 (from OEF).
Slaughter seasons: July to December.
Meat rate and fat rate were calculated as fat weight/1 kg of body weight and meat yeild/1 kg of body weight, respectively.
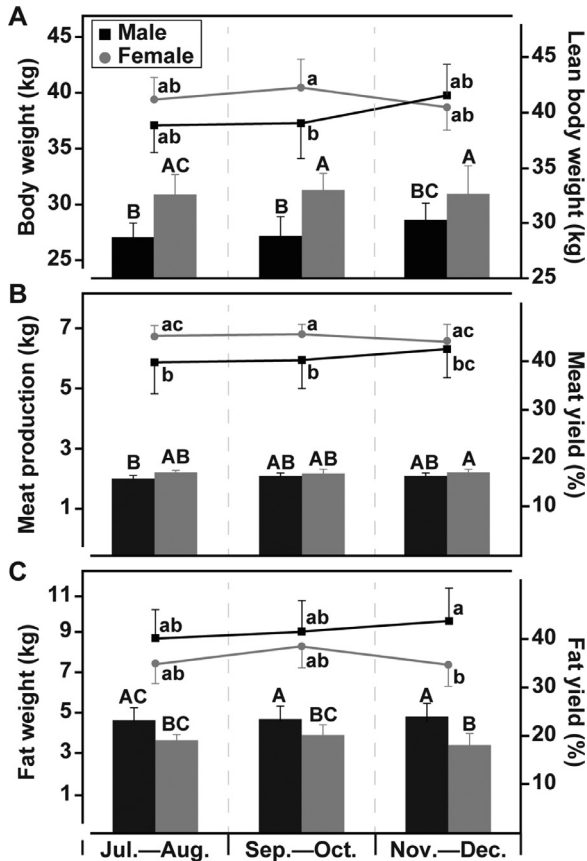*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$, n.s.; not significant.

Figure 1. The seasonal changes of carcass traits in male and female emu. Seasonal changes of average body weight and lean body weight (A), meat production and meat yield (B) and fat weight and fat yield (C). Lines showed body weight, meat production, and fat weight (left y-axis). Black squares and gray circles indicated mean ± SD in males and females, respectively. Bars showed lean body weight, meat production per 1 kg body weight and fat weight per 1 kg body weight (right y-axis), and black and gray indicated mean ± SD in males and females, respectively. Averages in July−August, September−October and November−December were calculated from data using 47 (male: female = 28: 19), 145 (male: female = 76: 69) and 117 (male: female = 72: 45) birds, respectively. Significant differences among seasons and genders were indicated by different characters ($P < 0.05$). Upper- and lower-case characters correspond to the right and left y-axis, respectively.

et al., 2014; Yokohama, 2014). The dispersion of fat weight was larger than the other traits in both sexes, which is consistent with a previous report (Yokohama, 2014). The fat melting point is known to be a factor in estimating the oil quality. The average fat melting points in females and males were 19.187 ± 3.391°C and 19.390 ± 3.387°C, respectively, with no significant differences between them, indicating that oils produced from 2-yr-old male and female birds might be of similar quality.

Seasonal Changes in Carcass Traits

None of the measured traits showed significant seasonal changes in males and females (Figures 1A−1C, Table S3). Although the mean body weight with total periods of females indicated higher values than males, a significant difference was observed between them only in

autumn (Figure 1A). Meanwhile, lean body weight indicated significant differences between genders in all investigated seasons. Meat production in summer and autumn was significantly higher in females than in males ($P < 0.05$), but gender differences in meat yield were not observed in any season (Figure 1B). Although there were no significant differences in fat weight between sexes in summer and autumn, those of males showed substantially higher values than females in the winter season ($P < 0.05$; Figure 1C). Similar to fat weight, the fat yield also showed larger values in males than females in autumn and winter ($P < 0.05$). Since the productivity of these traits during summer to winter did not change in either sex, we propose that emus should be slaughtered in the summer season for cost-effective production. In addition, as fat weight indicated a large dispersion, we suggested that fat productivity of emus may be increased through environmental and genetic improvement.

The emu begins laying eggs in November in northern Japan (Yokohama, 2014) and weight loss through the reduction of feed intake is recognized during the breeding season (Blache and Martin, 1999; Blache et al., 2001; Menon et al., 2013). However, our results showed no significant seasonal changes in carcass traits in either sex (Figure 1). In 2-yr-old birds, the body and fat weights of females tended to decrease from autumn to winter, while those of males tended to increase. Consequently, a large difference in fat productivity in winter was exhibited between the sexes. In the feral population, males incubate the eggs for approximately 50 d without feed intake; therefore, the accumulated fat is used as the energy source during brooding. Maintenance of body and fat weights during summer to winter observed in males might be a fixed genetic character for brooding after egg-laying and predicted that such habits were also retained even in captive breeding. Meanwhile, the reduction tendency of female fat observed in this study might be caused by consumption of lipids at the start of the egg-laying season. Although this study did not collect data from January to June, we predicted that the remarkable weight loss might be observed from January onward since the peak of egg-laying was February and March in northern Japan (Yokohama et al., 2014).

Relationship Between Productivity and Body Weight

Body weight is a simple marker for the prediction of certain productive traits. We analyzed the relationships between body weight and carcass traits, and the results are shown in Figure 2. Meat production was positively correlated with body weight (r = 0.75 and 0.76 in males and females, respectively; $P < 0.01$), indicating that large amounts of meat could be obtained from individuals with higher body weight (Figure 2A). In contrast, the meat yield was significantly negatively correlated with body weight (r = −0.52 and −0.49 in males and females, respectively; $P < 0.01$). Therefore, we revealed
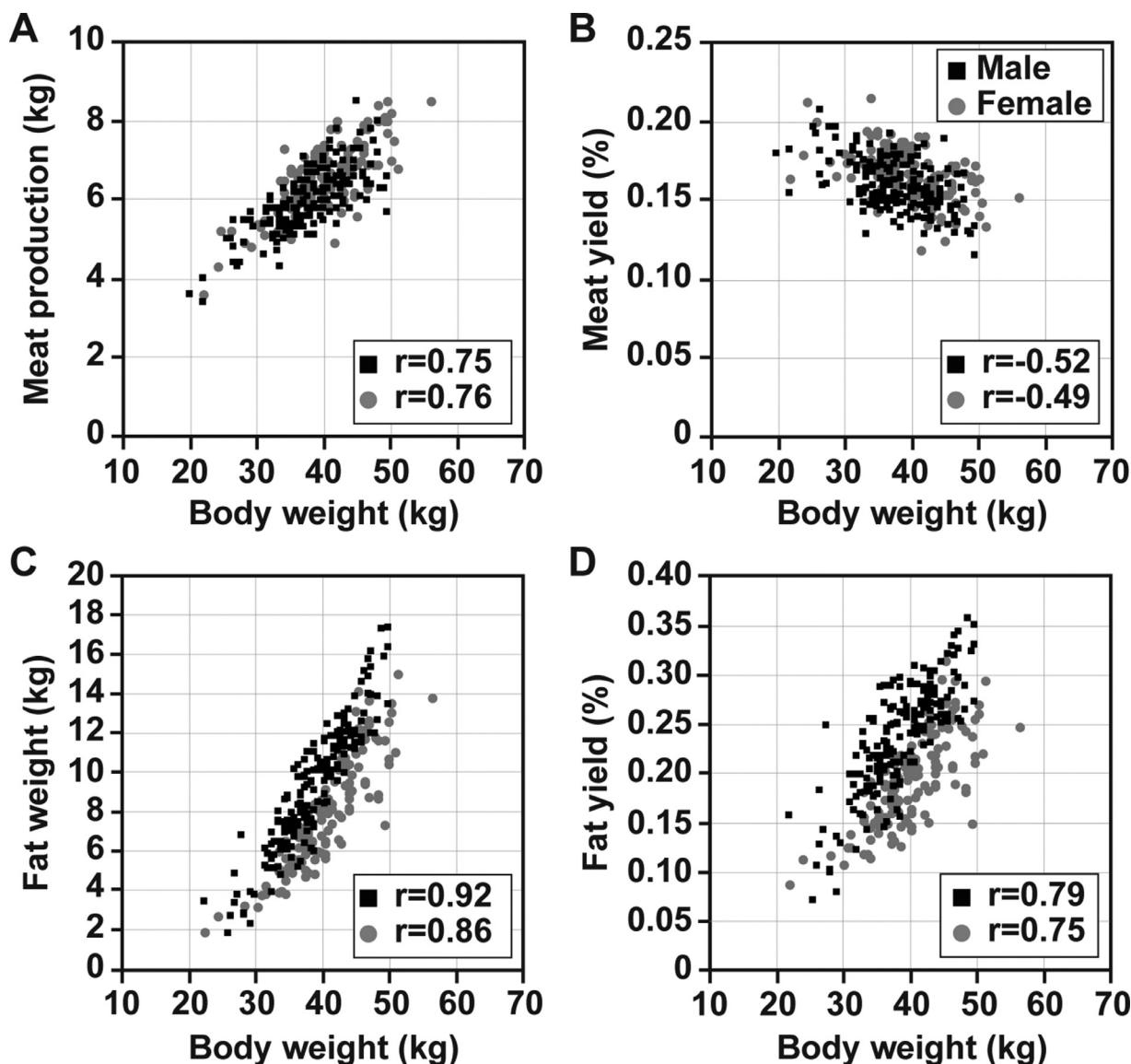
Figure 2. The correlation between body weight and productivity in 2-yr-old emu. The x-axis of all scatter plots indicated body weight, and the y-axis indicated meat production (A), meat production per 1 kg body weight (B), fat weight (C) and fat weight per 1 kg body weight (D). Black squares and grey circles indicated average values of data from males (n = 176) and females (n = 133), respectively.

that a large bodied individual has a low yield rate at 2 yr of age in meat production (Figure 2B). The fat weight showed a highly significant positive correlation with body weight in both males and females (r = 0.92, and 0.86 in males and females, respectively; $P < 0.01$), similar to meat production (Figure 2C). Moreover, a strong positive correlation was observed between the fat yield and body weight, which were different from the meat yields (Figure 2D). Such results are similar to a previous study in 4 to 5-yr-old emus (Yokohama, 2014). These results suggested that the increase in body weight in 2-yr-old was caused by the accumulation of adipose tissue rather than muscle and bone. Thus, we suggest that fat could be effectively obtained from individuals with high body weight in 2-yr-old birds, consistent with 4-yr-old birds (Yokohama, 2014). Yokohama (2014) reported that meat production and fat weight of 3- and 4-yr-old emus were 8.41 kg and 8.83 kg, respectively. Therefore, we revealed that the fat productivity of 2-yr-old emu is

similar to that of a 3- or 4-yr-old emu. Since Yokohama (2014) analyzed an identical population to our study, it was suggested that slaughter of 2-yr-old was appropriate to effectively harvest fat rather than 3- or 4-yr-old birds.

We next investigated the relationships between the fat melting point and other traits to identify a marker to estimate oil quality. The fat melting point did not correlate with body and fat weights, indicating no relationship with growth and fat accumulation (Figure 3). Our data were collected from emus bred under identical nutritional conditions in a farm (Table S1). Although individual rank in populations could be affected due to their nutritional conditions, it may be reflected in body weight increase. Our results may indicate that the known environmental factors, such as nutrition, do not affect the fat melting point in emus. Previous studies reported that the fat melting point did not correlate with fat weight in other livestock such as cattle, and some genetic polymorphisms (e.g., stearoyl-CoA
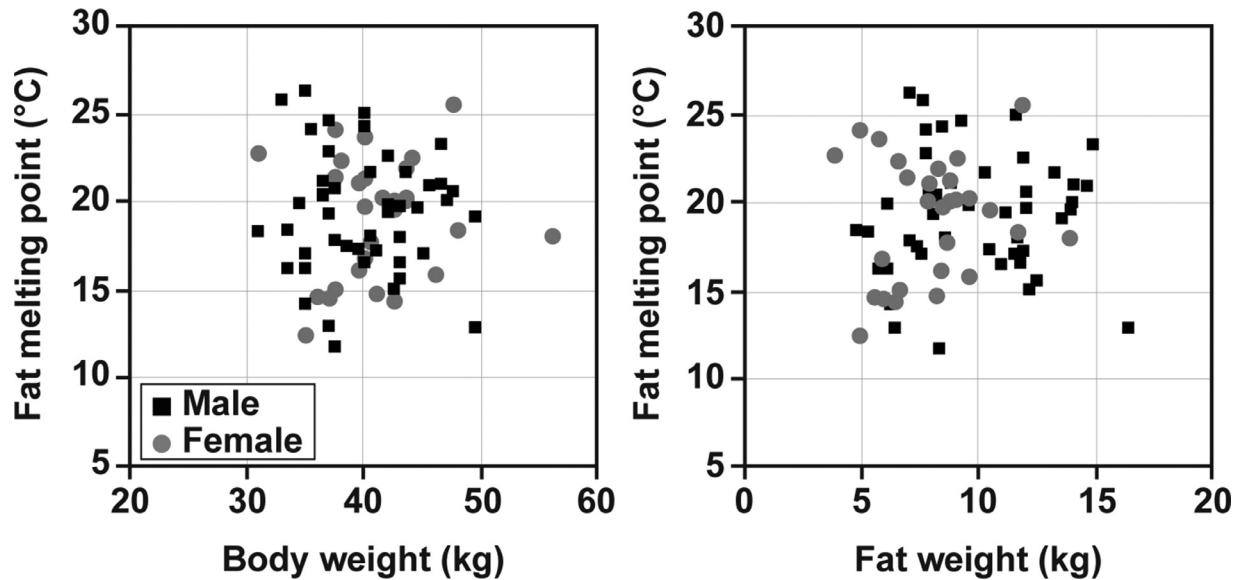
Figure 3. The relationships between carcass traits and fat melting point. Scatter plots showed relationships between body weight and fat melting point (left panel), between meat production and fat melting point (right panel). The x-axis indicated body and fat weights in left and right panels, respectively. The y-axis were values of fat melting point. Black squares and grey circles indicated average values from data of males (n = 46) and females (n = 28), respectively.

desaturase; SCD) were associated with the fat melting point (Oka et al., 2002; Ros-Freixedes et al., 2016). Thus, we speculated that the fat melting point with large dispersion is strongly affected by genetic factors harbored in emu individuals. In fact, we detected a non-synonymous substitution of the *SCD* gene in the emu (unpublished data).

Fatty Acid Composition of Fat Tissue

The fatty acid component plays an important role in the function of skincare in emu oil (Politis and Dmytrowich, 1998; Zanardo et al., 2017). Although the fatty acid composition of emu oil has been reported in previous studies, individual differences have not been investigated. In this study, we measured the concentrations of palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and α-linolenic acid (C18:3) in fat tissues derived from 12 individuals. A primary fatty acid of emu fat was C18:1 (54.11 ± 5.17%), followed by C16:0 (22.27 ± 3.50%), C18:2 (13.54 ± 7.80%), and C18:0 (9.37 ± 1.90%). Few C18:3 was detected in all of the examined samples (Table 3). Therefore, the fat tissue of the emu contained abundant C18:1n9, consistent with previous reports (Minnaar, 1998; Wang et al., 2000; Shimizu and Nakano, 2003). Meanwhile, Bucław et al. (2020) reported that the most abundant fatty acid component was C16:0 (41%) in 1- and 3-yr-old emus (Bucław et al., 2020). Bucław et al. (2020) attributed that the difference in fatty acid composition among reports might be caused by the age, sex, or nutritional condition of the tested emus, although forage contents were not disclosed in previous studies (Minnaar, 1998; Wang et al., 2000; Shimizu and Nakano, 2003). Our results obtained from 2-yr-old emus

indicated no gender differences in fatty acid components, similar to the data reported in previous studies (Wang et al., 2000; Shimizu and Nakano, 2003). The coefficient of variation (**CV**) values ranged from 0.1 to 0.2 in C16:0, C18:0 and C18:1, indicating that the large individual differences were not shown in these fatty acids. Meanwhile, the proportion of C18:2 indicated a large deflection, ranging from 0.3 to 19.9 (Table S4). According to previous reports, the C18:2 content of emu fat is approximately 20% (Minnaar, 1998; Wang et al., 2000) and 10 % (Shimizu and Nakano, 2003; Bucław et al., 2020). C18:2 is one of the essential fatty acids for animals, including avian and mammalian species; thus, it has to take up and accumulate from food. Since we analyzed populations under the same feeding conditions (Supplementary Table 3), individual differences in C18:2 content might be caused by unknown factors regarding its absorption or accumulation. Although the reasons for the scarcely detected C18:2n6 in some individuals were unclear, polyunsaturated fatty acids have an anti-inflammatory effect (Fritsche, 2015), and their content may be related to emu oil property. Since our study analyzed small sample sizes, the C18:2 content should be verified across seasons with many individuals.

We next investigated the relationship between the fat melting point and fatty acid composition. Among the 3 divided groups based on the fat melting point, no significant differences were observed in fatty acid composition among the 3 groups (Table 3). However, saturated fatty acids (**SFA**) in the high, medium, and low melting point groups were 33.91 ± 5.1, 31.49 ± 5.36, and 29.53 ± 4.44, respectively, indicating that SFA components tend to be reduced in association with a low melting point. In USFA and the C18:1/C18:0 ratio, tendencies to increase with a decreasing melting point were found, and the ranges in high to low were 66.09 ± 5.10 to 70.47 ± 4.44

Table 3. Fatty acid composition in each melting point of fat tissue.

Fatty acid	Total (n = 12)	Melting point (°C)		
		High (n = 4) 27.68 ± 1.94	Medium (n = 4) 19.19 ± 0.13	Low (n = 4) 14.98 ± 0.91
C16:0	22.27 ± 3.50	23.28 ± 2.69	21.39 ± 3.34	20.70 ± 4.00
C18:0	9.37 ± 1.90	10.80 ± 2.39	9.25 ± 1.55	8.19 ± 0.22
SFA	31.64 4.67	33.91 5.10	31.49 5.36	29.53 4.44
C18:1n9	54.11 ± 5.17	51.78 ± 3.65	52.79 ± 3.88	57.02 ± 6.46
USFA	68.36 4.67	66.09 5.10	68.51 5.36	70.47 4.44
Ole/Ste	5.99 1.22	5.27 1.50	5.76 0.87	6.94 0.98
C18:2n6	13.54 ± 7.80	13.47 ± 7.55	16.04 ± 8.16	12.94 ± 7.60
C18:3n3	0.71 ± 0.59	0.67 ± 0.03	0.53 ± 0.30	1.15 ± 1.05
PUFA	14.25 7.99	13.92 8.69	14.92 9.72	13.92 9.18
SFA/USFA	2.23 0.46	2.00 0.44	2.24 0.48	2.45 0.55

Values were average ± SD.

C16:0: palmitic acid, C18:0: stearic acid, SAF: C16:0+C18:0 (♂), C18:1n9: oleic acid, USAF: C18:1n9+C18:2n6+C18:3n3 (♂), Ole/Ste: C18:1n9/ C18:0, C18:2n6: linoleic acid, C18:3n3: α-linolenic acid, PUAF: C18:2n6+C18:3n3 (♂), USFA/SFA: C18:1n9+C18:2n6+C18:3n3/ C18:2n6+C18:3n3.

and 5.27 ± 1.50 to 6.94 ± 0.98, respectively. Especially, C18:1 content indicated the large differences between the high (51.78 ± 3.65) and low group (57.02 ± 6.46), and it may be associated with USFA contents and the C18:1/C18:0 ratio. Although there were no significant differences and a small sample size, we speculated that a large dispersion observed in the melting point influenced the fatty acid composition of emu fat regarding its quality. Next, we focused on the ratios of C18:1 and C18:0. C18:1/C18:0 is an indirect indicator of SCD activity (Estany et al., 2014). In this study, a negative correlation between the fat melting point and C18:1/C18:0 was observed (r = −0.62, $P < 0.05$; Figure 4). C18:1 melts at a lower temperature than SFAs such as C18:0, suggesting that fat with a low melting temperature contains relatively rich USFA. Although the fatty acid composition was reported in previous studies (Wang et al., 2000; Beckerbauer et al., 2001; Shimizu and Nakano, 2003; Bucław et al., 2020), our preliminary data revealed a relationship between the melting point and fatty acid composition in the emu fat tissues. Accordingly, we suggest that the fat melting point may be a useful indicator for cost-effective and simple estimation of C18:1/C18:0 ratio, providing an efficient selection system for its genetic improvement.

CONCLUSIONS

We characterized the carcass traits of 2-yr-old emu bred in Japan. In northern Japan, with cold climates, the productivity of emu fat has large gender differences and is prominent in the winter season. Fat productivity is strongly associated with body weight. The fat melting point might be independent of other traits such as body growth and environmental factors such as feed conditions in the emu. In addition, fat melting point is a good indicator of C18:1/C18:0 ratio in emu fat. Our data is the first report of large-scale data of more than 300 individuals of emu carcass characteristics and would provide useful information for not only the effective production of meats and oils but also the selection, breeding, and conservation of excellent individuals for genetic improvement in the emu.
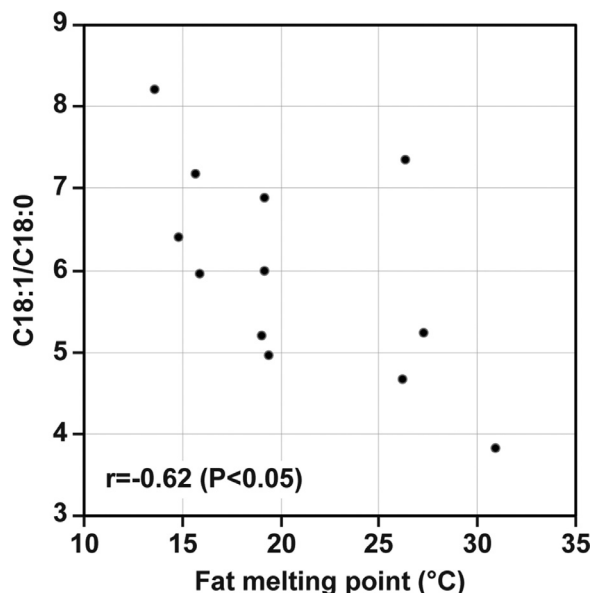
Figure 4. A correlation between fatty acid ratio and melting point in fat tissue. The x-axis indicated the ratio of oleic acid (C18:1) and stearic acid (C18:0), and the y-axis was fat melting point (n = 12).

DISCLOSURES

The authors declare no competing interests.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psj.2022.102050.

REFERENCES

Beckerbauer, L. M., R. Thiel-Cooper, D. U. Ahn, J. L. Sell, F. C. Parrish Jr, and D. C. Beitz. 2001. Influence of two dietary fats on the composition of emu oil and meat. Poult. Sci. 80:187–194.

Blache, D., and G. B. Martin. 1999. Day length affects feeding behaviour and food intake in adult male emus (*Dromaius novaehollandiae*). Br. Poult. Sci. 40:573–578.

Blache, D., J. K. Van Cleeff, M. Blackberry, and G. B. Martin. 2001. Seasonality in emus (Dromaius novaehollandiae). Pages 129−139 in Avian Endocrinology. A. Dawson, ed. Narosa Publishing House, New Delhi C.M.C..

Bucław, M., D. Majewska, D. Szczerbińska, and M. Ligocki. 2020. The influence of age and gender on emu (*Dromaius novaehollandiae*) fat. Sci. Rep. 10:11082.

Estany, J., R. Ros-Freixedes, M. Tor, and R. N. Pena. 2014. A functional variant in the stearoyl-CoA desaturase gene promoter enhances fatty acid desaturation in pork. PLoS One 9:e86177.

Fritsche, K. L. 2015. The science of fatty acids and inflammation. Adv. Nutr. 6:293S–301S.

Hayashida, M., K. Souma, K. Sugo, S.-I. Araki, F. Ishizaka, M. Ueda, T. Kasai, and T. Masuko. 2015. Sex and age differences in meat composition of Yeso sika deer (*Cervus nippon yesoensis*) reared for a short period after capture in the wild. Anim. Sci. J. 86:207–213.

Ichihara, K., A. Shibahara, K. Yamamoto, and T. Nakayama. 1996. An improved method for rapid analysis of the fatty acids of glycerolipids. Lipids 31:535–539.

Ito, M., K. Minami, Y. Sagane, T. Watanabe, and K. Niwa. 2016. Data on melanin production in B16F1 melanoma cells in the presence of emu oil. Data Brief 9:1056–1059.

Kanda, Y. 2013. Investigation of the freely available easy-to-use software "EZR" for medical statistics. Bone Marrow Transplant 48:452–458.

Koshiishi, Y., M. Murata-Okubo, S.-I. Fujisawa, G. Shimoi, H. Hirayama, Y. Kameyama, K. Souma, and K. Wada. 2020a. Development and characterization of ten novel microsatellite loci for the emu (*Dromaius novaehollandiae*) and genetic diversity of Japanese farm populations. Mol. Biol. Rep. 47:2521–2527.

Koshiishi, Y., H. Uchiyama, M. Murata-Okubo, K. Tanaka, Y. Kameyama, H. Hirayama, and K. Wada. 2021. Development of 49 novel microsatellite markers from Next-generation sequencing data and a robust method for parentage tests in the emu (*Dromaius novaehollandiae*). Gene 769:145238.

Koshiishi, Y., M. Ukita, M. Murata-Okubo, S.-I. Fujisawa, G. Shimoi, H. Hirayama, Y. Kameyama, K. Souma, and K. Wada. 2020b. Mitochondrial DNA variations in Japanese farmed emu populations. J. Vet. Med. Sci. 82:731–734.

Koshiishi, Y., and K. Wada. 2018. A simplified protocol for molecular sexing in the emu (*Dromaius novaehollandiae*). Poult. Sci. 97:1117–1119.

Menon, D. G., D. C. Bennett, A. M. Schaefer, and K. M. Cheng. 2013. Hematological and serum biochemical profile of farm emus (*Dromaius novaehollandiae*) at the onset of their breeding season. Poult. Sci. 92:935–944.

Menon, D. G., D. C. Bennett, B. Uttaro, A. L. Schaefer, and K. M. Cheng. 2014. Carcass yields and meat quality characteristics of adult emus (*Dromaius novaehollandiae*) transported for 6h before slaughter. Meat Sci 98:240–246.

Minnaar, M. 1998. The emu Farmer's Handbook-Volume 2-. Nyoni Publishing Co, Groveton, TX, USA.

Miyashita, T., K. Minami, M. Ito, R. Koizumi, Y. Sagane, T. Watanabe, and K. Niwa. 2018. Emu oil reduces LPS-induced production of nitric oxide and TNF-α but not phagocytosis in RAW 264 macrophages. J. Oleo Sci. 67:471–477.

Naveena, B. M., A. R. Sen, M. Muthukumar, Y. Praveen Kumar, and M. Kiran. 2013. Carcass characteristics, composition, physico-chemical, microbial and sensory quality of emu meat. Br. Poult. Sci. 54:329–336.

Oka, A., F. Iwaki, T. Dohgo, S. Ohtagaki, M. Noda, T. Shiozaki, O. Endoh, and M. Ozaki. 2002. Genetic effects on fatty acid composition of carcass fat of Japanese Black Wagyu steers. J. Anim. Sci. 80:1005–1011.

Politis, M. J., and A. Dmytrowich. 1998. Promotion of second intention wound healing by emu oil lotion: comparative results with furasin, polysporin, and cortisone. Plast. Reconstr. Surg. 102:2404–2407.

Ros-Freixedes, R., S. Gol, R. N. Pena, M. Tor, N. Ibáñez-Escriche, J. C. M. Dekkers, and J. Estany. 2016. Genome-wide association study singles out SCD and LEPR as the two main loci influencing intramuscular fat content and fatty acid composition in duroc pigs. PLoS One 11:e0152496.

Sales, J., J. Horbañczuk, J. Dingle, R. Coleman, and S. Sensik. 1999. Carcase characteristics of emus (*Dromaius novaehollandiae*). Br. Poult. Sci. 40:145–147.

Shimizu, S., and M. Nakano. 2003. Molecular species of triacylglycerol isolated from depot fats of ratites. J. Oleo Sci. 52:57–63.

Snowden, J. M., and M. W. Whitehouse. 1997. Anti-inflammatory activity of emu oils in rats. Inflammopharmacology 5:127–132.

Souma, K., P. Wang, F. Kanda, H. Igarashi, and T. Masuko. 2011. Influences of combination feeding of high moisture low quality grass-dominant mixture silage with corn silage on nutritive value and feed intake in sheep. Grassl. Sci. 57:18–22.

Wang, Y. W., H. Sunwoo, J. S. Sim, and G. Cherian. 2000. Lipid characteristics of emu meat and tissues. J. Food Lipids 7:71–82.

Yokohama, M. 2014. Statistical analyses of Emu products (fat and meat). J. Agric. Sci., Tokyo Univ. Agric. 59:39–43.

Yokohama, M. 2016. Emu for bioindustry. J. Agric. Sci., Tokyo Univ. Agric. 60:189–204.

Yokohama, M., and S. Ide. 2014. Mating and egg laying of the emu. J. Agric. Sci., Tokyo Univ. Agric. 59:145–149.

Yokohama, M., H. Jinushi, S. Imai, and K. Ikeya. 2014. Effects of pairing on egg laying in the Emu. J. Agric. Sci. Tokyo Univ. Agric. 58:229–234.

Zanardo, V., D. Giarrizzo, F. Volpe, L. Giliberti, and G. Straface. 2017. Emu oil-based lotion effects on neonatal skin barrier during transition from intrauterine to extrauterine life. Clin. Cosmet. Investig. Dermatol. 10:299–303.