Carcass Traits and Fat Quality of Breeding Emu (*Dromaius Novaehollandiae*) in Northern Japan

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Abstract

Characterisation 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 rate 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 $19.19 \pm 3.39^\circ\text{C}$ and $19.39 \pm 3.39^\circ\text{C}$, 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 may be used as a useful marker for the simple evaluation of oil quality.

Introduction

The emu (*Dromaius novaehollandiae*) is a ratite bird native to Australia. In the 1970s, the domestication of emus began in Australia^[1]; subsequently, its industrial utilisation 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^[2, 3] and reduces melanin production in melanoma cells^[4]. Emu oil also has high economic value as a skincare product^[5, 6].

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 centres 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^[7–9]. 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^[10–13]. 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^[8, 14]. Traits of emu carcass and their major products need to be characterised to extend the values of the emu industry through effective production based on genetic improvement. In particular, the characterisation 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 40–44 kg in body weight and approximately 10 kg in subcutaneous and abdominal fat^[1, 8, 15, 16]. At 4–6 years of age, female emus exhibited larger body weight than males, while fat accumulation in males was greater than that in

females^[8, 16, 17]. In addition, emus at 3–4 years of breeding in Japan abundantly accumulated more fat from July to December than from January to June^[8]. Fat accumulation is known to increase during the pre-breeding period in late autumn^[18, 19]. In Japan, the breeding period of emus starts in November and continues until April or May^[14].

Emus mature at approximately 1.5 years 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 years of age in the period from summer (July) to winter (December) during pre-breeding and initial breeding seasons to obtain both meat and oil. Consequently, information on carcass traits and fat quality in individuals aged ≥ 2 years old and more than 100 individuals have not been investigated. In addition, even though 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^[20–23], no information is available on its differences and relationships with the fat melting point.

In this study, we characterised carcass traits in 2-year-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 might be an independent trait from the others and correlates with the ratio of oleic/stearic acids. Moreover, we found that individuals produce fat with a remarkably low linoleic acid content.

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 production per 1 kg body weight (meat rate) was 0.164 ± 0.022 kg. In 2-year-old birds, approximately 16 % of the total body weight could be utilised as meat in the OEF. Fat weight and fat weight per 1 kg of body weight (fat rate) 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 years of age.

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^[8]. Meat production (meat rate) 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-year-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 rate

of males were significantly higher than those of females ($P < 0.01$) in the 2-year-old emus, consistent with data obtained from other ages^[8, 16]. The dispersion of fat weight was larger than the other traits in both sexes, which is consistent with a previous report^[8]. 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 $19.187 \pm 3.391^{\circ}\text{C}$ and $19.390 \pm 3.387^{\circ}\text{C}$, respectively, with no significant differences between them, indicating that oils produced from 2-year-old male and female birds might be of similar quality.

Seasonal changes in carcass traits

We divided the data of each trait into six conditions: male, female, and slaughtered periods: July to August (summer, no egg-laying), September to October (autumn, pre-egg-laying), and November to December (winter, initial egg-laying). None of the measured traits showed significant seasonal changes in males and females (Fig. 1A–C, Table S1). 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 (Fig. 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 rate were not observed in any season (Fig. 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 ($P < 0.05$) (Fig. 1C). Similar to fat weight, the fat rate 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, a large dispersion of fat weight compared to body weight, lean body weight, and meat production were found in males and females, suggesting that the fat productivity of the emu has the potential to be raised by further environmental and genetic improvement.

The emu begins laying eggs in November in northern Japan^[8], and weight loss through the reduction of feed intake is recognised during the breeding season^[17–19]. However, our results showed no significant seasonal changes in carcass traits in either sex (Fig. 1). In 2-year-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. Extra-pair copulations were frequently observed, demonstrated in a previous study using microsatellite markers, indicating that pairs of the emu are formed by fluxional behaviour during the same breeding season^[8, 24]. In the feral population, males incubate the eggs for approximately 50 days 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 wasting 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^[14].

Relationship between productivity and body weight

Body weight is a simple marker for the prediction of certain productive traits. We analysed the relationships between body weight and carcass traits, and the results are shown in Fig. 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 (Fig. 2A). In contrast, the meat rate was significantly negatively correlated with body weight ($r = -0.52$ and -0.49 in males and females, respectively; $P < 0.01$). Therefore, we revealed that a large bodied individual has a low yield rate at 2 years of age in meat production (Fig. 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 (Fig. 2C). Moreover, a high correlation was also observed in the fat rate, which was different from the meat rate (Fig. 2D). Such results are similar to a previous study in 4–5 year old emus^[8]. These results suggested that the increase in body weight in 2-year-olds 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-year-old birds, consistent with 4-year-old birds^[8]. Yokohama^[8] reported that meat production and fat weight of 3- and 4-year-old emus were 8.41 kg and 8.83 kg, respectively. Therefore, we revealed that the fat productivity of 2-year-old emu is similar to that of a 3- or 4-year-old emu. Since Yokohama^[8] analysed an identical population to our study, it was suggested that slaughter of 2-year-olds was appropriate to effectively harvest fat rather than 3- or 4-year-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 (Fig. 3). These results suggest that the known environmental factors, such as nutrition, did not affect the fat melting point. 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 desaturase; SCD) were associated with the fat melting point^[25, 26]. Thus, we speculated that the fat melting point with large dispersion is strongly affected by genetic factors harboured 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^[5, 6]. 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^[20, 23, 27]. Meanwhile, Buław et al. (2020) reported that the most abundant fatty acid component was C16:0 (41 %) in 1- and 3-year-old emus^[21]. Buław et al.^[21] 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^[20, 23, 27]. Our results obtained from 2-year-old emus indicated no gender differences in fatty acid components, similar to the data reported in previous studies^[20, 27]. 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 0.3–19.9 (Supplementary Table 2). According to previous reports, the C18:2 content of emu fat is approximately 20 %^[20, 23] and 10 %^[21, 27]. 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 analysed 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^[28]; thus, their content might be an important factor for determining oil quality. We propose that individuals with low C18:2 content should be removed from the breeding population to produce good-quality oils. Since our study analysed 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 three divided groups based on the fat melting point, no significant differences were observed in fatty acid composition among the three 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 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^[29]. In this study, a negative correlation between the fat melting point and C18:1/C18:0 was observed ($r=-0.62$, $P < 0.05$) (Fig. 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^[20–22, 27], 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 marker for cost-effective and simple estimation of the emu oil quality, providing an efficient selection system for its genetic improvement.

Conclusion

We characterised the carcass traits of 2-year-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. The fat melting point is associated with the fatty acid composition of emu fat and is a useful marker for oil quality estimation. 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.

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.

Characterisation of carcass traits of emu

A total of 309 2-year-old emus derived from the OEF (Hokkaido Abashiri in Japan, northern latitude of 44°) were randomly slaughtered from 2014–2018. Slaughtered birds were separately bred by their age. They were kept with free-enterable pens outdoors, and feed and water were provided *ad libitum*. The birds were not fed for 10–12 h before slaughter. The chemical components of the feed were analysed according to the procedures of our previous studies^[30, 31] 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). Fat and meat rates were calculated per 1 kg of body weight.

Fat melting point and fatty acid composition

We randomly selected 74 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, USA), according to the conditions of previously reported methods^[32]. 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 ionisation detector (Agilent Technologies). A DB-23 column (60 m × 0.25 mm i.d., 0.15 µm film thickness, J&W Agilent Technologies, CA, USA) 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, USA) were used to identify each component.

Statistical analysis

The data were statistically analysed 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 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^[33].

Declarations

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Author contributions

Y. Ko., K.S. and K.W. conceived the project, which was carried out by Y. Ka., M.M.O, H.N, R.M. and T.Y. T.M. analysed fatty acid compositions using GC-MS. The manuscript was written by Y. Ko. and K. W. Y. Ka., H. H., K. S. and M. Y. discussed and modified the manuscript. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

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Tables

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

Traits	Mean	±	SD	Unit	CV
Body weight	38.824	±	5.870	kg	0.15
Lean body weight	30.333	±	3.545	kg	0.12
Meat	6.328	±	1.192	kg	0.19
Cut meat	2.743	±	0.363	kg	0.13
Meat rate	0.164	±	0.022	kg	0.13
Fat weight	8.659	±	3.049	kg	0.35
Fat rate	0.216	±	0.055	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.

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

Traits	Female (n=133)					Male (n=176)					P
	Mean	±	SD	Unit	CV	Mean	±	SD	Unit	CV	
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	6.130	±	1.349	kg	0.22	***
Cut meat	2.850	±	0.350	kg	0.12	2.660	±	0.350	kg	0.13	***
Meat rate	0.164	±	0.016	kg	0.10	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	19.390	±	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.

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

Fatty acid	Total (n=12)			Melting point (°C)								
				High (n=4)			Medium (n=4)			Low (n=4)		
				27.68	±	1.94	19.19	±	0.13	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.

Figures

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 rate (B) and fat weight and fat rate (C). Lines showed body weight, meat production and fat weight (left y-axis). Black squares and grey 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 grey 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.

Koshiishi et al. Figure 2

Figure 2

The correlation between body weight and productivity in 2-year-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.

Koshiishi et al. Figure 3

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.

Koshiishi et al. Figure 4

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).

Supplementary Files

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