The body fat distribution and fatty acid composition of muscles and adipose tissues in geese

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ABSTRACT In this study, we evaluated the body fat distribution and fatty acid composition of muscles and adipose tissues of Yangzhou geese, including thirty 60-day-old goslings (15 males and 15 females) and 20 320-day-old geese (10 males and 10 females). Adipose tissues of Yangzhou geese were distributed widely and could be divided into 5 types: subcutaneous fat, abdominal fat, sartorial fat, neck fat, and mesenteric fat. Higher contents of abdominal fat, sartorial fat, neck fat, and mesenteric fat but a lower content of subcutaneous fat were found in adult geese than in goslings ($P \leq 0.05$). Adult female geese deposited more fat than adult male geese ($P \leq 0.05$). No difference was found in the fat distribution and fat content between male and female goslings ($P > 0.05$). The breast muscle of adult geese was characterized by a higher content of total monounsaturated fatty acids (**ΣMUFAs**) and a lower content of n-6 polyunsaturated fatty acids (**ΣPUFAs** n-6) than that of goslings ($P \leq 0.05$). Lower concentrations of total saturated fatty acids and ΣPUFA were found in adult female geese than in female goslings ($P \leq 0.05$). In comparison with adult female geese, the breast muscle of adult male geese had higher total saturated fatty acids and stearic acid ($P \leq 0.05$). For the thigh muscle, adult female geese had a higher ΣMUFAs content than adult male geese ($P \leq 0.05$). In adipose tissues, adult geese had a higher Σn-6/Σn-3 ratio but had lower contents of erucic acid, linolenic acid, arachidonic acid, docosatetraenoic acid, and ΣPUFA n-3 than goslings, and adult female geese had a higher ΣMUFAs content than adult male geese ($P \leq 0.05$). In conclusion, adult geese, especially adult female geese, accumulated more fat than goslings. Both age and sex affected the fatty acid composition of muscles and adipose tissues in geese. This research provides essential information not only for the nutritional evaluation of geese but also for the consumption and processing of goose products.

Key words: Yangzhou goose, fat, fatty acids, adipose tissue, breast and thigh muscle

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INTRODUCTION

After years of development, China's goose industry ranks first in the world in terms of raising and market output and plays an indispensable role in the world poultry industry. According to statistics, the total goose production (including guinea fowl) in China was approximately 2.52 million tonnes in 2018 and approximately 95.2% of the total global goose production (FAOSTAT, 2020).

Meat geese are usually slaughtered and sold at approximately 60 to 90 D of age to obtain what is regarded as optimal body weight and meat performance. However, people in some regions of China prefer adult geese because they think adult geese are more flavorful than goslings. An increase in age is usually accompanied by the accumulation of body fat (He et al., 2018). A high content of fat in meat and adipose tissue in the carcass may have a negative impact on the health of humans (Okruszek, 2012). When focusing on the fat content of products, it is more important to consider the overall fatty acid composition rather than studying the fat content of meat alone (Mcafee et al., 2010). Health organizations have recommended a reduction in total fat intake, particularly that of saturated fatty acids (**SFAs**), and an increased consumption of n-3 polyunsaturated fatty acids (**PUFAs**) (Department of Health, 1994). It has been shown that PUFA n-3 or a balanced

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Σn-6/Σn-3 ratio in the diet is critical for normal growth and development and decreases the risk of cardiovascular disease and diabetes (Poławska et al., 2011).

Geese fat is generally considered to be relatively safe in terms of consumer health due to its high content of oleic (**C18:1 n-9**), linoleic (**C18:2 n-6**), linolenic (**C18:3 n-3**), and arachidonic acids (**C20:4 n-6**) (Okruszek, 2012). A previous study between young and old ostriches showed that age can affect the fatty acid profile in muscle (Hoffman and Fisher, 2001). However, information on the effects of age on fatty acids in goose muscle and adipose tissues is limited. Moreover, the effect of sex on the fatty acid content in muscle was studied in native Czech geese and crossbred Novohradska geese at 8 wk of age (Uhlířová et al., 2019), but it has not been described in adult geese. Therefore, we conducted a research study to better understand the distribution of adipose tissue and the fatty acid composition of muscle and adipose tissues in geese, taking into account age and sex. The data of this study may be of interest and useful for both goose production and consumption.

MATERIALS AND METHODS

Ethics Statement

All procedures in our experiment were approved by the animal care and use committee of Yangzhou University (Yangzhou, China).

Animals, Slaughter, and Tissue Sampling

The experiment was carried out on Yangzhou geese, which is a major species in China. It was approved as the first national goose breed by the National Examination and Approval Committee of Domestic Animal and Poultry Breeds in 2006 (Shi et al., 2010) and is characterized by a medium size, high fertility rates, good meat quality, and high adaptability to poor feeding conditions (Liu et al., 2011). All geese were selected from the same commercial goose farm (Gaoyou, Yangzhou, China). Thirty 60-day-old healthy goslings (15 males and 15 females) were randomly selected from a flock of 2,000 goslings, and 20 320-day-old healthy geese (10 males and 10 females) were randomly selected from a flock of 1,000 adult geese. The geese were raised in the conventional method of stocking and supplementary feeding (11.03 MJ/kg ME, 17.99% CP, 0.46% calcium, and 0.91% available phosphorus for 60-day-old goslings; 11.69 MJ/kg ME, 15.47% CP, 0.11% calcium, and 0.14% available phosphorus for 320-day-old geese). In addition to feed, the geese were free to eat grass during grazing. The geese were maintained under natural daylight and temperatures.

The geese were transported from the farm to the experimental slaughterhouse by vehicle. Six hours before slaughter, geese were allowed access to only water. Birds were stunned using a stun bath and exsanguinated by severing the jugular vein and carotid artery on one side of the neck. The carcasses were scalded (approximately 3 min at approximately 70°C), plucked, and eviscerated. The eviscerated carcass, breast muscle, thigh muscle, subcutaneous fat, abdominal fat, sartorial fat, neck fat, and mesenteric fat were weighed. The percentages of these tissues were calculated relative to the eviscerated carcass weight. Then, approximately 50 g of breast muscle, thigh muscle, subcutaneous fat, and abdominal fat were sampled and immediately stored at −20°C for further analysis.

Lipid Contents and Fatty Acid Analysis

Muscle tissues and adipose tissue were preliminarily ground and then homogenized. Lipids were extracted from muscle and adipose tissues by a 2:1 chloroform–methanol mixture according to the method of Folch et al. (1957). Total lipid contents were determined by gravimetric analysis. Duplicate measurements were conducted for each sample.

The fatty acid composition was determined by gas chromatography. The extraction method of the total lipids from the 4 tissues was the same as described above. Fatty acids were detected as their methyl esters (**FAMEs**) according to the China National Standard (GB/T 5009.168-2016). A total of 8 mL sodium hydroxide methanol solution (2%) was added into the extracted fat and then incubated at 50°C under nitrogen (approximately 3 min) until oil droplets disappeared. After cooling on ice, 7 mL boron trifluoride methanol solution (14%) was added, mixed, and incubated at 50°C under nitrogen for 3 min. After cooling, 4 mL n-heptane was added, mixed, and allowed to stand for 10 min. Then, 20 mL of saturated saltwater was added and centrifuged at 1,200 × g for 5 min (4°C). The supernatant was transferred to a 1.5 mL finger-shaped tube, and a small amount of anhydrous sodium sulfate was added to the tube. The supernatant was filtered through a 0.45 μm filter membrane for gas chromatographic analysis.

The FAMEs were determined with a Shimadzu-GC 17B system (Shimadzu Corporation, Kyoto, Japan) coupled to a flame ionization detector and a FAME CP-Sil 88 capillary column (50 m × 0.25 mm × 0.20 μm film thickness, Varian Inc., Palo Alto, CA). Nitrogen was used as the carrier gas, and its flow rate was 1.3 mL/min. The air, hydrogen, and makeup gas flow rates of the flame ionization detector were 400, 40, and 30 mL/min, respectively. The following temperature settings were applied: initial temperature, 140°C; injector and detector temperature, 270°C and 280°C, respectively; and final temperature, 210°C. The injection volume was 1 μL, and the split ratio was 1:100. Fatty acids were identified by comparing the retention times of FAMEs with those of a standard FAME mixture (Sigma Chemical Co., St. Louis, MO), and fatty acid concentrations were calculated based on their peak areas.

Statistical Analysis

All data were initially processed using Excel and then analyzed using one-way ANOVA in SPSS 17.0 (SPSS Inc., Chicago, IL, 2004). The model design is indicated by: $Y_{ij} = \mu + A_j + e_{ij}$, where Y_{ij} is the value of the trait, μ is the overall mean, A_j is the effect of age under the same sex or the effect of sex under the same age, and e_{ij} is the random observation error. Data are expressed as the mean ± SE. Differences between groups were considered statistically significant at $P \leq 0.05$ by the least significant difference test.

RESULTS

Carcass Traits, Body Fat Distribution, and Fat Content

Table 1 shows the carcass traits and body fat distribution of geese. Adult geese had a higher breast yield but a lower thigh yield than goslings ($P \leq 0.05$). Higher contents of abdominal fat, sartorial fat, neck fat, and mesenteric fat but a lower content of subcutaneous fat were found in adult geese than in goslings ($P \leq 0.05$). In addition, adipose tissue distribution showed sex differences in adult geese, and adult female geese deposited more fat than adult male geese ($P \leq 0.05$). No difference was found in the fat tissue distribution between male and female goslings ($P > 0.05$).

The fat content in different tissues of geese is presented in Table 1. Adult geese had a higher fat content than goslings in the breast muscle and abdominal fat ($P \leq 0.05$). A higher fat content of subcutaneous fat was found in male goslings than in adult male geese ($P \leq 0.05$). The fat content of subcutaneous fat and abdominal fat showed sex differences in adult geese ($P \leq 0.05$). There was no difference in the fat content of thigh muscle ($P > 0.05$). No difference was found in the fat content between male and female goslings ($P > 0.05$).

Fatty Acid Composition

Table 2 shows the fatty acid composition of breast muscle. The breast muscle of adult geese was characterized by a higher content of total monounsaturated fatty acids (**ΣMUFAs**) and a lower content of total PUFAs (**ΣPUFAs** n-6) than goslings ($P \leq 0.05$). Lower concentrations of total SFAs (**ΣSFAs**) and ΣPUFAs were found in adult female geese than in female goslings ($P \leq 0.05$). For individual fatty acids, the breast muscle of adult geese was characterized by a higher content of palmitic acid (**C16:0**), palmitoleic acid (**C16:1**), and C18:1 n-9 and a lower content of stearic acid (**C18:0**), C20:4 n-6, and docosatetraenoic acid (**C22:4 n-6**) than that of goslings ($P \leq 0.05$). In comparison with adult female geese, the breast muscle of adult male geese had higher contents of ΣSFAs and C18:0 ($P \leq 0.05$).

The fatty acid composition in the thigh muscle is presented in Table 3. A higher ΣMUFA content was found in adult female geese than in adult male geese ($P \leq 0.05$). However, there were no differences in ΣSFAs and ΣPUFAs between groups ($P > 0.05$). Higher concentrations of myristic acid (**C14:0**), C16:1, and docosahexaenoic acid and lower concentrations of C22:4 n-6 were detected in the thigh muscle of adult geese than in that of goslings ($P \leq 0.05$). The content of heptadecanoic acid in the thigh muscle of adult female geese was lower than that of adult male geese ($P \leq 0.05$).

As shown in Table 4, adult geese had a higher Σn-6/Σn-3 ratio than goslings in subcutaneous fat ($P \leq 0.05$). Adult male geese had lower ΣPUFAs n-3, ΣMUFAs, and C18:1 n-9 but higher C16:0 and C18:0 than male goslings ($P \leq 0.05$). Concentrations of C14:0 and C18:2 n-6 were higher while those of erucic

Table 1. Carcass traits, body fat distribution, and fat content of geese.

Item	Youth		Adulthood	
	Male gosling (n = 15)	Female gosling (n = 15)	Male goose (n = 10)	Female goose (n = 10)
Body weight (g)	2486.1 ± 79.78^{b}	2373.7 ± 50.12^{b}	4805.0 ± 138.82^{a,x}	3,970 ± 132.31^{a,y}
Carcass traits (%)				
Dressing percentage	87.27 ± 2.17	85.48 ± 0.40	87.17 ± 0.76	88.34 ± 0.97
Breast muscle	6.03 ± 0.34^{b}	6.16 ± 0.41^{b}	13.71 ± 0.32^{a}	13.71 ± 0.35^{a}
Thigh muscle	16.15 ± 0.44^{a,y}	17.81 ± 0.43^{a,x}	15.20 ± 0.30^{b,x}	13.54 ± 0.44^{b,y}
Subcutaneous fat	13.45 ± 0.74^{a}	14.13 ± 0.55^{a}	5.87 ± 0.18^{b,y}	8.21 ± 0.37^{b,x}
Abdominal fat	0.86 ± 0.16^{b}	0.96 ± 0.15^{b}	2.30 ± 0.14^{a,y}	4.38 ± 0.24^{a,x}
Sartorial fat	0.33 ± 0.04^{b}	0.37 ± 0.05^{b}	1.26 ± 0.07^{a,y}	1.71 ± 0.08^{a,x}
Neck fat	0.25 ± 0.02^{b}	0.22 ± 0.04^{b}	0.39 ± 0.07^{a,y}	0.74 ± 0.07^{a,x}
Mesenteric fat	ND^{b}	ND^{b}	0.98 ± 0.10^{a,y}	4.83 ± 0.19^{a,x}
Fat content (%)				
Breast muscle	3.64 ± 0.14^{b}	3.29 ± 0.10^{b}	4.42 ± 0.18^{a}	4.61 ± 0.27^{a}
Thigh muscle	4.27 ± 0.20	4.76 ± 0.30	4.35 ± 0.34	4.32 ± 0.28
Subcutaneous fat	72.42 ± 2.39^{a}	69.09 ± 2.40	57.17 ± 3.50^{b,y}	72.37 ± 2.14^{x}
Abdominal fat	65.53 ± 4.72^{b}	61.85 ± 4.11^{b}	86.27 ± 4.56^{a,x}	78.54 ± 6.01^{a,y}

Results are presented as mean ± SE.
^{a,b}Means in the same row with different superscripts differ significantly regarding age under the same sex ($P \leq 0.05$).
^{x,y}Means in the same row with different superscripts differ significantly regarding sex under the same age ($P \leq 0.05$).
Abbreviation: ND, not detected.

Table 2. The fatty acid composition (% of total fatty acids) in breast muscle of geese.

	Youth		Adulthood	
Fatty acid	Male gosling (n = 15)	Female gosling (n = 15)	Male goose (n = 10)	Female goose (n = 10)
C12:0	ND	ND	0.02 ± 0.01	0.07 ± 0.03
C14:0	0.27 ± 0.01	0.30 ± 0.01	0.38 ± 0.01	0.44 ± 0.03
C16:0	19.62 ± 0.29^{b}	19.25 ± 0.30^{b}	21.05 ± 0.28^{a}	21.22 ± 0.30^{a}
C17:0	0.22 ± 0.01	0.17 ± 0.07	0.17 ± 0.01	0.22 ± 0.04
C18:0	13.24 ± 0.16^{a}	13.67 ± 0.25^{a}	10.99 ± 0.27^{b,x}	8.13 ± 0.36^{b,y}
C20:0	0.08 ± 0.02	0.03 ± 0.02	0.13 ± 0.01	0.08 ± 0.02
C24:0	0.01 ± 0.01	ND	0.11 ± 0.02	0.04 ± 0.01
C14:1	0.01 ± 0.01	ND	ND	0.02 ± 0.00
C16:1	1.09 ± 0.03^{b}	1.23 ± 0.10^{b}	1.74 ± 0.06^{a}	2.04 ± 0.03^{a}
C18:1 n-9	28.74 ± 0.77^{b}	27.29 ± 0.72^{b}	37.47 ± 0.66^{a}	40.53 ± 0.75^{a}
C22:1 n-9	0.04 ± 0.02	ND	0.05 ± 0.01	0.04 ± 0.00
C18:2 n-6	14.16 ± 0.24^{b}	14.52 ± 0.52	17.84 ± 0.24^{a}	15.60 ± 0.92
C18:3 n-3	0.81 ± 0.06	0.92 ± 0.11	0.60 ± 0.00	0.77 ± 0.07
C20:4 n-6	8.82 ± 0.49^{a}	9.16 ± 0.53^{a}	3.42 ± 0.40^{b}	3.06 ± 0.39^{b}
C22:4 n-6	2.04 ± 0.10^{a}	1.93 ± 0.14^{a}	0.57 ± 0.05^{b}	0.38 ± 0.03^{b}
C20:5 n-3	0.29 ± 0.07	0.17 ± 0.03	0.19 ± 0.02	0.08 ± 0.02
C22:6 n-3	0.26 ± 0.04	0.33 ± 0.02	0.56 ± 0.09	0.79 ± 0.13
ΣSFA	33.44 ± 0.23	33.41 ± 0.18^{a}	32.85 ± 0.48^{x}	30.18 ± 0.28^{b,y}
ΣMUFA	29.88 ± 0.78^{b}	28.52 ± 0.81^{b}	39.26 ± 0.71^{a}	42.63 ± 0.77^{a}
ΣPUFA	26.38 ± 0.63	27.03 ± 0.38^{a}	23.17 ± 0.34	20.67 ± 1.37^{b}
Σn-6	25.02 ± 0.62^{a}	25.62 ± 0.34^{a}	21.83 ± 0.27^{b}	19.03 ± 1.31^{b}
Σn-3	1.24 ± 0.10	1.41 ± 0.12	1.34 ± 0.08	1.63 ± 0.06
Σn-6/Σn-3 ratio	21.65 ± 1.66	19.80 ± 1.72	16.61 ± 0.74	11.62 ± 0.51

Results are presented as mean ± SE.

^{a,b}Means in the same row with different superscripts differ significantly regarding age under the same sex ($P \leq 0.05$).

^{x,y}Means in the same row with different superscripts differ significantly regarding sex under the same age ($P \leq 0.05$).

Abbreviations: C12:0, lauric acid; C14:0, myristic acid; C14:1, myristoleic acid; C16:0, palmitic acid; C16:1, palmitoleic acid; C17:0, heptadecanoic acid; C18:0, stearic acid; C18:1 n-9, oleic acid; C18:2 n-6, linoleic acid; C18:3 n-3, linolenic acid; C20:0, arachidic acid; C20:4 n-6, arachidonic acid; C20:5 n-3, eicosapentaenoic acid; C22:1 n-9, erucic acid; C22:4 n-6, docosatetraenoic acid; C22:6 n-3, docosahexaenoic acid; C24:0, tetracosanoic acid; ND, not detected; ΣMUFA, total monounsaturated fatty acids; ΣPUFA, total polyunsaturated fatty acids; ΣSFA, total saturated fatty acids.

Table 3. The fatty acid composition (% of total fatty acids) in thigh muscle of geese.

	Youth		Adulthood	
Fatty acid	Male gosling (n = 15)	Female gosling (n = 15)	Male goose (n = 10)	Female goose (n = 10)
C12:0	ND	ND	0.01 ± 0.01	0.01 ± 0.01
C14:0	0.22 ± 0.01^{b}	0.24 ± 0.01^{b}	0.35 ± 0.02^{a}	0.36 ± 0.01^{a}
C16:0	17.80 ± 0.37	19.12 ± 0.11	19.11 ± 0.17	19.71 ± 0.11
C17:0	0.18 ± 0.01	0.15 ± 0.01^{a}	0.16 ± 0.00^{x}	0.12 ± 0.01^{b,y}
C18:0	12.33 ± 1.25	10.47 ± 0.22	11.82 ± 0.38	8.50 ± 0.06
C20:0	0.08 ± 0.02	0.11 ± 0.01	0.11 ± 0.01	0.12 ± 0.01
C24:0	ND	ND	0.10 ± 0.01	0.02 ± 0.01
C14:1	ND	ND	0.02 ± 0.01	ND
C16:1	1.31 ± 0.08^{b}	1.62 ± 0.11^{b}	2.05 ± 0.10^{a}	2.27 ± 0.06^{a}
C18:1 n-9	34.99 ± 1.37	35.55 ± 0.98	34.22 ± 0.08	39.29 ± 0.38
C22:1 n-9	0.05 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.04 ± 0.00
C18:2 n-6	16.17 ± 1.52	17.42 ± 0.40	18.53 ± 0.49	17.61 ± 0.67
C18:3 n-3	0.93 ± 0.18	1.24 ± 0.07	0.60 ± 0.04	0.72 ± 0.02
C20:4 n-6	7.44 ± 1.31	5.36 ± 0.22	5.56 ± 0.34	4.57 ± 0.06
C22:4 n-6	1.35 ± 0.14^{a}	1.16 ± 0.07^{a}	0.77 ± 0.05^{b}	0.40 ± 0.01^{b}
C20:5 n-3	0.15 ± 0.04	0.18 ± 0.02	0.13 ± 0.02	0.06 ± 0.01
C22:6 n-3	0.28 ± 0.07^{b}	0.27 ± 0.04^{b}	0.78 ± 0.10^{a}	0.97 ± 0.06^{a}
ΣSFA	30.62 ± 1.34	30.10 ± 0.27	31.66 ± 0.45	28.84 ± 0.15
ΣMUFA	36.35 ± 1.44	37.27 ± 1.07	36.39 ± 0.15^{y}	41.60 ± 0.37^{x}
ΣPUFA	26.32 ± 0.43	25.63 ± 0.67	26.37 ± 0.43	24.34 ± 0.60
Σn-6	24.95 ± 0.46	23.94 ± 0.60	24.86 ± 0.40	22.59 ± 0.63
Σn-3	1.36 ± 0.13	1.67 ± 0.10	1.50 ± 0.08	1.73 ± 0.03
Σn-6/Σn-3 ratio	20.34 ± 1.81	14.99 ± 0.92	16.85 ± 0.84	13.12 ± 0.58

Results are presented as mean ± SE.

^{a,b}Means in the same row with different superscripts differ significantly regarding age under the same sex ($P \leq 0.05$).

^{x,y}Means in the same row with different superscripts differ significantly regarding sex under the same age ($P \leq 0.05$).

Abbreviations: C12:0, lauric acid; C14:0, myristic acid; C14:1, myristoleic acid; C16:0, palmitic acid; C16:1, palmitoleic acid; C17:0, heptadecanoic acid; C18:0, stearic acid; C18:1 n-9, oleic acid; C18:2 n-6, linoleic acid; C18:3 n-3, linolenic acid; C20:0, arachidic acid; C20:4 n-6, arachidonic acid; C20:5 n-3, eicosapentaenoic acid; C22:1 n-9, erucic acid; C22:4 n-6, docosatetraenoic acid; C22:6 n-3, docosahexaenoic acid; C24:0, tetracosanoic acid; ND, not detected; ΣMUFA, total monounsaturated fatty acids; ΣPUFA, total polyunsaturated fatty acids; ΣSFA, total saturated fatty acids.

Table 4. The fatty acid composition (% of total fatty acids) in subcutaneous fat of geese.

	Youth		Adulthood	
Fatty acid	Male gosling (n = 15)	Female gosling (n = 15)	Male goose (n = 10)	Female goose (n = 10)
C12:0	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.02 ± 0.00
C14:0	0.26 ± 0.01^{b}	0.29 ± 0.01^{b}	0.44 ± 0.02^{a}	0.45 ± 0.03^{a}
C16:0	20.16 ± 0.14^{b}	21.60 ± 0.22	24.99 ± 0.41^{a,x}	21.47 ± 0.49^{y}
C17:0	0.17 ± 0.01	0.14 ± 0.01	0.12 ± 0.01	0.10 ± 0.01
C18:0	5.13 ± 0.12^{b}	5.67 ± 0.17	8.45 ± 0.42^{a,x}	4.24 ± 0.20^{y}
C20:0	0.13 ± 0.01	0.15 ± 0.01	0.15 ± 0.01	0.13 ± 0.01
C24:0	0.01 ± 0.00	0.01 ± 0.01	0.03 ± 0.01	0.02 ± 0.01
C14:1	ND	ND	ND	0.01 ± 0.01
C16:1	1.94 ± 0.11	2.12 ± 0.09^{b}	1.96 ± 0.06^{y}	2.88 ± 0.20^{a,x}
C18:1 n-9	47.54 ± 0.34^{a}	46.55 ± 0.61	40.49 ± 0.60^{b,y}	47.11 ± 0.45^{x}
C22:1 n-9	0.09 ± 0.01^{a}	0.09 ± 0.01^{a}	0.02 ± 0.01^{b}	0.02 ± 0.01^{b}
C18:2 n-6	20.43 ± 0.33^{b}	19.34 ± 0.58^{b}	20.77 ± 0.60^{a}	21.31 ± 0.80^{a}
C18:3 n-3	2.40 ± 0.13^{a}	2.25 ± 0.15^{a}	0.98 ± 0.03^{b}	1.42 ± 0.13^{b}
C20:4 n-6	0.25 ± 0.01^{a}	0.29 ± 0.01^{a}	0.15 ± 0.01^{b}	0.07 ± 0.00^{b}
C22:4 n-6	0.11 ± 0.02^{a}	0.12 ± 0.02^{a}	0.07 ± 0.01^{b,x}	ND^{b,y}
C20:5 n-3	0.09 ± 0.01	0.08 ± 0.02	0.08 ± 0.03	0.05 ± 0.00
C22:6 n-3	ND	ND	0.05 ± 0.01	0.02 ± 0.01
ΣSFA	25.86 ± 0.11	27.86 ± 0.35	34.20 ± 0.82	26.43 ± 0.59
ΣMUFA	49.60 ± 0.40^{a}	48.80 ± 0.67	42.47 ± 0.61^{b,y}	50.02 ± 0.58^{x}
ΣPUFA	23.29 ± 0.34	22.07 ± 0.71	22.10 ± 0.65	22.87 ± 0.91
Σn-6	20.79 ± 0.33	19.74 ± 0.59	20.98 ± 0.60	21.38 ± 0.80
Σn-3	2.43 ± 0.12^{a}	2.26 ± 0.17	1.08 ± 0.05^{b,y}	1.47 ± 0.13^{x}
Σn-6/Σn-3 ratio	8.84 ± 0.48^{b}	9.21 ± 0.61^{b}	19.48 ± 0.34^{a,x}	15.17 ± 1.17^{a,y}

Results are presented as mean ± SE.

^{a,b}Means in the same row with different superscripts differ significantly regarding age under the same sex ($P \leq 0.05$).

^{x,y}Means in the same row with different superscripts differ significantly regarding sex under the same age ($P \leq 0.05$).

Abbreviations: C12:0, lauric acid; C14:0, myristic acid; C14:1, myristoleic acid; C16:0, palmitic acid; C16:1, palmitoleic acid; C17:0, heptadecanoic acid; C18:0, stearic acid; C18:1 n-9, oleic acid; C18:2 n-6, linoleic acid; C18:3 n-3, linolenic acid; C20:0, arachidic acid; C20:4 n-6, arachidonic acid; C20:5 n-3, eicosapentaenoic acid; C22:1 n-9, erucic acid; C22:4 n-6, docosatetraenoic acid; C22:6 n-3, docosahexaenoic acid; C24:0, tetracosanoic acid; ND, not detected; ΣMUFA, total monounsaturated fatty acids; ΣPUFA, total polyunsaturated fatty acids; ΣSFA, total saturated fatty acids.

Table 5. The fatty acid composition (% of total fatty acids) in abdominal fat of geese.

	Youth		Adulthood	
Fatty acid	Male gosling (n = 15)	Female gosling (n = 15)	Male goose (n = 10)	Female goose (n = 10)
C12:0	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00
C14:0	0.25 ± 0.01^{b}	0.27 ± 0.01^{b}	0.45 ± 0.03^{a}	0.44 ± 0.03^{a}
C16:0	20.64 ± 0.20^{b,y}	22.69 ± 0.21^{x}	24.67 ± 0.30^{a,x}	21.51 ± 0.58^{y}
C17:0	0.14 ± 0.01	0.16 ± 0.01^{a}	0.13 ± 0.01	0.10 ± 0.01^{b}
C18:0	6.13 ± 0.18^{b}	6.60 ± 0.21^{a}	7.96 ± 0.36^{a,x}	4.38 ± 0.04^{b,y}
C20:0	0.17 ± 0.01	0.16 ± 0.01	0.14 ± 0.01	0.15 ± 0.01
C24:0	0.01 ± 0.01	0.01 ± 0.00	0.07 ± 0.01	ND
C14:1	ND	ND	0.01 ± 0.00	0.01 ± 0.00
C16:1	1.55 ± 0.04	1.76 ± 0.08^{b}	1.87 ± 0.11^{y}	2.78 ± 0.20^{a,x}
C18:1 n-9	47.05 ± 0.46^{a}	45.44 ± 0.79	40.99 ± 0.33^{b,y}	46.40 ± 0.69^{x}
C22:1 n-9	0.11 ± 0.01^{a}	0.11 ± 0.01^{a}	0.04 ± 0.01^{b}	0.02 ± 0.01^{b}
C18:2 n-6	19.99 ± 0.42	18.83 ± 0.62	21.22 ± 0.84	21.78 ± 1.12
C18:3 n-3	2.18 ± 0.09^{a}	2.36 ± 0.12^{a}	1.48 ± 0.07^{b}	1.39 ± 0.11^{b}
C20:4 n-6	0.30 ± 0.02^{a}	0.30 ± 0.02^{a}	0.12 ± 0.01^{b}	0.08 ± 0.01^{b}
C22:4 n-6	0.22 ± 0.03^{a}	0.17 ± 0.01^{a}	0.07 ± 0.01^{b}	0.02 ± 0.01^{b}
C20:5 n-3	0.08 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.05 ± 0.01
C22:6 n-3	ND	ND	0.01 ± 0.00	0.02 ± 0.01
ΣSFA	27.34 ± 0.34^{b,y}	29.91 ± 0.35^{a,x}	33.43 ± 0.65^{a,x}	26.61 ± 0.62^{b,y}
ΣMUFA	48.71 ± 0.49^{a}	47.31 ± 0.84	42.90 ± 0.43^{b,y}	49.21 ± 0.83^{x}
ΣPUFA	22.78 ± 0.47	21.73 ± 0.71	22.96 ± 0.90	23.34 ± 1.20
Σn-6	20.52 ± 0.44	19.30 ± 0.63	21.42 ± 0.85	21.88 ± 1.12
Σn-3	2.21 ± 0.09^{a}	2.37 ± 0.12^{a}	1.52 ± 0.05^{b}	1.45 ± 0.10^{b}
Σn-6/Σn-3 ratio	9.49 ± 0.43^{b}	8.31 ± 0.32^{b}	14.10 ± 0.06^{a}	15.32 ± 0.72^{a}

Results are presented as mean ± SE.

^{a,b}Means in the same row with different superscripts differ significantly regarding age under the same sex ($P \leq 0.05$).

^{x,y}Means in the same row with different superscripts differ significantly regarding sex under the same age ($P \leq 0.05$).

Abbreviations: C12:0, lauric acid; C14:0, myristic acid; C14:1, myristoleic acid; C16:0, palmitic acid; C16:1, palmitoleic acid; C17:0, heptadecanoic acid; C18:0, stearic acid; C18:1 n-9, oleic acid; C18:2 n-6, linoleic acid; C18:3 n-3, linolenic acid; C20:0, arachidic acid; C20:4 n-6, arachidonic acid; C20:5 n-3, eicosapentaenoic acid; C22:1 n-9, erucic acid; C22:4 n-6, docosatetraenoic acid; C22:6 n-3, docosahexaenoic acid; C24:0, tetracosanoic acid; ND, not detected; ΣMUFA, total monounsaturated fatty acids; ΣPUFA, total polyunsaturated fatty acids; ΣSFA, total saturated fatty acids.

acid (**C22:1 n-9**), C18:3 n-3, C20:4 n-6, and C22:4 n-6 were lower in adult geese than in goslings ($P \leq 0.05$). In comparison with adult male geese, adult female geese had higher concentrations of ΣMUFAs and ΣPUFAs n-3 and a lower Σn-6/Σn-3 ratio ($P \leq 0.05$). Adult female geese had higher concentrations of C16:1 and C18:1 n-9 and lower concentrations of C16:0 and C18:0 than adult male geese.

The fatty acid composition in abdominal fat is shown in Table 5. Adult geese had a higher Σn-6/Σn-3 ratio but a lower ΣPUFA n-3 content than goslings ($P \leq 0.05$). In comparison with male goslings, adult male geese had higher ΣSFAs but lower ΣMUFAs in their abdominal fat ($P \leq 0.05$). For individual fatty acids, adult geese had higher contents of C14:0 but lower contents of C22:1 n-9, C18:3 n-3, C20:4 n-6, and C22:4 n-6 than goslings ($P \leq 0.05$). Higher concentrations of C16:0 and C18:0 and lower concentrations of C16:1 and C18:1 n-9 were found in the abdominal fat of adult male geese than in that of male goslings ($P \leq 0.05$). In comparison with adult female geese, adult male geese had higher ΣSFAs (including C16:0 and C18:0) but lower ΣMUFAs (including C16:1 and C18:1 n-9) in the abdominal fat ($P \leq 0.05$).

DISCUSSION

Geese have a wide distribution of adipose tissues. According to the location, the adipose tissues in geese can be divided into 5 types: subcutaneous fat, abdominal fat, sartorial fat, neck fat, and mesenteric fat. In this study, both age and sex influenced the deposition of adipose tissues. Compared with goslings, adult geese accumulated more abdominal fat, sartorial fat, neck fat, and mesenteric fat. However, the content of the subcutaneous fat of adult geese was lower than that of goslings, indicating that subcutaneous fat might be an early maturing adipose tissue, which is beneficial for the maintenance of body temperature of geese in early growth. Intriguingly, fat accumulated in the mesentery of adult geese, but there was no mesenteric fat in the goslings, indicating that mesenteric fat is the latest deposited adipose tissue of geese. This result was consistent with the study by Cahaner et al. (1986), in which age had a greater effect on mesenteric fat than on abdominal, gizzard, sartorial, and neck fat in broilers, and mesenteric fat was the last to develop. Although there was no difference in fat distribution between male and female goslings, adipose tissue distribution showed sex differences in adult geese, and that adult female geese accumulated more fat than adult male geese. Leenstra (1986) reported that females tend to be fatter than males and that older birds have a higher fat content than younger birds.

In addition to the subcutaneous fat and abdominal fat, the fat content of the breast muscle and thigh muscle was also measured. In the present study, the subcutaneous and abdominal fat contents were consistent with their accumulation in the body. Higher breast muscle fat and abdominal fat were found in adult geese than in goslings. These results also reflect that adult geese have a better fat deposition ability than goslings. He et al. (2018) reported that fat contents of muscle tissues increased in Sheldrake ducks during the aging process. Intriguingly, there was no difference in fat content between sex and age in the thigh muscle. These results indicated that the fat deposition ability of the thigh muscle remained relatively stable at different ages and for both sexes.

When focusing on the fat content of products, it is more important to consider the overall fatty acid composition (Mcafee et al., 2010). In muscle tissues, a total of 17 fatty acids, including 7 SFAs, 4 MUFAs, and 6 PUFAs, were identified and determined. The predominant SFA was C16:0, followed by C18:0, which together comprised more than 90% of the ΣSFAs. We found that C16:1 and C18:1 dominated the MUFA fraction in geese muscles. For PUFAs, C18:2 n-6 and C20:4 n-6 were the most abundant individual PUFAs in geese muscles. This was in agreement with previous studies on native Polish geese (Rypińska, Garbonosa, Kartuska, and Lubelska geese; Okruszek, 2012; Haraf et al., 2014), native Turkish geese (Kalayci and Yilmaz, 2014), Egyptian geese (Geldenhuys et al., 2013), Dongbei White geese (Liu and Zhou, 2013), and Sichuan geese (Sun et al., 2016).

Age affected the composition of fatty acids in the breast muscles of geese, but sex had less influence. In the breast muscle of goslings, the most abundant fatty acids were ΣSFAs (33.41–33.44%), followed by ΣMUFAs (28.52–29.88%) and ΣPUFAs (26.38–27.03%). However, the breast muscle of adult geese contained more ΣMUFAs (39.26–42.63%), followed by ΣSFAs (30.18–32.85%) and ΣPUFAs (20.67–23.17%). This was because of the increased C18:1 n-9 and C18:2 n-6 contents and the decreased C20:4 n-6 and C22:4 n-6 contents of breast muscle. These changes in fatty acid composition were also found in other studies, although the goose species that were studied differed (Okruszek, 2012; Liu and Zhou, 2013; Haraf et al., 2014; Sun et al., 2016). The ΣMUFA contents in the breast muscle of Dongbei White geese (Liu and Zhou, 2013) and Sichuan geese (Sun et al., 2016) were approximately 21 to 32% at 70 D, while those of native Polish geese (Okruszek, 2012; Haraf et al., 2014) were approximately 41% at 24 wk and 43% at 17 wk.

For thigh muscle, the fatty acid composition was less affected by age than that of the breast muscle. The contents of C14:0, C16:1, and docosahexaenoic acid were higher in adult geese, whereas the content of C22:4 n-6 was higher in goslings. The most abundant fatty acids of thigh muscle in both adult geese and goslings were ΣMUFAs (36.35–41.60%), followed by ΣSFAs (28.84–31.66%) and ΣPUFAs (24.34–26.37%). In addition, sex had little effect on the fatty acid composition of thigh muscles, and the only difference was in the content of heptadecanoic acid. These results show that the fatty acid composition in thigh muscles was hardly affected by age and sex. Thus, it was a tissue in geese exhibiting a relatively stable nutrient composition, and it could provide a consistent food source in different physiological periods.

In adipose tissues, there were a few main fatty acids. Here, C18:1 n-9, C16:0, and C18:2 n-6 were the predominant MUFA, SFA, and PUFA in subcutaneous and abdominal fat, respectively. These 3 fatty acids accounted for more than 80% of the total fatty acids. This was in agreement with previous studies on White Italian geese (Janicki et al., 2000) and native Polish geese (Okruszek, 2012; Haraf et al., 2014).

Both age and sex had an effect on the fatty acid composition of adipose tissue. Although there was no difference in the fatty acid composition of goslings, there was a significant sex difference in adult geese in both subcutaneous and abdominal fat, mainly in the high content of C18:0 and low content of C18:1 n-9 in adult male geese. The possible reason was the lower activity of stearoyl CoA desaturase in adult male geese. We know that C18:1 n-9 is a product of C18:0 formed by the stearoyl CoA desaturase enzyme. Compared with goslings, adult geese had a higher content of C18:2 n-6 in subcutaneous fat but had lower contents of C22:1 n-9, C18:3 n-3, C20:4 n-6, and C22:4 n-6 in both subcutaneous and abdominal fat. Wood et al. (2008) reported that C18:3 n-3 did not compete well for insertion into phospholipids compared with C18:2 n-6, and its incorporation into adipose tissue and muscle was less efficient. This may be the reason why the C18:2 n-6 content increased and the C18:3 n-3 content decreased with age. These results led to a lower PUFA n-3 content and a higher Σn-6/Σn-3 ratio in adult male geese than in goslings. Both PUFA n-6 and PUFA n-3 are beneficial, but the ratio in which these fatty acids are consumed must be considered because an increased intake of PUFA n-6 may decrease the levels of high-density lipoprotein cholesterol, leading to health risks (Smolin et al., 2003). According to the Nordic Nutrition Recommendations (2004), the Σn-6/Σn-3 ratio for adults ranges from 3 to 9. The ratios in goslings (9.49 in males and 8.31 in females) were close to the maximum, but the values of adult geese (14.10 in males and 15 in females) were higher than the recommended Σn-6/Σn-3 ratio. However, modern Western diets typically have a Σn-6/Σn-3 ratio of approximately 20:1 (Simopoulos, 2008).

In conclusion, age and sex affected the fat deposition and fatty acid composition of muscles and adipose tissues in geese. Adult geese, especially adult female geese, accumulated more fat than goslings. Age mainly affected the fatty acid composition of the breast muscle and increased the content of ΣMUFAs. The fatty acid composition in thigh muscles was less affected by age and sex than that of other muscles. In adipose tissues, adult geese had a higher Σn-6/Σn-3 ratio than goslings and adult female geese had a higher ΣMUFA content than adult male geese.

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