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Original Research Article

Comparison of fatty acid profile of three adipose tissues in *Ningxiang* pigs

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ABSTRACT

The present study is conducted to determinate fatty acids (FA) composition in 3 adipose tissues. Subcutaneous and perirenal adipose tissues were prepared from 24 *Ningxiang* castrated boars and 24 castrated gilts fattened by a traditional diet for 56 d, respectively. The results showed that the FA profile in the 3 adipose tissues (dorsal subcutaneous adipose [DSA], abdominal subcutaneous adipose [ASA], and perirenal adipose [PA]) differed greatly. In boars, the proportions of oleic acid (c18:1n9c) ($P < 0.05$), cis-11-20c acid (c20:1) ($P < 0.05$), and α-linolenic acid (c18:3n3) ($P < 0.05$) in DSA were the highest among 3 adipose tissues, whereas palmitic acid (c16:0) ($P < 0.05$) and stearic acid (c18:0) ($P < 0.05$) in DSA had the lowest proportion. In gilts, cis-11-20c acid (c20:1) ($P < 0.05$) in DSA was the highest, while stearic acid (c18:0) ($P < 0.05$) in subcutaneous adipose was the lowest among these deposits. Overall, the results indicate that from external to inner carcass of boars, the sum of saturated fatty acids (SFA) increase, but the sum of monounsaturated fatty acids (MUFA) decrease, while ASA of gilts have the greatest proportion of MUFA and the lowest SFA. Sex and adipose locations as significant effects on the FA profile are interaction.

1. Introduction

Adipose tissue, which is made of fatty acids (FA) and triglyceride, plays an essential role in chemical and sensorial traits of cured meat products (Delgado et al., 2002). Fatty acids have critical physical characteristics of fat, such as color, translucence and firmness (Delgado et al., 2002), and they are also precursors of most compounds for aroma. The types and proportions of FA are influenced by many factors such as feeding (Rentfrow et al., 2003; Rossi et al., 2010; Martins et al., 2012; Bee et al., 2002), breed (Franco et al., 2006), genotype (Kouba et al., 2003; Piedrafita et al., 2001; Martins et al., 2012) as well as genetic conditions (Monziols et al., 2007).

Ningxiang pig, as a well-known indigenous fat-type breed, exhibits early sexual maturity and has a better meat quality than other local pigs (Feng et al., 2012). This breed is highly appreciated by consumers because of the tender succulent meat with special flavor. Subcutaneous and visceral adipose tissues with different anatomical locations show specific development and metabolism, especially in the FA composition. However, the FA profile of *Ningxiang* pig has not yet been addressed. Therefore, the aims of this research are to study and compare the FA profile in the 3 adipose tissues (dorsal subcutaneous adipose [DSA], abdominal subcutaneous adipose [ASA], perirenal adipose [PA]) of *Ningxiang* pig breed.

2. Materials and methods

2.1. Animals and experimental treatments

Feed ingredients were purchased from Hunan Liushahe Spotted Pig Eco-Farm Co., Ltd. (Hunan, China). The nutrient levels of the

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experimental diets met the NRC (2012) recommendations for pigs and the Feeding Standard of Swine (NY/T 65-2004), and the detailed FA composition of diets are listed in Table 1. Unless specified, other chemicals and reagents were purchased from Sigma (St. Louis, MO, USA).

Twenty-four castrated boars (43.36 kg average BW) were randomly allotted to 8 pens and 3 pigs per pen for a 56 d period. Twenty-four castrated gilts followed the same setting. Pigs had free access to feed and water at all times throughout the experimental period. Methods were performed according to the guidelines of the Declaration of Helsinki, and all experimental protocols involving animal subjects were approved by Animal Welfare Committee of College of Animal Science and Technology, Hunan Agricultural University (No. 2013-06).

2.2. Sample collection and determination

At the end of the experiment, pigs (75.21 ± 1.40 kg BW) from each pen were randomly selected for sample collection. After anesthetized by the intravenous administration of sodium pentobarbital (50 mg/kg BW), the pigs were euthanized by exsanguination. Samples (approximately 10 g of each tissue) of adipose tissues (DSA, ASA and PA) were rapidly excised, and then stored at −20 °C until further analysis.

Lipids were extracted from the adipose tissue samples by the chloroform–methanol (1:1, vol/vol) procedure. Fatty acid methyl esters were prepared for GC determination using KOH/methanol (Demirel et al., 2004) and analyzed using an Agilent 6890N gas chromatographer equipped with a flame ionisation detector (Agilent Technologies). A CP-Sil 88 fused silica open tubular capillary column (100 m × 0.25 nm; Chrompack) was used. The oven temperature was initially set at 45 °C for 4 min, raised to 175 °C at a rate of 13 °C/min, and then held at 175 °C for 27 min, then increased to 215 °C at a rate of 4 °C/min, and then held at 215 °C for 35 min. The injector and detector temperatures were set at 250 °C. The carrier gas was hydrogen at a flow rate of 30 mL/min. Identification of individual FA methyl esters was accomplished by the retention times of an authentic standard. The concentration of individual FA was quantified based on the peak area, and expressed as a percentage of total FA (Yin et al., 2000).

2.3. Statistical analysis

Data obtained from this study were subjected to one way analysis of variance (ANOVA) using a general linear model of SAS software (SAS Inst. Inc., Cary, NC, USA). The differences between significant means were separated using Tukey's test. Probability values of 5% level of significance ($P < 0.05$) were used to detect significant levels.

Table 1
Fatty acid composition of diet (air-dry basis)[1].

Item	Percentage, %
myristic acid (c14:0)	0.47
palmitic acid (c16:0)	22.88
palmitoleic acid (c16:1)	0.52
margaric acid (c17:0)	0.19
stearic acid (c18:0)	9.63
elaidic acid (c18:1n9t)	0.06
oleic acid (c18:1n9c)	2.19
linoleic acid (c18:2n6c)	58.77
α-linolenic acid (c18:3n3)	2.40
γ-linolenic acid (c18:3n6)	1.04
arachidic acid (c20:0)	0.43
cis-11-20c acid (c20:1)	0.97
arachidonic acid (c20:4n6)	0.27
others	0.18

[1] Fatty acids were determined values.

3. Results

3.1. Fatty acid profile of three adipose tissues in boars

Table 2 shows that the proportion of saturated fatty acids (SFA) and the ratio of SFA to unsaturated fatty acids (UFA) in DSA of boars were significantly ($P < 0.05$) lower than those in ASA and PA, while the proportion of UFA in DSA was significantly ($P < 0.05$) higher than that in ASA and PA. The proportion of monounsaturated fatty acids (MUFA) in DSA was significantly ($P < 0.05$) higher than that in ASA and PA. The proportions of α-linolenic acid (c18:3n3) and docosahexaenoic acid (c22:6n3) were significantly different ($P < 0.05$) in the 3 adipose tissues. The proportions of α-linolenic acid (c18:3n3) in DSA and docosahexaenoic acid (c22:6n3) in ASA were the highest. The proportions of myristic acid (c14:0), palmitic acid (c16:0), margaric acid (c17:0), stearic acid (c18:0), linoleic acid (c18:2n6c), elaidic acid (c18:1n9t) in DSA were significantly ($P < 0.05$) lower than those in ASA and PA, while the proportions of oleic acid (c18:1n9c) and cis-11-20c acid (c20:1) in DSA were significantly ($P < 0.05$) higher, but no significant differences were observed in myristic acid (c14:0), palmitic acid (c16:0), margaric acid (c17:0), stearic acid (c18:0), linoleic acid (c18:2n6c), elaidic acid (c18:1n9t), oleic acid (c18:1n9c) and cis-11-20c acid (c20:1) between ASA and PA.

3.2. Fatty acid profile of three adipose tissues in gilts

Table 3 shows that UFA in the 3 adipose tissues in gilts was higher than SFA. The SFA proportion was significantly different ($P < 0.05$) among the 3 adipose tissues and the range was PA, DSA and ASA from high to low. The proportion of MUFA was significantly different ($P < 0.05$) among ASA, DSA and PA. The proportions of stearic acid (c18:0) and oleic acid (c18:1n9c) were significantly different ($P < 0.05$) in the 3 adipose tissues. The proportion of stearic acid (c18:0) in PA was the highest ($P < 0.05$). The proportion of oleic acid (c18:1n9c) in ASA was the highest ($P < 0.05$). The proportions of myristic acid (c14:0), palmitoleic acid (c16:1), α-linolenic acid (c18:3n3) and arachidonic acid (c20:4n6) in ASA were significantly ($P < 0.05$) higher than those in DSA and PA. These 3 locations of adipose from *Ningxiang* pigs had no significant influence on the proportions of palmitic acid (c16:0), margaric acid (c17:0), γ-linolenic acid (c18:3n6) and cis-8, 11, 14-eicosatrienoic acid (c20:3n6).

3.3. Fatty acid profile of three adipose tissues in general

The proportions of FA in ASA, DSA and PA are shown in Tables 2 and 3. The results showed that the FA composition in these 3 adipose tissues of *Ningxiang* pigs contained 4 major FA, which were oleic acid (c18:1n9c), palmitic acid (c16:0), stearic acid (c18:0) and linoleic acid (c18:2n6c). Within UFA, the proportion of MUFA was higher than that of polyunsaturated fatty acid (PUFA).

4. Discussion

Generally, these 3 adipose tissues, which are made of fat cells with lipid droplet, contain 90% to 98% triglyceride (Snyder, 1977). The FA composition mainly depends on the metabolism. For example, the difference in water content among these 3 tissues may change the FA profile, and DSA have higher water content than PA (Anderson et al., 1972). However, despite the difference in water content, the FA profile was very similar in the 3 adipose

Table 2
Fatty acid profile of 3 deposits in *Ningxiang* boars, %.

Item	DSA	ASA	PA	*P*-value
myristic acid (c14:0)	1.34 ± 0.05^{b}	1.71 ± 0.06^{a}	1.55 ± 0.05^{a}	<0.001
palmitic acid (c16:0)	24.81 ± 0.43^{b}	28.99 ± 0.47^{a}	28.54 ± 0.42^{a}	<0.001
palmitoleic acid (c16:1)	1.95 ± 0.10^{ab}	2.11 ± 0.18^{a}	1.69 ± 0.07^{b}	0.081
margaric acid (c17:0)	0.20 ± 0.01^{b}	0.25 ± 0.01^{a}	0.26 ± 0.01^{a}	<0.001
stearic acid (c18:0)	13.87 ± 0.55^{b}	17.92 ± 0.90^{a}	19.68 ± 0.44^{a}	<0.001
elaidic acid (c18:1n9t)	0.11 ± 0.010^{b}	0.23 ± 0.02^{a}	0.25 ± 0.02^{a}	<0.001
oleic acid (c18:1n9c)	46.93 ± 0.78^{a}	37.19 ± 1.03^{b}	36.72 ± 0.75^{b}	<0.001
linoleic acid (c18:2n6c)	8.75 ± 0.28^{b}	10.54 ± 0.63^{a}	10.29 ± 0.24^{a}	0.014
α-linolenic acid (c18:3n3)	0.35 ± 0.01^{a}	0.11 ± 0.00^{b}	0.06 ± 0.01^{c}	<0.001
γ-linolenic acid (c18:3n6)	0.03 ± 0.00^{a}	0.03 ± 0.00^{ab}	0.02 ± 0.00^{b}	0.013
arachidic acid (c20:0)	0.23 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.531
cis-11-20c acid (c20:1)	1.13 ± 0.05^{a}	0.48 ± 0.03^{b}	0.41 ± 0.01^{b}	<0.001
cis-8,11,14-eicosatrienoic acid (c20:3n6)	0.12 ± 0.01	0.12 ± 0.02	0.10 ± 0.01	0.477
arachidonic acid (c20:4n6)	0.13 ± 0.01^{a}	0.02 ± 0.00^{b}	0.15 ± 0.01^{a}	<0.001
docosahexaenoic acid (c22:6n3)	0.04 ± 0.00^{c}	0.08 ± 0.01^{a}	0.06 ± 0.00^{b}	<0.001
SFA	40.46 ± 0.79^{b}	49.08 ± 1.22^{a}	50.25 ± 0.73^{a}	<0.001
MUFA	50.12 ± 0.80^{a}	40.02 ± 1.14^{b}	39.08 ± 0.75^{b}	<0.001
PUFA	9.42 ± 0.31	10.90 ± 0.65	10.67 ± 0.23	0.055
UFA	59.54 ± 0.79^{a}	50.92 ± 1.22^{b}	49.75 ± 0.73^{b}	<0.001
S/U	0.68 ± 0.02^{b}	0.97 ± 0.05^{a}	1.01 ± 0.03^{a}	<0.001

DSA = dorsal subcutaneous adipose; ASA = abdominal subcutaneous adipose; PA = perirenal adipose. SFA = sum of saturated fatty acids; MUFA = sum of monounsaturated fatty acids; PUFA = sum of polyunsaturated fatty acids; UFA = sum of unsaturated fatty acids; S/U = values of ratio saturated and unsaturated fatty acids.
^{a,b}Within a row, means with different superscript letters differ significantly ($P < 0.05$).
Data are presented as means ± SEM. $n = 8$.

Table 3
Fatty acid profile of 3 deposits in *Ningxiang* gilts, %.

Item	DSA	ASA	PA	*P*-value
myristic acid (c14:0)	1.20 ± 0.03^{b}	1.34 ± 0.04^{a}	1.21 ± 0.03^{b}	0.009
palmitic acid (c16:0)	23.92 ± 0.18	23.87 ± 0.20	24.44 ± 0.40	0.298
palmitoleic acid (c16:1)	1.57 ± 0.05^{b}	2.43 ± 0.10^{a}	1.35 ± 0.09^{b}	<0.001
margaric acid (c17:0)	0.20 ± 0.01	0.21 ± 0.01	0.20 ± 0.01	0.789
stearic acid (c18:0)	15.01 ± 0.34^{b}	11.96 ± 0.38^{c}	17.76 ± 0.63^{a}	<0.001
elaidic acid (c18:1n9t)	0.10 ± 0.01	0.10 ± 0.00	0.10 ± 0.01	0.867
oleic acid (c18:1n9c)	47.66 ± 0.45^{b}	49.71 ± 0.54^{a}	45.24 ± 0.77^{c}	<0.001
linoleic acid (c18:2n6c)	8.19 ± 0.26^{ab}	8.60 ± 0.22^{a}	7.86 ± 0.22^{b}	0.103
α-linolenic acid (c18:3n3)	0.35 ± 0.01^{b}	0.38 ± 0.01^{a}	0.33 ± 0.01^{b}	<0.001
γ-linolenic acid (c18:3n6)	0.03 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.122
arachidonic acid (c20:0)	0.27 ± 0.01^{a}	0.17 ± 0.01^{b}	0.22 ± 0.02^{a}	<0.001
cis-11-20c acid (c20:1)	1.23 ± 0.03^{a}	0.86 ± 0.05^{b}	0.93 ± 0.06^{b}	<0.001
cis-8,11,14-eicosatrienoic acid (c20:3n6)	0.10 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	0.524
arachidonic acid (c20:4n6)	0.13 ± 0.00^{b}	0.16 ± 0.01^{a}	0.14 ± 0.00^{b}	<0.001
docosahexaenoic acid (c22:6n3)	0.05 ± 0.00^{b}	0.06 ± 0.00^{ab}	0.07 ± 0.00^{a}	0.012
SFA	40.59 ± 0.50^{b}	37.55 ± 0.50^{c}	43.83 ± 0.94^{a}	<0.001
MUFA	50.56 ± 0.47^{b}	53.10 ± 0.59^{a}	47.63 ± 0.81^{c}	<0.001
PUFA	8.85 ± 0.28^{ab}	9.35 ± 0.23^{a}	8.54 ± 0.24^{b}	0.091
UFA	59.41 ± 0.5^{b}	62.45 ± 0.5^{a}	56.17 ± 0.94^{c}	<0.001
S/U	0.68 ± 0.01^{b}	0.60 ± 0.01^{c}	0.78 ± 0.03^{a}	<0.001

DSA = dorsal subcutaneous adipose; ASA = abdominal subcutaneous adipose; PA = perirenal adipose; SFA = sum of saturated fatty acids; MUFA = sum of monounsaturated fatty acids; PUFA = sum of polyunsaturated fatty acids; UFA = sum of unsaturated fatty acids; S/U = ratio of SFA to UFA.
^{a,b}Within a row, means with different superscript letters differ significantly ($P < 0.05$).
Data are presented as means ± SEM. $n = 8$.

tissues of fat studied. The major FA were oleic and palmitic acid (the sum of these 2 FA represented about 70% of the total FA in DSA, ASA and PA), followed by stearic and linoleic acid, both of them reaching about 25%. This is similar to the study of Franco et al. (2006), Lorenzo et al. (2012) and Sellier et al. (2010). Furthermore, due to the analysis of the data, the variety of MUFA was richer than that of PUFA. The change in UFA mostly was influenced by MUFA while PUFA tended to be stable. The proportion of PUFA was much lower than that of SFA or MUFA because animals generally lack Δ12 and Δ15 desaturases, which means it is difficult for animals to produce PUFA (Pereira et al., 2003). From the nutritional perspective, diets rich in UFA decrease cholesterol levels in blood which leads to a low incidence of cardiovascular diseases (Lorenzo et al., 2012). Furthermore, the proportion of MUFA in PA, which is the major part of UFA, is lower than in ASA and DSA, which means that the PA is less healthy than ASA and DSA.

By comparing FA profile in different adipose, the results showed that there was a higher profile of SFA in PA compared with DSA in gilts and boars, which exhibited a similar pattern to in the results of Sellier et al. (2010). Furthermore, Nii et al. (2006) has proposed that the summary of quantitative trait loci of total SFA in PA is higher than inner layer dorsal back and outer layer back fat. Analyzed from the function of PA, it is used to make a fixed position for kidneys with higher temperature and DSA conjunct a lot of muscle for movement. Therefore, it is possible that there are some connections between the function of fat and the FA composition. The more SFA the fat contains, the higher melting point the fat has. The fat becomes more consistent with more SFA benefiting to fix kidneys. Lorenzo et al. (2012) showed a similar result in Celta pigs. Similar

results were also shown in other livestock, such as lambs (Szumacher-Strabel et al., 2004; Castro et al., 2005) and steers (Turner et al., 2015; Mapiye et al., 2015). This might be a common phenomenon in pigs or even in mammals.

This dissimilarity of PA and DSA could be majorly related to the proportion of stearic acid. This is also the same with the study of lambs (Szumacher-Strabel et al., 2004; Castro et al., 2005) and steers (Turner et al., 2015; Mapiye et al., 2015). Generally, the less mature adipose tissues situated externally, such as subcutaneous adipose, and the more saturated adipose tissues situated internally, such as PA (Lee et al., 2011; Jiang et al., 2013). This is related to a greater Δ-9 desaturase activity index in external fat depots as opposed internal ones, and replacement of stearic acid with oleic acid in external fat depots.

As for FA profile in DSA and ASA, SFA in ASA was higher than DSA in boars, while SFA in DSA was higher than ASA in gilts. The study of Lorenzo et al. (2012) also showed a similar result but no significance difference was observed. It may result from many factors, such as species, feeding, environment and so on.

5. Conclusion

In the fat of *Ningxiang* pig breed, oleic acid, palmitic acid, stearic acid and linoleic acid were major FA in DSA, ASA and PA. Significant differences were observed in the proportions of SFA, MUFA and the ratio of SFA to UFA related to the location of the fat in the carcass. Cis-11-20c acid (c20:1), stearic acid (c18:0) and MUFA showed the largest difference among 3 locations. These differences may have some relationships with the metabolism of specific location and sex, and relative factors need further study.

Conflicts of interest

The authors declare that they have no conflict of interest.

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