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Thermal analysis of lipids isolated from various tissues of sheep fats

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Abstract The physical–chemical properties and fatty acid composition of sheep subcutaneous, tallow, intestinal, and tail fats were determined. Sheep fat types contained $C_{16:0}$, $C_{18:0}$, and $C_{18:1}$ as the major components of fatty acid composition (19.56–23.40, 20.77–29.50, 32.07–38.30%, respectively). Differential scanning calorimetry (DSC) study revealed that two characteristic peaks were detected in both crystallization and melting curves. Major peaks (T_{peak}) of tallow and intestinal fats were similar and determined as 31.25–24.69 and 7.44–3.90 °C, respectively, for crystallization peaks and 15.36–13.44 and 45.98–44.60 °C, respectively, for melting peaks in DSC curves; but those of tail fat (18.29 and −2.13 °C for crystallization peaks and 6.56 and 33.46 °C for melting peaks) differed remarkably from those of other fat types.

Keywords Sheep fats · Fatty acids profile · Differential scanning calorimetry (DSC)

Introduction

The physical and chemical characteristics of fat have been important aspect for the evaluation, classification, and sensory properties of meat. For instance, soft fat is a critical factor decreasing the grade of a carcass in some countries [1]. Soft fat is characterized by its low melting point, which results in low processing properties. On the other hand, a low melting point of fat in foods has generally been considered to relate positively to the sensory properties, especially mouth feel [2].

In the countries such as Turkey who has a great animal fat capacity, it cannot be used effectively in the food or confectionary industry. However, cocoa butter, palm, coconut and palm kernel oil are used and imported as edible oils whose usage in food and confectionary products has been increasing steadily over the past few years [3]. Therefore, it is important to investigate the suitability of other fat sources such as edible sheep fats as replacements for more expensive fats and oils in the food and confectionery industries.

In mutton and other muscle foods, the melting properties of fat have generally been analyzed by glass-capillary tube method [1, 4, 5]. However, differential scanning calorimetry (DSC) is the thermo-analytical technique most employed to study oils and fats and a common acceptable method for determining the crystallization and melting characteristics of fats [6–8]. The methods of thermal analysis make it possible to follow the kinetics of thermally stimulated process like crystallization [9]. DSC can be used for determination of phase transitions of fats [6, 7]. Evaluation by differential scanning calorimetry provides direct measurements of energy involved in the process of melting and crystallization of oils and fats. Crystallization of fats results in shrinking volume, associated with an exothermic effect. Conversely, when fats melt, their volume expands, characterizing and exothermic effect [8, 10]. In addition, thermal analysis can be applied as a standard method in order to control lipid stability in meat, both in raw materials and in the further processed meat products [11].

The relationship between fatty acid composition and DSC properties of a fat has been pointed out in the literature [12, 13]. The fundamental differences between fat types with respect to their fatty acid composition can be a

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basis for detection of these fat types in some further processed meat products using melting thermogram of DSC. Therefore, physical characteristics of fats such as their melting temperatures should be investigated by interrelating them with their fatty acid compositions. In addition, the chemical and thermal data to be obtained in this way may be a beneficial basis for future researches to develop a feed or food products containing these fat types for agricultural (as a soap stock in animal feed) or food production purposes, respectively. So far, very little information regarding chemical composition and thermal properties of sheep fats has been reported. This study was undertaken to investigate the potential use of crystallization and melting curves of DSC for evaluation of the chemical and physical properties of sheep subcutaneous, tallow, and intestinal fats and present the basic physical–chemical and compositional differences between these fat types.

Experimental

Sample preparation

Subcutaneous, tallow, intestinal, and tail fat adipose tissues were obtained from sheep (Akkaraman, 48 months of age) fed at the Konet Slaughterhouse and Meat Products Processing Co., Konya, Turkey. Subcutaneous fat tissue samples (SF) were obtained from the areas under hide and carcass surfaces. Outer layer of fat tissue was used for sample. Tallow samples (TF) were collected from the fat tissues surrounding tripe. Intestinal fat tissue (IF) was sampled from the fat tissues holding the intestines together. Tail samples (TaF) were obtained from the tail of animal. After slaughtering, all fat tissue samples were immediately transferred in ice boxes to the laboratory. The samples were kept in a deep freezer at a temperature of −20 °C. After keeping in refrigerator (4 °C) until constant temperature, fat tissues were ground twice through a 3-mm plate. The fat samples were prepared by melting the related adipose tissue sample at 60 °C on a water bath, strained through a porous cloth, and used without further purification. The analyses were conducted on these extracted fat samples. These fat samples were transferred into glass containers and stored at −20 °C until analyses.

Melting point

Capillary tube methodology was used to determine the melting point (MP) of the fat samples. Samples were allowed to enter from the bottom of capillary tubes and rise to the level of 10 mm of height and then the samples in the capillary tubes were frozen. Frozen samples were attached near the bulb-end of a mercury thermometer and subsequently submerged into a temperature controlled water bath, temperature of which could be increased at the rate of 1 °C min^{-1}. MP was recorded at a temperature at which fat sample in the capillary tube became transparent [14].

Saponification number

Saponification number (SN) values of the fat samples were determined as outlined [14]. Fat sample was saponified with 0.5 N KOH solution by boiling for 60 min on heat plate attached with a water cooled reflux condenser. The saponified solution was titrated with 0.5 N HCl until brilliant color point. Same procedure was repeated for blank. The SN was calculated as follows:

$$\text{SN (mg KOH/g fat)} = \frac{[\text{HCl (mL) for blank} - \text{HCl (mL) for sample}] \times N\,(0.5) \times 56.1}{\text{Sample amount (g)}}$$

Iodine number

Wijs method was used to determine the iodine number (IN) of the fat samples [14]. 0.6 g of fat sample was dissolved in a flask containing 15 mL of CCl_4, followed by addition of 25 mL of Wijs solution into the flask. After agitation, the flask was covered and kept in a dark place for 1 h. Then 20 mL of 10% of KI, 150 mL of distilled water, and 1 mL of starch solution were added into the flask. The solution in flask was subsequently titrated with 0.1 N $Na_2S_2O_3$ solution until it became colorless. Same procedure was repeated for blank. The IN was calculated as follows:

$$\text{IN} = \frac{[\text{Na}_2\text{S}_2\text{O}_3\ \text{(mL) for blank} - \text{Na}_2\text{S}_2\text{O}_3\ \text{(mL) for sample}] \times 1.269}{\text{Sample amount (g)}}$$

Energy values

The energy values of fat samples were determined using a bomb calorimeter (IKA, C200, Germany). Approximately 0.1–0.2 ± 0.0001 g of fat sample was weighed into the burning crucible placed in the decomposition vessel of the

instrument. To optimize the combustion process, the decomposition vessel was filled with pure oxygen (99.95 %) until the pressure of oxygen atmosphere reached maximum 30 bars. The fat sample was ignited by the cotton thread as an ignition aid. The temperature increase in the calorimeter system was measured and the specific calorific value of the fat sample was calculated as follows [15]:

$$H_0 = [C \times \Delta T - (Q_{\text{External1}} + Q_{\text{External2}})]/m$$

where m was the mass of fat sample, C was the heat capacity (C-value, J g^{-1} K^{-1}), ΔT was the calculated temperature (°C) increase of water in inner vessel of measuring cell, $Q_{\text{External1}}$ (J) was the correction value for the heat energy generated by the cotton thread as ignition aid and $Q_{\text{External2}}$ (J) was the correction value for the heat energy from other burning aids.

Fatty acid analysis

Fat samples were methylated by the boron trifluoride-methanol, as outlined in the method of Yazıcıoğlu and Karaali [16] and obtained fatty acids methyl esters (FAME) were analyzed by a gas chromatograph (Shimadzu, GC-2010, Shimadzu Instrument Ltd., Kyoto, Japan) fitted with an FID detector. A polar silica fused capillary column TR-CN100 (0.25 mm i.d., 60 m length, and 0.20 μm film thickness; *Teknokroma* Ltd., Barcelona, Spain) was used at a pressure of 200 kPa. The temperature of the column was 90 °C, programed to increase to 90 °C for 7 min and 240 °C at 5 °C min^{-1} for 15 min. The temperature of the injector and detector was maintained at 260 °C. Nitrogen was used as a carrier gas at a flow rate of 1.51 mL s^{-1}. The FAMEs were identified by comparing the retention time of the samples with appropriate fatty acids methyl esters standards, purchased from Supelco, USA. The relative percentage of the area was obtained by using the following equation: Area% $FA_X = [A_X/A_R] \cdot 100$, where: FA_X = fatty acid to be quantified, A_X = area of the methyl ester X, and A_R = total area of the chromatogram. Peak areas lower than 0.1% of the total areas were not considered.

Differential scanning calorimetry

The DSC system (Shimadzu DSC-50, Shimadzu Instrument Ltd., Kyoto, Japan) was used to record the crystallization and melting curves of the fat types. The instrument was calibrated with indium and mercury for heat flow as outlined [17]. Fat samples (10 mg) were weighed into the aluminum hermetic pans and covers were crimped into place. An empty, hermetically sealed aluminum pan was used as a reference. The measuring cell was purged with nitrogen gas (30 mL min^{-1}) during analysis. The fat samples were subjected to the following temperature program: (a) heated to 75 °C to destroy crystal structure; (b) cooled at a rate of 5 °C min^{-1} from 75 to −65 °C using liquid nitrogen; (c) heated from −65 to 75 °C at 5 °C min^{-1}. The crystallization and melting characteristics of each sample, i.e., extrapolated onset temperature (T_{onset}), maximum peak temperature (T_{peak}), and enthalpy (ΔH) were obtained using a Shimadzu TA-50I data processor.

Statistical analysis

Statistical analysis was carried out by General Linear Model (GLM) procedure using the SPSS [18] with one-way allocation. Significant differences between the fat types were further analyzed using the Duncan's Multiple Range Test of Mstat C [19].

Results and discussion

Physical and chemical properties

Table 1 indicates the physical and chemical properties of the fat samples. MP point values of subcutaneous fat (SF) and tail fat (TaF) were found lower than those of tallow (TF) and intestinal fats (IF), while SN and IN values of TaF were found higher than those of SF, TF, and IF, which indicated that TF was a distinct fat among the fat types with respect to these physical and chemical properties. As far as an animal originated fat is concerned, this exceptional trait of TaF should be especially important for the human nutrition and health aspect. The results for MP values of SF and TaF were similar to those of Karakaya [20] who determined these values to be 40.5 and 38.0 °C for mutton and tail fats, respectively. Furthermore, Atay and Ertas [21] found the MP value of Akkaraman sheep to be 38 °C. On the other hand, Moharrery [22] reported that the MP values of meat, caudal, and omental fats from fat-tailed Badghisian sheep were 41.68, 31.91, and 47.99 °C, respectively, which were different from those in this study. This could be due to differences between breed, age, sex, and nutritional conditions as well as differences between molecular mass and saturation degree of different fat types [3].

SN value of TaF was found higher than those of TF and IF, which indicated that the molecular mass of TaF was lower as compared to those of other fat types. It was reported that SN of sheep suet ranged between 192 and 198 mg KOH/g fat [23–25]. IN, a measure of the unsaturation degree of a fat, was varied between fat types. IN value of TaF was lower than those of other fat types, which indicated that unsaturation degree of TaF was higher as compared to those of other fat types. Gökalp et al. [14] reported that IN values of sheep and tail fats ranged

Table 1 The physical–chemical properties and fatty acid composition of sheep subcutaneous, tallow, intestinal, and tail fats

Analyses	Fat types			
	Subcutaneous	Tallow	Intestinal	Tail
Physical and chemical properties[A]				
MP/°C	37.6 ± 1.0^{b}	46.7 ± 1.3^{a}	46.8 ± 0.7^{a}	37.4 ± 1.1^{b}
SN/mg KOH/g fat	182.8 ± 4.5^{b}	187.0 ± 9.7^{b}	188.9 ± 4.2^{b}	203.4 ± 4.9^{a}
IN	36.9 ± 1.3^{b}	34.4 ± 5.9^{b}	35.6 ± 1.9^{b}	42.6 ± 1.4^{a}
EV/kJ/100 g	3927 ± 102^{ab}	3871 ± 228^{b}	4086 ± 60^{a}	4038 ± 58^{a}
Fatty acid composition (%)[B]				
$C_{12:0}$	0.19 ± 0.02^{a}	0.22 ± 0.03^{a}	0.15 ± 0.05^{a}	0.16 ± 0.01^{a}
$C_{14:0}$	2.85 ± 0.06^{a}	3.97 ± 0.95^{a}	2.62 ± 0.30^{a}	2.45 ± 0.04^{a}
$C_{14:1\omega5}$	0.17 ± 0.01^{c}	0.70 ± 0.05^{a}	0.41 ± 0.03^{bc}	0.52 ± 0.11^{ab}
$C_{15:0}$	0.12 ± 0.01^{c}	0.27 ± 0.01^{b}	0.23 ± 0.03^{b}	0.44 ± 0.01^{a}
$C_{16:0}$	21.78 ± 1.39^{a}	23.40 ± 1.90^{a}	22.22 ± 3.26^{a}	19.56 ± 0.33^{a}
$C_{16:1\omega7}$	1.16 ± 0.47^{a}	0.25 ± 0.13^{a}	0.74 ± 0.46^{a}	0.81 ± 0.32^{a}
$C_{17:0}$	1.47 ± 0.29^{a}	0.82 ± 0.01^{bc}	0.74 ± 0.04^{c}	1.36 ± 0.30^{ab}
$C_{17:1}$	2.69 ± 0.15^{a}	2.15 ± 0.18^{a}	1.58 ± 0.01^{a}	2.03 ± 0.79^{a}
$C_{18:0}$	20.98 ± 0.94^{b}	27.12 ± 2.54^{ab}	29.50 ± 0.69^{a}	20.77 ± 0.75^{b}
$C_{18:1\omega9}$	34.70 ± 1.62^{a}	32.07 ± 1.15^{a}	35.83 ± 2.33^{a}	38.30 ± 3.74^{a}
$C_{18:2\omega6}$	1.66 ± 0.30^{a}	2.81 ± 0.23^{a}	1.29 ± 0.76^{a}	1.75 ± 0.26^{a}
$C_{18:3\omega3}$	0.20 ± 0.03^{a}	0.40 ± 0.04^{a}	0.21 ± 0.13^{a}	0.36 ± 0.18^{a}
$C_{20:0}$	0.41 ± 0.01^{a}	0.21 ± 0.01^{b}	0.24 ± 0.03^{b}	0.41 ± 0.04^{a}
$C_{20:1\omega6}$	0.36 ± 0.04^{a}	0.34 ± 0.07^{a}	0.49 ± 0.25^{a}	0.52 ± 0.13^{a}
∑SFA	47.77 ± 2.67^{b}	56.00 ± 0.36^{a}	55.68 ± 2.93^{a}	45.12 ± 1.46^{b}
∑MUFA	39.06 ± 2.28^{a}	35.49 ± 1.34^{a}	39.04 ± 2.16^{a}	42.16 ± 2.65^{a}
∑PUFA	1.85 ± 0.34^{a}	3.21 ± 0.28^{a}	1.50 ± 0.90^{a}	2.11 ± 0.43^{a}
∑UFA	40.91 ± 2.62^{a}	38.69 ± 1.06^{a}	40.54 ± 3.06^{a}	44.26 ± 3.08^{a}
UFA/SFA ratio	0.86 ± 0.10^{ab}	0.69 ± 0.03^{b}	0.73 ± 0.10^{b}	0.98 ± 0.10^{a}

MP melting point, *SN* saponification number, *IN* iodine number, *EV* energy value

[A] In each row, mean (±SD) values with different superscripts indicate significant differences ($p < 0.01$)

[B] *SFA* saturated fatty acids = $C_{14:0} + C_{15:0} + C_{16:0} + C_{17:0} + C_{18:0} + C_{20:0}$; *MUFA* monounsaturated fatty acids = $C_{14:1\omega5} + C_{16:1\omega7} + C_{17:1} + C_{18:1\omega9} + C_{20:1\omega6}$; *PUFA* polyunsaturated fatty acids = $C_{18:2\omega6} + C_{18:3\omega3}$; *UFA* unsaturated fatty acids = MUFA + PUFA

between 32 and 61 g/100 g and 39 and 44 g/100 g, respectively. Hamilton [24] reported that IN value of sheep suet ranged between 31–47 g/100 g. As seen, these results were similar to those in literature. The energy values of fat types were determined to range between 3871 and 4086 kJ/100 g. However, no remarkable difference was observed between the energy values of fat types, which indicated that all fat types could provide the similar energy level for human metabolism.

Fatty acid composition

Chromatograms and fatty acid profiles of sheep fat types are shown in Fig. 1 and Table 1, respectively. Fat types had similar amounts of $C_{16:0}$ and $C_{18:1\omega9}$, while $C_{18:0}$ was detected at higher amounts ($p < 0.01$) in TF and IF. On the other hand, heptadecanoic acid ($C_{17:0}$) and arachidic acid ($C_{20:0}$) amounts in SF and TaF was higher ($p < 0.01$) than those in TF and IF. Total saturated fatty acid (SFA) amounts in SF and TaF were determined lower ($p < 0.01$) than those in TF and IF, while total monounsaturated (MUFA) and unsaturated fatty acid (UFA) amounts were found at similar levels. UFA/SFA ratio values of SF and TaF were higher than those of TF and IF. On the other hand, no remarkable difference was found between the fat types with respect to remaining fatty acids. According to the above results, these fat types could be classified into two groups, the one with lower SFA content (SF and TaF) and the other one with higher SFA content (TF and IF).

The results for fatty acid profile of sheep fat types were similar to those reported by different researchers. Souci et. al [26] reported that myristic acid, palmitic acid, stearic acid, oleic acid, and linoleic acid contents of sheep subcutaneous fat were 1.90, 18.70, 22.20, 32.30, and 3.34%, respectively. However, the results in this study were not similar to those of Moharrery [22] who determined the

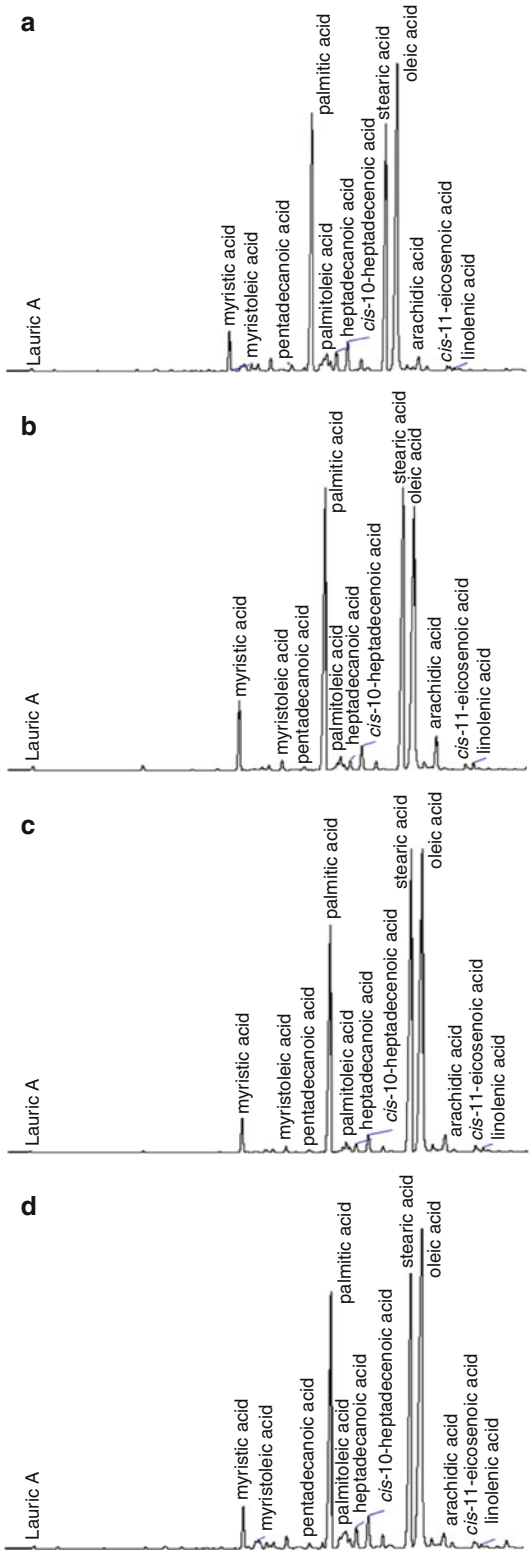

Fig. 1 Fatty acid chromatograms of subcutaneous (**a**), tallow (**b**), intestinal (**c**), and tail (**d**) fats of sheep

myristic acid, palmitic acid, stearic acid, oleic acid, and linoleic acid contents of meat fats from fat-tailed Badghisian sheep to be 6.04, 29.98, 10.63, 48.88, and 4.47 %, respectively. Myristic acid, palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, SFA, and UFA contents of omental fats from fat-tailed Badghisian sheep were determined to be 6.49, 29.55, 20.02, 39.00, 4.79, 0.14, 56.07, and 43.93%, respectively, which also differed from those in this study. Differences between the values in literature and those determined in this study could be attributed to the fact that the fatty acid composition is affected by breed, sex, age, and nutritional conditions [3–27]. Accordingly, Mehran and Filsoof [28] studied the fatty acid composition of sheep tail fats from five Iranian native breeds and concluded that there was a great variation between different sheep breeds with respect to their fatty acid compositions.

DSC analysis of fats

Figure 2 indicates the DSC crystallization curves of fat types. As can be seen in Fig. 2, two major exothermic peaks were observed between approximately −20 and 40 °C. T_{onset}, T_{peak}, and ΔH values of those peaks are shown in Table 2. As can be seen in Table 2, the highest values for T_{onset} and T_{peak} were determined in TF. The lowest values of T_{onset} and T_{peak} could be related to the highest percentage of the saturated fatty acids ($\sum$SFA = 56.00%) in TF. The differences of T_{onset} and T_{peak} between the fat types could be attributed to the physical properties of triglycerides. Sato [29] reported that the fats and lipids present in natural resources are mixtures of different types of triglycerides, and therefore, complicated behavior of crystallization of the real-fat systems could be partly due to the physical properties of the component triglycerides.

The DSC melting curves are shown in Fig. 3. The results showed that two major endothermic peaks were

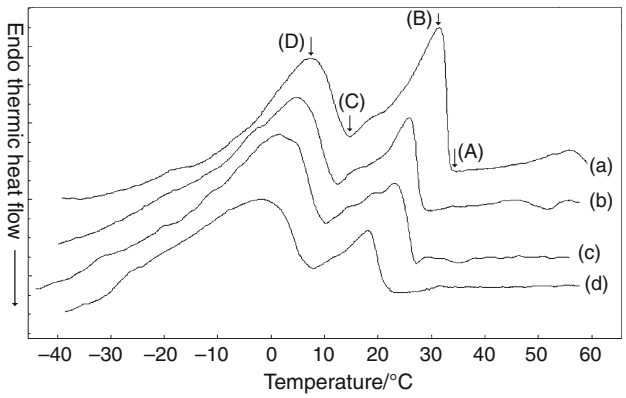

Fig. 2 DSC crystallization curves indicating endothermic heat flow/mW) for: (*a*) tallow, (*b*) intestinal, (*c*) subcutaneous, and (*d*) tail fats of sheep. *A*, *B*, *C*, and *D* indicate '1st onset temperature,' '1st peak temperature,' '2nd onset temperature,' '2nd peak temperature,' respectively

Table 2 T_{onset}, T_{peak}, and ΔH values obtained from crystallization peaks of different sheep fats

Fat types	First crystallization peak			Second crystallization peak		
	T_{onset}/°C	T_{peak}/°C	ΔH/J g^{-1}	T_{onset}/°C	T_{peak}/°C	ΔH/J g^{-1}
Subcutaneous	30.65 ± 0.01^{a}	26.32 ± 0.04^{b}	−12.22 ± 0.21^{b}	12.61 ± 0.30^{ab}	4.57 ± 1.41^{a}	−32.69 ± 0.52^{b}
Tallow	33.20 ± 0.14^{a}	31.25 ± 0.13^{a}	−25.19 ± 0.11^{a}	13.77 ± 0.01^{a}	7.44 ± 0.20^{a}	−25.31 ± 0.01^{d}
Intestinal	27.34 ± 1.21^{b}	24.69 ± 1.53^{b}	−12.83 ± 0.98^{b}	10.71 ± 0.83^{b}	3.90 ± 1.05^{a}	−29.13 ± 0.34^{c}
Tail	21.59 ± 0.28^{b}	18.29 ± 0.42^{c}	−6.42 ± 1.13^{c}	5.95 ± 0.16^{c}	−2.13 ± 0.39^{b}	−35.80 ± 0.55^{a}

In each column, mean (±SD) values with different superscripts indicate significant differences ($p < 0.01$)

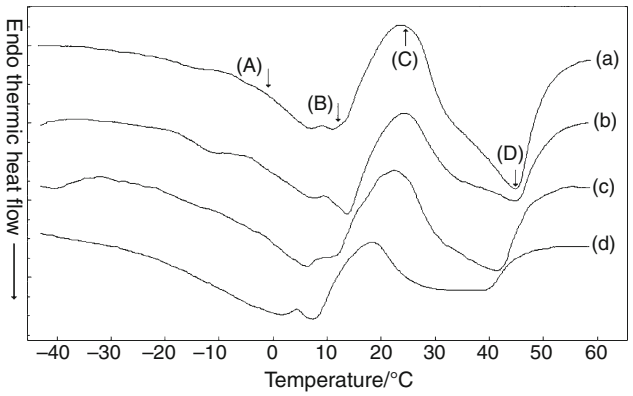

Fig. 3 DSC melting curves indicating endothermic heat flow/mW for: (*a*) tallow, (*b*) intestinal, (*c*) subcutaneous, and (*d*) tail fats of sheep. *A*, *B*, *C*, and *D* indicate '1st onset temperature,' '1st peak temperature,' '2nd onset temperature,' '2nd peak temperature,' respectively

observed. On the other hand, no further peak was found to exist in the temperature region beyond −7.86 °C because the majority of triglycerides present in the fat types were high-melting ones. T_{onset}, T_{peak}, and ΔH values of these peaks are shown in Table 3. As can be seen in Table 3, the lowest T_{onset} value was determined for 2nd peak of TaF. The lowest ΔH value was also determined in TaF. The low MP and high IN values of TaF (Table 1) were in accordance with DSC results. The lower T_{onset} of TaF could be attributed to its lowest percentage of saturated stearic acid ($C_{18:0} = 20.77\%$) and SFA ($\sum$SFA = 45.12%). De Man [12] reported that usually highly saturated triglycerides demonstrate a higher melting point than those which were highly unsaturated. The lower 2nd T_{onset} and T_{peak} values for TaF confirmed that the main components in the TaF were triglycerides with unsaturated fatty acids, which melted at low temperatures. Hence, this group of triglycerides could be categorized as low-melting ones. On the other hand, DSC heating profiles of TF and IF were found to show a sharp high-melting endothermic peaks at 45.98 and 44.60 °C, respectively, which could be a basis for further investigations where TF and IF fats in some further processed meat products would be aimed to detect and discriminate from other fat sources using melting chromatograms of DSC. Differences between above onset and peak temperatures were due to the physical properties of triglycerides. Accordingly, it was reported that the behavior of melting of the real-fat systems could, to some extent, result from the physical properties of the triglycerides [29].

Conclusions

DSC analysis of sheep adipose tissue fats may be useful to determine crystallization and melting properties. This could provide useful information about the nature of the thermodynamic characteristics associated with phase transitions of fat types and help to categorize these fat types according to their technological characteristics. Tallow and intestinal fats were higher melting fats. Therefore, these fats could be categorized as solid glycerides, which would be useful in any application where high melting glycerides are required. In addition, these types of fats are similar to the hydrogenated fats with respect to their melting characteristics, which make them useful as a hardening fat in shortening

Table 3 T_{onset}, T_{peak}, and ΔH values obtained from melting peaks of different sheep fats

Fat types	First melting peak			Second melting peak		
	T_{onset}/°C	T_{peak}/°C	ΔH/J g^{-1}	T_{onset}/°C	T_{peak}/°C	ΔH/J g^{-1}
Subcutaneous	−7.86 ± 1.84^{b}	9.68 ± 0.91^{b}	51.45 ± 0.74^{a}	27.50 ± 0.65^{a}	44.81 ± 0.66^{a}	38.77 ± 0.57^{b}
Tallow	−4.21 ± 0.52^{ab}	15.36 ± 0.33^{a}	35.80 ± 0.65^{b}	27.59 ± 1.39^{a}	45.98 ± 1.68^{a}	57.02 ± 3.42^{a}
Intestinal	1.86 ± 0.19^{a}	13.44 ± 0.30^{a}	33.84 ± 2.39^{b}	25.68 ± 0.25^{a}	44.60 ± 0.02^{a}	38.69 ± 3.73^{b}
Tail	−6.52 ± 2.02^{b}	6.56 ± 0.93^{b}	46.53 ± 0.82^{a}	18.99 ± 0.57^{b}	33.46 ± 5.76^{b}	24.51 ± 0.16^{c}

In each column, mean (±SD) values with different superscripts indicate significant differences ($p < 0.01$)

and margarine formulations. Tail fat started to melt at 18.99 °C, and was completely melted at 33.46 °C; therefore, could be useful as a confectionary fat and for some applications as a coating fat. The results of this study could be a basis for a future study where some food or fat adulterations are going to be assessed to monitor these fat types.

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