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ORIGINAL PAPER

Influence of Geographical Origins on the Physicochemical Properties of Hass Avocado Oil

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Abstract A study was conducted to compare the physicochemical properties of Hass avocado oil from different geographical locations (Mexico, Australia, United States and New Zealand). Regardless of geographical origins, Hass avocado pulp was characterized by high lipid content (61.27–62.66%). Among Hass avocados of different origins examined, avocado oil of New Zealand origin exhibited the lowest saponification value. The L^*, a^* and b^* values for avocados of New Zealand origin were higher than others, translating into the oil being the lightest in color and containing more red and yellow pigments. The predominant fatty acids in the Hass avocado oil were oleic (42.59–50.97%) and palmitic (20.61–25.63%) acids, whereas the predominant triacylglycerols (TAGs) were OOO (21.41–34.69%) and POO (19.65–24.68%), where O and P denote oleic and palmitic acids, respectively. The melting curves of Hass avocado oil displayed three endothermic peaks, whereas the crystallization curves displayed two endothermic peaks. Hass avocado oil of New Zealand origin contained a significant amount of natural pigments and unsaturated compounds (unsaturated fatty acids and tri-unsaturated TAGs) than Mexico, Australia and United States origins.

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Introduction

Avocado (*Persea americana* Mill.) is a dicotyledonous plant from the Lauraceae family. It grows in tropical or subtropical climates in countries such as Mexico, Australia, the United States and Malaysia. Mexico is the top avocado producing country in the world, producing 1.47 million metric tons of avocado fruits in 2013 [1]. The avocado tree can grow up to 30 m high and is frost sensitive [2]. The fruiting season varies according to the variety of avocado [3]. Avocado fruit is a nutritious and tasty fruit containing high amounts of lipids and minerals (potassium, phosphorus, magnesium and calcium) [4]. Avocado fruit also referred as 'vegetable butter' and 'butter fruit'. Avocado fruit does not ripen while remaining on the tree; it begins to ripen once it is detached from the tree.

More than 100 varieties of avocado have been registered in the database of California Avocado Society [5, 6]. Hass, Fuerte and Wagner are the most popular avocado varieties used for the export and industrialization purposes in Brazil [7]. Among these, Hass avocado has received particular interest and is the most common commercial avocado variety in the world [8], because the thicker peel in Hass avocado fruit makes it more tolerate to the postharvest and handling disorders [9]. Hass avocado is an oval-shaped fruit with thick pebbly skin texture. The immature Hass avocado fruit is green in color and it turns to black when fully ripe. The fruits weigh 130–200 g, and are 7.0–9.0 cm in length and 5.9–6.6 in diameter. Compared to other avocado varieties, the non-edible portions (peel and seed) of the Hass avocados constitute a smaller proportion of the whole (35%),

whereas the edible yellowish pulp constitutes the major portion (65%) of the fruit [10].

Unlike typical fruits which have a sweet or sour taste, avocado pulp has a smooth creamy taste; avocado pulp is commonly used as a salad dressing or processed into guacamole. Avocado oil is extracted from the pulp of the fruit. Owing to the fast absorption and high skin penetration ability, avocado oil is widely used in the cosmetic industry to produce various skin or hair care products [9]. Lately, avocado oil has been purposed as a new functional food ingredient because of its high concentration of oleic monounsaturated fatty acid and bioactive compounds [11]. Compared to other varieties of avocado, high oil yield in Hass avocado pulp makes it more suitable for the purpose of edible oil extraction [12]. As shown by Tango *et al*. [13], the lipid content in Hass avocado pulp (31.1%) was significantly greater than Fuerte (30.3%), Collinson (21.2%), Wagner (20.6%), Carlsbad (19.3%), Sinaloa (11.7%) and Pollock (5.3%) avocados pulp.

Hass avocado is originated from Southern California, America. It is then introduced into New Zealand, Australia and is now cultivated worldwide particularly in subtropical and tropical countries. Previous studies reported the oil content and compositional quality of fruits were affected by variety [13], harvest time [14], climate and geographical region [15]. The study from Woolf *et al*. [16] indicated sun exposed avocado fruits contained higher oil yield and saturated fatty acid, but lesser monounsaturated fatty acids than shaded avocado fruits. Mexico, Australia, United States and New Zealand are some of the countries that produce a number of Hass avocado fruits. These countries have very different climatic conditions and management systems, which can lead to a great different in the oil content and compositional quality of avocado oil produced. Therefore, the aim of the current study is to compare the physicochemical properties of oil extracted from the Hass avocado pulp collected from different geographical origins namely, Mexico, Australia, United States and New Zealand.

Materials and Methods

Materials

Hass avocado fruits (130–200 g) were purchased from different retailers (New Zealand origin from Avanza Ltd., Australia origin from Auspak Avocados, Mexico origin from Coliman and United States origin from Hand-Grown In California) in February 2017. The ripened avocado fruits were cut into halves and the pulp was manually separated from the seed and the peel. An air-oven (Memmert Universal UF 450, Germany) operated at 50 °C was used to dry the pulp for two consecutive days. The dried samples were ground into powder using a blender (Braun Multiquick ZK100, Germany) and sieved through a 20-mesh sieve. The powdered samples were kept in air-tight containers and stored at −20 °C until use. All the chemical reagents used in this study were of analytical grade, unless otherwise specified.

Oil Extraction

Avocado oil extraction was performed using a Soxhlet extractor according to the method described by AOAC 963.15 [17]. Briefly, 10 g of avocado powder was extracted with 200 mL of petroleum ether in a Soxhlet extractor for 8 h at 70 °C. The petroleum ether was removed by evaporation using a rotary evaporator at 70 °C in a water bath. The extracted oil was kept in the bottle and stored at −20 °C until use. Oil yield was expressed as the percent of oil obtained based on the weight of avocado powder used.

Analysis of Physical and Chemical Parameters

Iodine and saponification values of the oil samples were calculated by Biodiesel Analyzer© software [18] using the percentages of fatty acid methyl ester. The color of the oil samples was determined using a Hunter Labscan XE spectrophotometer (Hunter Associate Laboratory, USA) and the results were expressed as L^*, a^* and b^* values. Under the tristimulus color coordinate system, L^* measures the lightness and the value varies from −100 (black) to +100 (white), the a^* value varies from −100 (green) to +100 (red) and the b^* value varies from −100 (blue) to +100 (yellow) [19].

Analysis of Fatty Acid Composition

Fatty acid composition of the oil samples was examined by conversion of oil to fatty acid methyl ester (FAME) according to the method of Cocks and Rede [20]. Exactly 100 mg of oil was mixed with 5 mL of hexane and 250 µL of sodium methoxide reagent in a screw cap test tube. The test tube was vortexed for 1 min before adding 5 mL of saturated sodium chloride solution. The test tube was shaken vigorously for 15 s, then left standing for 10 min. The top layer was transferred to a 2 mL autosampler vial and analyzed using a gas-chromatograph (Agilent 6890, USA) equipped with a flame-ionization detector and a capillary column (60 m length, 0.25 mm internal diameter and 0.25 µm film thickness; SGE BPX70, USA). The oven temperature was programmed at 100 °C held for 2 min and increased at the rate of 5 °C/min to 230 °C and held for 10 min. Both injector and detector temperatures were maintained at 250 °C. The peaks of the samples were identified by comparison of the retention times with FAME standards. The percentage of fatty acid was calculated as the ratio of the partial area to the total peak area and only the most abundant peak areas (>0.2%) were evaluated [19].

Analysis of Triacylglycerol Composition

The triacylglycerol (TAG) composition of the oil samples was determined using a high-performance liquid chromatograph (Agilent 1100, USA) equipped with a refractive index detector (Agilent 1200, USA) on a reversed phase Lichrospher C-18 column (250 × 4 mm, with a particle size of 5 µm; Merck KGaA, Darmstadt, Germany) according to the method of Abdulkarim *et al*. [21] with modifications. The mobile phase was a mixture of acetone-acetonitrile (63.5:36.5) at a flow rate of 0.8 mL/min with a column temperature held at 30 °C. The injector volume was 10 µL of 5% (w/w) oil in acetone-acetonitrile. The TAG of the oil samples was quantified based on the retention time of TAG standards and the TAG profile of avocado oil reported previously by Lísa and Holčapek [22]. Peak areas produced by the data integrator were used to quantify the components based on their relative percentages.

Analysis of Thermal Behaviour

Thermal behaviour of the oil samples was analyzed using a differential scanning colorimeter (Mettler Toledo DSC 823, Switzerland) according to the method of Abdulkarim *et al*. [21]. Nitrogen gas at 99.99% purity was utilized as the purge gas at a rate of 20 mL/min. About 5–7 mg of the oil sample was weighed into an aluminum pan and then hermetically sealed. An empty hermetically sealed aluminum pan was used as the control. The sample was subjected to the following temperature program: the sample was held isothermally at 60 °C for 2 min to eliminate the thermal history, then cooled at 5 °C/min to −60 °C and held for 2 min. The sample was then heated from −60 to 60 °C at 5 °C/min.

Statistical Analysis

All the analyses were performed in triplicate and the results were expressed as the mean ± standard deviation. The data were analyzed by one-way analysis of variance (ANOVA) accompanied with Tukey's *post hoc* using Minitab 15 statistical software (Minitab Inc, USA). The level of significance was set at $p < 0.05$.

Results and Discussion

Basic Physical and Chemical Characteristics

The compositional quality of edible oils is affected by their physical and chemical characteristics. Table 1 shows the physical and chemical characteristics of Hass avocado oil from different geographical origins. A semi-continuous Soxhlet method was used to extract the oil from the dried Hass avocado pulp. Compared with other oil extraction methods, Soxhlet is the cheapest, simplest and most practical method to extract oil from avocado pulp [23]. The oil content in the Hass avocado pulp lies in the range of 61.27–62.66% and was unaffected by geographical origins. At room temperature, the oil appeared as a liquid. The observed oil yield in the present study was higher than the oils extracted from bittermelon (19.3%), kalahari melon (30.5%), kenaf (20.8%), pumpkin (34.9%) and roselle (14.6%) seeds [19]. High percentages of oil in the Hass avocado pulp (>60%) suggest suitability for the purposes of oil industry applications.

The iodine value measures the unsaturation levels in lipids. A high iodine value indicates the lipids contain high unsaturation levels [24]. The iodine values of Hass avocado oil were in the range of 85.83–92.10 g/100 g, which were higher than coconut (7–12 g/100 g) and palm (50.6–55 g/100 g) oils [25, 26]. High iodine values of avocado oil are due to the presence of high amounts of unsaturated fatty acids such as oleic and linoleic acids (Table 2).

The saponification values of Hass avocado oil (204.94–205.61 mg/g) were comparable to the oils extracted from kenaf (171.0 mg/g), kalahari melon (173.2 mg/g) and roselle (172.3 mg/g) seeds [19]. From Table 1, the saponification value of New Zealand avocados was significantly lower ($p < 0.05$) than those of other origins examined. Oil

Table 1 Physical and chemical characteristics of Hass avocado oil

Parameters	Australia	Mexico	New Zealand	United States
Oil yield (%)	61.61 ± 0.34^{a}	61.27 ± 0.86^{a}	62.66 ± 0.48^{a}	61.47 ± 0.63^{a}
Physical state[1]	Liquid	Liquid	Liquid	Liquid
Iodine value (g/100 g)	92.10 ± 0.45^{a}	86.98 ± 0.13^{b}	89.98 ± 0.01^{c}	85.83 ± 0.04^{d}
Saponification value (mg/g)	205.39 ± 0.03^{a}	$205.61 \pm 0.11^{b,a}$	204.94 ± 0.04^{c}	$205.19 \pm 0.04^{a,d}$
Colour				
*L**	28.44 ± 0.38^{a}	31.20 ± 0.17^{b}	31.97 ± 0.13^{c}	29.54 ± 0.17^{d}
*a**	7.39 ± 0.16^{a}	6.54 ± 0.01^{b}	10.54 ± 0.18^{c}	7.40 ± 0.14^{a}
*b**	44.08 ± 0.72^{a}	54.14 ± 0.54^{b}	60.71 ± 0.17^{c}	47.87 ± 0.76^{d}

[1] At room temperature

Mean values in the same row with different letters are significantly different at $p < 0.05$

Table 2 Fatty acid composition of Hass avocado oil

Fatty acids	Countries (%)			
	Australia	Mexico	New Zealand	United States
C16:0	25.63 ± 0.11[a]	22.59 ± 0.23[b]	20.61 ± 0.16[c]	22.24 ± 0.05[b]
C16:0	25.63 ± 0.11[a]	22.59 ± 0.23[b]	20.61 ± 0.16[c]	22.24 ± 0.05[b]
C16:1	7.29 ± 0.05[a]	11.63 ± 0.13[b]	10.31 ± 0.03[c]	13.14 ± 0.01[d]
C18:0	0.45 ± 0.16[a]	0.24 ± 0.02[a]	0.30 ± 0.01[a]	0.93 ± 0.08[b]
C18:1	42.59 ± 0.16[a]	49.19 ± 0.57[b]	50.97 ± 0.30[c]	47.69 ± 0.03[d]
C18:2	20.87 ± 0.10[a]	14.72 ± 0.06[b]	16.10 ± 0.11[c]	14.47 ± 0.01[b]
C18:3	3.19 ± 0.06[a]	1.63 ± 0.16[b]	1.72 ± 0.02[b]	1.54 ± 0.00[b]
SFA	26.07 ± 0.27[a]	22.83 ± 0.25[b]	20.91 ± 0.14[c]	23.16 ± 0.03[b]
MUFA	49.88 ± 0.11[a]	60.83 ± 0.45[b]	61.28 ± 0.27[b]	60.83 ± 0.04[b]
PUFA	24.06 ± 0.16[a]	16.35 ± 0.21[b]	17.81 ± 0.13[c]	16.01 ± 0.01[b]

Mean values in the same row with different letters are significantly different at $p < 0.05$

SFA saturated fatty acids, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids

Table 3 Triacylglycerol (TAG) composition of Hass avocado oil

TAG	Countries (%)			
	Australia	Mexico	New Zealand	United States
LLLn	0.83 ± 0.14[a]	0.51 ± 0.31[a]	0.49 ± 0.16[a]	0.98 ± 0.32[a]
LLL	0.27 ± 0.41[a]	0.17 ± 0.21[a]	0.16 ± 0.51[a]	0.33 ± 0.24[a]
LLO	6.44 ± 0.00[a]	4.61 ± 0.24[b]	3.31 ± 0.07[c]	5.49 ± 0.05[d]
LLP	2.99 ± 0.03[a]	1.50 ± 0.23[b]	1.23 ± 0.08[c,b]	2.54 ± 0.48[a,b]
PLPo	5.03 ± 0.06[a]	1.52 ± 0.19[b]	1.07 ± 0.05[b]	3.13 ± 1.39[a,b]
POL	6.31 ± 0.21[a,c]	7.81 ± 0.44[b]	6.74 ± 0.12[a,c]	9.60 ± 0.12[a]
POPo	11.54 ± 0.43[a]	7.38 ± 0.02[b]	7.36 ± 0.25[b]	6.89 ± 0.06[b]
PLP	6.96 ± 0.37[a]	5.05 ± 0.07[b]	2.42 ± 0.09[c]	7.24 ± 0.80[a]
PPPo	0.79 ± 0.29[a]	0.39 ± 0.19[a]	0.29 ± 0.26[a]	0.19 ± 0.02[a]
OOO	21.41 ± 0.27[a]	27.37 ± 0.23[b]	34.69 ± 0.03[c]	24.77 ± 1.36[d]
POO	19.65 ± 0.36[a]	24.68 ± 0.08[b]	21.61 ± 0.14[a,b,c]	23.05 ± 1.56[b,c]
POP	5.44 ± 0.17[a]	4.73 ± 0.04[a]	2.36 ± 0.06[a]	3.96 ± 0.25[a]
PPP	0.24 ± 0.18[a]	0.13 ± 0.10[a]	0.21 ± 0.10[a]	0.28 ± 0.14[a]
SOO	0.36 ± 0.37[a]	0.19 ± 0.10[a]	0.28 ± 0.01[a]	0.26 ± 0.04[a]
POS	0.11 ± 0.06[a]	0.23 ± 0.06[a]	0.10 ± 0.03[a]	0.06 ± 0.03[a]
Others[1]	11.66 ± 0.25	13.75 ± 0.04	17.73 ± 0.01	11.27 ± 0.02

Mean values in the same row with different letters are significantly different at $p < 0.05$

L linoleic acid, *O* oleic acid, *S* stearic acid, *P* palmitic acid, *Po* palmitoleic acid, *Ln* linolenic acid

[1] These are TAG peaks that are yet to be identified

with a higher saponification value indicates the existence of higher molecular weight triacylglycerols, and this suggests viability in the production of shampoo and liquid soap [19, 24].

Color is a fundamental parameter influencing the visual acceptance of the oil. The color of Hass avocado oil was expressed in terms of L^*, a^* and b^* values. From Table 1, the L^*, a^* and b^* values of New Zealand avocados were significantly greater ($p < 0.05$) than those of other origins examined. These indicate the oil produced from the New Zealand origin is lightest in color and contain more red and yellow pigments. The red and yellow pigments of the oils are constituted by carotenoids [27]. High readings of a^* and b^* values suggest the carotenoids content in the avocados of New Zealand origin is greater than those of other origins investigated.

Fatty Acid Composition

Table 2 shows the fatty acid composition of Hass avocado oil from different geographical origins. The predominant fatty acids in the Hass avocado oil were oleic acid

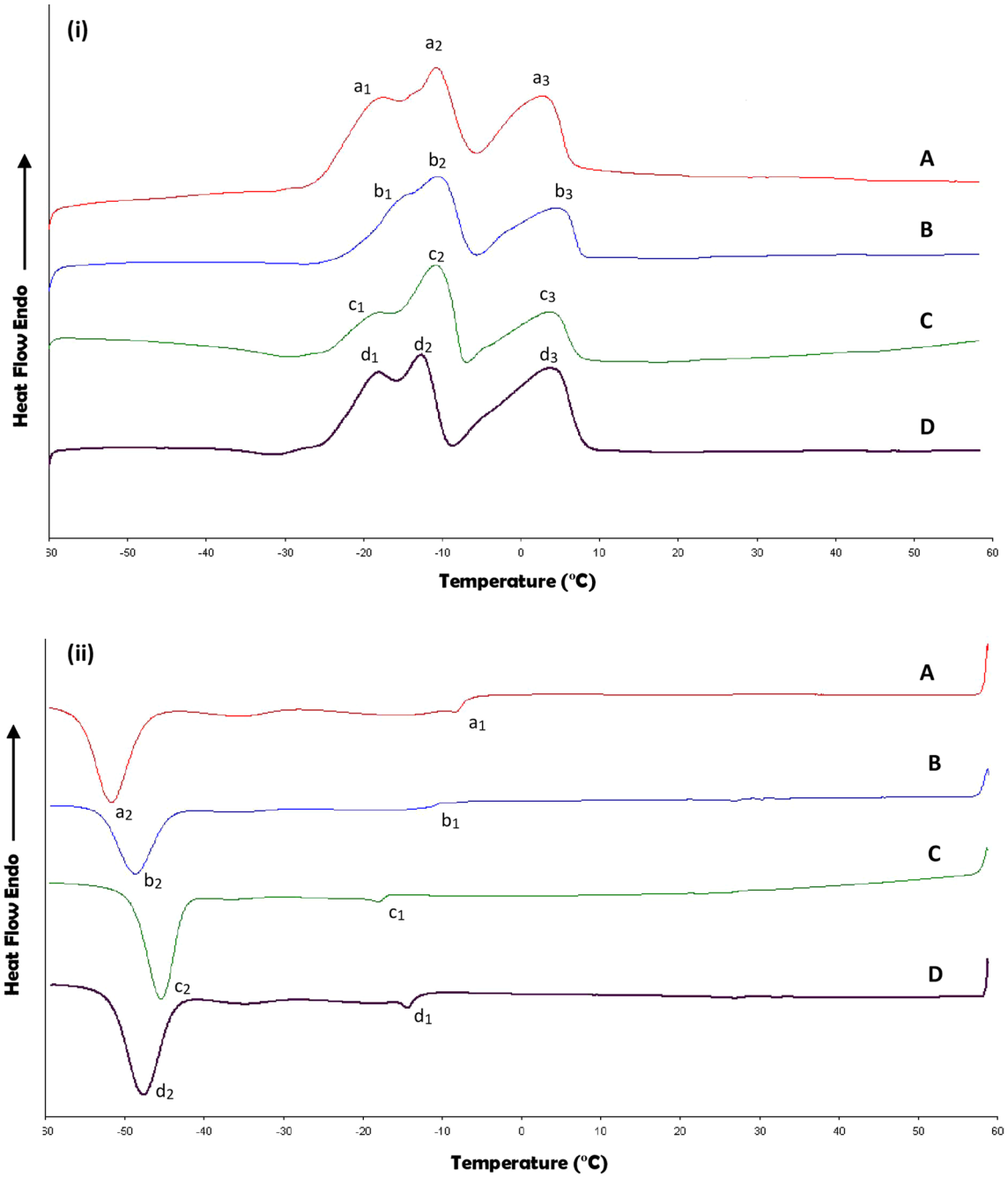

Fig. 1 Melting curves (**i**) and crystallization curves (**ii**) for Hass avocado oil from Australia (*A*), Mexico (*B*), New Zealand (*C*) and the United States (*D*) (color figure online)

(42.59–50.97%), followed by palmitic acid (20.61–25.63%) and linoleic acid (14.47–20.87%). The saturated fatty acids (SFA) of Hass avocado oil were low (< 30%), and the oil was mainly composed of unsaturated fatty acids such as monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). The proportional distributions of SFA, MUFA and PUFA of Hass avocado oil were affected by geographical origins. Compared to the other three origins examined, Hass avocado oil of Australian origin contained higher amounts of SFA and PUFA, but lower amounts of MUFA. Variation in the cultivation climate could account for the difference in the proportional distribution of fatty acids.

High oleic and linoleic acids plant oils could be used as salad oil or processed into margarine [19]. In addition, plant oils with high oleic acid contents are reported to have enough oxidative stability in domestic cooking applications

such as frying [19, 28]. The presence of high amounts of oleic (>40%) and linoleic (>14%) acids in the Hass avocado oil suggest its suitability as domestic cooking oil, besides being processed into other products such as margarine.

Triacylglycerol (TAG) Composition

The TAG composition of Hass avocado oil was characterized by using a reversed phase HPLC, in which the TAGs were separated according to the chain length and degree of unsaturation of the fatty acids [24]. The TAG composition of Hass avocado oil from different geographical origins is presented in Table 3. Within the experimental conditions used, fifteen TAG components have been identified in the Hass avocado oil. The trends of TAG components presented in the Hass avocado oil were unaffected by geographical origins and the most prominent TAGs were OOO (21.41–34.69%) and POO (19.65–24.68%). A trace amount of PPP (0.13–0.28%), the high melting tri-saturated TAG, was found in the Hass avocado oil. The TAG components in the Hass avocado oil were mainly constituted of di-unsaturated TAGs (38.29–45.88%) and tri-unsaturated TAGs (28.95–38.66%).

Melting and Crystallizing Characteristics

Melting and crystallization are two typical physical events used to characterize the thermal characteristics of oils. These physical events require the intake or release of thermal enthalpy and can be determined using a DSC [21]. In Fig. 1i, the melting curves of Hass avocado oil from the origins of Australia, Mexico, New Zealand and the United States are represented by curves (A), (B), (C) and (D), respectively. All the melting curves displayed three endothermic peaks, with a shoulder peak (a_1, b_1, c_1, and d_1) appeared at the initial point of the melting process, along with two well-separated major peaks (a_2, b_2, c_2, d_2 and a_3, b_3, c_3, d_3). As discussed, the TAG components in the examined Hass avocado oil were mainly composed of di- and tri-unsaturated TAGs (Table 3). These TAGs, also referred as low-melting TAGs, are high in degree of unsaturation and begin to melt at lower temperatures [21, 29]. The presence of shoulder peaks (a_1, b_1, c_1, and d_1) could possibly be due to unstable crystals in the low-melting TAGs, particularly the tri-unsaturated TAGs, which could have been prematurely melted. Meanwhile, the crystals of the more stable low-melting TAGs melted at higher temperatures, as indicated by peaks a_2, b_2, c_2 and d_2. The high-melting TAGs, such as tri-saturated and mono-unsaturated TAGs, contain a higher degree of saturation and the TAGs melt at the highest temperatures, as indicated by the peaks a_3, b_3, c_3 and d_3.

In Fig. 1ii, the crystallization curves of Hass avocado oil from the origins of Australia, Mexico, New Zealand and the United States are represented by the curves (A), (B), (C) and (D), respectively. All the crystallization curves displayed two exothermic peaks, with a small peak (a_1, b_1, c_1, and d_1) at the initial point of crystallization and a broader peak (a_2, b_2, c_2, d_2) at the end point of crystallization. During the crystallization process, the high-melting TAGs are crystallized first, successively followed by low-melting TAGs [21]. Thus, the small peak (a_1, b_1, c_1, and d_1) represents the high-melting TAGs whereas the broader peak (a_2, b_2, c_2, d_2) represents the low-melting TAGs. According to Table 3, the levels of tri-unsaturated TAG (LLLn, LLL, LLO and OOO) of New Zealand origin (38.66%) were greater than those of other origins examined (28.95–32.66%). Thus, the New Zealand origin oil crystallized completely at a much lower temperature at the end point of crystallization.

Conclusion

This study demonstrated that Hass avocado pulp was rich in lipid content. The fatty acid and TAG composition of Hass avocado oil were mainly constituted of unsaturated components. The proportional distributions of these unsaturated components were different with regard to the variation of geographical origins. In comparison to the Hass avocado oil of Mexico, Australia and United States origins, that of New Zealand origin contained a greater amount of unsaturated fatty acids and tri-unsaturated TAGs. As oil with a high degree of unsaturation could potentially be salubrious to human health, further study on the health properties of Hass avocado oil consumption is highly warranted.

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