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ORIGINAL PAPER

# *Yucca aloifolia* Seed Oil: A New Source of Bioactive Compounds

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**Abstract** *Yucca aloifolia* Linn (*Y. aloifolia*), also known as Spanish bayonet, is a drought-tolerant plant containing important bioactive compounds in various parts of the plant. *Y. aloifolia* is used as a natural medicinal herb. The purpose of the present study was to characterize and evaluate the seed oil extracted from *Y. aloifolia* seeds. The oil content of the seeds was 16.23%. The principal fatty acids in the oil were linoleic acid (73.38%), oleic acid (13.52%) and palmitic acid (8.18%). The oil has high vitamin E activity because of an appreciable concentration of tocols (204 mg/100 g), particularly tocotrienols, which represent 79% of the total amount of tocols. Tocotrienols have powerful antioxidant, anticancer, neuro/cardio protective and cholesterol-lowering properties. The thermal profile of *Y. aloifolia* seed oil was examined differential scanning calorimetry (DSC). *Y. aloifolia* seed oil is considered to be healthy dietary oil.

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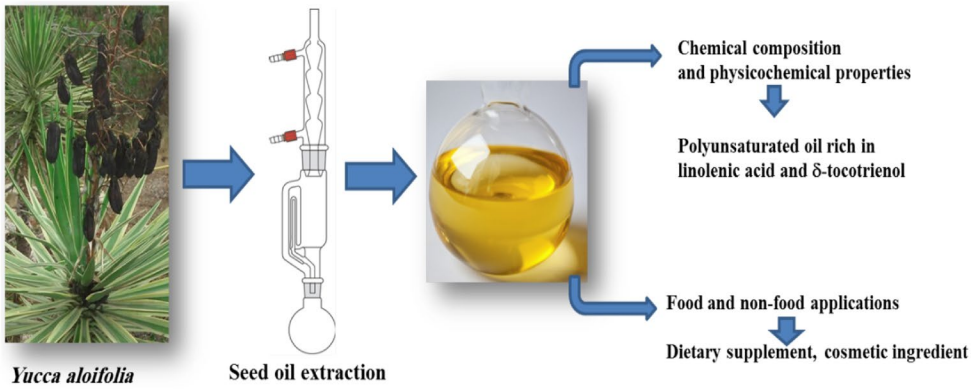
**Graphical Abstract**




**Keywords** *Yucca aloifolia* · Seed oil · Fatty acids · Tocotrienols · DSC · Health benefits

## Introduction

*Yucca aloifolia* Linn (*Y. aloifolia*), which is known as Spanish bayonet and *Aloe Yucca*, belongs to the Agavaceae family and is mostly adapted to arid conditions; the majority of Agavaceae species are xeromorphic and found as succulent rosette plants in desert regions [1]. The genus *Yucca* includes approximately 40 perennial shrubs and trees. These plants are native to the arid parts of North America, Central America, South America, and the Caribbean. The genus is found throughout Mexico and extends into Guatemala. *Yucca* plants have adapted to an equally vast range of climatic and ecological conditions throughout the world [1, 2]. Similarly to all *Yucca* species, *Y. aloifolia* is highly tolerant to drought, wind and salt. It is common in gardens in warm tropical regions. It thrives in any type of soil, including acidic, alkaline and sandy loam soil [3]. Spanish bayonet is a dense, upright, rhizomatous and evergreen shrub. It can reach a height of approximately 4.5 m, and its width depends on the degree of clumping. It has many stout, unbranched stems that can measure up to 10 cm in diameter [2]. *Y. aloifolia* can be cultivated in dry and arid non-arable lands [3]. The fruit, which are approximately 6–9 cm long, contains many seeds in the form of elliptical capsules. The fruit matures from summer into fall and does not open at maturity. The fruit is used as a purgative. The flowers contain aloifoline, and the seeds contain indole melanins. The leaves contain tigogenin (76%), sarsasapogenin, gitogenin, hecogenin, smilagenin, neotigogenin and samogenin [4]. Aloifoline is specifically active against Lewis lung tumor and transplanted mouse neoplasms. Several spirostanol saponin glycosides from rhizomes and inflorescence have been isolated [4]. The flat seeds occur in great numbers [2] are black and approximately 6 mm long and resemble small wafers. *Y. aloifolia* seeds contain unsaturated oil that can be used as a feedstock for biodiesel production [5].

This purpose of this study was to characterize *Y. aloifolia* seed oil as well as to provide information on its use in food and non-food applications and as a source of bioactive compounds. The results will be compared with those of the common olive oil.

## Materials and Methods

### Plant Material and Seed Oil Extraction

*Yucca aloifolia* fruits were collected in June 2013 from several shrubs located in Tunis (Tunisia) at latitude 24°48′41.44″N, longitude 46°49′04.13″E at an altitude of 586 m. Identification and confirmation were conducted by Dr. Jacob Thomas Pandalayil (Botany and Microbiology Department, Science College, King Saud University). A voucher specimen (no. KSU-22,534) was deposited at the Herbarium of the Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 1145, Saudi Arabia. The *Y. aloifolia* seeds were removed from the fruit, oven-dried at 60 °C for 24 h and ground into a fine powder using a high-speed miller. Seed oil extraction was performed using the Soxhlet method [6]. The Tunisian first cold-pressed olive oil (Rahma, Sousse, Tunisia, Lot 16,003, PD 02/16, ED 01/18) oil was purchased from local market.

### Analytical Methods

All analyses were performed in triplicate. The values of the various parameters were expressed as the mean plus or minus the standard deviation ($x \pm SD$).

### Seed Analysis

The weight of the oil extracted from 40 g of the seed powder was determined to calculate the lipid content. The ash content was determined by the incineration of approximately 2 g of powdered seeds in a porcelain crucible in a muffle furnace at 550 °C for 12 h until a gray ash was obtained. The moisture content was determined after oven drying approximately 2 g of ground seeds at 105 °C for 24 h.

### Seed Oil Analysis

*Fatty Acid Composition*

Fatty acid methyl esters (FAMEs) were prepared from the oil samples according to a previously described laboratory protocol [6] for quantitative analysis. A 1 µL aliquot of the prepared FAMEs was injected into a GC–MS (QP2010 Ultra, Shimadzu, Japan) chromatograph equipped with mass spectrometer quadrupole (QP2010) detector and an Rxi-5Sil MS column (30 m x 0.25 mm i.d., 0.25 µm film thickness). The carrier gas was He, which was supplied at a flow rate of 1.50 mL/min. The oven temperature was ramped from 150 to 180 °C at a rate of 15 °C/min, followed by an increase to 210 °C at 1 °C/min. The temperatures of the injector and detector were 220 and 275 °C, respectively. The MS was operated in electron ionization mode at 70 eV. The GC-MS solution integrated software (Shimadzu Cat. No. 225-21731-92) was used for the chromatogram analysis. The NIST11 mass spectral library of the GC/MS system and the NIST analysis software were also used for the interpretation of the mass spectra and the identification of each fatty acid methyl ester. Every peak of unknown FAME was identified by comparing them to the retention times of authentic standards of FAMEs (Sigma Chemical Co., St Louis, MO, USA).

*Tocol Composition*

The tocol content was determined according to the standard ISO 9936 procedure. A 0.5 g aliquot of extracted oil was dissolved in 25 mL of hexane, and 20 mL of the solution was manually injected into an HPLC (LC-20AT pump, Shimadzu, Kyoto, Japan) on a Hypersil silica column (15 cm x 3 mm I.D., 3 µm particle size; Thermo Scientific). Tocol separation was achieved by means of the isocratic elution with hexane/2-propanol (99.5:0.5; v/v) at a flow rate of 0.5 mL/min. The fluorescence detector was set at a 295 nm excitation wavelength and a 330 nm emission wavelength.

*Physicochemical Properties*

The peroxide value and acidity were determined by the official ISO 3960 and ISO 660 standard methods, respectively. The refractive index was determined using an Abbe refractometer (Bellingham and Stanley Ltd, Kent, England).

The iodine value was calculated based on the $^{1}$H NMR spectrum of the seed oil [7]. The average calculated molecular weight was determined by a weighted average method utilizing the fatty acid composition (Table 2) and the molecular weight of each fatty acid. The chlorophyll and carotenoid contents were determined according to the method described by Nehdi et al. [7].

*Thermal Analysis*

The thermal properties were analyzed by differential scanning calorimetry (DSC). A PerkinElmer Diamond DSC differential scanning calorimeter, equipped with Pyris data analysis software (PerkinElmer Corp., Norwalk, CT), was used. Nitrogen (99.999% purity) was the purge gas and flowed at 20 mL/min. Samples of 3–5 mg were weighed into aluminum pans to the nearest 0.1 mg, and covers were hermetically sealed into place. An empty, hermetically sealed aluminum pan was used as a reference. Prior to the analysis of the samples, the baseline was obtained with an empty, hermetically sealed aluminum pan.

## Results and Discussion

### Tocol Composition

Of the eight isomeric forms of vitamin E, *Y. aloifolia* seed oil contained five isomers: α-tocopherol, β-tocopherol, γ-tocopherol, γ-tocotrienol, and δ-tocotrienol (Table 1). The major isomers present are δ- and γ-tocotrienols at a concentration of 129.58 mg/100 g and 31.37 mg/100 g, respectively. The content of α- and γ- tocopherols is approximately 43 mg/100 g. *Y. aloifolia* oil has a tocol content of 203.94 mg/100 g, about

**Table 1** Tocol contents (mg/100 g) of *Y.aloifolia* and olive oils

| Tocols (mg/100 g) | *Y. aloifolia* oil | Olive oil |
|---|---|---|
| α-Tocopherol | 21.97 ± 0.46 | 21.65 ± 0.35 |
| β-Tocopherol | 0.36 ± 0.06 | 0.80 ± 0.05 |
| γ-Tocopherol | 20.66 ± 0.50 | 0.85 ± 0.06 |
| δ-Tocotrienol | – | 0.08 ± 0.01 |
| γ-Tocotrienol | 31.37 ± 0.66 | – |
| δ-Tocotrienol | 129.58 ± 1.95 | – |
| Total tocols | 203.94 | 23.39 |

nine times higher than this of olive oil (23.39 mg/100 g). Tocotrienols are considerably less widespread in the plant kingdom than tocopherols [8]. Compared to tocopherols, the antioxidant capacity of the tocotrienol family is believed to be more potent [9]. Indeed, tocotrienol was significantly more effective than α-tocopherol alone in inhibiting oxidative damage to lipids in isolated mitochondria from rats [10]. Due to the amount of unsaturation in these molecules, tocotrienols increase the curvature stress on phospholipid membranes [11]. Additionally, the unsaturated side chain of tocotrienol also enables more efficient penetration into tissues that have saturated fatty layers, such as the brain [12]. Parker et al. [13] found that tocotrienol suppresses the activity of 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase, which is the hepatic enzyme responsible for cholesterol synthesis. Furthermore, tocotrienols, but not tocopherols, have been shown to suppress the growth of human breast cancer cells [14]. Finally, *Y. aloifolia* seed oil can be used as a dietary supplement containing tocotrienols to prevent many diseases.

## Fatty Acid Composition

Figure 1 showed the fatty acid methyl esters chromatogram of *Y. aloifolia* seed oil. The fatty acid composition of the *Y. aloifolia* seed oil is shown in Table 2. GC/MS analysis indicated that *Y. aloifolia* seed oil was unsaturated oil. Indeed, linoleic acid (LA) (C18/2) was found to be the major acid at 73.38%. Other fatty acids found in large amounts were oleic acid (13.52%) and palmitic acid (8.18%). cis-Vaccenic acid and stearic acid were found in smaller amounts (1.39% and 2.26%, respectively).

Linoleic acid is an essential fatty acid for proper health. A dietary deficiency in LA causes skin problems such as dryness and roughness [6] as well as hair loss [15]. Oils rich in LA showed anti-inflammatory, acne reductive, and moisture retention properties [16–18]. Therefore, *Y. aloifolia* seed oil can be applied topically and used as an ingredient in beauty products.

Furthermore, *Y. aloifolia* seed oil was characterized by a high polyunsaturated/saturated (PUFA/SFA) ratio of 6.15, which was superior to that of olive oil (0.99). This low PUFA/SFA ratio of olive oil is due to its low LA content (17.78%) compared to this of *Y. aloifolia* oil (73.73%). A high ratio of PUFA/SFA is favorable for the prevention of

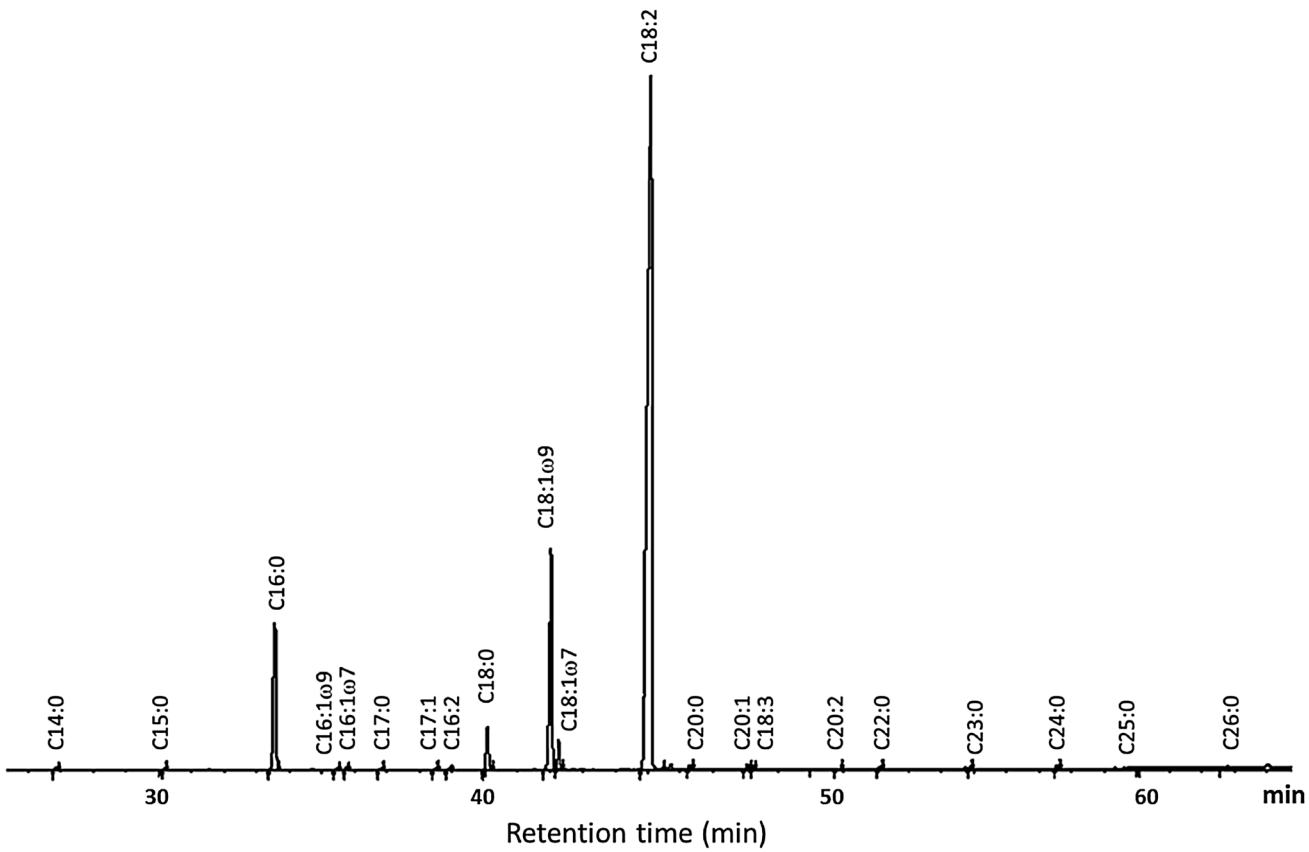



**Fig. 1** Fatty acid methyl esters chromatogram of *Yucca aloifolia* oil

**Table 2** Fatty acid compositions (%) of *Y. aloifolia* and olive oils

| Fatty acid | Common name | *Y. aloifolia* oil fatty acid composition content (%) | Olive oil fatty acid composition content (%) |
|---|---|---|---|
| C14:0 | Myristic acid | 0.11 ± 0.03 | – |
| C15:0 | | 0.02 ± 0.01 | – |
| C16:1(ω7) | | 0.14 ± 0.03 | 1.98 ± 0.07 |
| C16:1 (ω9) | Palmitoleic acid | 0.05 ± 0.01 | 0.07 ± 0.01 |
| C16:0 | Palmitic acid | 8.18 ± 0.21 | 15.18 ± 0.32 |
| C17:0 | Margaric acid | 0.04 ± 0.01 | 0.04 ± 0.01 |
| C16:2(ω6) | | 0.04 ± 0.01 | – |
| C17:1(ω7) | | 0.02 ± 0.01 | 0.08 ± 0.01 |
| C18:3(ω3) | Linolenic acid | 0.18 ± 0.03 | 1.07 ± 0.05 |
| C18:2(ω6) | Linoleic acid | 73.38 ± 0.52 | 17.78 ± 0.48 |
| C18:1(ω9) | Oleic acid | 13.52 ± 0.41 | 56.35 ± 0.62 |
| C18:1 (ω7) | cis-Vaccenic acid | 1.39 ± 0.04 | 3.48 ± 0.11 |
| C18:0 | Stearic acid | 2.26 ± 0.04 | 2.96 ± 0.09 |
| C20:2(ω6) | | 0.02 ± 0.01 | – |
| C20:1(ω9) | Eicosenoic acid | 0.25 ± 0.01 | 0.23 ± 0.01 |
| C20:0 | Arachidic acid | 0.16 ± 0.02 | 0.55 ± 0.06 |
| C22:0 | Behenic acid | 0.11 ± 0.02 | 0.15 ± 0.02 |
| C23:0 | Tricosilyc acid | 0.09 ± 0.02 | – |
| C24:0 | Lignoceric acid | 0.14 ± 0.02 | 0.08 ± 0.02 |
| C25:0 | Pentacosylic acid | 0.02 ± 0.01 | – |
| C26:0 | Cerotic acid | 0.02 ± 0.01 | – |
| ΣSFA | | 10.56 | 18.96 |
| ΣUFA | | 89.43 | 81.04 |
| ΣMUFA | | 24.42 | 62.19 |
| ΣPUFA | | 65.01 | 18.85 |
| ΣUFA/Σ SFA | | 8.46 | 4.27 |
| ΣPUFA/Σ SFA | | 6.15 | 0.99 |

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

heart disease and the reduction of serum cholesterol and atherosclerosis [19].

## Physicochemical Properties

Table 3 shows the physico-chemical properties of *Y. aloifolia* seeds and seed oil. *Y. aloifolia* contained 8.71% moisture, 2.69% ash, and 16.23% oil on a dry weight basis. The seed oil content was similar to that of *Washingtonia filifera* seeds (16.30%) [20]. The acidity of *Y. aloifolia* seed oil (11%) was relatively high, compared to that of olive oil (0.70%), probably due to a hydrolysis reaction. Before it is suitable for human use, crude *Y. aloifolia* oil must be refined to decrease the amount of free fatty acids. Crude olive oil is among the few vegetable oils that can be consumed in the raw state. The low peroxide value of the *Y. aloifolia* oil (3.92) showed that the oxidation of the oil was negligible. Furthermore, the high iodine value (154.81) and refractive index (1.4709) of *Y. aloifolia oil*, compared to those of olive oil, are correlated with the fatty acid composition (Table 2). Indeed, *Y. aloifolia* oil is polyunsaturated oil rich in LA (73.38%), however, olive oil is a monounsaturated oil rich in oleic and cis-vaccenic acids (59.83%).

*Y. aloifolia* seed oil could be considered as a drying oil for use in the paint and varnish industry. It is similar to safflower and nut oils in that it has a high iodine value (135–151) [21]. The chlorophyll and carotenoid concentrations in *Y. aloifolia* seed oil were low, similar to most fats and oils. Chlorophylls have a very significant impact on the oxidative stability of an oil; however, the protective action of beta-carotene against the deleterious effects of radiation on light sensitized cells has been well recognized [22] (O`Brien, 2009). Pigment concentrations in *Y. aloifolia* seed oil were comparable to that of *Tecoma stans* [23] and *Chaemarops humilis* [7] seed oils.

**Table 3** Physicochemical properties of *Y.aloifolia* oil compared to those of olive oil

| Parameter | Unit | *Y. aloifolia* oil | Olive oil |
|---|---|---|---|
| Seeds | | | |
| Ash (dry matter) | % | 2.69 ± 0.10 | – |
| Moisture content | % | 8.71 ± 0.15 | – |
| Yield | % (w/w) | 16.23 ± 0.20 | – |
| Seed oil | | | |
| Refractive index (21 °C) | | 1.4709 ± 0.006 | 1.4678 ± 0.004 |
| Peroxide value | meq $O_2$/kg oil | 3.92 ± 0.20 | 2.95 ± 0.08 |
| Free fatty acid | as oleic % | 10.99 ± 0.13 | 0.70 ± 0.05 |
| Iodine value | g/100 g oil | 154.81 ± 0.78 | 87.24 ± 0.18 |
| Molecular weight | g/mol | 863.38 ± 0.85 | 871.93 ± 0.46 |
| Color | | Yellow | Green |
| State at ambient temperature | | Liquid | Liquid |
| Chlorophylls | mg/kg | 0.83 ± 0.05 | – |
| Carotenoids | mg/kg | 1.005 ± 0.06 | – |

## Thermal Properties

The DSC curves for the *Y. aloifolia* seed oil are given in Fig. 2. The crystallization curves have two exothermic peaks. In the cooling profile, *Y. aloifolia* seed oil crystallized at −37.25 and −16.71 °C. The melting curves consisted of two peaks. One major endothermic melting peak was exhibited as a single, followed by a small peak at −29.75 °C and at −15.73 °C, respectively. The large endothermic peak is attributed to the melting of triacylglycerol (TAG) with a combination of unsaturated fatty acids such us trilinolein and dilinoeoyl-oleoyl-glycerol. However, the

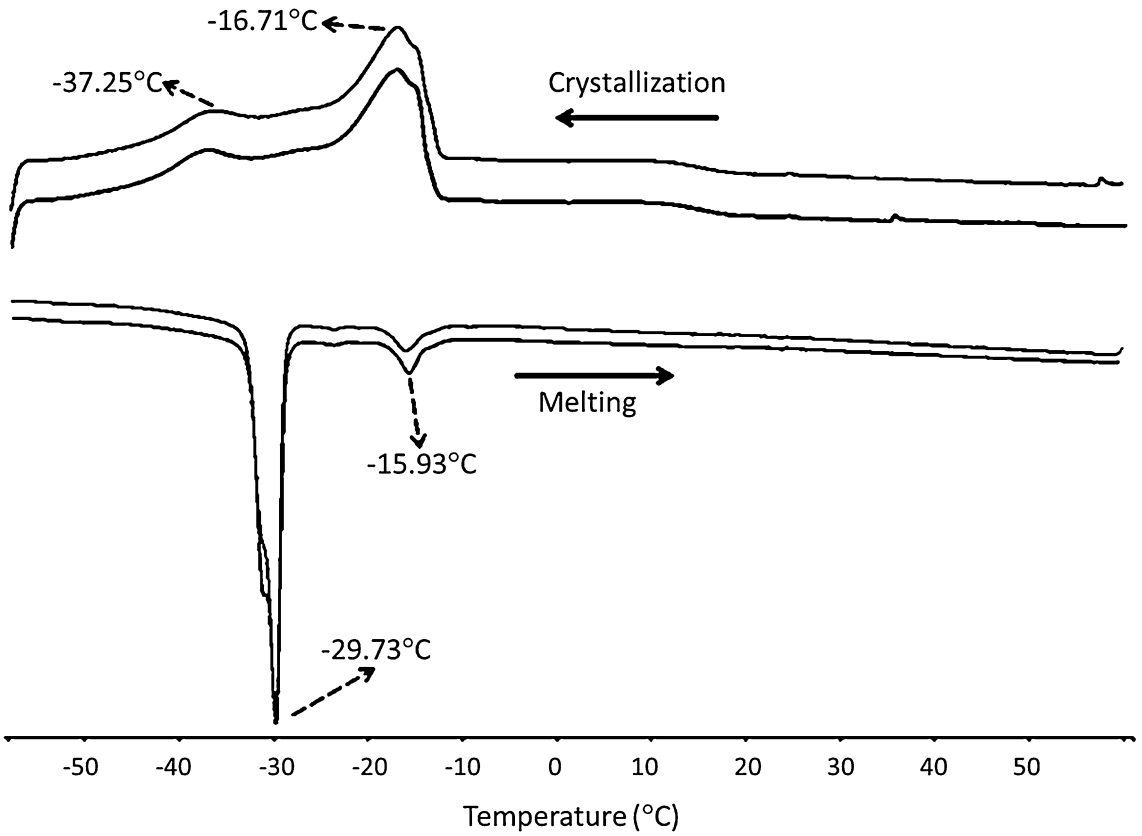



**Fig. 2** Cristallization and melting curves of *Y.aloifolia* seed oil

small endothermic peak may be ascribed to the melting of TAG with a combination of unsaturated and saturated fatty acids in the glycerol moiety, such as palmitoyl-dilinoleoyl-glycerol and palmitoyl-linoleoyl- oleoyl-glycerol.

## Conclusions

This study showed that *Y. aloifolia* seed oil is polyunsaturated oil high in LA (73.38%). This essential fatty acid showed moisture retentive, anti-inflammatory and acne reductive properties. Additionally, the high ratio of polyunsaturated to saturated fatty acids (6.15) is considered to be healthy. Furthermore, *Y. aloifolia* oil is a natural source of tocotrienols that possesses powerful neuroprotective, hypocholesterolemic and anti-cancer properties. *Y. aloifolia* seed oil can be considered functional oil that has beneficial effects on long-term human health and can be used effectively to treat human diseases. *Y. aloifolia* seed oil can also be used for cosmetics or in other technical applications. This current investigation expands our knowledge of the potential uses for this new plant seed oil.

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