Chapter 17
Avocado (*Persea americana* Mill.) Oil

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Abstract Avocado oil is growing in popularity as a source of specialty oil with health-promoting properties. Unlike typical fruit oils, avocado oil is extracted from the pulp instead of the seed and can be consumed in its crude form without the necessity of refining. The oil can be graded into extra virgin, virgin or pure, depending on the extraction methods and conditions. Over the last decades, several methods have been developed on avocado oil extraction and these methods are summarized and discussed. The intake of avocado oil is recommended in order to gain the full benefit of essential nutrients and health-promoting minor bioactive lipids that they contain, along with their desirable aroma and taste. Lately, much interest in the health benefits of avocado oil has led to numerous animal and human intervention studies. The therapeutic effects and other issues associated with avocado oil such as oxidative stability, authenticity and toxicity, are also compiled and highlighted.

Keywords Avocado oil · *Persea americana* · Functional oil

1 Introduction

Avocado (*Persea americana* Mill.) is an evergreen dicotyledonous plant from the Lauraceae family, which encompasses approximately 45 genera and 2850 species (Christenhusz and Byng 2016). The avocado plant has been cultivated in Central America since the pre-Columbian period. The plant grows in tropical or sub-tropical countries and can reach up to 30 m height when fully grown. The leaves are 15–25 cm long with well-developed petioles that are spirally arranged near the branch ends (Afahkan 2012). More than 500 varieties of avocado have been identified and the fruiting seasons vary according to the variety (Yahia and Woolf 2011). Avocado fruit begins to ripen once it is detached from the tree. The largest avocado

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fruit producing country in 2016 was Mexico (1889 thousand tons), followed by Dominican Republic (601 thousand tons) and Peru (455 thousand tons) (FAO 2017).

An avocado fruit can be divided into three anatomical parts, namely, peel, pulp and seed. The edible yellowish pulp constitutes the largest proportion of the fruit (65%) whereas the peel (15%) and the seed (20%) constitute the rest (Costagli and Betti 2015). Unlike typical fruits with acidic and/or sweet taste, avocado pulp has a smooth and butter-like consistency taste. It has been reported that avocado pulp contains abundant amounts of lipids and essential minerals like calcium, phosphorus, magnesium and potassium (USDA 2011). Owing to a high lipid content (15–36%) in the pulp (Maitera et al. 2014; USDA 2011), avocado fruit is also known as 'butter fruit' and 'vegetable butter'.

Plants with high amounts of lipids in either the pulp nor the seed can serve as an important raw material for edible oil extraction. One of the industrial usages of avocado fruit is the production of avocado oil from its fleshy pulp. Unlike other plant oils, avocado oil is extracted from the pulp instead of the seed as the seed contains hepatotoxic agents and a small quantity of oil (<2%) (Qin and Zhong 2016). Recently, avocado oil has been promoted as functional oil because of its high concentrations of oleic monounsaturated fatty acid and minor bioactive lipids, which are associated with human health.

2 Proximate Composition of Avocado Pulp

The proximate composition of avocado pulp has been reported by the United States Department of Agriculture (USDA 2011) as follows: moisture, 72.33%; crude oil, 15.41%; crude protein, 1.96%; dietary fiber, 6.80%; ash, 1.66%; carbohydrate (by difference), 8.64%. The oil content is comparable to the levels reported by Bora et al. (2001) while Maitera et al. (2014) reported a higher oil content (36.40%) in the pulp of avocado fruit grown in the tropical region of Nigeria.

3 Extraction and Processing of Avocado Oil

The initial step in avocado oil production involves peeling and destoning of the ripe fruit. Avocado pulp has a moderately uniform cellular composition, consisting of thin-walled parenchyma cells and thick-walled polyhedral- or round-shaped idioblast cells (Fig. 17.1). The latter are evenly distributed and are surrounded by parenchyma cells in a circular arrangement. The parenchyma cells contain finely dispersed oil emulsion whereas the idioblast cells contain a large droplet of oil sac (Qin and Zhong 2016). Both are the oil-bearing cells in the avocado pulp. Depending on the extraction method used, the avocado pulp may need to be dehydrated first before it is subjected to oil extraction. Avocado oil can be used in the crude form without the

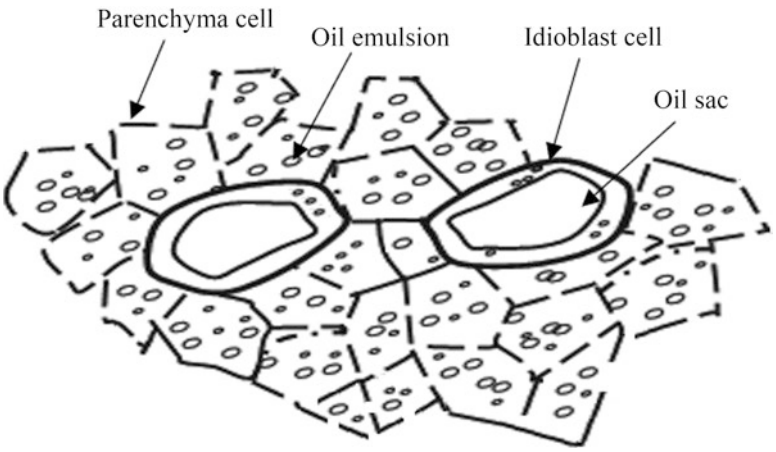

Fig. 17.1 Cellular structure of avocado pulp

Table 17.1 Classifications of avocado oil

	Extra virgin	Virgin	Pure
Fruit properties	Healthy or fruit with minor levels of physiological disorders and rots	Healthy or fruit with some levels of physiological disorders and rots	NR
Extraction conditions	Natural or mechanical approaches at temperatures <50 °C and without undergoing refining	Natural or mechanical approaches at temperatures <50 °C and without undergoing refining	NR
Flavor and odor	>40% grassy and mushroom or butter with some smoky	>20% grassy and mushroom or butter with some smoky	Bland or matches description of flavor
Oil color	Intense green	Green or yellow	Pale yellow
Smoke point (°C)	≥250	≥200	≥250
Acid value (%)	≤1.0	≤2.0	≤0.2
FFA (% oleic acid)	≤0.5	0.8–1.0	≤0.1
PV (meq O_2/kg)	≤4.0	<8.0	<0.5
Stability[a] (months)	24	18	>24

Woolf et al. (2009)
NR Not reported, *FFA* free fatty acids, *PV* peroxide value
[a]Stability: the oil flushed with nitrogen and stored in the dark area at ambient temperature

necessity of refining and can be graded into extra virgin, virgin or pure, depending on the extraction methods and conditions (Table 17.1). A number of studies demonstrating the extraction and processing of avocado oil have been undertaken and these are outlined below.

3.1 Solvent Extraction

Solvent extraction is the most common technique used at the laboratory scale to extract avocado oil. This method involves the use of heat or agitation. Organic solvents that have been used are typically nonpolar (e.g. hexane and petroleum ether) and/or alcohol-based (e.g. ethanol, isopropanol and acetone). According to Ortiz et al. (2004), the idioblast cells of avocado pulp became irregularly shaped and rough-surfaced after oil extraction with hexane. In contrast, deformation of the cellular structure occurred and most of the oil held inside the idioblast cells when acetone was used to extract oil. These observations imply the extraction efficacy of avocado oil is strongly dependent on the choice of organic solvents. Meanwhile, Mostert et al. (2007) reported that avocado oil extracted using hexane contained large amounts of non-triacylglycerol components such as gums, phospholipids and waxes.

Solvent extraction using a Soxhlet extractor, also known as Soxhlet extraction, is a standard technique for analyzing the lipid content in foods and the main reference method for evaluating the performance of new oil extraction alternatives (Wang and Weller 2006). Soxhlet extraction outperforms other conventional extraction techniques except for, in a limited field of applications, the extraction of thermolabile bioactive compounds (Azmir et al. 2013). The Association of Official Analytical Chemists (AOAC) official method for extraction of crude avocado oil has been applied in many studies (Abaide et al. 2017; Mostert et al. 2007; Tan et al. 2018a; Yanty et al. 2011). This standardized method extracts avocado oil using either petroleum ether or hexane in a Soxhlet apparatus for 8–12 h at 60–70 °C before recovering the oil using evaporation. Soxhlet extraction has been used to determine the theoretical maximum overall extraction yield of avocado oil (Corzzini et al. 2017).

Santana et al. (2015) employed an agitation-based solvent method to extract avocado oil. They mixed dried avocado pulp with the solvent [ethanol at 60 °C and pulp-to-solvent ratio of 1:4 (w/w) or petroleum ether at 45 °C and pulp-to-solvent ratio of 1:3 (w/w)] and agitated the mixture using a shaking water bath for an hour, followed by oil recovery using evaporation. Their study showed that the use of petroleum ether was capable of extracting a greater amount of oil yield than ethanol. However, this disagrees with Gatbonton et al. (2013), who reported that the use of alcohol-based organic solvents was better able at extracting a greater oil yield compared to the use of nonpolar organic solvents. The differences might be attributable to the extraction conditions such as extraction temperature and time.

Solvent extraction in oil manufacturing is acknowledged by the US Environmental Protection Agency (US EPA) as being the main contributor to hazardous air pollution (Gunstone 2011). The National Emission Standards for Hazardous Air Pollutants (NESHAP) for oil production has since been established. Moreover, the oil derived from solvent extraction contain residual solvent, which indicates the need of a refining step for further applications such as edible oil, cosmetic and pharmaceutical uses (Yahia and Woolf 2011).

3.2 Expeller Pressing

Expeller pressing is a mechanical approach to extracting oil from plant materials. This method is widely adopted in extracting oil from plant materials with high oil content such as peanut, flax seed, sunflower seed, palm kernel and cottonseed (Gunstone 2011). Traditionally, the high moisture content of avocado pulp is dehydrated first before it is subjected to expeller pressing using a screw press device (Southwell et al. 1990). A screw press device consists of a barrel made of narrowly spaced bars, in which a worm shaft rotates and presses the plant materials (Chapius et al. 2014). This device utilizes the continuous pressure and friction from the screw drives to compress the avocado pulp through a caged barrel-like cavity. Avocado oil is then expelled and seeps through the small openings into a container. Santana et al. (2015) reported the yield of avocado oil obtained from screw pressed was in the range of 55.7–61.2%. Frictional heat is generated when the worm shaft slides against the extracted materials and this might affect the quality of the extracted oil (Chapius et al. 2014).

3.3 Centrifugation

Centrifugation involves the application of centrifugal force to separate a suspension or mixture of liquid and solid particles into the supernatant and pellet through spinning. Extraction of avocado oil using this approach was first reported by Werman and Neeman (1987). They combined raw avocado pulp with water at a ratio of 1:3 (w/w) and agitated the mixture under different conditions [temperatures (25–85 °C), pH (4.5–8) and sodium chloride solution (0–8%)] for 30 min. Then, they centrifuged the mixture to obtain the top oil layer. The highest oil yield was obtained under the optimum conditions of 75 °C, pH 5.5 and the addition of 5% sodium chloride solution.

Based on the centrifugation method described above, Bizimana et al. (1993) examined the interrelationships between factors such as pulp-to-water ratio (1:3–1:5, w/w), temperatures (75–98 °C), pH (4–5.5), types (calcium carbonate, calcium sulfate, calcium chloride and sodium chloride) and concentrations (5–20%) of inorganic salt solutions and centrifugal forces (6000–12,300 g) on avocado oil yield. Their study showed the addition of calcium carbonate, calcium sulfate or sodium chloride solutions at concentrations ranging between 5% and 15% was capable of increasing the oil yield. The researchers advocated the necessity to limit the usage of inorganic salt solutions at 5% level as prolonged use of high concentrations (>5%) of inorganic salt solutions can lead to equipment corrosion. Thus, in this case, optimum conditions with highest oil yield were 1:5 (w/w) of pulp-to-water ratio, 98 °C, pH 5.5, addition of 5% inorganic salt (calcium carbonate, calcium sulfate or sodium chloride) solutions and centrifugal force of 12,300 × g.

In the late 1990s, Alfa Laval cooperated with a food company in New Zealand to develop a new method for the extraction of avocado oil using cold-pressing (Costagli and Betti 2015). The method was based on the modifications of existing cold-pressing olive oil method, whereby the extraction is carried out at low temperatures (<50 °C) and without the use of inorganic salts, enzymes or organic solvents (Wong et al. 2005). A 3-outlet decanter centrifuge is used to separate the malaxed avocado paste into oil, water and defatted solid cake. The recommended malaxing time and temperature for production of cold-pressed avocado oil were less than 50 °C and 90 min, respectively (Costagli and Betti 2015). The time and temperature used in malaxing avocado paste are longer than for olive paste due to the presence of finely dispersed emulsion in the avocado pulp cells.

3.4 Enzymatic Extraction

Enzymes are macromolecular biological catalysts. Addition of enzymes to plant-based oil bearing materials before or during oil extraction facilitates the degradation of cell wall components and hydrolysis of the structural polysaccharides and lipid bodies, thereby enhancing oil recovery. Due to the structural complexity of plant materials, the efficacy of enzymatic oil extraction is affected by numerous factors such as concentration and composition of enzymes, particle size and moisture content of the plant materials, pH, temperature, hydrolysis time and the solid-to-solvent ratio (Azmir et al. 2013).

Previously, enzymatic extraction of avocado oil has been carried out in three different ways, namely, aqueous enzymatic extraction, enzyme-assisted solvent extraction and enzyme-assisted expeller pressing (Buenrostro and López-Munguia 1986; Santana et al. 2015). Aqueous enzymatic extraction of avocado oil using different commercial enzymes (cellulase, α-amylase, pectinase and protease) was reported by Buenrostro and López-Munguia (1986). They added 1% of the enzymes separately to diluted avocado paste and incubated at 40 °C for an hour before recovering the oil by centrifugation. Their study showed the addition of 1% of α-amylase drastically increased the avocado oil yield compared with other enzymes studied and the negative control. Later, Santana et al. (2015) proposed the use of enzyme-assisted solvent extraction and enzyme-assisted expeller pressing of avocado oil. In their study, pectinase (0.05%) was added to the avocado paste before drying (45–60 °C) to constant weight. The researchers reported that the addition of enzyme to the pulp followed by solvent extraction or expeller pressing did not enhance the oil yield.

3.5 Ultrasonic Extraction

Ultrasound is a type of acoustic waves with frequencies greater than 20 kHz, which is above the threshold of human hearing range. It creates compression and expansion cycles when passing through a solid, liquid or gaseous medium. In liquid

medium, the expansion cycle generates bubbles and produces intensive localized pressure. The bubbles undergo implosive collapse once they have expanded to a certain degree. This process produces a phenomenon known as cavitation, which is capable of degrading the wall of the oil-bearing cells and the structure of the oil emulsion, thereby releasing their intracellular components into the extracting solvent (Tan et al. 2018a). The efficacy of ultrasonic oil extraction is influenced by numerous factors such as particle size and moisture content of plant materials, sonication conditions (temperatures, time and frequencies) and the choices of extracting solvents (Azmir et al. 2013).

Reddy et al. (2012) reported on the ultrasound-assisted solvent extraction of avocado oil where they sonicated avocado pulp with hexane in an ultrasonic bath at 60 °C for an hour. The oil was then recovered using evaporation. Tan et al. (2018a) introduced ultrasound-assisted aqueous extraction of avocado oil. The researchers added water to the avocado powder at various ratios and sonicated the mixtures in an ultrasonic bath under different conditions [temperature (20–40 °C) and time (10–30 min)], followed by expeller pressing and centrifugation to obtain the top oil layer. The highest oil yield was obtained under the optimum conditions of 6 mL/g of water-to-powder ratio, 35 °C of sonication temperature and 30 min of sonication time. Extraction of avocado oil under the optimum conditions of ultrasound-assisted aqueous extraction yielded 73% of the oil obtained using Soxhlet extraction.

The application of ultrasound in malaxed and non-malaxed avocado paste in avocado oil extraction was investigated by Martínez-Padilla et al. (2018). Their study showed that low (18 + 40 kHz) and high (2 MHz) frequencies ultrasound increased the oil yield obtained after centrifugation.

3.6 Supercritical Fluid Extraction

Supercritical fluid extraction is a unitary mass transfer operation involving the use of a fluid at a temperature and pressure above its critical point. The critical point is the point where pressure and temperature for any fluid become identical or supercritical. A basic supercritical fluid system consists of a tank of the mobile phase, a pump to pressurize the gas, a controller to regulate the pressure inside the system, co-solvent vessel and pump, an oven that contains the extraction vessel and a trapping vessel (Azmir et al. 2013). The efficacy of supercritical fluid oil extraction is affected by several factors like the choices of supercritical fluids, extraction conditions (temperature, pressure and time) and plant materials preparation (Wang and Weller 2006).

Supercritical carbon dioxide (CO_2) extraction of avocado oil at different temperatures (37–81 °C) and pressure (350–532 atm) was examined by Botha and McCrindle (2004). Their study showed the oil yield increased with increasing pressure and temperature. After 120 min of supercritical CO_2 extraction, the highest oil yield was obtained at operating temperature and pressure of 81 °C and 532 atm, respectively. Mostert et al. (2007) also reported on the extraction of avocado oil using supercritical CO_2 at 37 °C and 35 atm for an hour. These conditions yielded 83–90% of the oil obtained with Soxhlet extraction.

A two-step supercritical fluid extraction of avocado oil was reported by Corzzini et al. (2017). This is a sequential oil extraction method and each stage utilizes solvent with different polarity. Utilization of solvents with different polarities during oil extraction exploits the different solubilities of lipid components, thereby increasing the oil yield. The solvents used for the first and the second stages of the two-step supercritical fluid extraction of avocado oil were CO_2 and ethanol-CO_2 mixtures, respectively. The overall extraction time was 4.5 h, where the extraction time for the first stage was 3 h and the second stage was 1.5 h. When conducted at 400 bar and 60 °C or 80 °C, this extraction method yielded 98% of the oil obtained with Soxhlet extraction (Corzzini et al. 2017).

Recently, Tan et al. (2018b) reported on the subcritical CO_2 extraction of avocado oil. Unlike supercritical CO_2 extraction, subcritical CO_2 extraction operates below the critical pressure (72.9 bar) and temperature (31.1 °C) of CO_2. This allows the reduction in overall cost as the requirements of operating pressure and temperature are much lower when compared to supercritical CO_2 extraction. In comparison to Soxhlet extraction, subcritical CO_2 extraction of avocado oil at 27 °C and 68 bar for 7.5 h yielded 82% of the oil.

3.7 Pressurized Fluid Extraction

Pressurized fluid extraction, also known as accelerated fluid extraction, is the application of high pressure to maintain solvents remain beyond their normal boiling point, thereby promoting the process of oil extraction. This method allows rapid oil extraction due to the utilization of high temperatures and pressure, but a small amount of solvent. According to Azmir et al. (2013), the combination of high temperatures and pressure facilitates the mass transfer rate and solubility, while reducing the surface tension and viscosity of solvents, thereby, improving extraction rate.

Extraction of avocado oil using pressurized fluid extraction was conducted by Abaide et al. (2017). In their study, they extracted avocado oil using compressed liquefied petroleum gas for 10 min under various extracting pressure (0.5–2.5 MPa) and temperatures (293–313 K). The highest oil yield was achieved by compressed liquefied petroleum gas at 0.5 MPa and 293 K, which yielded 60% of the oil compared to Soxhlet extraction.

3.8 Refining of Avocado Oil

Depending on the extracting conditions and fruit quality, crude avocado oil may contain high levels of free fatty acids (Santana et al. 2015), which can affect the quality and edibility of the oil. Yahia and Woolf (2011) suggested that crude avocado oil extracted using 'harsh' technologies (e.g. high heat and/or organic solvents) to be further processed into refined avocado oil. The main focuses of avocado oil refining are to maximize the removal of undesirable components (e.g. free fatty

acids and undesirable organoleptic) and to minimize the loss of desirable components (e.g. bioactive components). This process considers other factors, such as increasing the conversion process, stability characteristics of oil, consumer preferences in taste, flavor and color of oil as well as the end use of oil such as cooking oil, shortening and margarine (Yahia and Woolf 2011). Refining of avocado oil involves four main steps, namely, bleaching, deodorizing, winterizing and neutralizing (Finau 2007). The resulting oil is light in yellow color, bland flavor and containing lower levels of health beneficial bioactive components.

4 Fatty Acid Composition and Acyl Lipids

Fatty acid composition affects the nutritional quality and physical properties of edible oil (Tan and Azlan 2016). The fatty acid profile of avocado oil has been relatively consistent among studies, but the relative concentration of each fatty acid component was found to vary considerably due to the geographical region (Ratovohery et al. 1988; Yanty et al. 2011), variety (Yanty et al. 2011), oil extraction method (Reddy et al. 2012; Werman and Neeman 1987) and harvest time (Ozdemir and Topuz 2004). The study by Woolf et al. (1999) showed that avocado oil extracted from fruit that was sun-exposed during growth contained a greater amount of saturated fatty acids (SFA), but a lesser amount of monounsaturated fatty acids (MUFA) than shaded fruit. Another study conducted by Werman and Neeman (1987) indicated the solvent-extracted avocado oil contained a greater proportion of SFA than centrifuge-extracted avocado oil.

Yanty et al. (2011) studied the variation in the fatty acid profile of four avocado varieties collected from different geographical regions. Irrespective of the variety and/or geographical location, oleic acid (43.65–63.73%), palmitic acid (14.80–30.37%) and linoleic acid (12.75–17.45) were the most abundant fatty acids in avocado oil (Table 17.2). A major portion of the avocado oil comprises MUFA (58%), followed by SFA (26%) and polyunsaturated fatty acids (PUFA) (16%). This is comparable to cashew nut oil (SFA 20%, MUFA 58% and PUFA 21%) (Ryan et al. 2006).

Avocado lipids can be classified into four main categories: (1) neutral lipids (tri-, di-, and monoacylglycerols); (2) glycolipids; (3) phospholipids and (4) free fatty acids. The main component of avocado oil is neutral lipids, which constitutes 96% of the total lipid content (Caballero et al. 2015). Similar to other plant oils, triacylglycerols (89.04–97.81%) comprises the majority of the neutral lipids of avocado oil, with small amounts of diacylglycerols (2.19–3.51%) and monoacylglycerols (0–6.39%) (Msika and Legrand 2010). The physical characteristics of oils are influenced by its triacylglycerols (TAG) profile. As can be seen in Table 17.3, the greatest proportions of TAG molecular species in avocado oil were dioleoyl-palmitoyl glycerol (22.42–27.41%), trioleoyl glycerol (11.42–29.00%), linoleoyl-oleoyl-palmitoyl glycerol (11.05–19.29%) and linoleoyl-dioleoyl glycerol (7.71–20.22%). It has been reported the TAG composition of the avocado oil is strongly affected by the variety and geographical regions (Yanty et al. 2011).

Table 17.2 Fatty acid composition of avocado oil

Fatty acid	Mean (%)	Range (%)
Palmitic acid (C16:0)	24.80	14.80–30.37
Palmitoleic acid (C16:1)	5.48	4.40–7.44
Stearic acid (C18:0)	1.04	0.27–1.56
Oleic acid (C18:1)	52.45	43.65–63.73
Linoleic acid (C18:2)	14.82	12.75–17.45
Linolenic acid (C18:3)	1.43	1.09–2.03
SFA	25.84	15.07–31.66
MUFA	57.93	48.87–68.59
PUFA	16.25	13.95–19.48

Yanty et al. (2011)
SFA total saturated fatty acids, *MUFA* total monounsaturated fatty acids, *PUFA* total polyunsaturated fatty acids

Table 17.3 Triacylglycerol composition of avocado oil

Triacylglycerol	Mean (%)	Range (%)
LLL	0.45	0–0.85
LLO	3.64	2.32–5.04
PLL	2.85	2.17–4.21
LOO	11.67	7.71–20.22
LOP	15.38	11.05–19.29
LPP	4.02	0–9.61
OOO	18.21	11.42–29.00
POO	24.29	22.42–27.41
LLLn	1.31	0.90–1.87
PPO	9.04	2.80–12.43
SOO	0.74	0.41–1.27
SOP	0.43	0–0.75
SPP	0.10	0–0.18
Others	7.86	3.42–11.69

Yanty et al. (2011)
L linoleic, *O* oleic, *S* stearic, *P* palmitic, *Ln* linolenic

5 Minor Bioactive Lipids

5.1 Tocopherols

Tocopherols can act as natural antioxidants to retard the autocatalytic lipid peroxidation process and the development of free radicals. The food industry utilizes tocopherols to enhance the stability and shelf life of food products. Four tocopherol isomers, namely, α-, β-, ϒ- and σ-tocopherols, have been reported in avocado oil. Of these, α-tocopherol, which act as a radical chain-breaking antioxidant in lipoproteins and membranes, was the most abundant (89 μg/g), followed by ϒ-tocopherol (38 μg/g), σ-tocopherol (14 μg/g) and β-tocopherol (8 μg/g) (Madawala et al. 2012). The total tocol content of avocado oil (149 μg/g) was greater than that in hazelnut (115 μg/g) and macadamia nut (54 μg/g) oils (Madawala et al. 2012).

Jorge et al. (2015) reported the total tocopherols of centrifuge-extracted avocado oil (30.47–36.73 mg/kg) contained almost similar levels as the commercial cold-pressed avocado oil (30.87 mg/kg). A recent study demonstrated the total tocopherols of avocado oil extracted *via* a two-step supercritical fluid method (15.4–28.2 mg/100 g) was five to nine times greater than a single step supercritical fluid method (3 mg/100 g) (Corzzini et al. 2017). The great differences of the tocopherols content may be due to the extracting conditions (solvent and time).

5.2 Phytosterols

Phytosterols are cholesterol-like compounds found in plant origin foods and it represents a major portion of the unsaponifiable fraction of plant oils. It plays an important role in inhibiting intestinal cholesterol absorption, inclusive of circulating endogenous biliary cholesterol, a key step in cholesterol elimination (Gupta et al. 2011). Piironen et al. (2003) evaluated the phytosterol content of several local fruits in Finland and results indicated the phytosterol content of avocado pulp (0.75 g/kg fresh fruit weight) was superior to those in the edible parts of grape, banana, apple, plum, orange and kiwi, with contents ranging from 0.12 to 0.23 g/kg fresh fruit weight. As most of the phytosterols are lipophilic in nature, they are most likely to be present in significant amounts in the oil. The most abundant phytosterols in avocado oil were sitosterol (3023 μg/g), followed by Δ-5-avenasterol (215 μg/g), campesterol (187 μg/g) and stigmasterol (7 μg/g) (Madawala et al. 2012). Centrifuge-extracted avocado oil (943.10–999.60 mg/kg) contained greater amounts of phytosterol content than commercial cold-pressed avocado oil (755.60 mg/kg) (Jorge et al. 2015), indicating that the extraction method had an important impact on the phytosterol yield.

Berasategi et al. (2012) compared changes in the phytosterol content of avocado and olive oils under high-temperature heat treatment. Both oils contained sitosterol as the main phytosterol, in which the level was twofold more in avocado oil compared to olive oil. Before heating, the total phytosterols of the avocado oil (339.64 mg/100 g) were greater than olive oil (228.27 mg/100 g). After heating at 180 °C for 9 h, the total phytosterols of avocado and olive oils were reduced by 20.37% and 7.87%, respectively. It has been reported the stability of phytosterols is affected by heating temperatures and time, lipid composition and sterol structure (Igoumenidis et al. 2011).

5.3 Carotenoids

Carotenoids are natural pigments that contribute to the red, orange or yellow colors of plant oils. Other than being vitamin A precursors, carotenoids also play an important role in preventing free radical chain reactions. Avocado oil was reported to

contain carotenoids such as lutein (1.6 μg/g), neoxanthin (0.2 μg/g), antheraxanthin (<0.5 μg/g) and violaxanthin (<0.5 μg/g). The total carotenoid content of cold-pressed avocado oil was reported to be 1.9 μg/g (Woolf et al. 2009). This value was far lower than the total carotenoid content of commercial cold-pressed avocado oil as reported by Flores et al. (2014), which was 11.1–46.9 μg/g. Carotenoids analytical techniques, plant cultivar and climatic conditions are the key factors affecting the carotenoids level detected in plant oils (Nehdi et al. 2010).

5.4 Total Phenolics

Phenolic compounds constitute a large portion of the phytochemicals found abundantly in plants (Tan and Azlan 2017). The total phenolic content (TPC) of plant oil is commonly determined using the Folin-Ciocalteu reagent assay. The TPC of selected crude and refined plant oils, expressed as μg caffeic acid equivalents (CAE)/g, were reported by Haiyan et al. (2007). In comparison to crude camellia, pumpkin and sesame oils (11.9–22.7 μg CAE/g), crude avocado oil (11.6 μg CAE/g) contained the least TPC. In contrast, refined avocado oil had the greatest TPC (12.8 μg CAE/g) compared to other three refined plant oils (camellia, pumpkin and soybean), with a range of 3.9–4.2 μg CAE/g. On the other hand, a comparison of changes in TPC of cold-pressed avocado and olive oils across various temperatures (25–290 °C) were performed by Forero-Doria et al. (2017). At 290 °C, the TPC of avocado oil and olive oil were reduced by 50.7% and 82.3%, respectively, when compared with their respective TPC at 25 °C. This shows that the phenolic compounds of the avocado oil are more resistant towards the temperature degradation.

The application of the ultrasound approach in extracting plant oils, which has been receiving considerable attention in the food industry in recent years, showed that this approach is capable of promoting the diffusion of phenolic compounds into the oil phase. As evidenced by Martínez-Padilla et al. (2018), the greatest TPC was detected in the avocado oil extracted from the high frequency (2 MHz) malaxed puree.

6 Volatiles Composition

Volatile compounds do not only affect the flavor of plant oils, but also its perception and acceptability. Table 17.4 summarizes the volatile compounds that have been identified in avocado oil. The volatile compounds of avocado oil extracted using organic solvents, namely, hexane and acetone were evaluated by Moreno et al. (2003). Their study indicated the hexane-extracted avocado oil contained more aromatic hydrocarbons while the acetone-extracted avocado oil was composed mainly of aldehydes, terpenoids and short-chain fatty acids. On the other hand, Haiyan et al. (2007) found that the volatile compounds present in cold-pressed avocado oil

Table 17.4 Volatile compounds of avocado oil

Method	Volatiles	Total[a]	Reference
Hexane (solvent) extraction[b]	1,2–Dimethylbenzene, 1,2-Dimethyl-4-ethylbenzene, 1,2,4-Trimethylbenzene, 1,4–Dimethylbenzene, 2-Proponoic acid, 2-ethylhexyl ester, 2,6-Dimethylundecane, Benzoic acid 2-hydroxymethyl ester, Decane, Dodecane, Pentadecane, Propanoic acid, 2-methyl-1-(1,1-dimethyl)-2-methyl-1,3-propamedyl ester, Propanoic acid, 2-methyl-3-hydroxy-2,4-trimethylpenthl ester, Tetradecane, Tridecane, Undecane	15	Moreno et al. (2003)
Acetone (solvent) extraction[b]	1,2–Dimethylbenzene, (*E*, *E*)-α-Farnesene, α-Bergamotene, α-Copaene, α-Cubebene, α-Humolene, β-Bisabolene, β-Caryophyllene, Caryophyllene oxide, Germacrene D, *trans*, *trans*-2,4–Decadienal, *trans*, *trans*-2,4-Decadienal isomer	12	Moreno et al. (2003)
Cold-pressed	1-Hexanol, 3-Carene, (*E*)-2-Hexenal, α-Piene, β-Piene, Acetic acid, Hexanal, Nonanal, Pentanal	9	Haiyan et al. (2007)
Refined	1-Penten-3-ol, 2-Butenal, Acetic acid, Furfural, Heptanal, Hexanal, Nonanal, Pentanal, Pentenal isomer, Toluene	10	Haiyan et al. (2007)
Cold-pressed	α-Piene, (*E*)-2-Hexanol, (*E*)-2-Hexenal, Acetic acid, Hexanal, Hexanol, Propanol	7	Woolf et al. (2009)

[a]Total identified volatile compounds
[b]Avocado pulp was vacuum oven dried at 70°C before oil extraction

were different from those in refined avocado oil. Woolf et al. (2009) reported that the avocado oil extracted from good quality fruit (healthy or fruit with minor levels of rots) contained higher levels of desirable volatiles like (E)-2-hexanol, (E)-2-hexenal, hexanal and hexanol. Conversely, avocado oil extracted from poor quality fruit (fruit with major levels of rots) contained a high level of undesirable volatile like acetic acid, most likely due to microbial activities.

7 Oxidative Stability

The stability of plant oils against oxidation depends on the degree of unsaturation and the concentration of minor bioactive lipids. By using the Rancimat method, Madawala et al. (2012) found the induction time at 100 °C of plant oils decreased in the order of avocado oil > hazelnut oil > almond oil > grapeseed oil > walnut oil. This indicates avocado oil was more oxidation resistant compared to the rest (hazelnut, almond, grapeseed and walnut oils). Moreover, the oxidative stability of avocado oil under high-temperature heat treatment was compared against olive oil using thiobarbituric acid reactive substances (TBAR) assay (Berasategi et al. 2012). After heating at 180 °C for 9 h, the TBAR value of avocado oil was lower than olive oil, indicating avocado oil was more heat stable than olive oil.

8 Health-Promoting Properties of Avocado Oil

Numerous scientific evidence demonstrates that regular intake of avocado oil lowers the risk of chronic diseases (Carvajal-Zarrabal et al. 2014; Furlan et al. 2017; Toro-Equihua et al. 2016; Torre-Carbot et al. 2015). This is due to the synergistic combination of compounds such as tocopherols, unsaturated fatty acids and bioactive phytochemicals (e.g. phytosterols, carotenoids and phenolics) that are responsible for the functionality and health-promoting properties of the avocado oil. Table 17.5 summarizes the health benefits of avocado oil. Up to now, health benefits of avocado oil are associated with lipid-lowering effect, hypotensive effect, cardio-protective property, diabetes management, anti-arthritic property, periodontal disease management, skin and wound healing and enhancement of nutrients absorption. Details of these health benefits are discussed below.

8.1 Lipid-Lowering Effect

Lipid-lowering effect of several plant oils (avocado, grape seed, canola, soybean, safflower and partially hydrogenated plant oils) was evaluated by Torre-Carbot et al. (2015) using Wistar rats. The rats were initially supplemented with 5.7% plant oils for 2 weeks before switching to a higher concentration of oils (11%) for another 3 weeks. Results showed that rats supplemented with avocado oil had the lowest concentration of total cholesterol and low-density lipoprotein (LDL) cholesterol. The researchers also reported the LDL/high-density lipoprotein (HDL) index of avocado oil supplemented group was the lowest, indicating the vascular-protective potential of avocado oil.

8.2 Hypotensive Effect

Study of the blood pressure response to angiotensin II and the fatty acid composition of renal and cardiac membranes after consumption of a diet enriched with 10% avocado oil was performed by Salazar et al. (2005). After 2 weeks of avocado oil intake, they found the fatty acid profile of renal and cardiac microsomes had altered and angiotensin II-induced blood pressure response was greater compared to the normal control. The researchers postulated the modification of essential fatty acid levels at the renal and cardiac membranes, as a result of avocado oil consumption, changed the way that kidney and cardiac respond to the hormone that modulate blood pressure.

Table 17.5 Health-promoting properties of avocado oil

Health effect	Study design/model	Results	Reference
Lipid-lowering	Healthy rats	Improved blood lipid profile and reduced food intake and weight gain	Torre-Carbot et al. (2015)
Hypotensive	Angiotensin II-induced rats	Modified fatty acid content in renal and cardiac membranes in a tissue-specific manner	Salazar et al. (2005)
Cardioprotective	Sucrose-induced metabolic alteration rats	Improved blood lipid profile and partially reversed the inflammatory process	Carvajal-Zarrabal et al. (2014)
	Cohort overweight human	Alleviated atherosclerosis risk factors and inflammation and potentially endotoxemia improvement	Furlan et al. (2017)
Diabetes management	Streptozotocin-induced diabetic rats	Improved brain mitochondrial function, decreased oxidative stress and modified diabetic dyslipidemia	Ortiz-Avila et al. (2015)
	Sucrose-induced insulin resistance rats	Improved glucose tolerance and insulin resistance while reducing the body weight gain	Toro-Equihua et al. (2016)
Anti-arthritic	Review of randomized, placebo-controlled and double-blind trials	Effective for the symptomatic treatment of osteoarthritis	Ernst (2003)
	Review of in vitro and animal studies	Positively regulated the altered phenotype of osteoarthritis subchondral bone osteoblasts, stimulated the synthesis of proteoglycans in chondrocytes cultures and decreased the synthesis of collagenases by synovial cells	Henrotin (2018)

(continued)

Table 17.5 (continued)

Health effect	Study design/model	Results	Reference
Periodontal disease management	Alveolar bone and periodontal ligament cells	Opposed cytokine effect and reversed the inhibiting effect of interleukin-1 beta (IL-1β)	Andriamanalijaona et al. (2006)
Skin and wound healing	Randomized, prospective clinical trial	No differences in the PASI score and 20 MHz sonography results of vitamin B_{12} ointment containing avocado oil and calcipotriol ointment	Stücker et al. (2001)
	Incisional and excisional cutaneous rats	Reduced inflammatory and improved tensile strength and collagen density	Oliveira et al. (2013)
Enhancement of nutrients absorption	Crossover trial	Improved carotenoids absorption	Unlu et al. (2005)

8.3 Cardioprotective Effect

The cardioprotective potential of avocado oil supplementation in sucrose-induced metabolic alteration rats was evaluated by Carvajal-Zarrabal et al. (2014). Supplementation with 7.5% avocado oil resulted in the reduction of high sensitivity C-reactive protein (hs-CRP), triacylglycerol, LDL cholesterol and very low-density lipoprotein (VLDL) cholesterol levels compared to the untreated rats. The researchers concluded that avocado oil can partially reverse the inflammatory process attributed to the sucrose solution consumption. Another cohort study conducted by Furlan et al. (2017) showed the replacement of butter with avocado oil regulated the negative physiological impact associated with a hypercaloric-hyperlipidic meal. Replacement of 9.3% butter with 9.6% avocado oil in the experimental meal consisted of bacon, eggs, iced sugar, potatoes and wheat bread improved the postprandial levels of interleukin-6, C-reactive protein, total cholesterol, LDL cholesterol, triacylglycerol, insulin and glycemia of overweight subjects. Their study highlighted the importance of correct fat quality choice as a fundamental of cardiometabolic risk modulation.

8.4 Diabetes Management

Ortiz-Avila et al. (2015) evaluated the effect of oral administration of avocado oil at a dose of 1 mL/250 g body weight on the oxidative status and brain mitochondrial function of streptozotocin (STZ)-induced diabetic rats for a period of 90 days. Compared

to untreated STZ-rats, although administration of avocado oil to the STZ-rats did not normalize serum glucose level, it was capable of reducing serum cholesterol and triacylglycerol levels. Avocado oil was also able to reduce lipid peroxidation and reactive oxygen species levels while improving the reduced/oxidized glutathione ratio. The impairment of mitochondrial transmembrane potential and mitochondrial respiration were also hindered after administration of avocado oil. The researchers suggested the potential of avocado oil on delaying the onset of diabetic encephalopathy.

In another study, Toro-Equihua et al. (2016) evaluated the effect of avocado oil supplementation on sucrose-induced insulin resistance rats. Addition of 5–20% avocado oil to the diet increased insulin sensitivity and normalized insulin resistance induced by a sucrose-rich diet. Besides that, avocado oil supplementation also reduced body weight gain while improving glucose tolerance.

8.5 Anti-Arthritic Effect

Avocado and soybean unsaponifiables (ASU) mixture is an anti-arthritic agent produced by mixing the unsaponifiable fraction of avocado and soybean oils at a ratio of 1:2, respectively (Henrotin 2018). The ASU mixture is now commercialized as an over-the-counter medicine known as Piascledine® 300 (Henrotin 2018). A systematic review proved the effectiveness of ASU mixture consumption in alleviating the symptoms of osteoarthritis (Ernst 2003). This systematic review includes only the "gold standard" of epidemiologic studies, which is the database of randomized, double-blind and placebo-controlled clinical trials. Most of the literature data in this review showed that consumption of ASU mixture at a dose of 300 mg/day exhibited superior outcomes than placebo on relieving the symptoms of osteoarthritis with no major adverse health effect being documented. The effect of ASU mixture on various animal (rat, mice, dog and sheep) and *in vitro* (chondrocytes culture, osteoblasts culture, chondrocytes/osteoblasts co-culture, synovial cells culture) models were recently reviewed by Henrotin (2018). The author concluded that ASU mixture provides health benefits on the metabolic changes in the tissues (cartilage, synovium and subchondral bone) associated with the pathophysiology of osteoarthritis.

8.6 Periodontal Disease Management

Periodontal disease is a pathological condition that involves inflammation of the tooth-supporting structure. An in vitro study to evaluate the effect of ASU mixture on the expression of bone morphogenetic protein-2 (BMP-2), transforming growth factor (TGF)-β_1 and TGF-β_2 in alveolar bone and periodontal ligament cells when exposed to the destructive interleukin-1 beta (IL-1β) was performed by Andriamanalijaona et al. (2006). They found that the expression of TGF-β_1, TGF-β_2

and BMP-2 of the cells were strongly reduced by IL-1β, the main driver of bone loss and tissue destruction in gum disease. In contrast, ASU mixture at a dose of 10 μg/mL was found to stimulate the production of TGF-β_1, TGF-β_2 and BMP-2. The researchers concluded that the ASU mixture can exert a preventive action on the erosive damage caused by IL-1β.

8.7 Skin and Wound Healing Property

The therapeutic effect of vitamin B_{12} cream containing avocado oil (VBAO) on the treatment of plaque psoriasis was reported by Stücker et al. (2001). The effectiveness of VBAO was compared against calcipotriol cream, a common treatment for psoriasis. Both creams were applied to psoriatic plaques on the contralateral body sides of each patient twice daily. After 12 weeks of therapy, the results of Psoriasis Area Severity Index (PASI) and 20 MHz sonography showed the VBAO produced similar effects as calcipotriol cream on alleviating plaque psoriasis. The researchers highlighted the potential of VBAO as a well-tolerated, long-term topical therapy of psoriasis.

Another study on the wound healing properties of avocado oil was demonstrated by an in vivo study that used incisional and excisional cutaneous rats (Oliveira et al. 2013). After 14 days of therapy, the percentages of wound contraction and reepithelialization of the rats applied with a semisolid formulation of avocado oil (SFAO) were better than the rats applied with petroleum jelly. Topical application of SFAO has been shown to reduce the number of inflammatory cells in the scar tissue and enhanced collagen synthesis during wound healing process. The researchers recommended SFAO as a new alternative for skin wounds treatment.

8.8 Enhancement of Nutrients Absorption

The health benefit of avocado oil supplementation on the bioavailability of carotenoids was demonstrated in a crossover trial by Unlu et al. (2005). Salad, which was prepared from low-fat but high-carotenoid ingredients (carrot, spinach, lettuce, read and salad dressing), served as an experimental diet. The absorption of carotenoids (α-carotene, β-carotene and lutein) by the human body was low when consumed the control meal (salad) alone. In comparison to the control meal, an addition of 24 g of avocado oil to the salad drastically increased carotenoids absorption (8.9 times greater for α-carotene, 17.4 times greater for β-carotene and 6.7 times greater for lutein) by the human body. The researchers pointed out the significant role of dietary lipids for effective carotenoid absorption and the necessity of taking dietary interactions into account when providing nutritional recommendations. Table 17.5 summarizes the health benefits of avocado oil.

9 Edible and Non-edible Applications of Avocado Oil

Depending on the extraction and processing methods, the flavors of crude avocado oil varies from buttery or grassy to mushroom-like or slightly nutty. These flavors are suitable for the application of uncooked dishes like dressing salads and marinades. Owing to a high smoke point (>200 °C) (Table 17.1), crude avocado oil is also suitable in high-temperature cooking like pan frying, barbeque, baking and roasting (Woolf et al. 2009). The pharmaceutical industry uses crude avocado oil to produce an array of dietary supplement and healthcare products due to its bioactive compounds. Refined avocado oil, which is light yellow color and has a bland flavor, is mostly utilized in cosmetics application rather than pharmaceutical application.

10 Other Issues

10.1 Authenticity and Adulteration

The scientifically proven health benefits of avocado oil, as highlighted in Table 17.5, command it a higher market price than other plant oils. Thus, there is a potential of avocado oil adulteration with other cheaper or inferior quality plant oils. Thermal analysis using a differential scanning calorimetry has been purposed as a rapid and simple method to authenticate the adulteration of plant oils. In a study conducted by Yanty et al. (2017), the addition of 5–9% of palm stearin and cocoa butter to avocado oil shifted the onset of crystallization temperatures and resulted in higher end-set melting temperatures. The researchers concluded the occurrence of these phenomena was due to the compositional changes, resulted from the increment of saturated fatty acids and di-/tri-saturated triacylglycerols.

10.2 Allergies and Toxicity

There have not been any reported cases of adverse effects, allergies or toxicity due to avocado oil.

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