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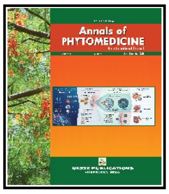

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Avocado (*Persea americana* Mill.) oil: Extraction techniques, composition, and health benefits

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Abstract

Avocado (*Persea americana* Mill.) pulp is used to produce avocado oil, a nutrient-dense oil prized for its unique composition and diverse applications in the culinary, medical, and cosmetic industries. Along with important bioactive substances like phytosterols, tocopherols, carotenoids, and polyphenols, it is especially prized for its high concentration of monounsaturated fatty acids, primarily oleic acid. These constituents to the oil's notable antioxidant activity and health benefits, including cardiovascular protection, cholesterol regulation, and anti-inflammatory effects. Extraction methods significantly influence the yield and quality of avocado oil. While conventional techniques, such as solvent extraction and mechanical pressing, are still employed, innovative approaches like cold pressing, supercritical CO_2 extraction, and ultrasound-assisted extraction are gaining attention for their ability to retain nutritional integrity and enhance environmental sustainability. The oil possesses favorable physicochemical and thermal properties, including a high smoke point and oxidative stability, making it suitable for both culinary and industrial uses. Nonetheless, it is susceptible to degradation from light, oxygen, and heat. Strategies such as antioxidant incorporation and microencapsulation are employed to preserve quality and extend shelf-life. In conclusion, avocado oil is a multifunctional, health-promoting oil with expanding market potential driven by ongoing advancements in extraction and preservation technologies.

1. Introduction

Native to Central America, the fruit (*Persea Americana* Mill.) that does well in warm and subtropical regions around the world. According to Tan *et al.* (2017), approximately 60% oil, 7% skin, and 2% seed. The modern term "avocado" comes from the Aztec "ahucatl". The avocado (Ranade and Thiagarajan, 2015) is also known as "butter fruit" and "alligator pear". The edible pulp of this evergreen dicotyledonous plant that is botanically classified as a member of the Lauraceae family is rich in lipids and essential minerals, including phosphorus, potassium, and magnesium (Tan, 2019b). The avocado is a flowering plant from the Lauraceae family, under Laurales, a part of the genus Persea, which is a member of the plant kingdom Plantae. According to Zafar and Sidhu (2011), 70 of the 150 species in the genus Persea were grown in the warm climate of America. The most popular avocado varieties for industrial use are "Hass" and "Fuerte," which have a 30% oil content. The greatest producer of avocado oil worldwide is Mexico (Fernandes and Da Silva Santos, 2020). Avocado trees, which range in height from 5 to 30 meters, are sensitive to cold and only ripen after harvest (Woolf *et al.,* 2009c). Main producers of avocado oil globally include the United states, Mexico, and New Zealand, along with Chile and South Africa somehow (Berasategi *et al.,* 2011).Avocado oil usage has surged recently in food industries and human nutrition sectors largely due to various health benefits, apparently. Due to its high content of bioactive substances like beta-sitosterol and alpha-tocopherol, as well as monounsaturated fatty acids like oleic acid, palmitic acid, and linoleic acid, which lower the risk of hypercholesterolemia, hypertension, diabetes, and fatty liver disease, it may be particularly beneficial for disease prevention and management. It also has antibacterial properties and lowers cardiometabolic risk (Tan, 2019).

Avocado oil lacks a fixed benchmark or specific standard altogether, apparently. Avocado oil currently utilizes recommended amounts of olive oil according to guidelines set forth by Codex Alimentarius and the International Olive Oil Council (IOC). Because of their

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hepatotoxigenic activity, which disrupts the hepatic lipid metabolism, avocados are chosen for oil extraction from their fleshy mesocarp rather than the seed (Tan, 2019). Avocado oil is categorized as "extra virgin," "virgin," "pure," or "mixed" based on the extraction process and fruit quality. Each kind has unique sensory and chemical traits. Superior avocado oil, known as "extra virgin," is made by hand, without the use of chemical solvents, using high-quality fruits and temperatures below 50°C. The lesser-quality fruit, which rots in small spots and alters physically, was mechanically removed at a temperature lower than 50°C without the use of chemical solvents. The word "pure" refers to avocado oil that has been deodorized and bleached without losing the natural flavour of the fruits or herbs. Macadamia, olive, and other oils are combined to create "mixed" avocado oil (Woolf *et al.,* 2009).

Mechanically or naturally produced well-ripened fruits at low temperatures under 50°C retain most color pigments and heat-labile bioactive components like natural flavor (Woolf *et al.,* 2009; Wong *et al.,* 2010). According to Flores *et al.,* (2019c), the process of extracting the avocado fruit's seed and pulp (*P. Americana)* is known as "crude oil of avocado" (Mexican standard). The edible avocado oil that is 98.5% refined is called "Pure." High heat and the extraction of organic solvents were two of the harsh methods used in the past to make avocado oil. The method is then refined, bleached, and deodorized (RBD) for superior organoleptic qualities (Yahia and Woolf, 2011).

This paper provides a clear insight about the composition of avocado oil and various methods of extraction, which include cold-pressed methods, solvent extraction, supercritical fluid extraction, ultrasound-assisted aqueous extraction, mechanical pressing, *etc*.

2. Composition of avocado

Compared to other fruits, avocados have a higher lipid content (Dabas *et al.,* 2013). Several parts of the avocado plant have yielded a large number of secondary metabolites. Avocados are primarily composed of lutein, with trace amounts of α-carotene, β-carotene, zeaxanthin, neoxanthin, and violaxanthin. Tocopherols were also discovered (Corral Aguayo *et al.,* 2008). Hass is the most popular commercial avocado variety (Dreher and Davenport *et al.,* 2013). Half of an avocado (68 g) contains nutrients and phytochemicals. Among the nutrients are 0.2 g of total sugar, 6.7 g (114 kcal) of high-monounsaturated fatty acids, and 0.2 mg of vitamin B-6. According to the American Dietetic Association (2009) and the USDA (2011), avocado oil has 43 µg of vitamin A and 1.3 mg of vitamin E, plus 85 µg of lutein/zeaxanthin beneath 6.0 mg of vitamin C and 57 mg of phytosterols somehow. It contains 14 µg of vitamin K1 and 60 mg of folate naturally with 1.3 mg of niacin and 5.5 mg of sodium generally. Potassium stands at 345 mg with pantothenic acid at 1.0 mg alongside 0.1 mg riboflavin and; surprisingly, 19.5 mg choline down below 4.6 g dietary fiber.

3. Macronutrient composition

3.1 Lipids

Oleic acid, a monounsaturated fatty acid, predominates in fresh avocados, making up roughly 59% of total fat according to USDA data. Linoleic acid 18:2n-6 constitutes roughly 11% of total fat as the predominant polyunsaturated fatty acid, while palmitic acid 16:0 comprises around 14% (Ford *et al.,* 2023). Palmitic acid content dwindles significantly at 20°C during ripening, but polyunsaturated fatty acids surge upward while monounsaturated ones stay pretty much the same (Meyer and Terry, 2010b). Preharvest conditions can significantly influence fatty acid profiles somewhat irregularly under various environmental factors. Growing temperatures decrease slowly, and the oil profile veers sharply towards oleic acid but away from palmitic acid (Ford *et al.,* 2023). Eating one avocado daily could achieve recommended energy displacement, and a weekly intake of one or more is linked with a 16% reduced CVD risk and a 21% lower risk of coronary heart disease (Pacheco *et al.,* 2022). Consuming at least one avocado daily over several weeks markedly improves blood lipid profiles in relatively healthy individuals with dyslipidemia and obesity (Dreher *et al.,* 2021). Substituting saturated fatty acids with unsaturated ones also correlates with significantly reduced total mortality rates overall (Ford *et al.,* 2023).

Table 1: Protein and amino acids in fresh Hass avocado pulp (Ford *et al.,* 2023)

Protein and amino acids g/100 g	USDA Food Data Central
Total protein	1.06
Amino acids taurine	NA
Hydroxyproline	NA
Aspartic acid	0.232
Threonine *	0.072
Serine	0.112
Glutamic acid	0.28
Proline	0.096
Lanthionine	NA
Glycine	0.102
Alanine	0.11
Cysteine	NA
Cystine	0.027
Valine *	0.11
Methionine *	0.04
Isoleucine *	0.08
Leucine *	0.14
Tyrosine	0.05
Phenylalanine *	0.1
Hydroxylysine	NA
Lysine *	0.13
Histidine *	0.05
Arginine	0.09
Tryptophan *	0.03

NA - Not applicable/avoidable, * Essential amino acids

3.2 Carbohydrates

Due mostly to a preference for oil buildup rather than the preservation of sugary compounds, avocados have a relatively low sugar content. The majority of their carbohydrates are made up of dietary fiber, which is a mixture of soluble and insoluble fibers, including pectin and cellulose (Pedreschi *et al.,* 2019).Global recommendations generally recommend that adults consume 25-30 g of dietary fiber per day; however, North Americans only consume an average of 17 g per day (McKeown *et al.,* 2022). A large amount of research has emphasized the many health advantages of fiber, including improved and regular laxation, decreased risk of cardiovascular disease, satiety effects, and positive effects on gut bacteria and general gut health (Slavin, 2013). According to USDA Food Data Central, there are 6.8 g of fiber in every 100 g of avocados. This is strange because pooled data says there are only about 3.87 g of fiber in every 100 g.

3.3 Fiber

About 80% of the carbohydrates in avocado fruit are dietary fiber. Most of this fiber is insoluble (70%), and a little amount is soluble (30%). Avocados are packed with a dietary fiber content of 2.0 g per 30 g and a higher 4.6 g per half of a large fruit (USDA, 2011). Since one-half of an avocado provides about one-third of this fiber level, moderate avocado eating aids in achieving an appropriate intake of 14 g of dietary fiber per 1000 kcal (Dreher and Davenport, 2013).

3.4 Proteins

Avocados contain various amino acids yet probably do not contribute significantly toward meeting daily protein needs ordinarily.

4. Micronutrients

4.1 Vitamins

Along with a startling 30% daily content of folate, a medium-sized Hass avocado has 30% daily value of vitamin K and 45% daily value of pantothenic acid (Ford *et al.,* 2023). Avocado has 21 µg of vitamin K per 100 g, according to USDA Food Data Central (2021), and values fluctuate greatly, ranging from 5 to 27 µg. Although avocado only contains 25% of the vitamin K found in fresh spinach or kale, its lipids greatly improve the absorption of fat-soluble elements (Ford *et al.,* 2023).

89 µg of folate per 100 g of avocado as listed by USDA Food Data Central (2021), which is in line with the 90 µg per 100 g pooled mean found in other databases and publications. As a cofactor in energy production, particularly in the synthesis of triacylglycerol, and in some way in the metabolism of lipoproteins, pantothenic acid is essential. According to USDA Food Data Central, avocados contain 1.46 mg of pantothenic acid per 100 g, which is almost twice the 0.89 mg found in other sources and databases. One medium-sized Hass avocado supplies 12% daily value of vitamin C alongside 18% daily value of vitamin E and 24% riboflavin with 18% niacin and vitamin B6 daily value. At 0.287 compared to some other seemingly relevant number, the USDA Food Data Central and pooled means for vitamin B6 are reasonably consistent. The levels of riboflavin were 0.143 and 0.28 mg per 100 g, respectively. Niacin stood at 1.91 versus 0.139 mg per 100 g, respectively, α-tocopherol stood at 1.97 versus 2.07 mg per 100 g, respectively, 2.13 mg per 100 g, respectively.

4.2 Minerals

A single medium-sized Hass avocado weighing around 150 g contains copper at 30% daily value and potassium at 18%. One avocado furnishes almost the entire daily copper requirement for infants, being roughly 0.2 to 0.22 mg. In addition to being an essential cofactor in many energy-producing pathways, copper also helps with iron metabolism and connective tissue creation. It has been suggested that dyslipidemia is partially caused by the about 30% of the general U.S. population that do not consume the required amounts of copper (Morrell *et al.,* 2017). Potassium plays a critical role somehow in blood pressure management very effectively within human physiology typically.

5. Bioactive compounds

5.1 Fatty acids

About 40% to 80% of avocado oil is made up of monounsaturated fatty acids, with oleic acid serving as the primary monounsaturated acid and palmitic acid as the predominant saturated acid. The type of extraction variety and the location of avocados under various conditions are somehow related to the variations in percentages discovered.The oils produced using different extraction techniques, such as Soxhlet and press extraction, varied from 19% palmitic acid with mechanical pressing to 21% *via* Soxhlet extraction, and from 57% oleic acid in some situations to 59% elsewhere (Krumreich *et al.,* 2018b). The oleic acid content of the same avocado species varies significantly depending on the location, ranging from 40 to 60% (Pantoja *et al.,* 2024b). Palmitic acid composition varied markedly, ranging from 17% up to 24%. In comparison to the ripest avocados, the oleic acid and palmitic acid concentrations varied from 22 to 56% and 22 to 36%, respectively, according to a prior study by Manaf *et al.* (2018). It appears that under some circumstances, linoleic acid may be present in much greater amounts than palmitic acid.This shift in profile may be mostly attributed to the fruit's maturation stage. While significant changes in the monounsaturated fatty acid profile are often avoided, distinct stages can cause variations in the linoleic acid content of up to 10%. The distribution of fatty acids is as follows: 50.95% is oleic acid, 5.69% is palmitoleic acid, 0.69% is stearic acid, and 28.21% is palmitic acid. Linoleic acid constitutes 13.87%, and linolenic acid accounts for 0.58%. Other fatty acids, including behenic and myristic, were investigated by De Oliveira *et al.* (2013) and found to exist in relatively lower amounts. Avocado oil contains significant amounts of lecithin, β-sitosterol, minerals, and vitamins, according to research by Husena *et al.* (2014).

5.2 Phenolics

The phenolic content of fresh avocado pulp varies quite a little, ranging from 1 to 26 mg per 100 g. An aromatic ring with at least one hydroxyl group and some sort of association with different functional units forms phenolic compounds.It appears that the number of benzene rings with hydroxyl substituents and the attachment of functional groups play a significant role in the classification of compounds. In the fruit, the following acids are identified in higher concentrations: epigallocatechin (1.03 mg GAE/100 g), quercetin (0.557 mg GAE/100 g), caffeic acid glucoside (0.270 mg GAE/100 g), ferulic acid (0.19 mg GAE/100 g), 5-feruloylquinic acid (2.11 mg GAE/100 g), coumaric acid (0.64 mg GAE/100 g), p-coumaric acid (0.58 mg GAE/100 g), p-coumaric acid glucoside isomers (2.62 mg GAE/100 g), p-coumaric acid rutinoside (0.45 mg GAE/100 g), and tyrosol-hexoside-pentoside (0.63 mg GAE/100 g) (Pantoja *et al.,* 2024c).

5.3 Fatty alcohols

According to numerous scientific investigations, avocados contain a number of quite uncommonlong-chain fatty alcohols with intriguing bioactive qualities.The fatty alcohols personone A, personone B, and acetylated-avocadene are present in nature in exceptionally large amounts. These substances, also known as acetogenins, have been intriguingly linked in a variety of medicinal contexts to proapoptotic and anticancer effects. At first, studies on avocado persenones indicated that they might naturally be relatively bioactive (Ford *et al.,* 2023c).While persenone A showed possible protective effects against arterial thrombosis with significantly extended coagulation time, persenone C exhibited antiplatelet action *in vitro* (Rodriguez-Sanchez *et al.,* 2015). Avocado extracts high in persenone A and C have recently been demonstrated to effectively and potently suppress *Listeria monocytogenes* growth *in vitro*. The amount of pulp was significantly larger than the minimal inhibitory values needed, ranging from 199 to 398 times. Under some circumstances, eating avocados effectively inhibits *Listeria* growth by providing sufficient acetogenin levels (Salinas Salazar *et al.,* 2016). Polyhydroxylated alcohols, specifically avocadyne and avocadene, are rather prevalent in avocado pulp along with other related chemicals. Under specific circumstances, avocadodyne has been demonstrated to potentially prevent fatty acid oxidation *in vitro* quite effectively. In some way, these molecules might counteract one another's actions. Surprisingly, avocadyne reduced cell engraftment *in vivo* by inhibiting the development of primary acute myeloid leukemia cells while sparing normal hematopoietic cells (Ford *et al.,* 2023c).

5.4 Carotenoids

Lutein predominates substantially in avocados (Ford *et al.,* 2023c). Ripe fruits have significantly greater quantities of this chemical, ranging from 53.3 to 74.10 µg lutein per gram, according to studies on the Hass variety. Carotenoid concentration increased at the end of the season in avocados harvested from Ventura, San Luis Obispo, and Riverside during different seasons from January to September. Pulp lutein content ranged from 2.82 to 8.42 µg lutein/g in San Luis Obispo and from 3.72 µg lutein/g in Ventura to 8.03 µg lutein/g in San Luis Obispo. The concentrations in the riverside and San Diego locations ranged from 4.31 to 6.02 µg lutein/g and 6.63 to 6.29 µg lutein/g, respectively.Higher levels of lutein were found in fruits with dark green skin, slightly greenish pulp, and a somewhat yellowish center close to the seed (Pantoja *et al.,* 2024c). The characteristics of the extraction procedure and temperature variations that occur prior to pulp-drying pretreatment are the main causes of the wide variations in carotenoid content. Using dry pulp at 40°C produces oil that contains 71.95 µg of β-carotene per gram; increasing the temperature further increases the amount of β-carotene to 88.72 µg/g after solvent extraction.When extracted using a mechanical press, the amount of β-carotene was around 75.00 µg/g at 40°C and increased dramatically to 104.62 µg/g at 60°C (Krumreich *et al.,* 2018c). Oil's carotenoid content varied greatly, ranging from 15.21 to 32.78 µg β-carotene per gram (Pantoja *et al.,* 2024c). It goes without saying that a healthy adult does not get the 40 mg of lutein they require each day from 150 g of avocado pulp. In such a situation, supplementation seems to be a far more beneficial option.

5.5 Tocopherols

Tocopherols come in various forms, namely α-tocopherol, β-tocopherol, and γ-tocopherol, and also δ-tocopherol, being essentially fat-soluble substances. Antioxidants found in nature are thought to be advantageous since they greatly extend the oil's shelf-life (Flores *et al.,* 2019c). The pulp of the Hass cultivar has about 19.7 mg of α-tocopherol per kilogram. According to a study by Tan *et al.* (2018), α-tocopherol levels in oil varied from 69.2 to 226.7 mg/kg, and oil of the Breda variety had α-tocopherol levels close to 105 mg/kg. Corzinne *et al.* (2016b) produced defatted avocado extract with 202 mg of α-tocopherol per kg at rather high temperatures (40°C and 60°C) and pressures (200 bar). Research indicates that α-tocopherol is present in avocado oil, although its concentration varies greatly depending on the temperature at which it is extracted, the stage at which it matures, and seasonal variations (Araújo *et al.,* 2018). Chinese cultivars of Fuerte and Hass avocados have fruit pulp extracted using the Soxhlet method that shows levels of α-tocopherol ranging from 12.8 mg/kg to 23.2 mg/kg (Pantoja *et al.,* 2024c). Santana *et al.* (2019) found that the ripening and harvest stage circumstances had a significant impact on the quantities of α-tocopherol in oil produced by expeller pressing. Peeled ripe fruits produced oil with a larger α-tocopherol concentration (74.2 mg/kg to 120.8 mg/kg) than green fruits (44.9 mg/kg to 104 mg/kg), and the preprocessing drying method had less of an effect. The amount of tocopherol in avocado oil increases as the fruit ripens and then gradually decreases over time. Depending on the fruit variety and extraction method, supercritical extraction with carbon dioxide as a solvent has demonstrated the highest quantities of α-tocopherol in oil.

5.6 Phytosterols

The amount of tocopherol in avocado oil increases as the fruit ripens and then gradually decreases over time. Depending on the fruit variety and extraction method, supercritical extraction with carbon dioxide as a solvent has demonstrated the highest quantities of α-tocopherol in oil.With a mean of 76 mg per 100 g reported by USDA Food Data Central and other pooled means of 57 mg, avocados are a rich source of β-sitosterol.The reported levels of β-sitosterol vary greatly, from 24 to 105 mg per 100 g (Salehi *et al.,* 2021).As part of a diet low in saturated fat, foods with 0.65 g per serving of plant sterol esters taken with meals may lower the risk of heart disease (Ford *et al.,* 2023).It seems that in order to get such a high level of nutrient consumption, fifteen avocados would be required each day. Vegan diets can naturally provide up to 600 mg of phytosterol per day; however, this is dreadfully insufficient (Trautwein *et al.,* 2018b).

6. Extraction techniques of avocado oil

High humidity levels inherent in avocado pulp during drying significantly impact subsequent oil extraction processes remarkably, according to some research by Costagli and Betti in 2015. Pulp vacuum-dried rather thoroughly at 60°C *via* the Soxhlet oil extraction method showed markedly increased quality metrics like peroxide value and iodine value and antioxidant activity.Mechanical pressure and air ventilation were employed alongside some other obscure methods pretty recently, according to Krumreich *et al.* (2018). Microwave-dried avocado pulp yields oil with remarkably higher oxidative stability at 20.8 h and a peroxide value of 4.79 mEqO, per kg with an acid value of 0.02% oleic acid. Fatty acid content remains remarkably stable with no significant alteration observed ($p > 0.05$), according to Santana *et al.* (2014). Avocado pulp subjected rather quickly to hot air drying contains significantly more vitamin E and exhibits greater antioxidant activity than vacuum-processed avocados or air-dried ones.

6.1 Cold-pressed method

The cold-pressed oil extraction method involved several different steps, such as destoning, grinding, malaxing, and decanting. The idioblast and oil-bearing cells were intact throughout the first stage, but the pulp's parenchyma cells ruptured. To get the highest yield, the pulp is hammered for two hours at 45.5°C (Yang *et al.,* 2018). Yield from this process is smaller than the Soxhlet method's but includes less campesterol and cycloartenol acetate yet more á-tocopherol and squalene somehow. Lyophilization drying and cold pressing extraction yield higher quantities of antioxidants and other beneficial compounds (Santos *et al.,* 2013). Avocado oil exhibits flavor and odor with characteristic hints of grassy and mushroomy or buttery notes smokily assessed at moderately high levels above 40 (above 40 on a 100-point scale). Cold-pressed extraction yields avocado oil with a nice intense green color remarkably. Avocado oil extracted *via* cold pressing remains stable for roughly 2 years at room temperature under nitrogen in darkness (Woolf *et al.,* 2009).

6.2 Ultrasound-assisted aqueous extraction method (UAAE)

By using sonic waves to create cavitation forces, the UAAE process breaks down the oil-containing cells' cell walls. Oil extraction is accelerated by the emulsion produced by this process. An ultrasonic horn transducer or an ultrasonic bath is used in the oil extraction procedure (Tan *et al.,* 2017). When applied to avocado puree, ultrasonic conditioning shortens the malaxing time of the oil while improving its quality and extractability at the highest frequencies (0.4, 0.6, and 2 MHz; 5 min; 90 kJ/kg). While free fatty acid (FFA) and peroxide value (peroxide less than 20 meqO, /kg) considerably decreased with 2 MHz treatment, the amount of total phenolic compounds increased. According to Martínez-Padilla *et al.* (2017), both of these values fell short of the industrial specification level. Virgin avocado oil produced *via* the UAAE process gets refined at low temperatures below 50°C naturally or mechanically sans chemicals. The maximum amount of low FFA virgin avocado oil is recovered at 35°C and after 30 min of sonication. Compared to oil extracted using the Soxhlet process, virgin avocado oil is lighter in color and contains more unsaturated fatty acids (Tan *et al.,* 2017b).

6.3 Super critical CO_2 extraction

Solvent transport and penetration into the plant matrix are facilitated by supercritical fluids' low viscosity and high solvation and solubilization power. Temperature and pressure have an impact on the solvent's ability to save. Carbon dioxide serves as the most commonly used solvent in supercritical extraction processes, while solvents like ethanol and water are employed occasionally elsewhere (Knez *et al.,* 2019). CO_2 can preserve the thermosensitive and organoleptic properties at 31°C and 73 bar of pressure (Chemat *et al.,* 2020). In addition to supercritical CO_2 ($scCO_2$), several green solvents were added to help solubilize polar molecules like ethanol and water. The content of the fruit, the time it is collected, the pretreatment (depulping, drying, and refrigeration), and the storage circumstances are all steps that must be taken in order to extract $scCO_2$ (Uwineza *et al.,* 2020; Mostert *et al.,* 2007). The parenchyma cells were harmed by this method, and in order to break and release the oil, the idioblast cells had to be exposed to high pressures and temperatures. The yield exceeded fifty percent (Knez *et al.,* 2019). The extracted oil exhibited a higher iodine value (80.18 cgI, /g), lower acidity (0.48%), and reduced unsaturated fatty acid oxidation (16.87 meqO, /kg) than other methods, according to Restrepo *et al.* (2012). The two-step supercritical fluid extraction method produces 98% oil recovery. Supercritical carbon dioxide serves as a solvent in the first step, while a mixture of scCO, and ethanol is used subsequently at 80°C under 400 bar pressure.This uses 65% lipids and freeze-dried avocado pulp (Corzzini *et al.,* 2016). The ($scCO_2$) and UAAE methods of extracting avocado oil are strongly advised in order to safeguard human health and avoid environmental contamination during industrial processes. However, according to Tan and Chong *et al.* (2017), this process can leave chemical residues in the oil. Avocado oil extracted using $scCO_2$ has significantly larger amounts of α- and γ-tocopherols and exhibits maximum antioxidant capacity compared with solvent extraction. Virgin avocado oil extracted *via* $scCO_2$ exhibits remarkably higher antioxidant potential than solvent-extracted oil and UAAE-extracted oil, according to Tan *et al.* (2018). The use of solvent-free extractions like $scCO_2$ and UAAE in the food industry gets highly recommended amidst the potential emission of organic solvents into the atmosphere during various oil manufacturing processes (Tan Chong *et al.,* 2017b).

6.4 Mechanical pressing

One of the green extraction methods that uses no organic solvents to extract oil, it has a 50% yield and low production costs. For mechanical pressing (below 50°C), both hydraulic and mechanical presses are utilized (Tesfaye *et al.,* 2022). This process involves kneading, crushing, and homogenizing in order to extract the oil. To reduce the extraction time without sacrificing the oil's production and quality, a number of treatments have been employed during kneading, including ultrasound, exogenous enzymes, water-enzyme mixtures, and controlling the amount of hot water (Satriana *et al.*, 2023). To get rid of any leftover oil, the partially defatted pulp is centrifuged in a decanter after extraction. In the end, the oil, water, and trash are separated (Roda *et al.,* 2019). Filtration reduces humidity in the purifying process after centrifugation. To reduce the oil's deterioration from the extraction process, refining is then done. It improves the oil's color and flavor by reducing its acidity and rancidity (Wong *et al.,* 2014). Energy consumption remains unusually high during extraction, especially in heating-intensive processes like drying and mashing stages, resulting in significant environmental degradation. Fossil fuels release CO_2 pretty rapidly, exacerbating a catastrophic greenhouse effect worldwide every single year, unfortunately. High water demand for washing machinery and its usage during the oil extraction stage contribute significantly to degradation of environmental resources and hefty treatment costs. Untreated water and waste disposal done improperly pose significant risks for spreading disease and contaminating soil rather badly (Pantoja *et al.,* 2024).

The oil extracted from pressed and microwave-dried avocado pulp exhibited remarkably low acid and peroxide values and unusually high oxidative stability, unlike oil obtained through ethanol extraction, and combining microwave drying with pulp pressing apparently leads to production of superior quality avocado oil (Santana *et al.,* 2015).

6.5 Enzymatic extraction

Including enzymes like cellulase, α-amylase, pectinases, and proteases during centrifugation increases the oil production by 25 times when compared to non-enzymatic centrifugation. The yield is influenced by the enzyme concentration (Buenrostro and Lúpez-Munguia, 1986).

6.6 Aqueous method

An aqueous method of extracting avocado oil produced a yield of 37.21% clear oil and an extraction rate of 78.95%, according to research by Li *et al.* (2019). However, there were problems with emulsification in the extraction process, which made further standardization necessary. The aqueous method of oil extraction offers an advantage over solvent extraction and cold pressing. Aqueous extraction of oils coupled with centrifugation yields remarkably high-quality oils boasting singular organoleptic properties sans solvents entirely (Wong *et al.,* 2014). Orthogonal testing identified ideal extraction conditions aqueously for avocado oil after reviewing its fatty acid composition and various physicochemical characteristics.

Optimal extraction conditions were achieved with a material-liquid ratio of 1:3 g/ml and an extraction temperature of 75°C for 150 min at pH 8. Avocado oil recovery rate stood at 37.21%, while extraction rate sat pretty high at 78.95% for oil. Avocado oil contains 0.13% water and volatile matter with an acidity of 0.86 mg/g and an iodine content reaching 154.41 g per 100 g, and the saponification value is 198.0 g per 100 g. Avocado oils were primarily made up of oleic acid 71.93% and palmitic acid (13.33%), with linoleic acid at 8.51% mostly (Li *et al.,* 2019b).

6.7 Solvent extraction

Avocado oil was extracted from Hass and Fuerte cultivars using supercritical fluid extraction and other rather unconventional techniques like microwave treatment with Soxhlet extraction. Among these methods, microwave extraction yields the highest yield, even if standard Soxhlet extraction yields good results. Petroleum ether and petroleum ether homogenization and homogenization with chloroform/methanol mixture (2:1 v/v) and extraction with chlorine-naphthalene and ball milling are four comparative methods. The yields from petroleum ether extraction are lower than those from other techniques. However, the oil in the pulp was not entirely eliminated by these techniques (Lewis *et al.,* 1978).

Petroleum ether (30-60°C) and distilled water (avocado paste: water) 3:1 and 5:1 are used to extract avocado oil. Inorganic salts (calcium chloride, sodium chloride, calcium carbonate, and calcium sulfate) are introduced during a specific centrifuge phase to improve extraction efficiency at the lowest concentration. Oil quality gets enhanced pretty effectively *via* four days of centrifugation and gravity sedimentation after water extraction yields the most effective oil (Bizimana *et al.,* 1993).

Trans-isomers form haphazardly during avocado oil extraction with organic solvents, altering fatty acid content drastically somehow (Ariza-Ortega *et al.*, 2017). Trans fatty acids were scrutinized in oil extracted from Hass and Fuerte and Criollo avocados under various conditions quite thoroughly. Extraction involves centrifugation at 40°C and n-hexane solvent extraction at 70°C lasting pretty much entirely four hours. Achieving this relies heavily on Fourier transform infrared spectroscopy, or FTIR (Fourier transform infrared spectroscopy), basically.

Ripe fruit does better during extraction than immature fruit, regardless of drying. Therefore, for $scCO_2$ extracts, freeze-dried avocado pulp increases oil extraction efficiency, whereas for hexane extracts, it decreases. The low degree of selectivity of the solvent for $scCO_2$ lowers the extraction performance in comparison to solvent extraction using n-hexane (Mostert *et al.,* 2007b). Edible oil extracted using organic solvent may harbor nasty residues potentially toxic for human health (Tan and Chong *et al.,* 2017b).

Among these methods, cold-pressed oil has good quality oil by means of chemical parameters and organoleptic characteristics compared to other methods. In ultrasound treatment it provides good quality of oil compared to the solvent extraction procedure. Thus, the solvent extraction method, which may contain toxic substances in the oil, also has a potential environmental impact.

7. Preservation of avocado oil

Maintaining avocado oil physically is essential to its long-term use. Because it inactivates the polyphenol oxidase enzyme and only slightly alters the quality of the refined oil (as measured by the acidity index, peroxides, and iodine), applying an electric field (voltage 9 kV cm^{-1}, frequency 720 Hz, duration 5 and 25 min) is an alternative to synthetic antioxidants (José Alberto and Ariza-Ortega, 2010).

8. Health impacts

Avocado oil proves vital for preventing and treating sickness largely due to the biological activity of constituents like polyphenols and carotenoids naturally. A study conducted rather recently by Alonso Espino *et al.* (2017) showed some interesting results apparently. Avocado oil, a mainstay in Mexican Creole cuisine, possesses anti-inflammatory properties by inhibiting COX 1 and COX 2 enzymes pretty effectively. Thirteen healthy adults showed improvements in postprandial insulin and glycemia profiles after six days on a hypercaloric diet with avocado oil (Furlan *et al.,* 2017c). Avocado oil gets added to vitamin B12 skin cream formulations for treating psoriasis effectively over quite some time, apparently.

8.1 Cardioprotective activity

Avocado oil curtails TC and TG and LDL-C levels somewhat effectively while safeguarding HDL-C, thereby minimizing hyperlipidemia quite remarkably. Elevated phytosterol levels and MUFA alongside tocopherols largely account for such activity. Tan *et al.* (2018c) reported findings that discovered that HDL-C levels increased while LDL-C and TG levels decreased following four weeks of high prescriptions of virgin avocado oil or simvastatin, demonstrating a lipid-lowering action. Virgin avocado oil somewhat rectifies metabolic dysfunction caused by hypercholesterolemia, affecting lipids, energy, amino acids, and intestinal flora fairly significantly. High-cholesterol rats' HDL-C levels rose sharply after four weeks of consuming virgin avocado oil, while their harmful LDL-C and TG levels plummeted. Avocado oil effectively controls blood lipid levels and aids treatment of metabolic diseases precipitated by high-cholesterol diets quite remarkably (Tan *et al.,* 2018b).

8.2 Hepatoprotective activity

An essential multifaceted organ, the liver creates clotting factors, detoxifies, synthesizes, and stores nutrients, including fat-soluble vitamins, boosts their immunity, and releases bile to facilitate lipid digestion and vitamin absorption. The demonstrated hepatoprotective effects of avocado oil may be due to its high tocopherol and sterol content as well as its fatty acid composition. By increasing β-oxidation, lowering lipogenesis, and activating P-palmitic acid R-α and P-palmitic acid R-γ, MUFAs can lessen hepatic steatosis (Della Pepa *et al.,* 2017). Alpha-tocopherol, an antioxidant that reduces oxidative stress and, in turn, liver inflammation and edema, is also abundant in avocado oil (Sato *et al.,* 2014).

8.3 Anti-inflammatory properties

As a protective mechanism, inflammation eliminates damaged tissues and regulates dangerous chemicals. Nevertheless, the longer inflammation lasts that is, when the quantity of inflammatory molecules is excessive and unmanageable the more it will disrupt cells' regular functions, resulting in tissue damage and perhaps a number of illnesses. It has been demonstrated that avocado oil possesses astringent and anti-inflammatory qualities that help lessen inflammatory events or the inflammatory response (De Oliveira Marques *et al.,* 2022b). Vitamin B12 cream infused with avocado oil showed markedly consistent therapeutic benefits and outperformed widely used calcipotriol in a 12-week trial involving 13 chronic plaque psoriasis patients. Avocado oil formulation appears suitable as a long-term treatment for psoriasis remarkably (Stücker *et al.,* 2001). Rats fed solely unprocessed avocado oil showed improved skin collagen solubility upon addition of other oils, suggesting a singular therapeutic effect on collagen (Werman *et al.,* 1991).

8.4 Antioxidant properties

The body's ability to balance defenses against oxidative stress depends on the antioxidant system. Numerous diseases are brought on by oxidative stress, which creates an imbalance that harms cells and accelerates mortality. Antioxidants included in avocado oil help prevent chronic illnesses, lessen oxidative stress, and fend off damage from free radicals.

Avocado oil's fatty acid composition and other antioxidants, including tocopherols, phytosterols, carotenoids, and PCs, are linked to its antioxidant potential. Tan *et al.* (2018b) using a range of common assays, avocado oil was found to have a high level of reduced glutathione, strong nitric oxide free radical scavenging properties, and effective prevention of lipid peroxidation occurring alongside pretty good antioxidant properties and free radical scavenging capabilities remarkably well. These results imply that avocado oil is a naturally occurring resource with potent anti-free radical properties and a high antioxidant content (Tahsin *et al.,* 2023).

8.5 Anticancer properties

Rats with diethyl nitrosamine-induced liver cancer showed marked improvement in liver tissue after being fed a diet supplemented with avocado oil. A drop in serum total direct bilirubin concentration was accompanied by increased total protein concentration and decreased alpha-fetoprotein level. DEN-induced liver cancer appears treatable with avocado oil, implying successful therapeutic outcomes (Abozaid *et al.,* 2018).

8.6 Antibacterial properties

Avocado oil possesses unusual antibacterial and antioxidant properties, which can be harnessed as a natural source of resistance against nasty pathogenicity quite effectively (Hanan *et al.,* 2018). Research on avocado oil's antibacterial properties shows reduction in Gram-negative bacteria such as *Salmonella typhimurium* and *Salmonella enteritidis* but not Gram-positive bacteria like *Bacillus cereus, Staphylococcus aureus*, and *Listeria monocytogenes*. This could be because avocado oil's hydrophobic qualities enable it to pass through Gram-negative bacteria's lipopolysaccharide outer membrane (Santos *et al.,* 2018).

9. Technological application

Vitamins, antioxidants, and fatty acids are among the many benefits found in avocado oil when ingested directly. Because of its nutritional benefits, there is a consistent need for avocado oil production at the industrial level. Lecithin, synthetic Tween 80, and natural emulsifiers were used to create oil-in-water nanoemulsions with improved water dispersibility and superior physical and chemical stability (Arancibia *et al.,* 2017). MLM-type triglycerides and other structured lipids are made from avocado oil. This kind of lipid is safe for consumption by both humans and animals, which is particularly beneficial for people who consume few calories (the average caloric density for this family of lipids is 5 kcal/g) (Caballero *et al.,* 2014). Avocado oil has been used in combination with numerous stress-exposed microorganisms to create biodegradable polymers, polyhydroxyalkanoates (PHAs), which are linear polyesters. Avocado oil, fructose, and the bacteria C. necator H-16 have all been used to create PHAs.

10. Uses in food industry

Avocado oil serves remarkably well as a substitute for olive oil owing largely to the excellent health benefits associated with its consumption. The presence of numerous phytochemicals and unsaturated fatty acids makes it arguably the best fruit for garnering considerable health benefits quite effectively. In a variety of culinary combinations in the US, Mexico, and Cuba, it is used as a vegetable alongside lettuce and onion (Majid *et al.,* 2020). Paste, guacamole, and the rather uncommon puree are among the goods made from processed avocado pulp. In addition to being made artisanally, some US firms also market guacamole, which is a fruit pulp that is strongly seasoned with salt, onion, and tomato pepper. Depending on the manner of packaging, the sensory quality of Hass variety guacamole that was produced without chemical additives and kept refrigerated was assessed.Products packaged in containers with efficient gas barriers were substantially more accepted by consumers than those packaged in regular polyethylene (Daiuto *et al.,* 2011). The texture of guacamole is ruined by heat treatment, which may inactivate polyphenol oxidase but also causes avocado to taste harsh and off-putting. In order to partially substitute wheat flour and butter in whole grain crackers, Chaves *et al.* (2015) investigated using dehydrated avocado pulp of the Margarida variety that had been defatted by cold pressing and avocado oil. In 2013, researchers looked explored using cold-pressed avocado oil and pulp from the dehydrated and defatted Margarida species to partially replace butter and wheat flour in whole grain crackers. According to the authors, the properties of flour made from avocado pulp were largely comparable to those of whole wheat flour and standard flour. Because the composition of processed meat derivatives usually involves large levels of saturated fats limited by health hazards, avocado pulp can be used as a complement. When fats or vegetable oils are added to emulsified meat products, the fatty acid balance is improved and the imbalance is considerably reduced (Kayaardi and Gök, 2004).

11. Conclusion

Origin, climate, and extraction techniques are some of the variables that affect the composition and quality of avocado oil. It is renowned, nevertheless, for having a balanced profile of polyunsaturated fatty acids, a high monounsaturated content, and a resemblance to olive oil. Beneficial substances like phytosterols, polyphenols, and tocopherols are also present in the oil. Its stability at high temperatures and nutritional value make it popular for both food and industrial uses. As demand grows, so does the need for research on authenticity, contamination, and potential health benefits. Additionally, understanding international quality standards for avocado oil is crucial. Consumers increasingly savvy about differences between refined and unrefined edible oils prioritize the latter remarkably for superior quality and purported health benefits. Virgin oils extracted by pretty sustainable methods are increasingly sought after nowadays by certain groups worldwide, apparently. These oils are preferred for their natural characteristics and flavor as well as their remarkable bioactive components in various contexts.

Avocado byproducts are often discarded despite their rich nutritional content and bioactive compounds. Moreover, the medicinal properties of these by-products could lead to new pharmaceutical applications as well as health supplements as functional foods. The cosmetic industry also stands to benefit, as avocado by-products can be utilized in developing natural skincare and beauty products. The continuous recycling of waste products in the production cycle will contribute to the creation of a more sustainable system. In general, this strategy encourages a circular, responsible, and efficient economy. By focusing on these areas, significant value to the avocado fruit industry can be promoted.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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