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Avocado (*Persea americana* Mill.) as a source of bioactive compounds: A review on its nutritional, phytochemical, industrial and health aspects

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Abstract

Avocado (*Persea americana* Mill.) is often considered a superfood due to its rich composition of healthy fat, protein, fibre, vitamins, and minerals. Apart from its nutrient-dense fruit pulp, Avocado leaves, seeds, and peels also contain valuable bioactive compounds, antioxidants, and essential nutrients, making them a potential source for pharmaceutical and cosmetic industries. Studies suggest that Avocado consumption improves cardiovascular health, enhances gut health microbiota, promotes skin elasticity, and boosts cognitive function in older adults by increasing lutein absorption. Avocado by-products, which are usually considered waste, have shown promising potential as a source in various industries like textiles, food, cosmetics, energy, and bioplastics. This review provides a comprehensive analysis of Avocado's nutritional and phytochemical composition, focusing on its health benefits, industrial and therapeutic applications.

1. Introduction

Avocado (*Persea americana* Mill.) or alligator pear, an evergreen tree approximately 20 m high (Adeyemi *et al.*, 2002), is a member of the Lauraceae family, which originated in Central America, but grows in many tropical and subtropical regions, such as Indonesia. Most laurales have foliage with fragrance when crushed, like that of the Mexican race of Avocado, which is utilized for the production of tea and wine. Carolus Linnaeus initially placed Avocado in the *Laurus* genus, with the *Greek laurel*, and it was Miller in 1754, who recognized *Persea* as a valid genus. The genus *Persea* contains around 50 species, with “*americana*” being the true Avocado (Bergh and Ellstrand, 1986). Abraham *et al.* (2018) assessed the morphological diversity of Avocado (*Persea americana* Mill.) trees mainly by evaluating their vegetative and reproductive characteristics. The fruit shapes range from pyriform, narrowly obovate, ellipsoid, clavate, rhomboid, oblate, spheroid, and high spheroid. The diverse morphological traits observed among the Avocado trees indicate significant genetic variation and ecological adaptation, likely influenced by differing soil and climatic conditions across the study regions. Additionally, long-term cross-pollination between local populations may have contributed to the variations, despite their shared ancestry. Global Avocado exports are projected to grow by approximately 20% in 2023, reaching around 3 million tonnes. This increase was primarily driven by favourable supply conditions in Mexico, the world's leading exporter of Avocados. Mexico accounts

for over 28% of the global Avocado production, with over 2.75 million metric tons in 2025 (USDA, 2025). On the other hand, the United States is one of the largest consumers of Avocados in the world. Almost all parts of this plant have been used in traditional medicine by local communities (Adeyemi *et al.*, 2002). Avocados come in many varieties, with Hass being the most popular and favoured variety in the United States due to its higher fat content, unique taste, and creamy flesh.

The Chontales of Tabasco, Mexico, believe that gods reside in trees, emphasizing the need for their conservation. Among the numerous trees valued by Mesoamerican societies, Avocado held a prominent place in diet, nutrition and mythology. Even before the origin of agriculture, they valued the Avocado fruit as nutritious, and cultivated the crop within its natural habitat (Gama-Campillo and Gomez-Pompa, 1992). Avocado is one of the few commercially significant members of the genus *Persea*, and the fruit is called Ahuacatl by Aztecs in Mexico, which was later derived as Avocado, Avocat in French, Abacate in Portuguese, and Aguacate in Spanish. The Aztecs considered Avocado as aphrodisiac mainly due to the fruit's shape, and called it ahuacatl (meaning testicles) (Yahia and Woolf, 2011). Avocado seeds were found in ancient human settlements in the Tehuacan valley, suggesting that Avocado could have been used as early as 8000 to 7000 BC by Mesoamerican groups and could have been possibly domesticated at those times. From early times, commercial exchange was widely popular, and studies suggest that Avocado could have been an important exchange product (Galindo-Tovar *et al.*, 2007). Coming to the colonial period, Martín Fernández de Enciso in “La Suma de Geografía” (1519), mentioned Avocado as an orange with a buttery flavour (Popenoe and Zentmyer, 1997). Throughout history, various chronicles have described Avocados in many ways, highlighting its unique texture, flavour and health benefits.

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The Avocado has been evolved from a regionally significant fruit to a globally cultivated commodity. It was introduced to California by Nicaraguan settlers in 1856 and to Israel in 1908 and its expansion was accelerated, reaching Central America, the Caribbean, Africa, Asia, Oceania, and Europe.

The Avocado species have generally been divided into three races: Mexican, Guatemalan, and West Indian, of which a few hybrids are created, *viz.* “Hass” and “Fuerte”. A typical healthy Avocado tree in California can produce up to a million flowers a year. Still, on average, fewer than 200 flowers per tree will set fruit that will hold and develop to maturity and harvest. Commercial Avocado production is based on grafting cultivars onto rootstocks, mainly of the Mexican and Guatemalan races. In subtropical climates, the Guatemalan genotypes represent the dominant horticultural race (Ibarra *et al.*, 2015). Studies show that diseases like anthracnose, armillaria root rot, Avocado black streak, bacterial canker, dematophora, or rosellinia root rot are common in Avocado.

The recent popularity of Avocado is increasing not only because of its nutritional benefits but also for the presence of potential bioactives, which can be the source for cardiovascular and neuroprotective agents, whereby industries can generate economic gains by replacing the existing expensive drugs. In addition to its diversified health benefits, Avocado is gaining significant popularity for its active compounds, which can be used in various industries. This review is focusing to outline the various aspects of Avocado, highlighting its phytochemistry, pharmaceutical, nutraceutical, and industrial importance.

2. Varieties of Avocado

Avocado varieties are commonly grouped into three major types based on their geographical origin and characteristics: the West Indian, Guatemalan, and Mexican types. Each type exhibits unique traits in terms of fruit size, skin texture, oil content, and climatic adaptability, making varietal selection a critical factor in establishing a successful Avocado industry (Vosbury, 1919).



Figure 1: A typical West Indian Avocado (Source: Ledesma and Campbell, 2005).

2.1 West Indian type

West Indian Avocado varieties are known for their thin-skinned fruit with variation in size, shape, color, and fruiting season, and may

have originated in the lowlands of Central America (Figure 1). Other characteristics of this race are fruit with a leathery, pliable skin and a tree of almost tropical tendency with foliage being injured at temperatures lower than 30°F (Scott, 1918). Some of the West Indian varieties include Trapp, Walden, Baker, McKean, Pollock and Butler (Vosbury, 1919).

2.2 Guatemalan type

Guatemalan varieties are known for their thicker, leathery skin, often termed “shell-like skin”. They are more cold-tolerant, generally withstand 3-5°F than the West Indian type, and have late season fruiting (Vosbury, 1919). The fruit shows no fibre or only a slight trace, and has a very high oil content with a rich nutty flavour (Scott, 1918). Taft, Fuerete (Figure 2), McDonald, Wagner, Atlitxco, Solano, and Collins are some of the notable Guatemalan varieties (Vosbury, 1919).



Figure 2: Guatemalan variety Fuerete Avocado.

2.3 Mexican type

The Mexican Avocado varieties are the hardest, with some resistance to cold as the round orange but having a small fruit making them not ideal for commercialization (Vosbury, 1919). They can withstand temperatures as low as 25°F and even lower without serious injuries. The fruits have a considerable amount of fibre and a high oil content. The leaves have a characteristic anise odor (Scott, 1918). Common varieties include Puebla (Figure 3), San Sebastian, Harmon and Gottfried (Vosbury, 1919).



Figure 3: Mexican variety Puebla Avocado.

3. Phytochemical profile

3.1 Phenols

Studies conducted by Velderrain *et al.* (2021) on Avocado peel, seed coat and seed revealed a remarkably diverse and rich profile of phenolic compounds. Using UPLC-ESI-MS/MS analysis, the researchers identified a wide range of bioactive compounds, including vanillin, hydroxytyrosol, hydroxytyrosol glucoside, hydroxysalidroside, hydroxytyrosol glucoside arabinoside, salidroside, and tyrosol. In addition to these simple phenols and their derivatives, a comprehensive range of phenolic acids was reported, such as p-hydroxybenzoic acid, vanillic acid, syringic acid, protocatechuic acid, and its glucoside, along with various hydroxycinnamic acid derivatives including p-coumaric acid, coumaric acid glucoside, coumaroylquinic acid, caffeic acid and its glucoside forms, dihydrocaffeic acid glucoside, and caffeoylshikimic acid. Several chlorogenic acid isomers namely 3-O-, 4-O-, and 5-O-caffeoylquinic acids were also identified, along with dicaffeoylquinic acid and a series of ferulic acid-related compounds such as ferulic acid, ferulic acid glucoside, dihydroferulic acid glucoside, and their respective feruloylquinic acid conjugates (3-O-, 4-O-, and 5-O-feruloylquinic acid).

Among the three Avocado residues analyzed, the peel exhibited the highest total phenolic content (309.95 ± 25.33 mMol gallic acid equivalents/100 g extract), flavonoid content (12.54 ± 0.52 mMol catechin equivalents/100 g extract), and anthocyanin content (622.37 ± 17.26 mMol cyanidin-3-glucoside equivalents/100 g extract), followed by the seed coat and seed. Antioxidant activity assessments using DPPH, ABTS, and FRAP assays confirmed the potent antioxidant properties of these extracts.

3.2 Flavonoids

Velderrain *et al.* (2021) also mentions the presence of flavonoids like catechin, epicatechin, catechin glucoside, epicatechin glucoside, epigallocatechin, epicatechin gallate, catechin derivative, epicatechin derivative, procyanidin dimer (type A), procyanidin dimer (type B), procyanidin trimer (type A), procyanidin trimer (type B), procyanidin tetramer, procyanidin pentamer, procyanidin hexamer, quercetin, quercetin arabinoside, quercetin glucoside, quercetin rhamnoside, quercetin glucuronide, quercetin acetylglucoside, quercetin arabinoside glucoside, quercetin rutinoside, quercetin diglucoside, quercetin glucoside rhamnoside, isorhamnetin, isorhamnetin derivative, isorhamnetin arabinoside, isorhamnetin glucoside, isorhamnetin glucuronide, isorhamnetin arabinoside glucoside, kaempferol arabinoside, kaempferol glucoside, kaempferol rutinoside, kaempferol arabinoside glucoside, naringenin, naringenin glucoside, sakuranetin, luteolin, and luteolin arabinoside glucoside. The peel extract, in particular, exhibited the highest flavonoid content among the residues studied, contributing significantly to its superior antioxidant activity. Similar results were reported by da Silva *et al.* (2022) showing that the ethanolic extract of Avocado peels exhibits higher flavonoids compared to seeds. These flavonoid compounds, recognized for their free radical scavenging abilities, may contribute to the biological activities observed in the extracts, including antiproliferative effects against certain cancer cell lines. Velderrain *et al.* (2021) emphasized the role of these flavonoids not only as potent antioxidants but also as bioactive constituents with promising applications in functional foods, nutraceuticals and cosmetic formulations.

3.2.1 Catechins

Catechin, epicatechin, and epicatechin gallate are prominent dietary catechins known for their beneficial effects on human health. Among these, (+)catechin and (-)epicatechin were conclusively identified in Avocado peel extracts through their retention times and mass spectrometric data, which aligned with those of commercial standards. In addition to monomeric catechins, the presence of oligomeric procyanidins, specifically dimers and trimers, has been reported in microwave-assisted extracts of Avocado peel. These compounds, formed through the polymerization of catechin and epicatechin units, contribute significantly to the antioxidant capacity of the peel (Figuerola *et al.*, 2021).

3.3 Saponins

Studies by Adesola *et al.* (2025) revealed the presence of saponins in Avocado leaf extract, leaf flour, leaf protein isolate flour, and leaf protein hydrolysates, among which the total saponin content was higher in Avocado leaf flour and leaf extract samples (17.7 mg/g). Another study by Rahman *et al.* (2022) showed that the presence of saponin content in the Avocado peels was about $8.874\% \pm 0.031\%$.

3.4 Alkaloids

Rahman *et al.* (2022) showed the presence of alkaloid content in Avocado peels as 9.95 ± 0.035 mg CE/g extract, and Adesola *et al.* (2025) reported the presence of alkaloids (1.4%) in Avocado leaf extract. Oluwaniyi *et al.* (2017) stated the presence of 5.40 mg/100 g of alkaloids in Avocado seed.

3.5 Phytosterols

β -sitosterol, a predominant phytosterol in Avocado, has garnered significant attention due to its potential health benefits, particularly its role in lowering cholesterol levels and supporting cardiovascular health. β -sitosterol is one of the most significant phytosterols present in Avocado fruit, and its presence is found to increase during ripening (Villa-Rodriguez *et al.*, 2020). Other phytosterols such as stigmasterol (absent in certain stages), ergosterol, and brassicasterol have also been reported (Flores *et al.*, 2019; Saha *et al.*, 2019). Stigmasterol, in particular, is known to be absent in certain stages of Avocado ripening, as highlighted by Flores *et al.* (2019). The presence of these phytosterols, including β -sitosterol, is significant due to their potential health benefits, including their role in cholesterol regulation, anti-inflammatory properties, and their potential to prevent certain chronic diseases (Jones and Abu Mweis, 2009). Research indicates that beta-sitosterol is the most abundant phytosterol in Avocados, with an average content of 76.4 mg/100 g of raw edible fruit. Campesterol is present at approximately 5.1 mg/100 g, while stigmasterol levels are below 3 mg/100 g (Lu *et al.*, 2005).

3.6 Carotenoids

The study conducted by Villa-Rodriguez *et al.* (2020) examined how ripening affects the phytochemical composition of 'Hass' Avocado mesocarp, particularly focusing on methanolic extracts and their cytotoxic activity. In unripe mesocarp, the predominant carotenoids include lutein, violaxanthin, and neoxanthin, which are known for their antioxidant properties. As the fruit ripens, the levels of some carotenoids, especially lutein, tend to decrease. This shift in carotenoid profile during ripening may affect both the nutritional value and the bioactive potential of Avocado, highlighting the importance of fruit maturity in determining its health benefits.

4. Nutritional profile

4.1 Avocado seed

Avocado seeds are rich in various nutritional and bioactive compounds, especially proteins, starch, lipids, crude fibre, vitamins, minerals, and various other phytochemicals. According to studies conducted by Ifesan *et al.* (2015), Avocado seeds have a protein content of 23% and minerals like calcium (0.82 mg/100 g), potassium (4.16 mg/100 g), phosphorus (0.09 mg/100 g), and zinc (1.41 mg/100 g). Presence of vitamin A (10 mg/100 g), thiamin (0.33 mg/100 g), riboflavin (0.29 mg/100 g), niacin (0.06 mg/100 g), ascorbic acid (97.8 mg/100 g) and vitamin E (0.12 mg/100 g) was mentioned by Bangar *et al.* (2022). Carbohydrates are said to make up a significant portion (64.9%), and starch makes up the total carbohydrate content in Avocado seeds to 91.2% (Tesfaye *et al.*, 2018). Among the various components of Avocado seed, lipids play a significant role in determining its functional properties. Báez *et al.* (2019) analyzed the fatty acid composition of Avocado seeds, identifying the presence of saturated, monounsaturated, and polyunsaturated fatty acids. Palmitic acid (7.1 µg/g) was the most abundant saturated fatty acid, followed by stearic acid (5.06 µg/g) and myristic acid (2.49 µg/g). Oleic acid (5.32 µg/g) is the predominant monounsaturated fatty acid, while linoleic acid (4.06 µg/g) represents the major polyunsaturated component. Other notable fatty acids include tetracosanoic acid (4.29 µg/g), behenic acid (3.63 µg/g), and arachidic acid (2.39 µg/g), which contribute to the seed's stability and potential applications. The antioxidant activity of the Avocado seed powder

was determined as approximately. 122 mMol TEAC/100 g (dry matter) (Siol and Sadowska, 2023).

4.2 Avocado pulp

Avocado trees have a long flowering period that lasts up to 3 months, however the percentage of flowers that become mature fruit is extremely low. Fruit maturation require 5 to 15 months after pollination and the fruit can remain in the tree for more than 12 months, but it does not ripe on the tree. Avocado is a chimeric fruit that only starts ripening after the fruit has been picked from the tree (Hernández *et al.*, 2016). Studies show that Avocado pulp is rich in nutritional properties as mentioned in Table 1. Avocado is classified as a non-acid fruit, and compared to other fruits, it contains very low amounts of citric and malic acid, acid, tartaric acid, and ascorbic acid being the predominant organic acid (Pedreschi *et al.*, 2019). Avocado lipids are classified into neutral lipids (mainly triacylglycerols or TAGs), phospholipids, and glycolipids. Neutral lipids make up 96% of the total lipid content, with TAGs being the predominant form. The primary fatty acids in TAGs include oleic acid (18:1) at 59-81%, linoleic acid (18:2) at 7-14%, palmitic acid (16:0) at 7-22%, and palmitoleic acid (16:1) at 3-11%. The lipid content and composition vary across different Avocado cultivars and among the mesocarp, exocarp, and seed. Galvao *et al.* (2014) reported average mesocarp fat contents (g/100 g) of 16.2, 13.6 and 11.9 for Fortuna, Collinson, and Barker cultivars. Avocado pulp comprises 67%-78% moisture, 13.5%-24% lipids, 0.8%-4.8% carbohydrates, 1.0%-3.0% protein, 0.8%-1.5% ash, 1.4%-3.0% fibre and an energy density of 140-228 kcal (Soares and Ito, 2000) (Figure 4).

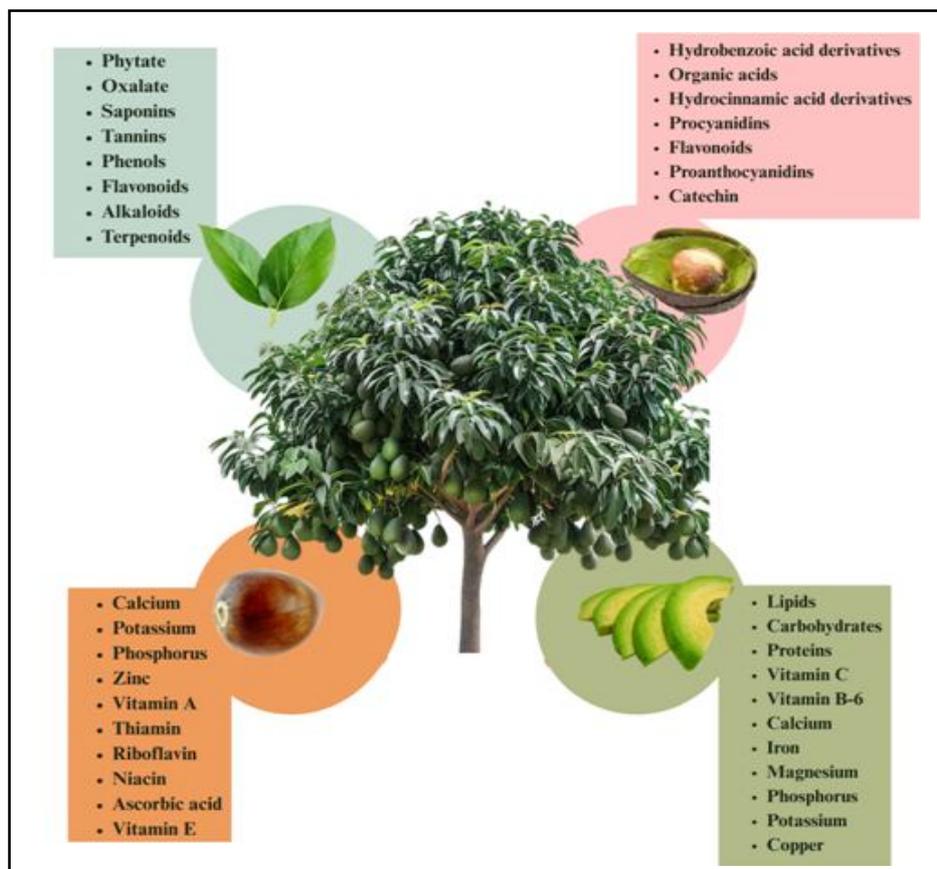


Figure 4: Avocado parts showing essential bioactive compounds.

Table 1: Composition of edible portion (Avocado Hass variety) (Source: USDA Food Data Central, 2024)

Nutrient/phytochemical	Value per 100 g	Unit
Water	67	g
Energy	223	kcal
Nitrogen	0.29	g
Protein	1.18	g
Total lipid	20.3	g
Carbohydrates	8.32	g
Calcium	14	mg
Iron	0.61	mg
Magnesium	32.8	mg
Phosphorus	42	mg
Potassium	576	mg
Sodium	<2.49	mg
Zinc	0.46	mg
Copper	0.285	mg
Manganese	0.197	mg
Vitamin C	<4	mg
Vitamin B-6	0.167	mg
Folate	129	µg

4.3 Avocado peel

The Avocado peel consists of 62%-73.3% carbohydrates, 4.4%-9.1% lipids, 4%-8.3% proteins, about 50% fibres, and 4%-6.1% ashes (Dominguez *et al.*, 2014). Avocado peel is enriched with three times higher polyphenol content than pulp and seed, conventionally extracted by maceration of dried material using hot water (Calderón *et al.*, 2016). Avocado peel contains various bioactives such as alkaloids (56.5063 µg/ml), flavonoids (245.6875 µg/ml), tannins (27.03 µg/ml), phenols (15.65 µg/ml), saponins (22.73 µg/ml),

phytate (9.68 µg/ml), and oxalate (13.65 µg/ml) (Figure 5) (Sunday *et al.*, 2022). The major compounds present in Avocado peel extracts include hydrobenzoic acid derivatives, organic acids, hydrocinnamic acid derivatives, procyanidins, flavonoids, proanthocyanidins, and (epi) catechin derivatives at various degrees of polymerization (Stephen and Radhakrishnan, 2022). Hass and Fuerte Avocado variety peel extracts inhibited the release of pro-inflammatory cytokines TNF-α and inflammation mediator nitric oxide, suggesting a probable role in the decrease of free radicals action during infection (Tremocoli *et al.*, 2018).

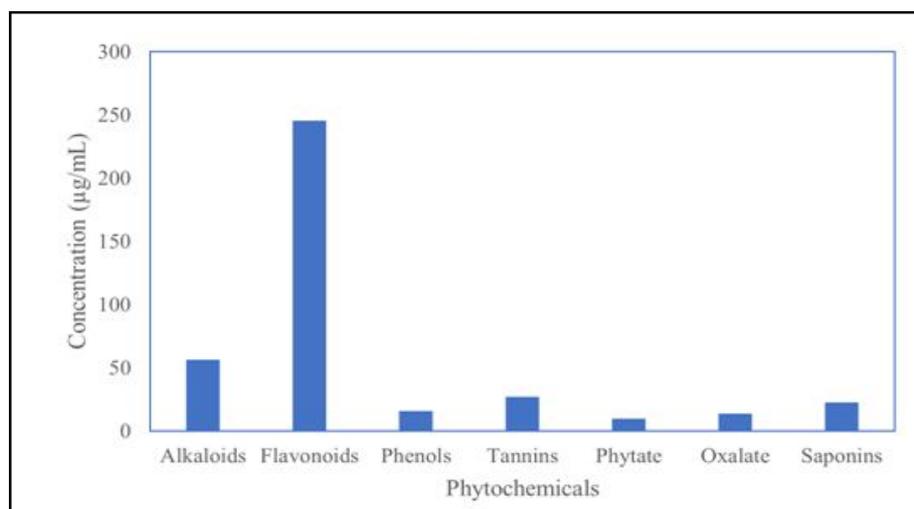


Figure 5: Graphical representation of the results of quantitative phytochemical analysis of Avocado peel (Source: Sunday *et al.* 2022).

4.4 Avocado leaf

Studies conducted by Adesola *et al.* (2025) on Avocado leaves flour (ALF), aqueous extract (ALE) protein isolate (API), Avocado leaves pancreatin-protein hydrolysates (APHPAN) and Avocado leaves lactic acid bacteria-protein hydrolysates (APHLAB), showed the moisture, fat, protein, ash and fibre contents. Leaf flour showed the highest moisture content of 9.38% which shows an important role in stability and shelf life, whereas the protein content was about 11.60% and

fibre was reported to be around 7.02% (Table 2). Avocado leaf extract shows a protein content of about 37.54%, and a low fibre content of 1.87%. Leaf extracts exhibited levels of vitamin C of around 9.32 mg/100 g and 8.66 mg/100 g for leaf flour. Due to the presence of vitamin C, Avocado leaf extract can be used as a strong antioxidant. The presence of phenols (237.8 mg/g), flavonoids (40.4%), saponins (17.7 mg/g), and alkaloids (1.4%) (Table 3) also contributes to the antioxidant property of Avocado leaf extract (Figure 6).

Table 2: Proximate mineral and vitamin composition of ALF, ALE, API, APHPAN, and APHLAB (Source: Adesola *et al.* 2025)

Composition (%)	ALF	ALE	API	APHPAN	APHLAB
Protein	18.54 ± 0.02	21.43 ± 0.02	85.12 ± 0.01	87.54 ± 0.02	88.21 ± 0.01
Fat	6.13 ± 0.01	4.75 ± 0.01	2.89 ± 0.02	3.02 ± 0.01	3.54 ± 0.02
Fibre	12.43 ± 0.02	8.75 ± 0.01	2.65 ± 0.01	1.89 ± 0.01	1.32 ± 0.02
Carbohydrates	49.65 ± 0.01	53.64 ± 0.02	1.38 ± 0.02	1.12 ± 0.01	1.89 ± 0.01
Energy	273.42 ± 0.01	269.54 ± 0.02	357.32 ± 0.01	359.21 ± 0.02	360.65 ± 0.01
Calcium	134.5 ± 0.02	145.2 ± 0.01	98.3 ± 0.01	92.1 ± 0.02	95.8 ± 0.01
Iron	2.13 ± 0.01	2.05 ± 0.02	1.65 ± 0.01	1.42 ± 0.01	1.58 ± 0.02
Vitamin C	17.2 ± 0.01	19.4 ± 0.02	8.3 ± 0.01	7.6 ± 0.01	9.2 ± 0.02
Vitamin A	32.4 ± 0.02	38.1 ± 0.01	22.7 ± 0.01	19.9 ± 0.02	25.3 ± 0.01

Table 3: Phytochemical profile of Avocado leaf extracts and products (Source: Adesola *et al.* 2025)

Phytochemicals	ALP	ALE	API	APHPAN	APHLAB
Phytate (mg/100 g)	112 ± 0.3b	168 ± 0.0a	102.6 ± 1.0c	100 ± 1.0d	99 ± 1.0d
Oxalate (mg/100 g)	0.5 ± 0.0a	0.3 ± 0.0b	0.3 ± 0.0b	0.3 ± 0.1b	0.3 ± 0.0b
Saponins (mg/g)	17.7 ± 1.0a	17.7 ± 0.2a	11.9 ± 1.0b	10.3 ± 1.0b	10.3 ± 1.0b
Tannins (mg/g)	35.3 ± 1.1b	37.3 ± 0.1a	23.6 ± 1.0c	12.5 ± 1.0d	13.2 ± 1.0d
Phenols (mg/g)	233.8 ± 4.1a	237.6 ± 1.5a	211.4 ± 1.0b	211.6 ± 1.0b	210.4 ± 1.0b
Flavonoids (%)	48.4 ± 0.1a	40.4 ± 0.4b	33.2 ± 1.0c	24.2 ± 1.0d	23.1 ± 1.0d
Trypsin inhibitor (mg/g)	48.4 ± 0.4a	39.5 ± 0.3b	23.9 ± 1.0c	20.7 ± 1.0d	21.2 ± 1.0d
Alkaloids (%)	1.1 ± 0.1b	1.4 ± 0.1a	0.7 ± 0.1c	0.4 ± 0.3d	0.3 ± 0.1d
Terpenoids (%)	19.5 ± 0.0a	20.7 ± 0.3a	11.4 ± 0.6b	8.4 ± 1.0c	8.3 ± 1.0c

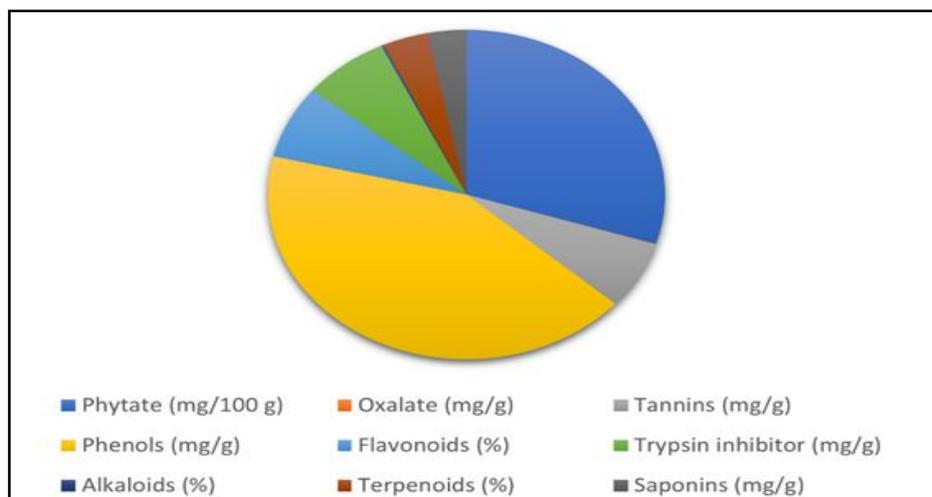


Figure 6: Graphical representation depicting the phytochemicals in Avocado leaf extract.

5. Nutraceutical and pharmaceutical importance of Avocado

5.1 Cardiovascular and metabolic health benefits of Avocado

Avocado contains considerable amounts of bioactive compounds, especially phytosterols, which are most abundant in the lipid fraction, and the main representative is β -sitosterol (Salgado *et al.*, 2008). Diets high in β -sitosterol have been associated with the reduction of total cholesterol and LDL cholesterol levels. According to Duster, (2002), Avocados are the richest fruit source of phytosterols, with about 26 mg/30 g. A study conducted by Pieterse *et al.* (2005) suggest that Avocado consumption significantly increases plasma oleic acid levels while reducing myristic acid levels and the overall reduction in BMI and body fat percentage. Carranza *et al.* (1995) examined the impact of Avocado consumption on blood lipid levels in patients with phenotype II and IV dyslipidemia. In this study, eight patients from each phenotype followed a diet rich in monounsaturated fats, with Avocados as the primary source, and also a diet low in saturated fat without Avocados for four weeks. Results showed a considerable reduction in total cholesterol and low-density lipoprotein cholesterol in phenotype II dyslipidemia patients, which suggests that the consumption of Avocado may help lower harmful cholesterol levels, which are major risk factors for cardiovascular diseases. Another remarkable finding by Brai *et al.* (2007) suggests that the treatment of hypercholesterolemic rats with aqueous solutions and methanolic extracts of Avocado leaves (10 mg/kg) for eight weeks reduced body weight gain by 25% when compared to that in the controls. However, since Avocados contain high calories and fat, the consumption control should be maintained by individuals who take cholesterol-lowering drugs and those who are under medications for anticoagulants, and nonsteroidal anti-inflammatory drugs.

5.2 Effects on gut health

Research by Thompson *et al.* (2021) evaluated the effects of daily consumption of Avocado on daily gut microbiota and metabolite concentrations over 12 weeks in adults with overweight and obesity. The results demonstrated that Avocado intake led to increased microbial diversity, enriched beneficial bacteria like *Faecalibacterium*, *Lachnospira*, and *Alistipes*, and an 18% increase in faecal acetate concentrations. Despite consuming more fat, participants had significantly lower faecal bile acid concentrations, including 91% and 57% reductions in cholic acid and chenodeoxycholic acid, respectively.

5.3 Effects on skin health

A study performed by Henning *et al.* (2022) highlighted that the daily consumption of Avocado improved skin firmness and elasticity, particularly in the forehead and under-eye regions, and also showed a significant reduction in skin fatigue after repeated stretching. Roberts *et al.* (2009) suggest that Avocado's highly bioavailable lutein and zeaxanthin may help to protect skin from damage caused by both UV and visible radiation.

5.4 Effects on brain health

Studies by Scott *et al.* (2016) suggest that the consumption of Avocado enhances cognitive functions, especially in older adults, likely due to the increased lutein deposition in brain tissue. The study also put forward that despite Avocados containing relatively low levels of lutein compared to green leafy vegetables, the lipid-rich composition enhances lutein absorption and bioavailability. Observational analysis

conducted by comparing cognitive functions between Avocado consumers and non-consumers among older Americans found that Avocado consumers exhibited considerably better memory performance and overall global cognition scores (Cheng *et al.*, 2021).

5.5 Anticancer activity

Cancer is the second leading cause of mortality worldwide, following cardiovascular diseases. It accounts for approximately one in six deaths globally, making it a major public health concern (WHO, 2022). Studies conducted by Lu *et al.* (2005) mention that the acetone extract of Avocado (300 μ g/ml) showed 60% inhibition of the proliferation of human prostate cancer cell lines. Chloroform extract of Avocado selectively inhibits the growth of malignant and pre-malignant human oral cell lines (Ding *et al.*, 2007). Water extract of Avocado had low LC_{50} values, 13.3/ μ g/ml in HepG-2 and 22/ μ g/ml in the case of the HT-29 cell lines, respectively. Hence, Avocado is a very good source of anticancer drugs as it is helpful in the treatment of liver and colon cancers (Khalifa *et al.*, 2013).

5.6 Anti-inflammatory activity

Studies by De Oliveira *et al.* (2013) showed that Avocado oil reduces inflammatory cells within scar tissue, suggesting its capacity to modulate the inflammatory process involved in wound healing. This anti-inflammatory action is primarily due to the concentration of oleic acid in Avocado oil. Oleic acid competes with linoleic and linolenic acids for the same enzymes (cyclooxygenases and lipoxygenases), leading to the production of less potent inflammatory mediators compared to those derived from arachidonic acid, which produces a less intense local inflammatory reaction, allowing for the development of a better healing environment. The anti-inflammatory properties of Avocado leaf extract were demonstrated in mice with carrageenan-induced oedema, and a 10/g/kg dose of the extract significantly reduced swelling following its administration (Adeyemi *et al.*, 2002). Studies conducted by Marra *et al.* (2025) suggest that amphiphilic compounds extracted from Avocado juice and the by-products (especially total amphiphilic content (TAC) extracts) show strong anti-inflammatory and anti-PAF (platelet-activating factor) effects shown by their low IC_{50} values.

In recent developments, Avocado oil has been explored as an innovative lipid carrier for curcumin delivery, offering a promising strategy to overcome curcumin's inherent limitations, such as low solubility and rapid metabolic degradation. Avocado oil, known for its richness in bioactive compounds and monounsaturated fatty acids, contributes not only to the stability of the formulation but also enhances the therapeutic potential of curcumin. Studies on the resulting nanoemulsion system have demonstrated significantly improved hepatoprotective activity, especially at higher concentrations, when compared to conventional curcumin preparations. This approach highlights the dual benefit of using Avocado oil both as a functional carrier and a bioactive enhancer in phytopharmaceutical applications (Kumari and Kumar, 2024).

5.7 Antioxidant activity

Studies by Marra *et al.* (2025) utilized ABTS, DPPH, and FRAP assays, all of which exhibited high antioxidant capacity in the TAC extracts of Avocado, which contain high levels of phenolic compounds and carotenoids, which are well-known antioxidants. Although, the peel extract showed the highest antioxidant activity, the seed coat demonstrated the highest ferric reducing power in the FRAP assay,

suggesting its strong potential as a reducing agent (Velderrain *et al.*, 2021). The methanol extract of Avocado peel exhibits significant antioxidant activity, measured at approximately 185.891 ± 1.598 ppm. The extract was rich in bioactive compounds, including total phenols (21.833 ± 0.118 mg/100 g of extract), total flavonoids (2.607 ± 0.111 mg/100 g of extract), total tannins (38.357 ± 0.202 mg/100 g of extract), saponins ($8.874\% \pm 0.031\%$), and total alkaloids (9.95 ± 0.035 mg/g of extract) (Rahman *et al.*, 2022). Recently, several studies have mentioned the antioxidant activity of Avocado seed, peel, and pulp, respectively (Kurniawan and Rahmat, 2023; Lyu *et al.*, 2023; Arackal and Parameshwari, 2021).

6. Industrial applications of Avocado

6.1 Avocado seeds as a source for the textile industry

Avocado seeds, which are usually treated as waste in agro-industrial processes, have shown promising potential as a source of high-quality starch, with an extraction yield of around 64% based on the dry weight. Detailed analysis conducted by Tesfaye *et al.* (2018) confirmed that the seeds contain intact starch suitable for use. When this starch was tested in textile applications, it performed similarly to commercially available starch, suggesting it could serve as an effective alternative in the industry. The extraction process was optimized using response surface methodology, taking into account factors such as sodium sulphate concentration, temperature, and extraction time. A visual comparison between fabrics printed with synthetic sodium alginate and those using Avocado seed starch showed no noticeable difference in quality, which indicates that Avocado seed starch could potentially replace synthetic thickeners in textile printing.

6.2 Avocado seeds as a source of natural dyes

Avocado seeds contain anthocyanins which have the potential to give red to purple colour so that they have the potential to be used as natural dyes for textiles. A study conducted by Kusumastuti *et al.* (2023) to determine the quality of colour strength, the quality of colour fastness to soap washing and the quality of colour fastness to sunlight. In this study, they extracted anthocyanin-rich pigments from Avocado seeds and applied them to cotton fabrics using different mordants like alum, lime, and ferrous sulphate. The study assessed colour strength and fastness to washing and sunlight. Ranawaka *et al.* (2023) investigated the feasibility and sustainability of using Avocado waste as a natural dye for cellulose-based fabrics, specifically focusing on linen materials. Avocado seeds and skins were utilized to develop a cost-effective dyeing technique. Another study conducted by Utami *et al.* (2011) showed that Avocado seed extract can be used as a natural dye and an alternative to textile dyes for cellulose fibres.

6.3 Biogas production

Biogas production from organic waste has gained significant attention as an alternative energy source, offering both environmental and energy sustainability benefits. Among various organic wastes, Avocado fruit peel has emerged as a promising substrate for biogas production. A study conducted by Kenasa and Kena (2019) showed that Avocado fruit peel waste is a potential substrate for biogas production. The high organic content and biodegradability of Avocado peels make them an ideal candidate for anaerobic digestion, a process used to generate biogas. Similarly, Gracia *et al.* (2023) stated that biogas production using Avocado peels can be a promising option to produce decentralized energy.

6.4 Bioplastic production

The non-biodegradable nature of traditional plastics means they persist in the environment for hundreds of years, leading to long-term ecological damage (Lebreton *et al.*, 2012). In response to these environmental concerns, the need for bioplastics has gained considerable attention. Ginting *et al.* (2018) explored how the use of chitosan as a filler and glycerol as a plasticizer, along with varying gelatinization temperatures and filler ratios, influenced the strength and durability of bioplastic films. Their results indicated that higher filler content and elevated processing temperatures yielded stronger films. Merino *et al.* (2021) developed a biodegradable bioplastic from Avocado seed waste using acid hydrolysis, plasticizers, and pectin-based crosslinking. The film exhibited improved elongation at break and tensile strength, surpassing the mechanical performance observed in earlier research. Notably, the material also showed antioxidant properties, enhancing its potential as active food packaging. Avocado seed starch (ASS) films show great potential for sustainable packaging due to their high starch content and biodegradability. Reinforcing these films with starch nanocrystals improved their strength and reduced water vapor permeability. The films also exhibited strong antioxidant activity and fully degraded within 48 h under composting, making them an eco-friendly alternative to plastic packaging (Muñoz-Gimena *et al.*, 2024). Acquavia *et al.* (2023) reported that paper-based films reinforced with ethyl cellulose and Avocado by-product extracts showed improved strength, water resistance, biodegradability, and antimicrobial activity, making them a sustainable alternative for food packaging.

6.5 Food preservatives

Food preservation is a vital process in the food industry, aiming to extend the shelf-life of perishable products by preventing microbial growth, enzymatic degradation, and oxidative spoilage. A study conducted by Permal *et al.* (2020) suggested that Avocado wastewater (AWW), a by-product of cold-pressed Avocado oil production, was spray-dried at temperatures between 110°C and 160°C, enhancing its antioxidant properties. The resulting AWW powder was incorporated into pork sausages to assess its preservative effects. Remarkably, the treated sausages exhibited a significant reduction in lipid oxidation, which is a major factor contributing to spoilage in meat products. Lipid oxidation leads to the formation of rancid flavors, off-odors, and potentially harmful compounds. By mitigating these effects, AWW powder effectively prolonged the freshness and safety of the meat, serving as a natural preservative. Avocado seeds and peels are rich in phenolic compounds, flavonoids, and other phytochemicals with antioxidant properties, making them suitable for developing natural preservatives. Additionally, the application of plant-based antioxidants in meat products has been shown to improve the shelf-life of meat products. (Petcu *et al.*, 2023).

6.6 Cosmetic industry

Research by Laksmiani *et al.* (2020) demonstrated that Avocado seed extracts possess skin-lightening properties due to their high flavonoid content. These compounds act by inhibiting tyrosinase, the enzyme responsible for melanin synthesis through the oxidation of tyrosine. Another study by Kupnik *et al.* (2025) suggests that cellulose nanofibril (CNF) films enriched with Avocado seed extracts showed excellent antimicrobial activity against *E. coli* and *S. aureus*, matching the effectiveness of clindamycin. These pH-responsive, highly swellable films (up to 65.67%) enabled sustained bioactive

compound release and demonstrated strong potential for use in cosmetics, biomedicine, and pharmaceuticals. Due to the antibacterial and antifungal properties of these chemicals, Avocados are an excellent natural resource for treating a wide range of microbial illnesses (Robin *et al.*, 2024).

7. Avocado cultivation and conservation

The connection between Avocados and human traces back to ancient times, with evidence showing that they were valued as a nutritious food source even during prehistoric periods (Galindo *et al.*, 2008). Avocado fruit is widely used globally, especially for its nutritional properties. Many often include Avocado in their diet for weight loss, diabetes, heart disease, and for skin health (Henning, 2022; Tabeshpour *et al.*, 2017). Avocados are also rich in saturated fatty acids, dietary fibre, and antioxidant vitamins like vitamin C and E, carotenoids, phenolics, and phytosterols, making Avocado a superfood. Studies show that, apart from fruit, Avocado leaves, seeds, and peels are also a source of different nutrients. According to Téliz (2000), Avocado orchards contribute to employment generation by requiring labor across various stages, including cultivation, harvesting, packinghouse activities, transportation, and marketing. But the rapid expansion of Avocado farming threatens critical ecosystems like pine-oak forests and contributes to water scarcity, making conservation efforts essential for sustainability. Sustainable practices like agroforestry and water management can help mitigate environmental impacts and support long-term productivity. Additionally, promoting legal and transparent farming practices can protect farmers from exploitation and improve economic stability, ensuring a more resilient Avocado industry (Denvir, 2023). Barrientos (1999) highlights the importance of conserving Avocado genetic resources through both *in situ* and *ex situ* methods. While *in situ* conservation allows its preservation in the natural habitat, it is often threatened by environmental hazards like drought and fire. *Ex situ* conservation, although it is more commonly applied to fruit species, faces financial limitations that hinder the long-term maintenance of Avocado gene pools. Barrientos also mentions the proposal made during the World Avocado Congress IV in 1999 to establish an international Avocado gene bank, which reflects a significant step toward safeguarding global Avocado diversity.

8. Conclusion

Avocado, being a nutritionally rich plant with significant health benefits, has been cultivated widely across the globe. Beyond its widely consumed pulp, recent research highlights the potential of its seed, peel, and leaves as a valuable source of various bioactive compounds, including phenols, flavonoids, saponins, tannins, and alkaloids. These contribute to its antioxidant, antimicrobial, and anti-inflammatory properties, suggesting its possible applications in pharmaceuticals and cosmetics apart from the food industry. The presence of various bioactive compounds in Avocado contributes to its immense role in promoting health and well-being. Various studies pinpoint the application of Avocado for gut, skin, brain, and cardiovascular health. Continued research and further exploration of its bioactive compounds may unlock new possibilities for enhancing human health and disease prevention.

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Conflict of interest

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

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