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Review article

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NUTRITIONAL PROFILES OF *PERSEA AMERICANA* AND *TELFAIRIA OCCIDENTALIS* SEEDS: POTENTIAL APPLICATIONS IN FOOD FORMULATIONS

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Edible seeds, functional food, health benefits, nutritional composition, *Persea americana*, *Telfairia occidentalis*

ABSTRACT

Underutilized plant seeds represent a valuable but often overlooked resource for improving food security, promoting sustainable agriculture, and expanding the availability of nutrient-dense ingredients. Avocado (*Persea americana*) and fluted pumpkin (*Telfairia occidentalis*) seeds have gained attention due to their health benefits and nutritional advantages. *P. americana* seeds are not agro-waste; rather, they are an excellent supplier of bioactive chemicals that may find use in the food and pharmaceutical industries. *T. occidentalis* seeds mostly re-cultivated for its consumable leaves are rich in antioxidants and other essential nutrients, serving functional roles and demonstrating diverse health-enhancing properties. This review investigates the nutritional profile of two underexploited seeds — *P. americana* seeds and *T. occidentalis* seeds — with emphasis on their nutritional composition, health benefits and approaches to emphasize their use as functional food components and their prospective incorporation into dietary supplements. To find pertinent research on the nutritional makeup of *P. americana* and *T. occidentalis* seeds, an organized search for literature was carried out across several web-based databases (Google Scholar, PubMed, ScienceDirect, Google Search Engine, Springer Link, and Web of Science). The seeds of *P. americana* and *T. occidentalis* exhibit a comparable nutritional profile which include macronutrient, mineral content, and phytochemical constituents that together provide their therapeutic benefits including antimicrobial, antioxidant, anti-obesity, anti-inflammatory, antidiabetic, anticancer, and enhancing fertility. Both seeds can be processed and effectively integrated into various food products, thereby improving their functional attributes. The review highlights the underutilized nutritional and functional potential of these seeds, providing scientific support for their incorporation into food formulations and value-added product development. Valorizing *T. occidentalis* and *P. americana* seeds could therefore contribute to waste reduction, economic diversification, and improved dietary quality, especially in regions where these crops are abundant.

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Открытый доступ

ПРОФИЛИ ПИТАТЕЛЬНЫХ СВОЙСТВ СЕМЯН *PERSEA AMERICANA* И *TELFAIRIA OCCIDENTALIS*: ПОТЕНЦИАЛЬНЫЕ ВИДЫ ПРИМЕНЕНИЯ В СОСТАВЕ РЕЦЕПТУР ПИЩЕВЫХ ПРОДУКТОВ

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КЛЮЧЕВЫЕ СЛОВА: АННОТАЦИЯ

съедобные семена, функциональные продукты, полезные свойства, состав питательных веществ, *Persea americana*, *Telfairia occidentalis*

Семена растений представляют собой ценный, но зачастую неиспользуемый ресурс, способный повысить продовольственную безопасность, развить устойчивую систему сельского хозяйства и увеличить потребительскую доступность ингредиентов, плотно насыщенных питательными веществами. Семя авокадо (*Persea americana*) и семена рифленой тыквы (*Telfairia occidentalis*) привлекли к себе внимание благодаря своим полезным для здоровья свойствам и питательной ценности. Семя *P. americana* не является сельскохозяйственным отходом; напротив, оно представляет собой отличный источник биологически активных веществ, которым можно найти применение в пищевой и фармацевтической промышленности. Семена *T. occidentalis*, в основном повторно культивируемые ради получения съедобных листьев, богаты антиоксидантами и другими необходимыми питательными веществами, выполняют функциональные задачи и обладают разнообразными свойствами, полезными для здоровья. В этой работе исследуется питательный профиль двух недооцененных семян — семян *P. americana* и семян *T. occidentalis* — с особым вниманием к их питательному составу, пользе для здоровья и подходам к их использованию в качестве функциональных пищевых компонентов, и перспективе их включения в пищевые добавки. Для поиска соответствующих исследований по питательному составу семян *P. americana* и *T. occidentalis* был проведен организованный поиск источников в нескольких веб-базах данных (Google Scholar, PubMed, ScienceDirect, Google Search Engine, Springer Link и Web of Science). Семена *P. americana* и *T. occidentalis* обладают сопоставимыми профилями питательных веществ, включающими макронутриенты, минералы и фитохимические компоненты, которые в совокупности обеспечивают их терапевтические свойства, включая антимикробное, антиоксидантное, антиадипозное, противовоспалительное, противодиабетическое, противораковое действие, а также повышение фертильности человека. Оба вида семян могут быть переработаны и эффективно интегрированы в различные пищевые продукты, тем самым улучшая функциональные свойства такого пищевого продукта. В статье подчеркивается недооцененность питательного и функционального

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потенциала этих семян, дается научное обоснование для их включения в пищевые рецептуры и разработки продуктов питания с добавленной стоимостью. Таким образом, использование семян *T. occidentalis* и *P. americana* может способствовать сокращению объема отходов, диверсификации экономики и улучшению качества питания, особенно в регионах, где эти культуры широко произрастают.

1. Introduction

Edible seeds play a crucial role in human nutrition, offering a wide array of phytochemicals with various important biological functions, including antioxidant, antitumor anti-inflammatory, and antidiabetic effects [1–3]. Many phytochemicals may enhance the activity of enzymes that detoxify carcinogens and other harmful substances in the body [4,5]. There has been a growing demand for vegetables, fruits, seeds, and nuts extracts as essential components of the diets that supports prevention of disease condition [6–9]. This trend is driven by the rising prevalence of several diseases such as cancer, cognitive capacities decline, hypertension, malaria [10], diabetes, and oxidative stress condition [11,12]. These conditions could potentially be prevented or mitigated through modifications in dietary habits [13,14]. Avocado (*Persea americana*) is a tree that produces edible fruit, originating from Mexico and Central America, but now cultivated in various tropical regions. It belongs to the *Lauraceae* family of the flowering plants [15]. Recently, *P. americana* has gained recognition as a “superfood” due to its exceptional nutritional and phytochemical profile compared to other fruits [4]. The *P. americana* fruit is classified as a berry containing a single large seed. While the fruit’s flesh is widely consumed for its nutritional benefits, the seed is typically discarded as an inedible part, thus resulting in substantial waste of the vegetative biomass. However, these seeds represent an affordable source of potential bioactive compounds that are currently underutilized [11]. Because of their poor flavor and processing challenges necessary to deploy their nutritional and functional benefits, *P. americana* seeds are always considered as waste despite their potential benefits. Research has shown that *P. americana* seeds possess a distinctive nutritional composition, containing significant amounts of proteins, complex carbohydrates, beneficial fats, vitamins, minerals, and phytochemicals [16,17]. In industrial processing, only the pulp of *P. americana* is used, while the skin and seeds are discarded. These byproducts are rich in phytochemicals, possess antioxidant potential and have medicinal applications [6,7]. The seed of *P. americana* features anti-inflammatory, antioxidant, antimicrobial, anti-diabetic, neuroprotective, and anti-carcinogenic properties [7,18]. Extracts from *P. americana* seeds offer pharmacological benefits in managing certain health conditions, such as hypertension, diabetes etc. [17].

Fluted pumpkin, scientifically known under the name *Telfairia occidentalis*, is a member of the *Cucurbitaceae* family, it thrives in tropical climates. This plant is primarily cultivated for its consumable leaves and seeds [19]. *T. occidentalis* is acknowledged for its high nutritional value, containing vital nutrients that contribute significantly to human dietary needs. The plant’s seeds are particularly noteworthy, with a wide array of nutrients and bioactive components that potentially offer considerable health advantages. These seeds have been utilized in traditional cooking practices and folk remedies for long time [20]. *T. occidentalis* seeds are rich sources of various beneficial compounds including, antioxidants, essential amino acids, vitamins, proteins, phenolics, minerals, and other essential nutrients. These components not only serve regulatory and functional roles but also demonstrate diverse health-improving properties [21].

In recent years, there has been growing interest for the seeds of *P. americana* and *T. occidentalis* due to their potential health benefits and nutritional advantages. Although these plants are primarily cultivated for their edible fruits and leaves, respectively, the research has shown that their seeds contain a diverse range of nutrients and bioactive compounds that could significantly benefit human health and wellness. The nutritional profile and possible health advantages of these seeds are underscored within their potential as valuable assets in promoting nutrition and health. As global interest in viable and nutrition based in plants continues to expand, the exploration of underutilized plant components, such as these seeds, becomes increasingly important. This review, therefore, aims to provide an overview of the nutritional benefits of *P. americana* and *T. occidentalis* seeds, thus providing an insight for a complete analysis their potential contributions to human health and nutrition.

2. Methodology

The literature was chosen using the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) technique. Initially, for this review 758 scientific papers were found. After the preliminary analysis, 245 duplicate publications were removed from the array of the sources in order to eliminate repetitive material, because they were repeatedly found across numerous databases. Furthermore, 151 papers were excluded

because they did not meet the eligibility and inclusion criteria and were irrelevant to the research topic. For a variety of reasons, including as being outside the designated field of study or having restricted access, additional 182 studies were excluded. A total of 180 studies advanced to the screening stage after their abstracts were reviewed. 42 of these studies were rejected because they did not meet the study’s goals while 41 of the 138 remaining items were excluded after their relevance was assessed. In the end, 97 articles were reviewed. Figure 1 displays the PRISMA flow chart used to choose the literature sources.

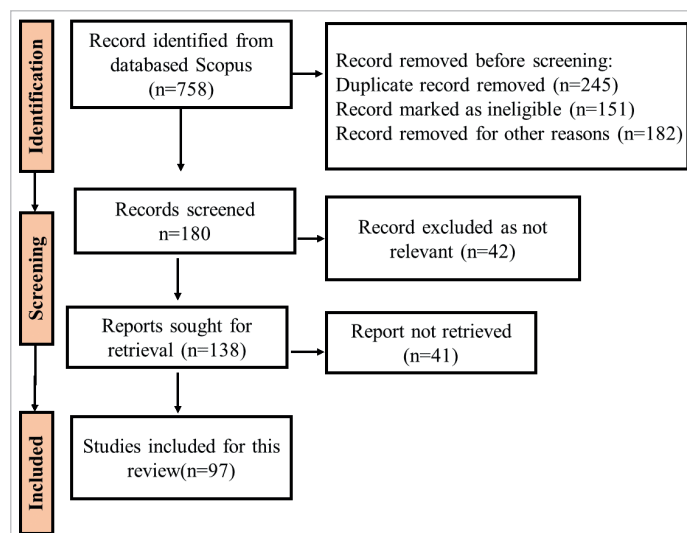


Figure 1. PRISMA flow chart

Рисунок 1. Блок-схема (PRISMA)

3. Nutritional composition

3.1. Nutritional composition of *P. americana* seeds

P. americana seeds boast a diverse nutritional composition, containing substantial quantities of both macro- and micronutrients, as well as phytochemicals. These seeds are acknowledged for their potential health advantages, which are ascribed to their versatile chemical composition. *P. americana* seeds serve as an excellent source of macronutrients, including carbohydrates, fats, and proteins, along with dietary fiber and bioactive compounds [17]. Carbohydrates are considered to comprise a substantial percentage of the macromolecules present in *P. americana* seeds as evidenced by several studies which reported carbohydrates content as high as 64.9% [7], 44.7% [22], 32.05% [23]. Research by Báez-Magaña et al. [24] indicates that *P. americana* seed extract is rich in fatty acids. Their study quantified fatty acids profile comprised of arachidic (2.39 µg/g), behenic acid (3.63 µg/g), erucic (2.44 µg/g), linoleic (4.06 µg/g), myristic (2.49 µg/g), nervonic (2.88 µg/g), oleic (5.32 µg/g), palmitic (7.1 µg/g), tetraacosanoic acid (4.29 µg/g), and stearic acid (5.06 µg/g) as well as their derivatives such as pahuatins (4.26 µg/g), persins (10.12 µg/g), polyhydroxy fatty acids (24.26 µg/g) and avocatin (32.28 µg/g). Additionally, fats content in *P. americana* seeds have been reported to be as high as 14.1% [22] and 25.73% [25]. Protein represents a major macromolecular component in *P. americana* seeds, with multiple studies reporting on its presence as 2.64% [26], 7.75% [27], 15.55% [28], 17.94% [29], and 23% [22]. The approximate composition of *P. americana* seeds is also significant in their nutritional profile. Egbonu et al. [26] demonstrated that the moisture content, dry matter, crude fibre and ash content available in *P. americana* seeds amount to 13.09%, 86.91%, 2.87% and 3.82% respectively. In addition, Okorie et al. [25] reported a relatively low moisture content of 8.98% and ash content of 3.28%.

P. americana seeds are a valuable source of various minerals and vitamins, including calcium, copper, phosphorus, lead, potassium, sodium, iron, zinc, cobalt, magnesium, and vitamins A, B (B1, B2, and B3), C, E, and K [7]. Due to their mineral content, these seeds are considered beneficial for both animal feed and human consumption to address micronutrients deficiencies. The availability of the vitamins such as E (an antioxidant), B complex (involved in energy metabolism), and K (essential for blood clotting) in *P. americana* seeds may boost immune system function.

P. americana seeds contain several nutrients based on available research and these nutrients are included into the general recommended daily intakes (RDIs). *P. americana* seeds contain about ~60–65 g carbohydrates (mostly starch), ~2–24 g protein content, a relatively low lipid content that includes healthy unsaturated fatty acids, and up to 50% of its dry weight is made up of dietary fiber [7]. Micronutrients such as calcium, potassium, phosphorus, magnesium are present at measurable amounts while iron, zinc, copper are present in trace amounts. Vitamins A, B1 (thiamine), B2 (riboflavin), B3 (niacin), C, E are present but typically lower than in the fruit flesh of *P. americana* [7]. Table 1 shows the comparison of nutrient presence in *P. americana* seeds to a typical adult person's RDIs (general nutrient needs). *P. americana* seed nutrients is comparable to other foods known for providing the same nutrient. *P. americana* seed outrun a lot of other seeds in fiber and antioxidants content, but feature lower protein/fat than oilseeds like almonds. Table 2 depicted the comparison of *P. americana* seed with other seeds/nuts nutrients per 100 g. Nutritional facts of chia seeds indicated that they possess high fiber content, rich in antioxidants and moderate level of protein [31,32] which is similar to *P. americana* seed. However, almond possesses higher protein and fat level (21 and 50 g per 100 g respectively), and low fiber content (12 g) [33,34] compared to *P. americana* seed. Antioxidants such as catechins and procyanidins are present in *P. americana* seed in high amounts [35]. However, there's no official RDI, but high intake of antioxidant is correlated with reduced risk of disease development. *P. americana* seed contains catechins similar to those in green tea but often in higher concentrations when calculated by weight. Additionally, the seed has significantly higher phenolic content than the edible pulp [17]. *P. americana* seed contains a mix of soluble and insoluble fiber, though exact numbers vary because a large portion of the seed is actually starch (carbohydrate), not just fiber. The fiber content is estimated to be 30–45 g per 100 g (dried/ground) while fiber RDI is 25–36 g per day. In comparison with oatmeal, a tablespoon of avocado seed powder has sufficient amount of soluble fiber, but a bowl of oatmeal (4 g fiber per cup) is a good source as its unique feature is its rich content of dietary fiber [36].

Table 1. Approximate nutritional composition per 100 g (dried *P. americana* seed flour/powder)

Таблица 1. Приблизительный состав питательных веществ в 100 г. (мука/порошок из сушеных семян *P. Americana*)

Nutrient	Amount per 100 g	% of adult RDA/RDI*
Energy	~350–400 kcal	~18–20% (2000 kcal diet)
Protein	12–18 g	24–36% (50 g RDA)
Total fat	13–19 g	Variable (mostly unsaturated)
Carbohydrates	48–58 g	High (mostly starch)
Dietary fiber	30–45 g	107–160% (28 g RDA women/34 g men)
Potassium	~800–1200 mg	17–26% (4700 mg AI)
Magnesium	~150–250 mg	36–60% (400 mg RDA men)
Calcium	~100–200 mg	10–20% (1000 mg RDA)
Phosphorus	~200–400 mg	29–57% (700 mg RDA)
Iron	~5–10 mg	28–56% (18 mg RDA women)
Zinc	~2–4 mg	18–36% (11 mg RDA men)

* RDA/RDI based on NIH/USDA for the adults (19–50 years; varies by sex), AI = Adequate Intake. Note: *P. americana* seeds are exceptionally high in phenolics/antioxidants (often >2000 mg GAE/100g), thus far exceeding many seeds. Data are adopted from Bangar et al. [7], OASH [30].

Table 2. Comparison of *P. americana* seed nutrient with almond and chia seed (per 100 g, approximate dry/roasted)

Таблица 2. Сравнение питательных свойств семян *P. Americana* с миндалем и семенами чиа (приблизительно на 100 г. сушеных/жареных семян)

Nutrient (per 100 g)	<i>P. americana</i> seed	Almonds	Chia seed
Protein	12–18 g	21 g	17 g
Fat	13–19 g	50 g	31 g
Fiber	30–45 g	12 g	34 g
Magnesium	150–250 mg	~270 mg	335 mg
Zinc	2–4 mg	~3 mg	4.6 mg
Iron	5–10 mg	~4 mg	7.7 mg
Energy (kcal)	~350–400	~579	486

Data are adopted from Bangar et al. [7], Kulczyński et al. [31], Barreca et al. [34].

The seeds of *P. americana* contain high levels of bioactive phytochemicals, including alkaloids, flavonoids, saponins, tannins, oxalates, phytates, and phenolics [37]. Other significant phytochemicals found in these seeds are lycopene and phytosterols, which contribute to their antioxidant properties and their ability to protect body against oxidative stress and chronic diseases [25]. The composition of phytochemicals in *P. americana* seed reported by Setyawan et al. [16] include alkaloids (5.40 mg/100 g), tannins (0.76 mg/100 g), flavonoids (20.33 mg/100 g), oxalates (4.40 mg/100 g), saponins (0.52 mg/100 g), and phytates (0.44 mg/100 g). Additionally, Okorie et al. [25] stated that the seeds are rich in flavonoids (34.14 mg/100 g), phenols (3.51 mg/100 g), and beta-carotene (32.24 mg/100 g). Furthermore, Jimenez et al. [35] identified and quantified several polyphenols in *P. americana* seed which include catechin (24.3–2000 mg/100 g), caffeic acid (13.7–22.5 mg/100 g), chlorogenic acid (0.0516–1953 mg/100 g), (epi)catechin (1106–2906 mg/100 g), ferulic acid (0.09–1.2 mg/100 g), kaempferol (10.74 mg/100 g), kaempferide (10.74 mg/100 g), procyanidins (152–5560 mg/100 g), rutin (0.22 mg/100 g), trans-5-O-caffeoyl-D-quinic acid (163–574 mg/100 g) and vanillic acid (286 mg/100 g). Further polyphenol compounds discovered in *P. americana* seeds are 3-O-p-coumaroylquinic acid, 3-O-caffeoylquinic acid, procyanidin trimer A(I) and procyanidin trimer A(II). It's worth noting that diverse species of *P. americana* produce variable amounts of phenolic compounds and the phenolic compounds profile of the seed can be categorized into alkanols, flavonoids, glycosides, furan ring-containing derivatives, terpenoid and coumarin [16]. These bioactive compounds present in *P. americana* seed have demonstrated their various biological activities such as antioxidant and anti-inflammatory properties which enhance their potential as a nutraceutical [38]. Consequently, the considerable nutrient content of *P. americana* seeds could justify their use in human dietary supplements.

3.2. Nutritional composition of *T. occidentalis* seeds

T. occidentalis seeds are an important part of human diet since they are a substantial source of nutrients and bioactive substances. These seeds are especially well-known for their high fat and protein content, as well as their wide range of phytonutrients and essential amino acids [20]. Different processing techniques result in varying nutritional compositions for *T. occidentalis* seeds [39,40]. Protein content in both raw and roasted fluted pumpkin seeds ranges from 21.46 to 30.28%, lipid content from 37.25 to 38.13%, carbohydrate content ranging from 24.54 to 32.70%, ash content from 4.13 to 4.56%, moisture content from 0.27 to 0.86%, and crude fiber content from 2.06 to 2.49% [40]. According to another research, the protein level was as high as 29.15%, and the lipid content was similarly significantly high, with values of 35.62%, 35.62% fat, 28.40% carbohydrate, 4% ash, and 2.83% moisture [41]. *T. occidentalis* dried seeds contain moisture (1.40%), lipid (32.50%), protein (34.56%), ash (4.40%), fibre (15.71%) and carbohydrate (11.43%) [42]. The nutritional profile of fermented, roasted, and boiled samples of *T. occidentalis* seeds varied, according to Nzeagwu and Amadi [43]. They showed that the nutritional properties and functional qualities of the fermented and boiled samples of *T. occidentalis* seeds were superior. Mineral composition of fermented *T. occidentalis* seeds include iron (3.96 mg/100 g), zinc (2.68 mg/100 g), calcium (0.67 mg/100 g), magnesium (1.29 mg/100 g), copper (0.23 mg/100 g), selenium (0.16 mg/100 g), manganese (0.24 mg/100 g), iodine (0.12 mg/100 g), phosphorus (0.79 mg/100 g). Additionally, energy value and vitamin composition (vitamin C and vitamin E) of fermented *T. occidentalis* seeds was equal to 467.58 kcal, 0.55 mg/100 g and 0.43 mg/100 g respectively [43].

Arginine (0.37 mg/100g), aspartic acid (0.15 mg/100 g), cystine (4.44 mg/100 g), lysine (0.3 mg/100 g), leucine (0.21 mg/100 g), and methionine (3.7 mg/100 g) are among the amino acids found in *T. occidentalis* seed powder [41]. The seeds of *T. occidentalis* include both saturated and unsaturated fatty acids, with neutral lipid, glycolipid, and phospholipid contents of 16, 26, and 58%, respectively. Oleic acid is the most prevalent fatty acid, making up around 36% [44]. Compounds like pentadecanoic acid, hexadecanoic acid, pentanoic acid, dodecanoic acid, linoleic acid, palmitoleic acid, elaidic acid, and benzoic acid were found in the seeds [44]. These compounds help with a range of biological functions, including hepatoprotective, antioxidant, antimicrobial, anti-inflammatory, anticancer, and haematological functions of a body. The high nutritional value of *T. occidentalis* seeds is attributed to their high unsaturated fatty acid content [44]. The pharmacological activities of *T. occidentalis* seeds are influenced by a number of phytochemicals, including polyphenols, flavonoids, and tannins, based on phytochemical examination of the powdered seeds. According to Ouattara et al. [41], the phytochemical composition of *T. occidentalis* seeds included alkaloids (1.1 mg/100 g), flavonoids (8.32 mg/100 g), tannins (165.09 mg/100 g), phytates (49.39 mg/100 g), oxalates (43.5 mg/100 g) and polyphenols (272.68 mg/100 g). Thus, *T. occidentalis* seeds varied range of nutrients improves their usage as food.

T. occidentalis seeds are excellent sources of several nutrients such as protein, magnesium, phosphorus, iron, zinc, and healthy fats, making them nutrient-dense foods capable of contributing substantially to daily nutrients intake requirements. Nutritional composition showing how *T. occidentalis* contribute to Recommended Daily Intakes and how they compare with other well-known nutrient-rich foods are presented in the Table 3 and 4 respectively. *T. occidentalis* seeds nutrient composition for protein content is equal to ~25–35 g per 100 g with RDI of ~50 g, fat is ~40–50 g per 100 g (RDI of 44–77 g), iron (~8–15 mg per 100 g with RDI of 8 and 18 mg for men and women respectively), dietary fibre is 5–6 g per 100 g with RDI of 25–28 g (Table 3). Pumpkin seed (*Cucurbita* sp.) are significantly rich sources of proteins, fats and minerals [45]. *Cucurbita* sp seeds contain lipids (37.8–45.4%), fiber (3–6%), and proteins (25.2–37.0%) [46] which is similar to *T. occidentalis* seeds nutritional content. Additionally, sunflower seeds are also very nutritive with higher proteins and lipids content of 33.85% and 65.42% respectively [47]. Soybeans contain about 37% protein, 28% fat and 5% fibre [48]. *T. occidentalis* seeds stand out for higher content of protein compared to chia seeds, while being similar to sunflower in fat content as shown in the Table 4.

Table 3. Nutritional composition of *T. occidentalis* seeds per 100 g (dry/roasted seeds)

Таблица 3. Состав питательных веществ в семенах *T. occidentalis*, на 100 г. (сушеные/жареные семена)

Nutrient	Amount per 100 g	% of Adult RDA/RDI*
Energy	550–612 kcal	~28–31 % (2000 kcal diet)
Protein	30–33 g	60–66 % (50 g RDA)
Total fat	46–49 g	65–75 % (70 g RDA)
Carbohydrates	4–15 g	22–30 % (27 g RDA)
Dietary fiber	5–6 g	18–24 % (25–28 g RDA)
Magnesium	~500–592 mg	120–148 % (400 mg RDA)
Phosphorus	~1200 mg	~170 % (700 mg RDA)
Potassium	~800–900 mg	17–19 % (4700 mg AI)
Zinc	~10–15 mg	91–136 % (11 mg RDA men)
Iron	~8–15 mg	44–83 % (18 mg RDA women)
Calcium	~200–250 mg	20–25 % (1000 mg RDA)

* RDA/RDI based on NIH/USDA for adults (19–50 years; values vary by sex/age). Data are adopted from Ouattara et al. [41], Nzeagwu & Amadi [43], OASH [30].

Table 4. Comparison of *T. occidentalis* seeds with other seeds (per 100 g, approximate)

Таблица 4. Сравнение свойств семян *T. occidentalis* с другими семенами (приблизительно, на 100 г.)

Nutrient (per 100g)	<i>T. occidentalis</i> (Fluted Pumpkin)	<i>Cucurbita</i> sp (Common Pumpkin)	Sunflower	Chia	Soybean
Energy (kcal)	~580	~559	~584	486	~447
Protein	30–33 g	30 g	17–21 g	17 g	43 g
Fat	46–49 g	49 g	51 g	31 g	22 g
Fiber	5–6 g	6–18 g	9–11 g	34 g	18 g
Magnesium	500–600 mg	~535 mg	~325 mg	335 mg	~228 mg
Zinc	10–15 mg	~7–10 mg	~5 mg	4.6 mg	~4.9 mg
Iron	8–15 mg	~8–9 mg	~5 mg	7.7 mg	~16 mg

Data are adopted from Kulczyński et al. [31], Ouattara et al. [41], Nzeagwu & Amadi [43], Batoool et al. [45], Petraru et al. [47], Aanchal [48].

3.3. Anti-nutritional factors in *P. americana* and *T. occidentalis* seeds

Plants produce biologically active secondary metabolites known as anti-nutritional factors as a defense mechanism against the animal seedeaters and for survival in harsh conditions. These compounds can negatively impact the nutritional value of food by interfering with nutrient absorption and reducing bioavailability of the nutrients [49]. Various heat-stable and heat-labile anti-nutritional factors with toxic potential have been identified in foods, including saponins, cardiac glycosides, tannins, gossypol, phytic acid, alkaloids, protease inhibitors, lectins, amylase inhibitors, goitrogens, metal binding ingredients, and antivitamin factors. These substances, found in plant seeds, can lead to nutrition-related issues and adverse health effects [50]. High concentrations of anti-nutrients in the diet may cause toxicity, thus motivating the efforts to reduce their content in foods. Traditional and technological processing methods such as soaking, cooking, milling, roasting, debranning and fermentation have been used to decrease anti-nutritional components in foods [50]. Researchers have shown significant interest

in anti-nutritional factors due to their potential beneficial biological activities for humans [51].

P. americana seeds contain anti-nutritional factors like saponins, alkaloids, tannins, and cyanogenic glycosides that can affect their nutritional value by interfering with nutrient absorption and digestion [26,37]. These compounds have various physiological effects and may be toxic if consumed in large quantities [26]. Most of these components can be eliminated through culinary processing techniques such as drying, soaking, cooking, fermentation and roasting. While studies of the effects provided to the human's health with the antinutrients in *P. americana* seeds are still lacking, studies on the animals using *P. americana* seed ethanol extract have shown no genotoxic effects, suggesting its potential use in cosmetic, food, or pharmaceutical application [17].

T. occidentalis seeds have been found to contain anti-nutritional compounds such as phytates, oxalates, tannins, and cyanogenic compounds, which can hinder nutrients absorption and digestion [41]. The significant anti-nutrient composition of *T. occidentalis* seed powder could decrease nutrients bioavailability and potentially cause adverse effects if consumed over an extended period [20]. However, anti-nutritional factors in *T. occidentalis* seeds can be reduced through processing like fermentation, boiling, steaming, and roasting [40]. Unripe *T. occidentalis* seeds are nutritionally preferable as food due to their lower anti-nutrient content and sweeter taste compared to the mature seeds [44].

4. Potential health benefits of *P. americana* and *T. occidentalis* seeds

4.1. Health benefits of *P. americana* seeds

Research has explored the potential health advantages of *P. americana* seeds, particularly in relation to diabetes, digestive health, cancer, liver protection, and weight management [4,52,53]. These seeds contain various bioactive compounds that contribute to their antioxidant and anti-inflammatory properties, which are responsible for their therapeutic effects [7]. The antioxidant potential of *P. americana* seeds is proved by their ability to stabilize free radicals produced by oxidative stress, which are associated with various disease conditions. Moreover, these seeds exhibit anti-inflammatory properties by reducing the excessive release of inflammatory mediators linked to the health conditions such as atherosclerosis, diabetes, tumor growth, and immunological illnesses [7]. Studies have shown that *P. americana* seed extract decreases the secretion of interleukins and tumor necrosis factor (TNF)- α in lipopolysaccharide-stimulated RAW264.7 cells. Aqueous extracts of *P. americana* seeds have demonstrated anti-inflammatory properties, particularly in the models of cadmium-induced nephrotoxicity, reducing levels of inflammatory markers like interleukin-2 [54]. The seeds' extracts also showed potential in reducing inflammation associated with liver cancer via enhancing apoptotic activities in affected tissues [53].

The anti-cancer potential of *P. americana* seeds and their biologically active components has been observed in human and animal cell lines, including those of lung, colon, breast, prostate, and hepatocellular carcinoma [55,56]. Polyphenols extracted from *P. americana* seeds have been found to inhibit various cancer cells, with inhibition rates of 19, 19.1, 67.6, and 132.2 μ g/mL for prostate, breast, lung, and colon cancer cells, respectively, in a dose-dependent manner [56]. Avocatin B, a mixture of avocadene and avocadyne identified in *P. americana* seeds, has shown potent anticancer activity by selectively targeting and eliminating leukemia stem cells [18].

P. americana seeds have been reported to have diabetes-preventing and cholesterol-regulating properties [4]. The antidiabetic activity of *P. americana* seeds aqueous extract has been linked to the triggering of the PI3K/Akt pathway and inhibition of β -cell death, which may be the principal mechanism by which it enhances insulin sensitivity and controls glycolipid metabolism, thus ensuring a beneficial effect on diabetic conditions [57]. Additionally, Makasa [58] reported that crude extracts of *P. americana* seeds provided positive changes in both biochemical and hematological indices in diabetic rats, thus proving their potential use in diabetes management. The *P. americana* seed extract also exhibited hypoglycemic and antihyperglycemic effects by significantly lowering blood glucose levels in rats, this way highlighting its potential in the treatment of diabetes mellitus.

In cases of acetaminophen-induced liver damage, *P. americana* seed extracts have shown hepatoprotective effects. These extracts aid in restoring liver function and architecture, with the potential to reverse disruptions in liver integrity and function, and reestablish balance in the endogenous antioxidant system, comparable to the effects of silymarin, a well-known liver-protective agent [59]. The antioxidant properties of the seeds contribute to their ability to mitigate liver damage and improve overall liver health.

The substantial phenolic content in *P. americana* seeds is thought to contribute to their anti-obesity properties. Research on rats with obesity induced by high-fat diets showed that *P. americana* seed powder significantly decreased weight gain and enhanced lipid profiles, indicating its potential as an anti-obesity supplement [60]. *P. americana* seeds' flavonoids and saponins have been connected to the inhibition of inflammatory pathways that contribute to the development of obesity and its related comorbidities. These compounds could be the cause of the observed weight-reducing effects of *P. americana* seed powder [60]. In rats given a high-fat/high-fructose diet, *P. americana* oil has been shown to improve mitochondrial activity and lower levels of reactive oxygen species, pro-inflammatory markers, and lipid peroxidation, thereby alleviating down the non-alcoholic fatty liver disease, hyperglycemia, and dyslipidemia [61].

P. americana seeds demonstrate antimicrobial efficacy against bacteria, fungi, and parasites, suggesting their potential use in fighting infections and promoting overall gut health [7]. The antimicrobial efficiency of *P. americana* seed extracts is attributed to the various biologically active compounds available in the seeds. As antimicrobial resistance increases and synthetic drugs become less effective and more toxic, there is a growing interest for the alternative biologically active substances [11]. The seeds have antibacterial qualities, especially against the bacterium *Helicobacter pylori*, which is connected to stomach disorders. By preventing *H. pylori* growth, the bioactive substances in the seeds — such as phenolic and lipophilic compounds — may lower the incidence of stomach ulcers and associated disorders [62]. Additionally, petroleum ether extracts of the seeds showed inhibitory efficacy against *S. aureus*, and the seed extracts in methanol and chloroform had antifungal properties against *Cryptococcus neoformans* [63]. Jiménez-Arellanes et al. [64] reported anti-parasitic activity of the seeds against *E. histolytica* and *G. lamblia*. Research indicates that various *P. americana* seed extracts inhibit the growth of several microbial strains [11].

Restoring acetylcholine by blocking acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) is how *P. americana* seeds are used in treating neurodegenerative diseases because Alzheimer's patients' brain impulse transmission may be hindered by low acetylcholine levels [7]. *P. americana* seed aqueous extracts was reported to have IC₅₀ values of 27.93 and 30.08 mg/mL, respectively, for inhibiting the AChE and BChE enzymes [65]. By blocking these enzymes, phenolic substances like the caffeic acid found in *P. americana* seeds prevent butyrylcholine and acetylcholine from being broken down in brain neurons, which raises the amounts of both neurotransmitters at the synaptic clefts. As a result, nerve cell communication is eventually enhanced, and neurodegenerative diseases like Alzheimer's disease are better managed [7].

4.2. Health benefits of *T. occidentalis* seeds

The seeds of *T. occidentalis* provide numerous health advantages due to their nutritional and phytochemical content, making them a beneficial addition to health-promoting and disease-preventing diets [20]. These seeds are utilized for their medicinal properties, including antioxidant, antinociceptive, anti-inflammatory, anti-diabetic, anti-cholesterol, reproductive, hepatoprotective, and various other effects.

T. occidentalis seeds have shown considerable antioxidant capabilities, containing various phytochemicals such as flavonoids, tannins, and phenolic compounds. These components enable the seeds to neutralize free radicals, thereby preventing oxidative harm within the body and lowering the risk of chronic illnesses [66]. Extracts from these seeds display notable free radical scavenging ability and reducing power, thus suggesting their potential as a natural source of antioxidants [21]. Additionally, they have anti-inflammatory qualities that could help treat illnesses linked to inflammation. In experimental models, the seeds also show antinociceptive qualities, which lessen pain, supporting its historic usage to treat convulsions and pain. The phytochemicals in these seeds may inhibit the release of vasoactive substances and prostaglandins, potentially reducing inflammation [21].

Research on diabetic rat models has demonstrated that boiled *T. occidentalis* seeds can significantly decrease blood glucose levels, dyslipidemia, hyperglycemia and diabetic hepatocellular damage in alloxan-induced diabetes in rats, indicating their potential as an affordable alternative treatment for diabetes [67]. Additionally, peptide hydrolysate derived from *T. occidentalis* seed protein reduced fasting serum glucose and improved insulin levels in streptozotocin-induced diabetic rats [68]. *T. occidentalis* seeds assist in regulating blood glucose levels due to their hypoglycemic properties, making them valuable for diabetes management [69].

T. occidentalis seeds contain antioxidants that protect the heart from oxidative damage. Their high levels of beneficial fats, particularly unsaturated fatty acids, can contribute to lowering cholesterol and decreasing heart disease risk, thus supporting cardiovascular system health. Re-

search by Onuegbu et al. [70] demonstrated that *T. occidentalis* seeds significantly reduced lipid profiles in Wistar rats, suggesting potential use in managing dyslipidemia. Additionally, Daramola et al. [71] found that the methanol extract of *T. occidentalis* seeds lowered serum cholesterol levels, potentially reducing risk of cardiovascular system disease.

Studies show that *T. occidentalis* exhibits anticancer properties by mitigating oxidative stress and suppressing cancer cell growth [44]. The seed's crude extract demonstrated anticancer activity by notably inhibiting oxidative burst in whole blood, isolated polymorphonuclear cells, and mononuclear cells [72]. The presence of compounds such as hexadecanoic acid, octadecatrienoic acid, eicosatrienoic acid, monoterpenes like phellandrene and borneol, and unsaturated fatty acids may contribute to the seed extract's anticancer effects. The anticancer mechanism involves interfering with cell division processes [72].

Traditional uses of *T. occidentalis* seeds suggest potential human reproductive system health benefits, as they are commonly used to enhance fertility [73]. These seeds contain essential nutrients that may improve sperm quality and reproductive health [74]. Njoku and Abarikwu [73] reported that *T. occidentalis* seed can alter male gonadal functions. Their study showed that diets supplemented with these seeds decreased steroidogenic enzyme activity, serum and intratesticular testosterone concentrations, and sperm quality parameters, including count, motility, viability, and normal morphology. Boiled *T. occidentalis* seed-supplemented diets exhibited protection against spermatotoxic effects and altered testosterone profiles in rats. The seeds' ability to induce these changes in sperm quality is attributed to compounds like saponins and alkaloids, which possess anti-infertility properties. Furthermore, Ademiluyi et al. [75] noted the use of *T. occidentalis* seeds in managing erectile dysfunction, as the seeds demonstrated anti-infertility effects in rats by reversing testicular injury and improving testosterone levels, testicular weight, sperm count, and motility.

5. Comparison of nutritional benefits

The primary objective of comparing the nutritional profiles of *P. americana* (Lauraceae family) and *T. occidentalis* (Cucurbitaceae family) despite their distinct botanical families is to promote the valorization of underutilized agro-industrial by-products and highlight their potential application as sustainable, nutrient-dense food ingredients. Additionally, the comparison evaluates and contextualize the nutritional potential of the underutilized *P. americana* seed against a well-established, edible indigenous *T. occidentalis* seed in order to assess its possible relevance for food, livestock feed, or nutraceutical applications. *P. americana* seeds comprise 13–17% of the fruit weight and are discarded as waste, and *T. occidentalis* seeds are the by-products in regions where the leaves are primarily consumed. Both seeds possess complementary nutritional advantages: *T. occidentalis* seeds contain high amount of protein (30–33%), fat (46–49%), and minerals like magnesium and zinc while *P. americana* seeds stand out for exceptional amount of dietary fiber (30–45%), moderate protein amount, and high antioxidant phenolic content. This comparison demonstrates how blending or co-using of these unrelated seeds can yield balanced composite flours with improved macronutrient ratios, enhanced essential amino acid scores, and superior functional properties (e.g., for gluten-free products, weaning foods, or food supplements). Studies have directly compared them in formulated diets to evaluate amino acid, proximate, and mineral compositions, showing their potential for addressing protein-and-energy malnutrition, reducing waste, and supporting circular economy principles in tropical horticulture [76,77]. Botanical family differences are irrelevant here, as the attention is focused on functional nutrition and sustainability, rather than taxonomic relatedness. This approach aligns with broader efforts to upcycle diverse underutilized seeds for ensuring food security and health benefits.

5.1. Similarities between *P. americana* and *T. occidentalis* seeds

Although the seeds of *P. americana* and *T. occidentalis* belong to different plant families and have different tastes and textures, they have a number of shared nutritional and therapeutic advantages. Both seeds are comparable in a number of ways, including their nutritional makeup, prospective applications, and health advantages. Nutrient-rich composition such as health beneficial lipids (unsaturated fats), protein, carbohydrates, fiber, vitamins, and minerals is all abundant in both seeds [17,41]. Additionally, both seeds are rich in bioactive phytochemicals, such as flavonoids, phenolics, and alkaloid, which make them excellent sources of antioxidants that shield the body from oxidative damage [25,41]. Due to their nutritional and phytochemical composition, which supports their anti-inflammatory and antioxidant qualities and gives them therapeutic effects, both seeds also offer a range of health benefits. They are used for their medical qualities, which include hepatoprotective,

anti-inflammatory, anti-diabetic, anti-cholesterol, anti-cancer, and anti-oxidant qualities. As such, they are a good supplement to diets that support health and prevent disease [7,20]. Anti-nutrients such as tannins, phytates, and saponins are found in both seeds which can prevent some minerals from being absorbed. To minimize anti-nutrients content levels and optimize the advantages of both seeds, proper preparation techniques like soaking, boiling, roasting, or fermenting are essential [26,40]. Both seeds can be used in soups, ground into a powder and used as flour in food products, or undergo oil extraction among other uses [17,20].

5.2. Unique benefits of each seed type

Both *P. americana* and *T. occidentalis* seeds provide significant health advantages, they exhibit disparities in their nutritional profiles, applications, and therapeutic properties, which collectively offer a diverse array of distinct benefits that enhance nutrition and overall health. Table 5 highlights the differences in nutritional profiles and therapeutic benefits of both seeds. *P. americana* seeds are characterized by elevated concentrations of polyphenols, flavonoids, and tannins, which substantiate their potent antioxidant properties [17]. These seeds also contain a moderate amount of protein and a high level of dietary fiber, which are beneficial for gastrointestinal health and serve as prebiotic agents [7]. The using of *P. americana* seed powder and extracts spans across various culinary applications, as the seed extracts are used in beverages as antioxidant-rich teas, while the seed powder is involved in the formulation of breads, cakes, and cookies [7]. *P. americana* seeds exhibit distinctive medicinal properties, including antimicrobial, anti-diabetic, and anti-inflammatory effects and are attributable to the health beneficial plants due to their substantial phytochemicals content [7]. Figure 2 displayed the health benefits of *P. americana* seed extract which includes neuroprotective, anti-microbial, anti-inflammatory, antioxidant, anti-cancer and antidiabetic activity.

Table 5. Comparison of nutritional profiles and therapeutic benefits of *P. americana* and *T. occidentalis* seeds

Таблица 5. Сравнение профилей питательных и терапевтически полезных свойств семян *P. americana* и *T. occidentalis*

Nutritional profile/therapeutic properties	<i>P. americana</i> seeds	<i>T. occidentalis</i> seeds
Protein	Moderate amount	Higher content
Dietary fibre	High level	Moderate content
Lipids	Moderate	Higher content
Phytochemicals	Higher constituent	Moderate constituent
Medicinal properties	Antioxidant, antimicrobial, and anti-inflammatory effects	Antinociceptive, antioxidant, anti-inflammatory, and fertility enhancement effects

Source: Elaboration by Osukoya et al. [21], Marra et al. [53], Ademiluyi et al. [75], Ekayoda et al. [76].

T. occidentalis seeds are distinguished by their high protein content and prevalence of unsaturated fatty acids, along with moderate dietary fiber and phytochemical components [41]. The seeds are amenable to multiple preparation methods, including roasting, fermentation, boiling, and consumption in their entirety, or milling into flour for using in soups,

stews, and baked food [20]. *T. occidentalis* seeds are acknowledged for their unique health-promoting properties as depicted in the Figure 3 such as antinociceptive effects, antioxidant, anti-inflammatory property, free radical scavenging potential, enhancement of human fertility [21,73], and support for cardiovascular system health due to their abundant healthy unsaturated fats and free radical scavenging potential [71].

P. americana seeds exhibit a higher concentration of antioxidants and fiber, primarily acknowledged for their digestive and anti-inflammatory advantages, while *T. occidentalis* seeds feature superior levels of protein, essential fatty acids, and minerals, rendering them particularly beneficial for cardiovascular system protection, human fertility enhancement, and energy augmentation. Both seeds are nutritionally beneficial; however, difference in their health-related applications is based on their specific intrinsic properties.

6. Effects of varieties on nutritional and nutraceutical properties

6.1. Effects of *P. americana* varieties on nutritional and nutraceutical properties

P. americana encompasses over 500 cultivars worldwide, classified into three ecological races: Mexican (*P. americana* var. *drymifolia*), Guatemalan (*P. americana* var. *guatemalensis*), and West Indian (*P. americana* var. *americana*) [78]. The most notable varieties include Hass, Fuerte, Zutano, Bacon, Reed, Ettinger, and Maluma Hass. These varieties exhibit significant differences in nutritional composition (e.g., lipids, proteins, minerals content) and nutraceutical properties (e.g., antioxidants, phenolics, bioactive substances content), influenced by variety genetic factors, environmental conditions (soil, climate, altitude above the sea level), and stages of ripeness [79]. Commercial cultivars like Hass dominate over the global markets due to high oil content and long shelf life, but regional or lesser-known varieties often surpass them in specific nutrients or bioactive substances, offering untapped potential for functional foods, supplements, and pharmaceuticals [4,80]. These variations can affect health benefits, such as cardiovascular system protection, anti-inflammatory effects, and antioxidant capacity, making cultivar selection critical for the specific targeted applications. Although *P. americana* shows a great deal of variety among its cultivars, most of this diversity is still unexplored, particularly in terms of its nutritional profiles and functional qualities. Recent research has shown that various avocado cultivars and plant parts, such as pulp, leaves and seeds, vary significantly in their phytochemical profiles, antioxidant capabilities, and mineral contents [81].

P. americana varieties differ significantly in nutritional elements density and nutraceutical potency, driven by type of the variety, maturation ripeness stage, and region. According to Nasri et al. [82], eight Moroccan cultivars (Ettinger, Fuerte, Hass, Reed, Zutano, Bacon, Maluma Hass, Choquette) showed variations in the major lipid, and mineral profiles. They reported that Ettinger variety had the highest lipid (30.44 g/100 g) and energy (316.8 kcal/100 g) content, while Maluma Hass had high moisture (84.71 g/100 g) but low lipid (8.41 g/100 g) content. Protein ranged within 5.78–8.61 g/100 g (the highest was found in Bacon variety), carbohydrates varied with 5.63–14.61 g/100 g (the highest was found in Fuerte). Lipids were monounsaturated-dominant (76.89–84.7 g/100 g fatty acids), with oleic acid 50.38–71.49 g/100 g content (the highest was found in Zutano). Phytosterols totaled 2818.86–5401.36 mg/kg (highest

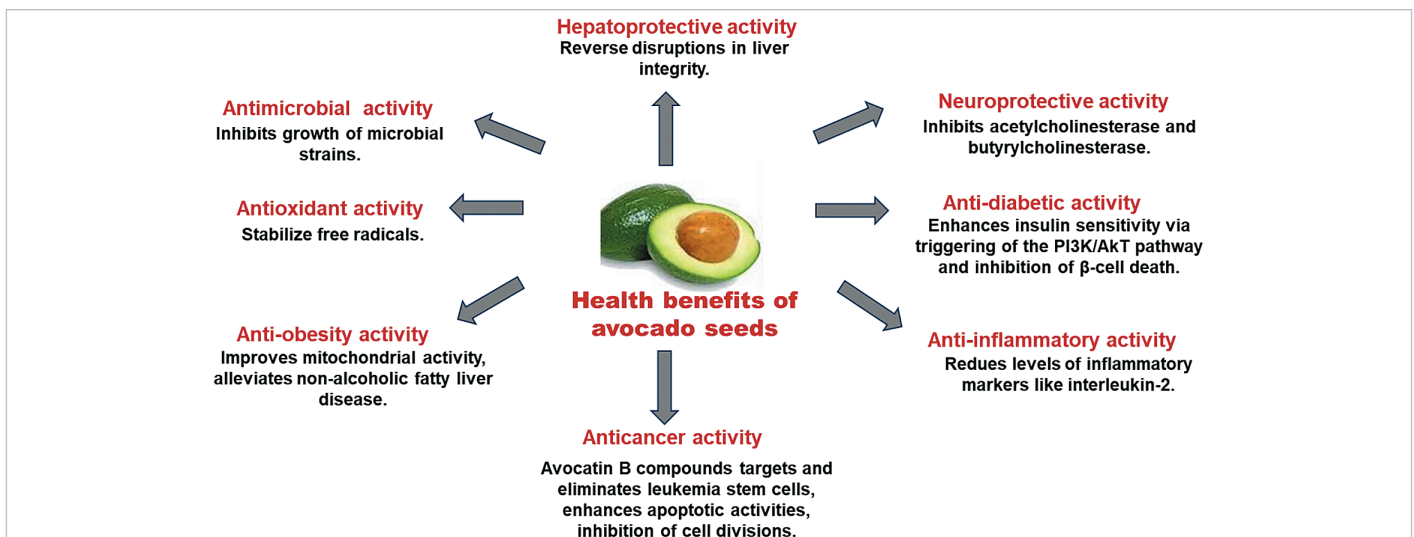
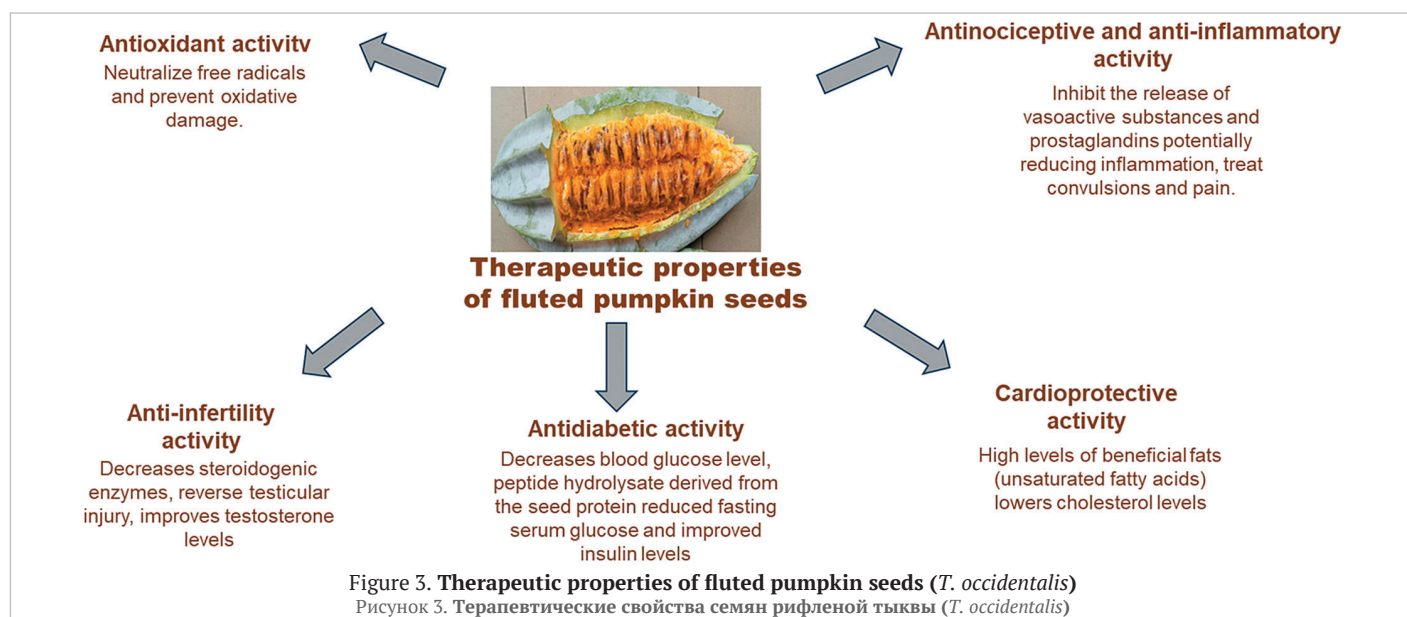


Figure 2. Health benefits of avocado seeds (*P. americana*)

Рисунок 2. Полезные свойства семян авокадо (*P. americana*)



in Choquette), tocopherols accounted for 77.22–332.18 mg/kg (the highest was found in Fuerte). Minerals varied: calcium 295.95–531.67 mg/kg (the highest was found in Ettinger), magnesium 246.29–339.84 mg/kg content (the highest was found in Reed), iron 8.5–20.32 mg/kg (the highest was found in Hass). Three Brazilian cultivars (Margarida, Breda, and Geada) were examined by de Oliveira et al. [83], who found that the peel, seed, and pulp had unique phytochemical profiles that were strongly correlated with antioxidant capability. The Breda cultivar, in particular, had the greatest total phenolic content in the seed (83.38 mg GAE/g), this way proving its potential for the production of useful ingredients. Similarly, a compositional analysis of the Hass variety was carried out by Ford et al. [84], confirming its constant nutritional profile and highlighting its position as a global standard.

Nutraceutically, antioxidants and bioactive substances (phenolics, carotenoids, acetogenins) are higher in the fruit by-products (peel, seeds) than in a pulp, with overripe fruits boosting content of phenolics. Regional Madeira varieties (e.g., thin purple skin) outperformed Hass in antioxidants and lipids content, with unique arachidonic acid and superior peel extracts for radical scavenging [80]. Hass (Guatemalan) is rich in procyanidins and catechins, Fuerte (Mexican) is rich in tocopherols, while West Indian hybrids like Shepard show lower content in some element assays. These support cardiovascular system (cholesterol-lowering via phytosterols), provide antidiabetic (glycemic control via consumption of fiber/ Monounsaturated Fatty Acids), and anticancer (due to cell apoptosis via seed extracts activity) benefits [85].

6.2. Effects of *T. occidentalis* Varieties on Nutritional and Nutraceutical Properties

T. occidentalis exhibits considerable varietal diversity, expressed through differences in seed size, seed coat color, oil yield, growth habit, and biochemical composition. These varietal differences arise from genetic variations, agro-ecological conditions, and cultivation practices, and they significantly affect the nutritional and nutraceutical quality of the plant, particularly its seeds and leaves [86]. The nutritional and nutraceutical properties of *T. occidentalis* are influenced heavily by two biological factors: the sex of the plant (male vs. female) and the morphotype (broad leaves vs. narrow leaves). Unlike *P. americana* which have standardized commercial names (e.g., Hass, Ettinger, Fuerte), *T. occidentalis* varieties are typically categorized by these physical and biological traits in the local agriculture. *T. occidentalis* cultivars can be identified by their seed color, vine thickness, leaf size, growth vigor, number of days before flowering, and succulence. *Ugu-ala* and *ugu-elu* are the two primary cultivars in Nigeria [87]. *Ugu-ala* has succulent, broad leaves, little black seeds, a thick stem, and moderate growth, while *ugu-elu*, has a quick growth rate, large brownish seeds with high viability, and a thin stem with small leaves [88]. The species exhibits genetic diversity through local accessions, genotypes, and sex-based variations (male vs. female plants), which influence agronomic traits, yield rate, and biochemical substances profiles. While research on varietal effects is emerging, studies on 20 accessions across locations in Nigeria reveal significant genotypic variability in proximate composition, minerals, vitamins, carotenes, and anti-nutrients, driven by genetic factors (with high heritability 60–100% for most traits) and geno-

type with environment interactions [89]. Similarly, cultivars like *ugu elu* and *ugu ala* show differences modulated by soil type and amendments, with principal component analysis (PCA) explaining 70% of variation primarily through agronomic and nutritional traits [88]. Sex dimorphism further affects properties, with female leaves often superior in proteins, vitamins, and antioxidants content. These variations enhance the species' potential for breeding nutrient-dense varieties for food security, malnutrition consequences alleviation, and nutraceutical applications, such as antioxidant supplements or anti-diabetic formulations [90].

T. occidentalis cultivars (*ugu elu*, *ugu ala*), and sexes impact nutritional and nutraceutical traits. *Ugu elu* had higher lipids content (1.625–2.0%) than *ugu ala* [90]. Female *T. occidentalis* exceed the male plants in protein (16.00% vs. 12.00% male), fiber (9.22% vs. 8.18%), ash (8.02–8.05% vs. 6.02–6.05%). Minerals such as potassium 224.4–261.8 mg/100 g (mean 240.8 mg/100 g), calcium 57.84–74.60 mg/100 g (mean 64.99 mg/100 g), magnesium 60.64–74.84 mg/100 g (mean 65.78 mg/100 g) are also higher in female plants. Furthermore, female *T. occidentalis* are higher in calcium, magnesium, iron content while males are higher in sodium, manganese content. Vitamin C content 95.48–117.5 mg/100 g (mean 105.7 mg/100 g) and carotene content 2.65–4.18 mg/100 g (mean 3.24mg/100 g) are higher in the male plants [91].

In terms of nutraceuticals, male specie of *T. occidentalis* feature greater concentrations of vitamin C, total antioxidants, and minerals than female plants. These substances are important due to their possible antioxidant and immune-stimulating qualities [91]. *Ugu ala* features higher antioxidant potential. These plants possess anti-diabetic, hepatoprotective, and antimicrobial benefits which are perfect for nutraceutical needs [90].

7. Potential applications in food formulations

7.1. Inclusion into dietary supplements

The seeds of *P. americana* and *T. occidentalis* are abundant in antioxidants, vital nutrients, and medicinal properties, what makes them essential components for dietary supplements aimed at addressing multiple health conditions and enhancing overall wellness. The inclusion of *P. americana* and *T. occidentalis* seeds into dietary supplements represents a promising strategy for augmenting nutritional value and mitigating various health challenges. Empirical evidence suggests that these seeds exhibit considerable health-promoting attributes, rendering them appropriate for diverse dietary applications [7,20]. The assimilation of these seeds can be accomplished through multiple methodologies, encompassing direct supplementation and innovative food fortification techniques. To ensure the safe incorporation of these seeds into food supplements, meticulous processing is crucial to preserve the nutrients while guaranteeing food safety for its consumption; appropriate preparation techniques such as soaking, boiling, roasting, or fermenting are crucial [26,40]. The seeds are ground into a fine powder to facilitate their using in the form of flour or extract. The processed seed powder can be integrated into diet in various supplement formats, including encapsulation, protein powder, functional foods, and tea. Furthermore, these seed extracts can be incorporated into liquid supplements to promote rapid absorption and easiness of consumption. Investigations have confirmed

that direct supplementation with *P. americana* seed flour has potential health benefits [7]. The research conducted by Uchenna et al. [92] revealed that the inclusion of *P. americana* seed flour in the diet had observable effects on the feeding and growth performance of rats. Additionally, diets supplemented with *P. americana* seed powder for culled female quail enhanced kidney and liver functions [93]. The seeds of *T. occidentalis* are occasionally processed into flour or fermented for its using as a protein supplement, functional agent, or flavoring component in a variety of local culinary applications [20]. The supplementation of foods such as broken rice flour with defatted *T. occidentalis* seed flour has demonstrated improvements in protein content, potentially mitigating protein-energy malnutrition [94]. Furthermore, Ali et al. [20] reported that diets supplemented with *T. occidentalis*-substituted bread exhibited significantly improved values of weight gain, protein efficiency ratio, and both apparent and true digestibility compared to the diets formulated with 100% wheat flour bread, thus suggesting an expansion in the using of nutritional benefits of *T. occidentalis*-substituted composite bread. Although the integration of *P. americana* and *T. occidentalis* seeds into dietary supplements reveals substantial potential, concerns regarding their anti-nutritional factors necessitate careful consideration during formulation.

7.2. Uses in functional foods

Functional foods are specifically formulated to offer health advantages that extend beyond fundamental nutrition, thereby playing an essential role in the prevention and management of chronic illnesses. These foods are augmented with bioactive compounds that contribute to enhanced health outcomes [95]. The seeds of *P. americana* and *T. occidentalis* are increasingly acknowledged for their potential in functional foods, due to their rich nutritional composition and associated health benefits. These seeds serve as a significant source of vital nutrients and

also demonstrate a range of bioactive properties that can promote human health. Empirical research suggests that these seeds can be effectively integrated into various food products, thereby improving their nutritional composition and functional attributes [17,20]. Figure 4 and 5 displayed *P. americana* and *T. occidentalis* seeds extracts and powder potential application in the functional foods. *P. americana* and *T. occidentalis* seeds can be effectively incorporated into functional food products such as baked goods, beverages, soups, as well as both dairy and non-dairy alternatives, and snacks. The incorporation of *P. americana* seed powder into snacks, baked foods, and beverages can substantially elevate their antioxidant capacity [17,96]. Furthermore, functional food products that include *P. americana* seed powder have received favorable responses in sensory evaluations, indicating a positive level of consumer acceptance [7,96]. *T. occidentalis* seeds can be used in a variety of food products, enhancing their nutritional value and potentially contributing to the mitigation of malnutrition consequence [94]. Additionally, their application in traditional culinary dishes, such as soups and stews, underlines their versatility in gastronomic applications [20].

7.3. Potential for nutraceutical development

The capacity of plant seeds for the advancement of nutraceuticals is substantial, as they are abundant in bioactive components that confer a multitude of health advantages and serve as a source of proteins, vitamins, and phytochemicals, which can be used for the formulation of functional foods and dietary supplements. Furthermore, they demonstrate antioxidative and anti-inflammatory properties, which contribute to the mitigation of various diseases [97]. The seeds of *P. americana* and *T. occidentalis* provide considerable promise for nutraceutical innovation due to their extensive nutritional composition and bioactive elements. Empirical studies suggest that these seeds encompass a diverse array of

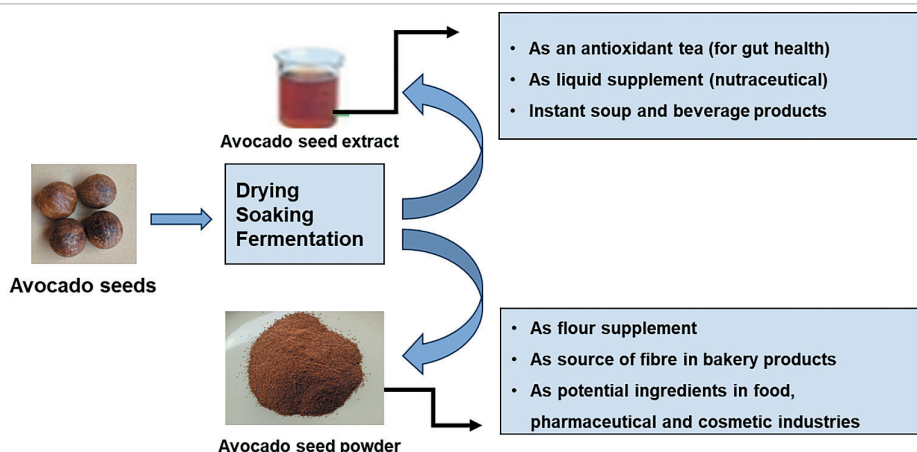


Figure 4. Several applications of avocado seed powder and extracts in food formulations

Рисунок 4. Некоторые виды применения порошка и экстрактов из семени авокадо в составе рецептуры пищевых продуктов

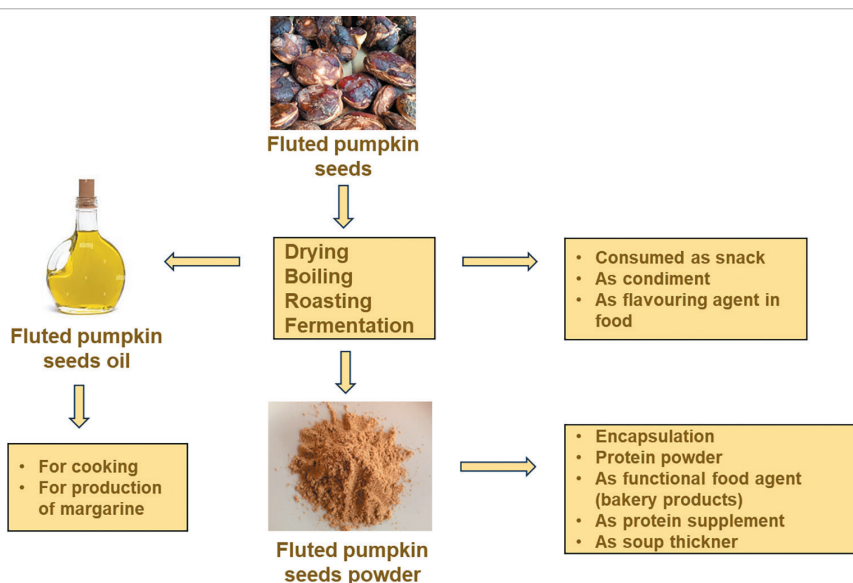


Figure 5. Applications of *T. occidentalis* seed powder and extracts in food formulations

Рисунок 5. Виды применения порошка и экстрактов из семян *T. occidentalis* в составе рецептур пищевых продуктов

phytochemicals, antioxidants, and essential micronutrients, establishing them as a valuable asset for health-enhancing applications [25,41]. Prominent domains for the nutraceutical application of *P. americana* seeds include: (1) antihyperglycemic effects — the extract of *P. americana* seeds markedly reduces blood glucose concentrations in lab rats, thus underlining its prospective utility in the management of diabetes [58]; (2) antioxidant products — *P. americana* seeds provide protection to cells against oxidative damage due to having polyphenols and flavonoids, which play a crucial role in combating oxidative stress [7]; (3) gut health and digestive support — *P. americana* seeds are characterized by a high dietary fiber content that fosters a balanced gut microbiota. This property enhances their antimicrobial characteristics, providing protection against pathogenic intestines bacteria and intestines infections [11]; (4) anti-obesity properties — *P. americana* seed powder has shown its ability to significantly mitigate weight gain and improve lipid profiles, thus reflecting its potential as an anti-obesity supplement [60].

In addition, *T. occidentalis* seeds are used for the advancement of nutraceuticals aimed at enhancing health outcomes in the following ways: (1) antioxidant capabilities — these seeds are rich in various phytochemicals, including flavonoids, tannins, and phenolic compounds, which facilitate the neutralization of free radicals, consequently preventing oxidative damage of cells within the organism and diminishing the likelihood of chronic diseases onset [66]; (2) cardiovascular system health supplements — the extracts derived from *T. occidentalis* seeds lower cholesterol levels owing to their abundance in unsaturated fatty acids, which contribute to cholesterol reduction, thereby decreasing the risk of cardiovascular system diseases and promoting heart health [71]; (3) human fertility and reproductive health nutraceuticals — *T. occidentalis* seeds are frequently used to augment human fertility and enhance sperm quality parameters [73]; (4) anti-diabetic property — *T. occidentalis* seeds assist in the regulation of blood glucose levels attributable to their hypoglycemic characteristics, making them significantly useful for diabetes management [69].

T. occidentalis and *P. americana* seeds exhibit substantial potential for the development of nutraceuticals. Through appropriate processing, formulation, and adherence to regulatory standards, they can serve as a valuable component in dietary supplements, functional foods, and herbal medicines.

7.4. Correlation between incorporated seed components, RDI achievement, and nutrients bioavailability

The correlation between the incorporated components of *P. americana* seeds and *T. occidentalis* seeds is defined by their nutritional complementation and functional synergy. Incorporating components from *P. americana* seeds and *T. occidentalis* seeds typically through blending them into composite flours involves using their complementary nutritional profiles for better complying with recommended daily intakes for key macronutrients and micronutrients. Although direct studies on blends of both seeds are not numerous, research on their individual flour supplementation highlights potential synergies [7,20,93,94]. *P. americana* seeds provide exceptional dietary fiber, and phenolic antioxidants, while *T. occidentalis* seeds deliver high-quality protein and mineral density (e.g., Mg, Zn). Blending balances and creates nutrient rich ingredients for functional foods like gluten-free breads, weaning food formulas, or supplements, addressing protein-energy malnutrition in tropical regions.

T. occidentalis seeds contribute directly and substantially to RDIs via their high protein, minerals and healthy fats contents. Seeds protein covers a large share of daily protein needs, while minerals (Mg, Fe, Zn, P) content often meet or exceed 50–100% of RDIs while healthy lipids enhance caloric density and fat-soluble vitamin utilization absorption. Since it is a high-oil seed (~50% fat), it meets the RDI for energy and healthy fatty acids. *P. americana* seeds contribute minimally to RDIs in absolute terms but provide with dietary fiber, polyphenols and antioxidants. Incorporating both seeds together in order to comply with RDIs for protein and minerals might be achieved mainly through consuming *T. occidentalis* while dietary fiber and antioxidant intake may be enhanced by *P. americana*. The combination of both seeds will improve nutrients diversity.

Both seeds share a major flaw — they contain anti-nutrients that lock away their nutrients from being digested, this way preventing the body from absorbing them (so called low bioavailability). Bioavailability which implies that part of nutrients is absorbed and utilized by body, but some part remains intact, is reduced by anti-nutrients; but it improves significantly with seeds processing. Phytates found in both seeds bind to minerals like iron, zinc, and calcium, reduce the minerals absorption and can hinder their utilization [37,41]. Tannins found in high concentrations in *P. americana* seeds (which cause the bitterness) [26] and in moderate concentrations in *T. occidentalis* seeds, bind to proteins, thus reducing their digestibility [20]. To improve bioavailability, both seeds must undergo similar processing methods (roasting, fermentation, soaking). Fermentation significantly increases the bioavailability of the nutrients in *T. occidentalis* seeds [40] while drying reduces the tannin content in *P. americana* seeds, making the limited range of minerals it possesses more absorbable [26].

8. Conclusion

The nutritional composition of *P. americana* and *T. occidentalis* seeds lays emphasis on their prospective health advantages. These seeds exhibit a robust nutritional profile distinguished by substantial concentrations of nutrients, phytochemicals, and minerals. Notwithstanding the abundant nutritional attributes of these seeds, they also contain anti-nutritional factors that may cause digestion complications. The presence of anti-nutritional factors necessitates appropriate processing of the seeds in order to augment their bioavailability and mitigate potential negative effects; such factors can be alleviated through suitable processing methodologies. This indicates that with proper and relevant preparation, *P. americana* and *T. occidentalis* seeds can be used more efficiently in food products, thereby potentially improving their nutritional profile. Both seeds exhibit comparable content of nutritional components; therefore, it is crucial to acknowledge that they also possess peculiar properties and should be used for specific applications. This highlights the varied potential applications of these seeds within diverse health support contexts. While the integration of *P. americana* and *T. occidentalis* seeds into dietary supplements demonstrates considerable promise, it is imperative to take into account the variability in individual responses to dietary modifications and the necessity for further investigation of the seeds properties in order to comprehensively understand the long-term implications, optimal strategies of their inclusion into food, and potential interactions with other pharmaceutical substances, which could constrain their using in nutraceuticals.

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Conflict of interest	Конфликт интересов
The authors declare that there is no conflict of interest.	Авторы заявляют об отсутствии конфликта интересов.