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Potential of tiger nuts (*Cyperus esculentus* L.) as a functional food: nutritional composition, health-promoting properties, utilization, and contributions to sustainable agriculture

Potenciál tigrích orechov (*Cyperus esculentus* L.) ako funkčnej potraviny: nutričné zloženie, zdraviu prospešné vlastnosti, využitie a prínos k trvalo udržateľnému poľnohospodárstvu

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ABSTRACT

Tiger nuts (*Cyperus esculentus* L.), also known as chufa or earth almonds, are increasingly recognized not only as a health-promoting functional food but also for their sustainable agricultural benefits. Although their cultivation has a rich history, today they are considered a forgotten agricultural crop. The review particularly focuses on their nutritional profile, bioactive compounds, associated health-promoting activities, and diverse potential applications. Tiger nuts are a valuable source of fibers, vitamins, minerals, and bioactive compounds that offer a wide range of health benefits. These include cardiovascular and metabolic improvements, diabetes prevention, antimicrobial and antioxidant properties, as well as potential anti-carcinogenic and hepatoprotective effects. Additionally, this review highlights their underutilized status, which could support the diversification of food sources and enhance food security. Currently, tiger nuts are regarded as a valuable component of a health-promoting and balanced diet, deserving of greater scientific attention, interest from consumers, and engagement by the food industry. The sustainable cultivation of tiger nuts should be encouraged, along with clinical investigations into their experimentally proven biological activities, to establish safe and effective dosage levels for their potential use in the prevention and treatment of civilization diseases. This paper underscores the importance of further research and promotion of tiger nuts as a valuable resource for the global population.

Keywords: *Cyperus esculentus* L., nutrition, health benefits, applications, disease prevention, sustainable agriculture

ABSTRAKT

Tigrie orechy (*Cyperus esculentus* L.), známe aj ako chufa alebo zemné mandle, sú čoraz viac uznávané nielen ako funkčná potravina podporujúca zdravie, ale aj pre ich udržateľné poľnohospodárske výhody. Hoci ich pestovanie má bohatú históriu, dnes sú považované za zabudnutú poľnohospodársku plodinu. Prehľad sa zameriava najmä na ich nutričný profil, bioaktívne zlúčeniny, aktivity súvisiace s podporou zdravia a rôzne potenciálne aplikácie. Tigrie orechy sú cenným zdrojom vlákniny, vitamínov, minerálnych látok a bioaktívnych zlúčenín, ktoré ponúkajú širokú škálu zdravotných benefitov. Zahŕňajú kardiovaskulárne a metabolické zlepšenia, prevenciu cukrovky, antimikrobiálne a antioxidačné vlastnosti, ako aj potenciálne antikarcinogénne a hepatoprotektívne účinky. Okrem toho, prehľad zdôrazňuje ich nedostatočne využitie, ktoré by mohlo podporiť diverzifikáciu potravinových zdrojov a zvýšiť potravinovú bezpečnosť. V súčasnosti sú tigrie orechy považované za cennú zložku zdraviu prospešnej a vyváženej stravy, ktorá si zaslúži väčšiu vedeckú pozornosť, záujem spotrebiteľov a angažovanosť potravinárskeho priemyslu. Malo by sa podporiť trvalo udržateľné pestovanie tigrích orechov spolu s klinickým skúmaním ich experimentálne overených biologických aktivít, aby sa stanovilo bezpečné a účinné dávkovanie pre ich potenciálne využitie pri prevencii a liečbe civilizačných chorôb. Tento dokument podčiarkuje dôležitosť ďalšieho výskumu a propagácie tigrích orechov ako cenného zdroja pre globálnu populáciu.

Kľúčové slová: *Cyperus esculentus* L., výživa, prínosy pre zdravie, aplikácie, prevencia chorôb, trvalo udržateľné poľnohospodárstvo

INTRODUCTION

Worldwide, there is a growing interest in previously lesser-known plants and forgotten agricultural crops, particularly due to their medicinal and therapeutic effects (Clemen-Pascual et al., 2022). These plants primarily serve as valuable sources of biologically active substances (Bezerra et al., 2022; Feitosa et al., 2022). The edible perennial sedge plant, *Cyperus esculentus* L., also known as earth almonds, tiger nuts, or chufa, is believed to originate from Africa and Asia (Bazine and Arslanoğlu, 2020). It is now cultivated worldwide (Edo et al., 2023), including the Mediterranean region, India, North America, Mexico, and Peru (CABI, 2020). In the past, some countries regarded it as a weed, which contributed to its underutilization and the limited research into its potential as a promising raw material (De Vries, 1991). *C. esculentus* L. is closely related to *C. rotundus* L. (Holm et al., 1977). Although both species have a long history of human use, their applications differ. *C. esculentus* L. is primarily valued for its nutritional profile (De Vries, 1991; Zhang et al., 2022), whereas *C. rotundus* L., being less palatable but richer in secondary compounds, is more commonly used as a medicinal plant (Taheri et al., 2021). They are not easily distinguished, frequently occur together, and are often traded under similar or identical vernacular names. To protect consumers, it is crucial to differentiate them in commercial samples. However, this is not easily achievable through morphological markers and is often impossible due to the extensive processing of the material (Wetters et al., 2024).

The cultivation of tiger nuts can be traced back to ancient Egypt (Pascual et al., 2000; Bamishaiye and Bamishaiye, 2011). Tiger nuts are particularly prominent in Valencia (Spain), where they are grown using organic farming principles. Approximately 8,360 tons of dried tiger nuts are produced annually in this area (Pelegrín et al., 2022). In recent years, production and consumption have increased significantly, especially in China, Italy, and Bulgaria (Zhang et al., 2022). Generally, West African countries such as Nigeria, Senegal, and Ghana are among the largest producers of tiger nuts (Ezeh et al., 2014). However, under certain conditions of limited water availability, poor soil management, or inadequate organic material supplementation, the tiger nuts produced tend to be harder, have lower nutritional value, and may contain undesirable substances due to uncontrolled agricultural practices. In Slovakia, tiger nuts are not commercially cultivated, and their occurrence is limited to isolated findings where the species has been recorded as an invasive weed rather than an agricultural crop.

Tiger nuts are an underutilized tuber crop that could help bridge the current gap in the natural products market due to their significant potential and wide range of promising applications. In the future, this raw material is expected to play a key role in addressing the growing issue of food shortages. According to the World Bioenergy Association (WBA), which annually publishes the Global Bioenergy Statistics (2023), fossil fuels still dominate global energy supply. To meet the Sustainable Development Goals, specifically Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action), renewable energy technologies must grow at a much faster pace. Therefore, the potential use of tiger nuts (*C. esculentus* L.) in bioenergy highlights another important opportunity for this crop beyond the food and health sectors.

Organic cultivation and efficient utilization of tiger nuts are essential for their further development. Therefore, the aim of this review is to systematically evaluate the research on tiger nuts (*C. esculentus* L.) as a promising crop with potential for sustainable development. The review particularly focuses on their nutritional profile, bioactive compounds, associated health-promoting activities, and the diverse potential applications of this crop.

BOTANICAL BACKGROUND, MORPHOLOGICAL CHARACTERISTICS, AND AGROECOLOGICAL CONDITIONS OF TIGER NUT CULTIVATION

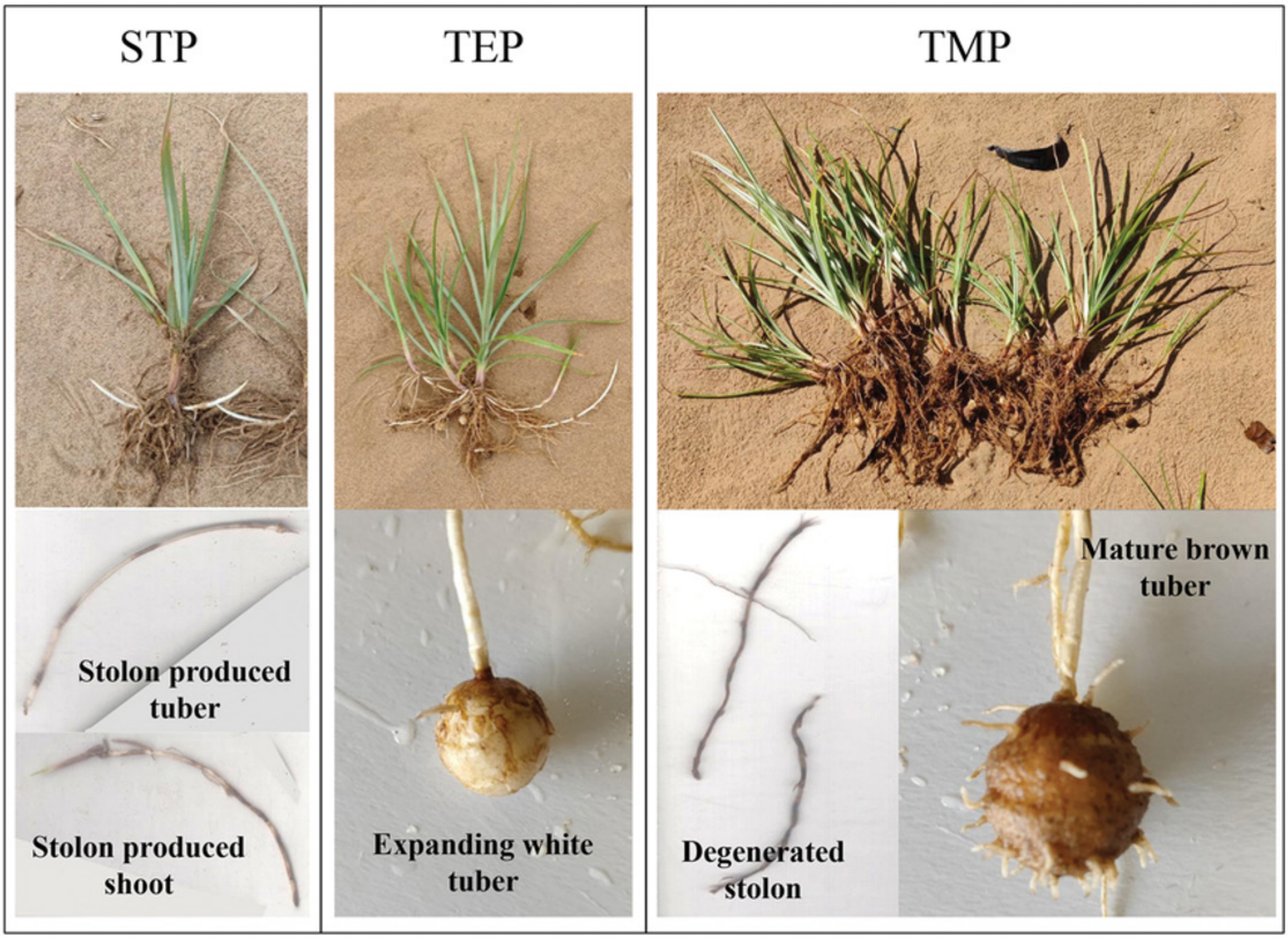
Tiger nuts belong to the *Cyperaceae* family (Bazine and Arslanoğlu, 2020). Botanically, among several known varieties, only four wild varieties (*C. leptostachyus*, *C. esculentus*, *C. hermanii*, and *C. macrostachyus*) and one cultivated variety (*C. sativus*) are recognized (Pascual et al., 2000).

C. esculentus is an upright plant with yellow-green leaves. Its superficial rhizomes are capable of storing proteins, starches, and other important nutrients, leading to the production of tubers. The tiger nut plant forms a complex system of fine fibrous roots (AbdelKader et al., 2017). Despite their name, tiger nuts are not actual nuts but rather 1.0 - 2.0 cm long tubers, similar to almonds, with a spherical or ovoid shape (Rebezov et al., 2021). As the tubers mature, parenchymal cells expand and accumulate high concentrations of starch (Wills et al., 1980). *C. esculentus* L. is a monocotyledonous and perennial plant (Ekeanyanwu and Ononogbu, 2010) with C4 photosynthetic metabolism (Ren et al., 2021), which enhances its adaptability to warm climates. Morphologically, this plant grows rapidly to a height of 20 - 70 cm, with the most suitable environment being a temperate climate with temperatures of 20 - 30 °C (Bazine and Arslanoğlu, 2020), and a soil pH of 5.0 - 7.50.

The inflorescence of the tiger nut consists of 5 - 10 stems bearing terminal spikes with pinnate spikelets and golden-brown flower heads. The seeds are yellowish, three-sided achenes with limited viability and 1.20 - 1.50 mm long. Its flowers are bisexual and arranged in spikelets (Follak et al., 2016). The leaves are bright green with pronounced medium veining, a waxy surface, and pointed tips. They are arranged in groups of three, forming a sheath around the stem, measuring 4.0 – 9.0 mm in width and 20 - 90 cm in length (Bazine and Arslanoğlu, 2020). The most significant morphological changes during tiger nut growth occur in the stolons and tubers. Additionally, variations in reproductive organs reflect physiological transitions from an intense to a stable growth stage (Follak et al., 2016).

Figure 1 represents three periods of significant morphological variations in the reproductive organs of tiger nuts. In the first period, tiger nuts produce stolons but no tubers, known as the stolon tillering period (STP), occurring 20 - 30 days after planting. In the second period, tiger nut tubers are initiated and expand rapidly (in this period, tubers are white and immature, known as the tuber expanding period - TEP), occurring 50 - 60 days after planting. In the final period, tiger nut tubers reach maturity (known as the tuber mature period - TMP), occurring 100 - 120 days after planting (Tan et al., 2022).

C. esculentus L. tolerates high soil moisture and grows best in moist, sandy-loam soils (Bamishaiye and Bamishaiye, 2011).



STP - stolon tillering period, TEP - tuber expanding period, TMP – tuber mature period

Figure 1. Characteristics of the tiger nut at different periods of growth (Source: Tan et al., 2023)

However, soils with higher salinity negatively affect their growth and functionality (Bazine and Arslanoğlu, 2020).

The cultivation of tiger nuts is economical compared to some other forage and crop plants, such as alfalfa and sorghum, because they are well-adapted to survive in semi-arid and arid conditions. This adaptability makes them suitable for areas with limited water resources (Du et al., 2023). Additionally, tiger nuts are naturally resistant to many pests and diseases, reducing the need for extensive pesticide use and other chemical applications (Novor and Donkor, 2024).

The nitrogen-fixing ability of certain bacteria is of great importance, as it increases soil fertility and enhances the productivity of many crops (Mus et al., 2016). As tubers, tiger nuts exhibit excellent potential for interacting with nitrogen-fixing bacteria, offering promising opportunities to reduce reliance on synthetic nitrogen fertilizers (Wang et al., 2022), lower greenhouse gas emissions (Acharya et al., 2018), increase crop yields, and improve the economic efficiency of growers (Acharya et al., 2018). Looking ahead, tiger nuts offer the potential for harnessing the development of sustainable agriculture (Novor and Donkor, 2024) through reduced chemical inputs and enhanced soil health.

VARIETIES OF TIGER NUTS

Red and black tiger nuts are traditionally cultivated and consumed in Ghana and Cameroon (Sidohounde et al., 2018), and both types have similar lipid levels.

Yellow tiger nuts are often preferred by consumers due to their attractive color and larger size. Additionally, they contain more protein and less fat compared to the red variety (Jing et al., 2015). Color differentiation arises from enzymatic browning and other chemical changes during the drying process. Consequently, some experts believe that the yellow and brown varieties of tiger nuts may actually be the same (Sidohounde et al., 2018; Edo et al., 2023). According to a study by Emurotu (2017), the yellow and brown varieties can be easily substituted for each other. However, there is a significant difference in mineral composition between the two, with the yellow variety having a higher composition of mineral elements.

NUTRITIONAL ASPECTS AND BIOACTIVE COMPOUNDS OF TIGER NUTS

The nutritional composition of tiger nuts depends on various factors such as variety, soil and environmental conditions, cultivation method, and notably, storage practices (Dey et al., 2020). When stored for extended periods, tiger nuts tend to exhibit higher sugar content, and increased activities of α-amylase and lipase enzymes have been observed under refrigeration or freezing (Armeli et al., 2021).

In terms of energy, tiger nut tubers provide between 400 - 414 kcal/100 g (Nwosu et al., 2022). They contain high amounts of carbohydrates (47%) (Arafat et al., 2009; Edo et al., 2023) and fats (20 - 38%) (Oladele and Aina, 2007; Nina, 2019; Gadanya et al., 2021; Nwosu et al., 2022). Tiger nuts also possess a significant starch content (14 - 37%) (Li et al., 2017; Yan et al., 2022), comparable to that of cassava (*Manihot esculenta*) and potatoes (*Solanum tuberosum*) (Fabunmi et al., 2016). The protein content of tiger nuts is comparable to that of rice and sorghum (Edo et al., 2023). Although *C. esculentus* L. is relatively low in protein (6 - 10%) and high in fiber (4.53 - 17.50%) (Oladele and Aina, 2007; Nina, 2019; Gadanya et al., 2021; Nwosu et al., 2022), tiger nuts are still considered a substantial dietary choice. Despite not being particularly high in protein, four types of protein have been identified, with glutelin being the most abundant (47.50%), followed by albumin (31.80%), globulin (4.70%), and prolamine (3.80%) (Kizzie-Hayford et al., 2015). The fiber content contributes to alleviating digestive problems and obesity (Ihedioha et al., 2019). The fat content of tiger nuts is very similar to that of olive oil (Willis et al., 2019). Regarding lipid composition, tiger nuts are rich in triacylglycerols (65.90%), glycolipids (5.60 - 6.90%), and phospholipids (1.40 - 3.10%) (Othman et al., 2019). *C. esculentus* L. is a rich source of both saturated and unsaturated fatty acids (Ahaotu et al., 2020). They contain high levels of oleic acid (56 - 85%), along with smaller amounts of palmitic acid (10 - 20%), linoleic acid (8 - 12%), and stearic acid (0.30 - 5.30%) (Edo et al., 2023). Linolenic and palmitoleic acids are present in minor concentrations (Fabunmi et al., 2016). Tiger nuts are also rich in non-essential amino acids such as aspartic acid, glutamic acid, and alanine, as well as the semi-essential amino acid arginine and the essential amino acid leucine (Wagner et al., 2002). L-arginine is particularly important because it promotes protein anabolism, serves as the primary precursor of nitric oxide (NO), and acts as a non-cholinergic and non-adrenergic neurotransmitter with potent vasodilatory effects (Akpoghelie et al., 2022).

Numerous studies indicate that tiger nuts contain all the essential elements necessary for healthy growth and development in both children and adults. They contain high amounts of calcium, magnesium, phosphorus, and potassium (Willis et al., 2019), as well as iron (Owheruo et al., 2023), copper, zinc, and manganese (Arafat et al., 2009). The high calcium content in tubers (94.39 mg/100 g) (Suleiman et al., 2018) is crucial for bone and tooth formation in children (Oladele and Aina, 2007). The high potassium content (267.18 mg/100 g) (Suleiman et al., 2018) supports nerve impulse transmission, as well as cardiac and muscle activity (Onyibe et al., 2021). The phosphorus content in tiger nuts is around 158.86 mg/100 g, and the magnesium content is about 118.14 mg/100 g (Suleiman et al., 2018). Tiger nuts are relatively low in sodium, with an average of approximately 17.02 mg/100 g (Anand et al., 2015; Suleiman et al., 2018). They are also rich in water-soluble vitamin C (30.70 mg/100 g), fat-soluble vitamin A (0.87 mg/100 g) (Suleiman et al., 2018), and E (Sánchez-Zapata et al., 2012). In addition, they contain vitamin B1 (1.67 mg/100 g) and B2 (0.09 mg/100 g) (Ayoola et al., 2022).

Tiger nuts are rich in polyphenols, alkaloids, steroids, terpenoids, flavones, saponins, tannins, and other important phytochemical compounds, which have recognized pharmaceutical potential (Codina-Torrella et al., 2015; Ogunlade et al., 2015; Metsämuuronen and Sirén, 2019; Guo et al., 2021; Nwosu et al., 2022). Furthermore, their excellent antioxidant properties, attributed to their flavonoid content, can serve as a natural defense against free radicals (Samuel et al., 2024).

FOOD APPLICATIONS

C. esculentus L. is a high-quality oil crop of great interest in the food industry (Zhang and Sun, 2023). Tiger nuts are known for their sweet, nutty flavor, similar to that of almonds (Roselló-Soto et al., 2019), which explains their wide range of uses. Tiger nuts are small, approximately the size of peanuts (Adenowo and Kazeem, 2020), and can be eaten raw or after being soaked in water for a few hours (12 - 48 h). They are primarily consumed as dried or processed tubers (Figure 2), but they are also commonly roasted, grated, or ground into flour.

Tiger nut flour

Studies using sensory evaluation have demonstrated that tiger nut flour has a characteristic sweet flavour, making it ideal for a variety of confectionery applications (Das et al., 2014). Furthermore, the fact that the flour is gluten-free makes it suitable for individuals with gluten allergies (Adenowo and Kazeem, 2020). Tiger nut flour significantly increases the level of resistant starch. Composite flours enriched with tiger nut flour exhibit higher total phenolic content and enhanced antioxidant activity (Adeyanju et al., 2024). The flour has high nutritional and biological value, containing, per 100 g: 28.36 g of lipids, 22.36 g of starch, 10.40 g of protein, 20.20 g of fibre, and 15.80 g of glucose. Among the amino acids, valine is the most abundant (67.59 µg/100 g), followed by leucine (3.02 µg/100 g), phenylalanine (1.77 µg/100 g), lysine (0.95 µg/100 g), histidine (1.05 µg/100 g), and tryptophan (0.06 µg/100 g) (Codina-Torrella et al., 2015). Enriching food products with tiger nut flour is an effective way to enhance their nutritional value.

Tiger nuts with skin (4A), peeled tiger nuts without skin (unroasted) (4B), tiger nut flour (4C), tiger nut oil (4D)

Figure 2. Dried underground tubers of tiger nuts (*C. esculentus* L.) (Source: Lenická, D.)

Tiger nut oil

Tiger nut oil contains a significantly high proportion of unsaturated fatty acids, including oleic acid 64.0 - 73.30% and linoleic acid 11.0 - 15.50% (Huang et al., 2013; Roselló-Soto et al., 2018). It is currently utilized in the food industry as an edible oil (Nkafamiya et al., 2010; Allouh et al., 2015). Compared to other vegetable oils, tiger nut oil exhibits improved oxidation stability (Melse-Boonstra, 2020). Dun et al. (2019) identified 75 odor-active molecules in roasted tiger nut oil that enhance its unique aroma profile, making it suitable for flavoring applications. These compounds include 5-hydroxymethylfurfural, ethyl hexadecanoate, and n-propyl-9,12-octadecadienoate, among others (Ogheneoruese Onoharigho et al., 2022). Tiger nut oil contains various bioactive components, such as phytosterols (present in higher concentrations than in olive oil), such as stigmasterol (17 - 21 mg/100 g), β-sitosterol (43 - 61 mg/100 g), campesterol (11 - 17 mg/100 g), and cycloatroxanol (Lopéz-Cortés et al., 2013; Olabiyi et al., 2017; Chao et al., 2021), which contribute to reducing the risk of cardiovascular diseases.

Additionally, Carvalho Barros et al. (2020) evaluated the replacement of beef fat with a tiger nut oil emulsion in burgers, resulting in a healthier meat product characterized by a higher content of unsaturated fatty acids, lower total fat, and reduced saturated fatty acids. The complete substitution of beef fat with tiger nut oil emulsion led to a healthier meat product with high consumer acceptability. Moreover, the nutritional indices (except for the n-6/n-3 ratio) indicate that including tiger nut oil improves the nutritional quality of burgers. Until recently, there was no available information on the use of tiger nut oil as a raw material in margarine production. The study by Dong et al. (2023) provided valuable insights into its application in healthy margarine formulations. Tiger nut oil was successfully interesterified with palm stearin to produce a healthy margarine fat with low levels of trans and saturated fatty acids. This development further broadened the applications of tiger nut oil, enhancing both its nutritional value and market potential.

Tiger nut milk - Horchata de chufa

Tiger nut milk or drink, also known as *"kunnu aya"* in northern Nigeria, is a nutritious and healthy beverage (Ogbuagu and Airaodion, 2020). In Spain, the nuts are primarily used to make a traditional beverage called *"horchata de chufa"*. Recently, chufa has gained attention as a functional food due to its richness in dietary fiber and its role as a source of unsaturated fatty acids (Wetters et al., 2024). It is also a rich source of vitamins C and E, minerals including phosphorus, magnesium, potassium, calcium, and iron, as well as carbohydrates and certain digestive enzymes (Ogbuagu and Airaodion, 2020). In fact, compared to cow's milk, this beverage contains higher levels of iron, magnesium, and carbohydrates (Djomdi et al., 2020). Additionally, the absence of lactose, casein, milk proteins, and cholesterol makes tiger nut milk an ideal beverage for individuals with gluten intolerance or those who cannot consume cow´s milk (Subramaniam et al., 2019). Tiger nut milk is also used as a milk substitute in yoghurt and other fermented foods (Adebo and Gabriela Medina-Meza, 2020).

Other applications and future perspectives

Tiger nuts are often added as flavoring and coloring agents to soft malt drinks and dark beers, as malt can be extracted from the tubers to produce caramel (Bamishaiye and Bamishaiye, 2011). They are also used in the food industry as gluten-free ingredients and in the production of energy bars (Novor and Donkor, 2024). Tiger nuts enhance the nutritional profile of meals, making them a valuable functional food (Wetters et al., 2024).

After evaluating the positive effects of tiger nuts on human health, it can be concluded that fortifying foods with tiger nut extracts offers potential for developing new functional food products. Tiger nuts are a source of α-cellulose, which can be considered a precursor for biopolymers with innovative applications in food packaging (Pelegrín et al., 2022). An alternative plant-based milk made from tiger nuts serves as a suitable substitute for dairy products, especially for individuals with lactose intolerance (Novor and Donkor, 2024). A major advantage of tiger nuts is that they are free from common allergens like gluten, dairy proteins, soy, and tree nuts (Galindo Bonilla et al., 2002; González de Olano et al., 2013), which is particularly beneficial nowadays, as food intolerances, allergies, and autoimmune diseases are becoming increasingly common. This suggests that tiger nuts hold strong potential as a future raw material not only due to their nutritional and functional value but also because of their contribution to food security. The global climate agreement signed by the political leaders of most countries (Paris Climate Conference in 2015) commits nations to decarbonize their economies. Alongside the growing need to diversify sources of bioenergy production, *C. esculentus* L. emerges as a crop with promising future potential. Through the lens of Sustainable Development Goals, the use of tiger nuts (*C. esculentus* L.) in alternative food production appears to be highly relevant from a sustainability perspective. Based on the hypothesis that "feeding the hungry is the oldest philanthropic act in the world," this crop offers an opportunity to diversify agriculture not only toward alleviating hunger and improving quality of life but also toward strengthening global food security.

The usefulness of tiger nuts has also been demonstrated in livestock production. For example, when tiger nut meal comprised 33 - 75% of broiler chicken feed, it had a positive effect on growth and development, while also proving to be economically efficient in carcass processing. Interestingly, chickens fed tiger nut meal consumed less feed than those given standard feed (Si-qun et al., 2016). These findings suggest that incorporating tiger nut meal into poultry feed can increase profitability while reducing costs (Awolu et al., 2017). Similar benefits were observed in West African dwarf goats, which showed significant weight gain and a higher feed digestibility coefficient compared to those fed a standard diet. A study by Toungos and Babayola (2019), conducted on tiger catfish, showed that tiger nut meal positively affected fish development, leading the authors to conclude that it is a better feed alternative than corn meal. Overall, tiger nut meal can be considered an excellent component of animal feed, contributing to increasing production at a lower cost.

In addition to its applications in human nutrition and livestock feed, tiger nut oil has also shown promise in the field of biofuel production. Studies have demonstrated that transesterification of tiger nut oil produces methyl and ethyl esters with properties comparable to those of other commonly used biofuels. Soybean oil (*Glycine max*) and jatropha oil (*Jatropha curcas*) are frequently used feedstocks in biodiesel production, and tiger nut oil demonstrates similar potential in this field (Okyere and Odamtten, 2014).

POTENTIAL MEDICINAL AND HEALTH BENEFITS OF TIGER NUTS

Protective activity against cardiovascular and metabolic diseases

Consumption of tiger nuts has been shown to positively affect individuals with hypercholesterolemia (Viuda-Martos et al., 2010), a key risk factor associated with the pathogenesis of atherosclerosis, coronary heart disease, and other cardiovascular diseases (Adekiya et al., 2018). The oleic acid found in tiger nuts also plays a role in preventing myocardial infarction (Kim et al., 2007). Additionally, eating tiger nuts helps lower blood pressure (Oyedemi et al., 2017), as well as cholesterol and triglyceride levels, thereby reducing the risk of cardiovascular diseases (Novor and Donkor, 2024). Tiger nuts inhibit the development of atherosclerosis by decreasing the formation of atherosclerotic lesions and reducing the number of monocytes and macrophages in the blood (Onuoha et al., 2017). Research results show that the consumption of tiger nuts can positively contribute to the regulation of the number and viability of inflammatory cells involved in the progression of atherosclerosis (Onyibe et al., 2021). In Nepal, fresh, roasted, or dried tiger nut tubers are consumed as an adjunct treatment for thrombosis (Maharjan et al., 2021). Other studies report that tiger nuts strengthen the cardiovascular system by improving blood flow in arteries and veins and reducing the risk of thrombosis (George et al., 2019).

Tiger nuts are also considered a food that positively affects blood sugar levels (Mallo et al., 2024), which is particularly important for individuals with type 2 *diabetes mellitus* and thus serve as an effective nutritional agent in the prevention of obesity (Ihedioha et al., 2019). The high fiber content of tiger nuts is responsible for their ability to regulate blood sugar, resulting in a significant reduction in glucose levels (Selma-Royo et al., 2022). Additionally, their flavonoid and phenoli acids content enhances antidiabetic properties (Sánchez-Zapata et al., 2012).

Anticarcinogenic activity

Although the anticancer effects of tiger nuts have not been extensively studied, preliminary research suggests promising results. The anticancer inhibitory activity of tiger nut extracts was evaluated in a study by Nwosu et al. (2022), where ethanol and hexane extracts showed no toxic effects at higher concentrations (350 µg/mL) on the HeLa cell line. The cytotoxicity of several tiger nut samples from different botanical origins was also found to be effective against the MCF-7 cell line (Singh et al., 2016). These cytotoxic effects are believed to result from the phenolic constituents of tiger nuts. Among them, 5,7-dihydroxyflavone (chrysin), a significant phenolic flavone compound, has been shown to exert toxic effects on the MCF-7 cells (Chander, 2018). Tiger nuts have also been reported to exhibit anticarcinogenic and antiproliferative activities through various biological pathways (Armeli et al., 2021).

Achoribo and Ong (2019) conducted a study to evaluate the cytotoxic effects of tiger nut milk and its aqueous-ethanolic extracts on various cancer cell lines. Their findings revealed that tiger nut extracts had an antiproliferative effect on both MCF-7 and MDA-MB-231 cell lines. The presence of flavonoids, phenolic compounds, and sterols may contribute to the observed cytotoxic effects. The authors suggested that aqueous extracts of tiger nuts could serve as a potential adjuvant treatment for breast cancer due to their antiproliferative properties. Mezher and Saqban (2020) further confirmed the cytotoxic effects of crude aqueous and alcoholic extracts of *C. esculentus* L. on MCF-7 cancer cells. Among all concentrations tested (31.25 – 1000 µg/mL), the highest inhibitory activity was observed at 1000 µg/mL after 72 hours exposure. At this concentration, the aqueous and alcoholic extracts exhibited inhibition rates (IR) of 68% and 73%, respectively, with statistically significant differences ($P \leq 0.01$). Based on these findings, *C. esculentus* L. is considered to be one of the most promising medicinal plants for cancer therapy due to its cytotoxic and growth-inhibitory effects on cancer cells.

Hepatoprotective activity

Tiger nuts exhibit hepatoprotective properties, including the prevention of DNA damage in hepatocytes. Studies by Sobhy et al. (2015), Udefa et al. (2020), and Umukoro et al. (2020) have demonstrated these effects, attributing them to the antioxidant compounds present in tiger nuts. Further supporting this, a study by Onyibe et al. (2021) investigated the impact of tiger nuts on liver health in rats. In this *in vivo* study, hepatotoxicity was induced using carbon tetrachloride (CCl_4). Rats pre-treated with tiger nuts for 21 days before CCl_4 administration exhibited significant reductions in liver enzymes, including aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), and lipid peroxides, indicating a protective effect on the liver. These findings suggest that tiger nuts may offer protection against liver injury by acting as natular antioxidants and further support their reputation as an effective natural liver tonic.

Protective activity on the gastrointestinal system and gut microbiome

Tiger nuts act as a carminative, alleviating digestive discomfort (Adejuyitan, 2011). The tubers contain digestive enzymes such as amylase, lipase, and catalase, making them effective in relieving flatulence (Saei and Barzegari, 2012), serving as a natural remedy against diarrhea (Bazine and Arslanoğlu, 2020), and reducing the risk of diverticulitis, constipation, and hemorrhoids (Igwebuike et al., 2022) due to their high fiber content.

Consuming tiger nuts supports the proper function of the gut microbiome, which serves as the first line of defense for the immune system and overall health (Igwebuike et al., 2022). Their positive effects on the microbiome are mainly attributed to their high fiber and prebiotic content, which promote the growth and activity of beneficial gut bacteria (Sánchez-Zapata et al., 2013). Additionally, tiger nuts have been traditionally used in the treatment of dysentery (Abano and Amoah, 2011). Inflammatory bowel diseases, such as Crohn's disease and ulcerative colitis, are characterized by chronic inflammation and imbalance in the intestinal microflora (Becker et al., 2015), and the beneficial effects of the fiber and prebiotic compounds in tiger nuts are increasingly recognized in this context. In addition, tiger nuts are considered an effective nutritional agent in the prevention of colorectal cancer (Ihedioha et al., 2019).

Antimicrobial activity

The phenolic extract of tiger nut milk at a concentration of 150 mg/mL exhibited strong antimicrobial activity against pathogenic microorganisms in the following order: *Escherichia coli* > *Staphylococcus aureus* > *Salmonella typhimurium* > *Pseudomonas aeruginosa* > *Candida albicans* > *Aspergillus niger* (Naeem and Youssef, 2022). Another study examined the antimicrobial activity of tiger nut extracts in comparison with pharmaceutical agents of similar effects. Nwosu et al. (2022) found that tiger nut extracts were effective against *Shigella* spp., *Salmonella* spp., *Staphylococcus aureus*, and *Escherichia coli*, with the highest inhibition observed at a concentration of 350 mg/mL. Furthermore, their research revealed the antibacterial properties of these plant extracts, confirming their effectiveness in traditional medicine and highlighting their potential in the development of modern drugs to fight microorganisms. The ethanolic extract of tiger nuts was also shown to be effective against *Salmonella typhi*, with results comparable to those of the fluoroquinolone antibiotic ciprofloxacin (Adeniyi et al., 2014). In addition, Hasan et al. (2013) conducted a study evaluating the effects of ethanolic extract from tiger nut tubers on endometritis induced by *Escherichia coli*. After a week of administration, improvements in hematological parameters and white blood cell counts were observed. Interestingly, the results in the group treated with tiger nut extract were similar to those in the group treated with the aminoglycoside antibiotic gentamicin, which exhibits bacteriostatic to bactericidal properties.

Other positive effects of consuming tiger nuts

Tiger nuts are known for their anti-inflammatory effects (Bazine and Arslanoğlu, 2020) and antimicrobial properties (Jing et al., 2016). Due to their high calcium content, tiger nuts are effective in preventing bone demineralization (Weaver et al., 2000), and their amino acid profile also helps prevent the development of muscle atrophy (Lee et al., 2014). Many studies indicate that in traditional communities in India, tiger nuts are used to treat conditions such as tuberculosis, urolithiasis, malaria, loss of libido, muscular disorders, and wounds (Khan and Yadava, 2010). Additionally, tiger nuts are believed to influence testosterone biosynthesis and have anti-memory loss effects. These benefits may be attributed to the antioxidant properties of quercetin, as well as vitamins E and C, which improve the antioxidant status of the cellular environment and help alleviate issues caused by oxidative stress (Zhang and Sun, 2023). Vitamin C in tiger nuts promotes iron absorption and helps to maintain vitamin E levels, thereby supporting immune system function (Roselló-Soto et al., 2019). The high vitamin E content also enhances fertility in both men and women (Allouh et al., 2015), while contributing to slowing down the ageing process, improving skin elasticity, and reducing the appearance of wrinkles, acne, and other skin-related problems (Bamishaiye and Bamishaiye, 2011). Vitamins B1 and B2 found in tiger nuts play a role in the proper functioning of the central nervous system and help the body adapt more effectively to stress. In addition, tiger nuts have been shown to have a positive effect in alleviating symptoms associated with arthritis (Edo et al., 2023).

Potential risks to the consumer

Tiger nuts are susceptible to microbial contamination, particularly when they are collected, stored, processed, packaged, transported, or sold under inadequate hygienic conditions (Aderonke et al., 2024). The extent and type of microbial growth are influenced by temperature, packaging, storage conditions, and the biochemical composition of the product (Okorie et al., 2014). Reported bacterial contaminants include *Staphylococcus aureus*, *Salmonella*, *Bacillus cereus*, *Clostridium* spp., *Acinetobacter*, *Enterobacter*, and others (Ibrahim et al., 2016; Pandukur et al., 2019), while fungal contamination often involves *Aspergillus niger*, *A. flavus*, *A. fumigatus*, and *Penicillium citrinum* (Chukwu et al., 2013; Bolarinwa et al., 2021). These microorganisms may produce harmful mycotoxins such as aflatoxins, ochratoxins, and fumonisins (Shamsuddeen and Aminu, 2016).

In addition, contamination with heavy metals (i.e., mercury, cadmium, arsenic, chromium, thallium, and lead) has been reported (Deka et al., 2023), which may contribute to serious health problems, including cardiovascular diseases, diabetes mellitus, cancer, and sensory impairments (Al-Shaikh, 2013). From a nutritional perspective, the high fiber content of tiger nuts, while generally beneficial, may cause bloating, flatulence, or gastrointestinal discomfort in sensitive individuals or those with conditions such as irritable bowel syndrome (Edo et al., 2024). Although rare, IgE-mediated allergic reactions have also been documented, including anaphylaxis, oral allergy syndrome, urticaria, bronchospasm, and angioedema of the tongue and lips (Galindo Bonilla et al., 2002).

CONCLUSION

Scientific research confirms that tiger nuts possess antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, and anticarcinogenic properties. Their cytotoxic effects against certain cancer cell lines are primarily attributed to their phenolic constituents. In addition to biomedical applications, tiger nuts are also relevant to the agri-food and energy sectors. Tiger nut oil demonstrates high oxidative stability and suitability for biofuel production, while tiger nut flour and milk are valuable components of gluten-free and lactose-free diets, aligning with current nutritional trends and consumer demands. Scientific evidence supports the integration of tiger nuts into human and animal nutrition, pharmaceutical development, and sustainable agricultural systems. Due to their multifunctionality and environmental adaptability, tiger nuts represent a promising crop for promoting both human health and ecological resilience. Currently, tiger nuts can be regarded as a valuable component of a health-promoting and balanced diet that deserves greater scientific and commercial attention. However, further clinical studies are essential to confirm their effects and to thoroughly explore their preventive and therapeutic potential. At the same time, the sustainable cultivation of tiger nuts should be supported, alongside rigorous clinical investigations into their experimentally proven biological activities, so that safe and effective dosage levels can be established for their potential use in the prevention and treatment of civilization diseases.

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