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Review

Human Health Benefits through Daily Consumption of Jerusalem Artichoke (*Helianthus tuberosus* L.) Tubers

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Abstract: "Let food be thy medicine and medicine be thy food", is one of the most famous phrases attributed to Hippocrates, the father of medicine. Scientific research on superfoods has increased in the last six years. These foods have nutritional and pharmacological properties, such that they can help to fight against diseases and poor nutritional status. *Helianthus tuberosus* L., or Jerusalem artichoke, appears to be a superfood that provides benefits to human health at the level of the digestive, gastrointestinal, and dermatological systems, being fit for patients with diabetes mellitus due to its high content of inulin and use in an optimal hypocaloric diet due to its low carbohydrate content. In fact, 5 to 15 g per day is beneficial, with evidence of a prebiotic effect. Unfortunately, its consumption and cultivation are not well known worldwide. For this reason, the present review describes the benefits of *H. tuberosus* in human health to promote knowledge about its nutritional benefits.

Keywords: *Helianthus tuberosus* L.; human health; nutritional quality; gastronomic applications

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1. Introduction

Helianthus tuberosus L. or Jerusalem artichoke is a plant native to North America from the family Asteraceae. Genome skimming suggests the ancestor of *Helianthus annuus* gave rise to *H. tuberosus* through hybridization between two types of perennial sunflowers: Hairy and Sawtooth [1]. The morphological characteristics of this species, including size, rhizome morphology, cultivation practices, distribution, and adaptability, have been previously described [2,3]. At the physiological level, *H. tuberosus* is a perennial plant with tuberous roots, that can be propagated in different ways: rhizomes, grafts, tubers, cuttings, seeds, and tissue culture [4].

Tubers are the edible part of this plant. The morphology of the tubers of *H. tuberosus* might vary between these forms: pyriform, oval, clavate, rounded and elongated. Plants present a variable number of buds, scale-like rings, tuber colors, tuber surface types, tuber pith colors, possible daughter tubers, dents, and knobs [5]. In different countries, collections exist to study this species for its high nutritional and pharmacological value, and raw materials to produce bioethanol. In the INRA-Montpellier located in France, for example, a collection of 140 cultivated clones with peculiar typologies and genetics exists, including hexaploids (2n = 6x = 102), tetraploids (2n = 4x = 68) and hybrids with sunflower (2n = 34) [6].

Different factors could alter their development. Abiotic stress can be caused by environmental conditions such as soil type, wind, radiation, temperature, drought, salinity, and photoperiod [2,7]. Biotic stress may be imposed by saprophytic fungi and nematodes [2] (Table 1). Despite the above, *H. tuberosus* is an invasive plant that has been highly successful in invading new territories, with economic and cultural consequences, altering biodiversity [8].

Table 1. Different species that produce biotic stress in *H. tuberosus*. Summarizes information adapted from [2,7].

Fungi	Annelids	Nematode	Insects
Sclerotinia sclerotiorum	*Strauzia longipennis*	*Ditylenchus dipsaci*	*Macrosiphum euphorbiae*
Sclerotium rolfsii		*Meloidogyne* spp.	*Trama penecaeca*
Botrytis cinerea		*Heterodera schachtii*	*Trama troglodytes*
Alternaria helianthi		*Heterodera marioni*	*Uroleucon compositae*
Rhizopus nigricans		*Caconema radicicola*	*Uroleucon gobonis*
Erysiphe cichoracearum		*Aphelenchoides ritzemabosi*	*Uroleucon helianthicola*
Puccinia helianthi			*Cochylichroa hospe*
Bipolaris zeae			*Homoeosoma electellum*
Fusarium spp.			
Penicillium spp.			

2. Main Uses of *H. tuberosus*

The chemical composition of *H. tuberosus* varies according to the timing of harvest (week) and between varieties. Additionally, storage conditions influence the quality, causing weight loss, changes in dry matter, soluble solids and total sugars, and sucrose contents [9]. Harvest time causes changes in volatile concentrations and sensory scores, as reported by Bach et al. [10], where tubers were collected at different times from planting in soil (30, 38, and 46 weeks).

The phytocomposition of *H. tuberosus* has been described in several publications [3,11–14]. In general, the authors have studied the compounds of *H. tuberosus* from three perspectives: bioethanol production, biological control, and human health.

2.1. Bioethanol

In comparison with corn, rice, sugarcane, and wheat, *H. tuberosus* has double the cellulose production, depending on the month of harvest, with differences of up to 88% in biomass productivity [15]. The principal carbohydrate of *H. tuberosus* is inulin (~50%), which is used as a substrate to generate bioethanol in two manners: after pretreatment, it can hydrolyze and ferment inulin or saccharify and ferment inulin [16]. Information about bioethanol production with *H. tuberosus* can be found in several publications [2,3,17–19].

2.2. Biological Control

The allelopathic potential of this crop has been demonstrated with shoot extracts of *H. tuberosus*, where diethyl ether and aqueous extract inhibited the growth of lettuce seedlings, and salicylic acid, p-hydroxybenzaldehyde, o-coumarin, and coumarin were identified in the extracts [20]. *Helianthus Tuberosus* produces chemicals with allelopathic effects on other plants or weeds, generating a long-term problem with crop rotation [21]. Additionally, plant pathogens and biological pests could be controlled with *H. tuberosus* secondary metabolites or compounds of different extracts [22].

2.3. Human Health

The effects of *H. tuberosus* on human health have been widely studied. The use of *H. tuberosus* as a source of chlorophyll [23], prebiotics [24], protein [25], and other benefits is described in the following sections.

3. Nutritional Value of *H. tuberosus*

The nutritional value of *H. tuberosus* has been addressed in recent publications and reviews [26–29]. Table 2 summarizes the principal components found in *H. tuberosus*. However, as described before, harvest time (weeks after planting) and seasonal changes contribute to changing nutritional components such as soluble carbohydrates [30]. This effect is very important because properties such as the high content of inulin are crucial to human health.

Table 2. Principal components with nutritional value found in *H. tuberosus* varieties.

H. tuberosus Variety	Composition	Total Protein (%)	Amino Acids	Vitamins	Minerals	Reference
Rote zonenkugel (red variety)		6.36%	H, I, L, K, M + C, F + Y, T, W, V	-	-	[26]
Red and white varieties	Water, ash, protein, fat, crude fiber, inulin-type fructans	-	-	Thiamin, niacin, pantothenic acid, pyridoxine, vitamin C	Fe, Ca, Mg, P, K	[27]
Albik and Rubik varieties	Soluble dry mass, inulin, crude fiber, crude fat, crude protein, true protein, total amino acids	-	-	Ascorbic acid	N, P, K, Mg, Ca, Na	[28]

Inulin is the principal nutritional component in *H. tuberosus*, and fresh tubers have 80% water, 15% sugar, and 2% protein. The difference between *H. tuberosus* and another tubers as potatoes is the inulin content, because in *H. tuberosus* starch and sucrose are replaces by inulin [31]. It has been demonstrated that inulin is an antimicrobial and anti-inflammatory agent and can heal wounds [32]. Unfortunately, this bioactive ingredient has been underestimated in comparison to those of other crops, such as wheat or rice. Rubel et al. [33] reported a thorough analysis of the biosynthesis and biotechnological applications of inulin from *H. tuberosus* and its effects on human health.

Inulin extraction is approached with different experimental methodologies. Jantaharn et al. [34] suggested an inulin extraction method through frequency and vibration, producing fragments with different molecular weights. On the other hand, Bedzo et al. [35] reported that in the protein purification of *H. tuberosus*, the fraction with inulin was 82.3%, but *H. tuberosus* slices were more efficient in inulooligosaccharide production. Srinameb et al. [36] proposed a fast laboratory methodology to obtain an inulin production yield of 92.5%.

Essential amino acids can be found in *H. tuberosus*: histidine, isoleucine, leucine, lysine, methionine + cystine, phenylalanine + tyrosine, threonine, tryptophan, and valine [26]. The content and concentration of different amino acids depend on the cultivar and even the storage time, where the principal essential amino acids are arginine, asparagine, glutamine and alanine, and non-essential amino acids are conserved [37]. Regarding protein content, proteome analysis of *H. tuberosus* was recently reported, revealing the existence of proteins related to health and controlling human metabolism, with applications in the management of Parkinson's, Huntington's, and Alzheimer's diseases [25]. In the same research, they found two Kunitz-type and serine hydroxy-methyltransferase proteins, which were antifungal and anticancer as well as antimicrobial and antineoplastic agents, respectively. The high protein content of *H. tuberosus* (5.82–13.36% crude protein) makes it a candidate for feeding ruminants [38].

4. Applications of *H. tuberosus* in Human Health

4.1. Antioxidant Capacity

A wide range of compounds and secondary metabolites from *H. tuberosus* can be used in human health and can be extracted from its tubers, leaves, and flowers. A 2018 study by Wang et al. [39] found 23 compounds in its flowers. As a result, the compound feradiol demonstrated antiproliferative activity against colon cancer cell lines and ent-kaur-16-en-19-oic acid and β-sitostenone showed antimicrobial activity against *Enterococcus faecium*. Similar research found 21 compounds in flowers, where 3,4,2′-tri-hydroxychalcone4′-O-β-D-glucoside was the principal compound in the water-soluble fraction. Tyrosol has powerful activity in scavenging free radicals, and quercetin-3-O-β-D-glucopyranoside inhibited the α-glucosidase enzyme [40]. Using the nematode *Caenorhabditis elegans*, the antioxidant activity of the flowers of this species has been proven, whereby the ethyl acetate fraction increases catalase and superoxide dismutase enzyme activity [40].

The tubers also present antioxidant activity, as was demonstrated by Mariadoss et al. [41]. In the ethyl acetate fraction, phenolic compounds with benefits to human health, such as chlorogenic acid, were detected, proving antidiabetic and wound-healing properties. The quantities of antioxidant compounds are influenced by the environmental conditions because overwintering tubers have a minor antioxidant capacity, which could be related to mass concentration [42].

The leaf extract inhibited lipid peroxidation, protecting Chang cells from oxidative stress [43]. Using DPPH and ABTS assays revealed 5,8-diOH-6,7diMeO-2-(3,4-diMeOPh)-4-benzopyrone and 5,8-diOH-6,7,4′-triOMe had high antioxidant activity, which was better than that of the positive control [44].

Showkat et al. [45] analyzed and compared phenolic contents from different organs of *H. tuberosus*: tubers, flowers, stems, and leaves. These organs demonstrated major quantities of phenolic acids with a high content of chlorogenic acid and its isomers. A comparison of *H. tuberosus* with *Helianthus salicifolius* was made using bulked and dried aerial parts demonstrated that the two extracts have potential application as natural antioxidants with biocidal activity [46].

4.2. Dermatological Treatments

Helianthus tuberosus can also be applied externally and internally. Ethanol extracts applied in mice with atopic dermatitis caused by the mite *Dermatophagoides farina* and HaCaT keratinocytes demonstrated relief and attenuation of symptoms and a decrease in epidermal thickness, alongside enhanced expression of filaggrin [47]. Inulin isolated from *H. tuberosus* has been used to develop cosmetic products, such as a body wash gel, decreasing the skin irritation [48].

4.3. Digestive System

The principal beneficial of *H. tuberosus* is inulin, a fructan type compound stored in plants as a reservoir; in *H. tuberosus*, carbohydrate content range between 65–82%, and inulin corresponds to 22.4% [49]. Inulin is useful as a prebiotic and probiotic in the human body because it influences probiotic adhesion to intestinal epithelial cells, allowing the survival of probiotics under gastrointestinal conditions [50,51]. For this reason, inulin incorporation in foods could help to improve health. For example, studies in the development of yogurt with added inulin from *H. tuberosus* as a prebiotic at a 5% concentration show that this treatment reduced blood glucose, cholesterol, and total lipids [52]. Another study with sixty-six volunteers proved that inulin increases the levels of *Bifidobacteria*, *Lactobacillus*, and *Enterococcus* genera [53]. Additionally, supplying older adults with 5 g/day of *H. tuberosus* powder in the morning was beneficial to intestinal microbiota [54].

In animals, the efficacy of *H. tuberosus* has also been demonstrated. In rats, supplementation of daily food with *H. tuberosus* powder at different concentrations increased *Lactobacillus* spp. and *Bifidobacterium* spp. and aided the absorption of calcium and phosphorous [55]. The addition of *H. tuberosus* to the boar diet decreased the levels of pathogenic bacteria and consequently skatole, a toxic compound [56].

4.4. Improvement of Biochemical Parameters

Helianthus tuberosus consumption, at a 10% administration rate, induces gene expression related to enzymes involved in fatty acid synthesis, fibrosis, and inflammation, improving the prevention of type 2 diabetes and nonalcoholic fatty liver disease in rats [57]. Similar results in sugar blood and hepatic lipids have been described [58,59], where a biochemical analysis revealed a decrease in blood glucose level, liver triglyceride, and total cholesterol in rats fed with 10 w/w% *H. tuberosus*. In older adults, *H. tuberosus* consumption reduces glucose levels [40]. Despite these encouraging results, an excessive intake of *H. tuberosus* is not recommended because it could aggravate diabetes [43].

4.5. Superfood

Due to its nutritional qualities, investigations are focusing on the applications of *H. tuberosus* in gastronomic preparations such as flour, chips, noodles, and pastries, among others. Figure 1 shows the potential applications for *H. tuberosus* in human health.

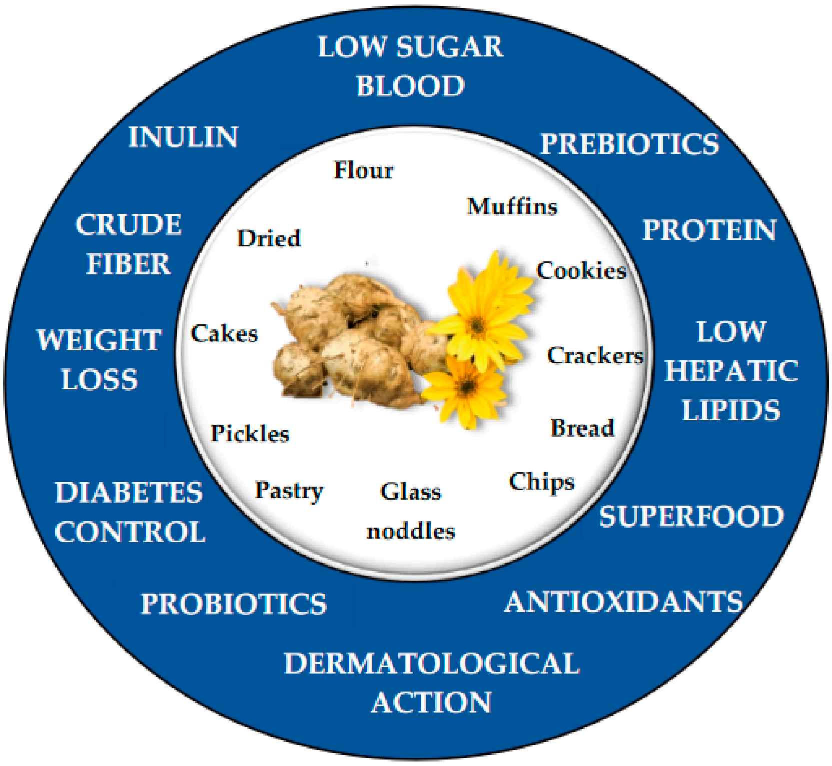

Figure 1. Summarize gastronomic preparations and human health benefits of *H. tuberosus*.

5. *Helianthus tuberosus*: Increasing Quality of Foods for Cooking

Helianthus tuberosus varieties may differ in their contents of nutritional components. For example, Wang et al. [44] analyzed the components of seven varieties from Lithuania, China, and Thailand harvested at different weeks. Crop relocation changes the chemical composition of tubers so that edaphic and genetic factors are key in the nutritional components of *H. tuberosus* [28]. Pinar et al. [38] recommended genetic analysis to choose the best variety according to the given use; for example, *H. tuberosus* destined to a source of roughage for ruminants or animals with offspring must have high quality, with appropriate and necessary nutrients for the developmental stage of the animal [38]. The above was verified in Abd El-Mola and Aboulfotoh [60], where Ossimi rams were fed with *H. tuberosus* in different proportions. As a result, nutrient digestibility, feeding values, and some blood parameters were better than those of the control.

The applications of *H. tuberosus* in the food industry are wide (Table 3). Slapkauskaite et al. [61] fermented tubers with lactic acid bacteria to improve the nutritional quality of dairy products. *Helianthus tuberosus* was well accepted because its organoleptic qualities were better than those of the other plants tested. In addition, the powder of *H. tuberosus* was used to optimize glass noodles, a very common food in the Asian diet. Powder incorporation in glass noodle production provided acceptable organoleptic parameters including good hardness, cohesiveness, springiness, and gumminess, and nutritionally, the glass noodles had increased fiber and sugar quantities [62]. In China, *H. tuberosus* is prepared as a pickle and produces a smooth, sweet, smelly, and crisp product [63]. Bread enrichment with inulin from *H. tuberosus* at a low concentration (2.5 g/100 g flour) increases crumb hardness and chewiness [64]. Another report suggests that adding 5% *H. tuberosus* powder results in bread with good organoleptic qualities, long shelf life, and high nutrient contents [65]. *Helianthus tuberosus* powder has been investigated for its ability to make pastry products healthier. Similar to the addition of the powder to the bread, changes were observed in appearance, organoleptic qualities, and nutritional value. A large quantity of *H. tuberosus* powder decreased the content of kcal in cakes, butter biscuits, and honey biscuits [66]. Sensorial studies of cookies, muffins, cracker bread, and mash with *H. tuberosus* powder generally indicated a good reception, especially by women [67].

Table 3. Summary of cooking products with *H. tuberosus*.

Product	Organoleptic Qualities	Reference
Cookies	Cookies with antioxidant capacity. Hard cookies with more *H. tuberosus* flour. Darker cookies with *H. tuberosus* flour, in comparison with potato flour. Elastic dough with more *H. tuberosus* flour.	[68] [69]
Cake	30% of *H. tuberosus* powder improves organoleptic qualities such as aroma, texture, softness, porosity, appearance, and color, among others. 5–10% of *H. tuberosus* powder change cake color, decreases softness, but evaluators qualified well as a source of inulin.	[70] [71]
Muffins	The addition of 10.99% of *H. tuberosus* powder and 71.40% of oligosaccharide is the optimum formulation to prepare muffins with good organoleptic qualities.	[72]
Pickles	Inactivation of inulinase enzyme and marination to produce a better taste.	[63]
Bread	A percentage of *H. tuberosus* flour in the bread preparation (5%), adds essential amino acids, micro, and macronutrients, extends its useful life, and improves its organoleptic qualities.	[65]
Chips	Chips with low or without calories and sugar. Probing the best preparation of *H. tuberosus* chips in a deep fat fryer or microwave oven.	[73]
Glass noodles	Define optimum concentrations for glass noodles with more fiber and sugar, with other good organoleptic qualities such as cohesiveness and gumminess.	[62]
Other cooking preparations	Inulin extracted from *H. tuberosus* is used in preparations such as ice porridge, instant cereal drinks, ready mixed soya power chocolate malt mixed beverage	[74]

6. Challenges and Perspectives

This review demonstrates that *H. tuberosus* is a tuber with a great potential in the pharmaceutical and gastronomic areas. As Hippocrates said, consumption of quality food, such as *H. tuberosus*, can improve health. Cultural barriers and lack of knowledge are the principal problems with *H. tuberosus* use in the feeding of the population because being an unknown food generates mistrust. Government campaigns and measures or the Ministry of Health could help people incorporate this plant into their regular diet.

Interestingly, in Chile and other South American countries, *H. tuberosus* is not a well-known superfood. However, cooperatives located in southern Chile and people who live on farms have cultivated this crop for personal consumption or recently for commercialization in small local markets. Additionally, in recent years, *H. tuberosus* has received particular attention from research centers with efforts focused on increasing the quality of the extraction and determining the nutritional compounds present in these tubers; producers have received support from the government to increase the quality of the production process. For this reason, this review attempts to promote the important quality traits to maintain the health benefits of incorporating this tuber into foods, which might even be better if added to high-consumption foods such as bread. In addition, because it is a very low-cost food, this crop could serve as an important nutritional source in poor regions of the world, while in more privileged regions, it is now consumed as gourmet food. This would help to significantly improve the health of the population, especially elderly individuals, according to the points that we have discussed and presented above.

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