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Nutraceutical potential of quinoa for improved health and well-being: A review

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Abstract
Quinoa is a gluten-free, ancient pseudocereal crop that has gained popularity due to its excellent nutritional profile and potential health benefits. It is a rich source of protein, dietary fiber, vitamins, minerals, and antioxidants, making it a suitable food ingredient for improving human health and well-being. In addition, various processing methods have been used to enhance the nutritional and functional properties of quinoa, such as germination, fermentation, malting, roasting, dehulling or decortications, dehydration, heat application, and sprouting. These processing methods can increase the bioavailability of nutrients and reduce the content of antinutrients, resulting in improved health outcomes. This review aims to provide an overview of the nutraceutical potential of quinoa, its nutritional composition, processing methods, and their impact on health and well-being.
SFA: Saturated fatty acids
MFA: Monounsaturated fatty acids
PFA: Polyunsaturated fatty acids.

Keywords: Nutraceutical potential, quinoa, health, well-being

Introduction

In recent times, there has been a growing trend towards adopting healthier lifestyles, which includes changes in dietary habits. People are increasingly choosing foods that are rich in bioactive compounds that can provide health and wellness benefits, in addition to satisfying their nutritional needs. *Chenopodium quinoa* Willd, commonly known as quinoa being one of those food has gained significant attention in recent times as a crop with numerous health and nutritional benefits (Pereira *et al*., 2019) [28]. Quinoa (*Chenopodium quinoa* Wild) is a plant native to the Andes in South America and is classified as a pseudo-cereal, as it shares similar characteristics with cereal crops, but is not part of the grass family. It belongs to the same family as spinach and beetroot, known as Chenopodiaceae. Quinoa is highly nutritious and has been recognized by the Food and Agriculture Organization (FAO) as a crop with the potential to provide food security due to its quality proteins and abundance of vitamins and minerals (Nosi *et al*., 2020) [24].

Quinoa is a significant food crop that originated from and has remained important in the Andean regions, which include Bolivia, Peru, Ecuador, Colombia, Argentina, and Chile. This area has been recognized as one of the great centers for the origin of cultivated species, as posited by Vavilov. The closest ancestors of quinoa are believed to be either a single species, *C. berlandieri* var. nuttalliae Staff., widely distributed in North America, or a multi-species origin that includes *C. pallidicaule Aellen* (Kañahua), *C. petiolare* Kunth, C. carnasolum Moq., and the tetraploid species, C. hircinum Schard. or C. quinoa var. Melanospermum growing in the southern hemisphere. All these species originated in the Andean block, suggesting that they are closely related to quinoa. (Jaikishun *et al*., 2019) [15]. Quinoa is an annual plant indigenous to the Andes, and its seeds were the primary crop of Andean cultures in South America for over 5000 years. However, the cultivation and consumption of quinoa were largely eliminated after the arrival of the Spaniards, and only remained in farming traditions. The plants are characterized by tall stature, branching, long vegetative period, and broad leaves. The grains produced by quinoa plants are flat, ranging in size from large to small, and oval-shaped, usually pale yellow in color but can vary from pink to black (El *et al*., 2020) [10].

Quinoa's broad genetic diversity enables it to thrive in diverse altitudes and climates, including harsh environments such as highlands and frost. This adaptability is due to its facultative short-day plant nature, allowing it to flower under a range of day lengths. (Nowak *et al*., 2016) [25].

It is a crop that exhibits remarkable tolerance to extreme environmental conditions, including salinity, cold, solar radiation, and drought. It is particularly suited to cultivation in high altitudes, where it can replace other crops such as maize that struggle to grow. This adaptability is a result of the plant's broad genetic variability, which enables it to thrive in diverse environments spanning a wide range of latitudes from 20° North in Colombia to 40° South in Chile. Quinoa has been observed to grow well across a range of altitudes, from sea level up to 3,800 m. (Hernández, 2019) [13].

Quinoa is a rich source of bioactive compounds such as phenolic compounds, polysaccharides, and saponins, which are known to possess various health benefits. Phenolic compounds present in quinoa have been observed to exhibit potent antioxidant, anti-inflammatory, and anticancer activities. Polysaccharides present in quinoa are known to enhance the immune system. Saponins, on the other hand, are known to exhibit a range of effects, including anti-inflammatory, antioxidant, anticancer, and cholesterol-lowering effects (Ng & wang 2021) [22]. Quinoa is classified as a pseudocereal due to its characteristics of grains, despite not belonging to the Gramineae family. Its seeds are milled into flour and used as a cereal crop, and this flour is utilized in the production of a variety of baked goods such as bread, cookies, biscuits, noodles, pasta, tortilla, and pancakes. Additionally, fermented quinoa seeds are used to produce beer and "chicha," an alcoholic beverage consumed in South America. Quinoa leaves can be consumed in a similar manner to spinach, and the germinated seedlings are also consumed as a food source (Garcia *et al*., 2015) [48].

Over the past few decades, there has been a steady increase in quinoa production, and its consumption has exponentially risen, particularly during the International Year of Quinoa in 2013. This growth in interest can be attributed to the crop's nutritional and functional properties and its ability to be grown in adverse climate conditions, making it suitable for areas prone to food insecurity. Quinoa is a plant that exhibits tolerance to frost, salinity, drought, and has the ability to grow on marginal soils. However, this increase in production and demand may negatively impact the native regions where quinoa is a crucial source of nutrition and economic survival, highlighting the need for sustainable management practices and equitable distribution of resources. (Angeli *et al*., 2020) [2]. While quinoa consumption is increasing in high-income countries, it still remains low compared to the main producer countries. For example, Bolivia and Peru have annual consumption rates of 2.37 kg/person and 1.15 kg/person, respectively, whereas the consumption rate in the US is only 0.03 kg/person (Vilcacundo & Hernández, 2017) [40].

Nutrient composition of quinoa

Quinoa Protein

Quinoa is a nutritious pseudocereal that contains a significant amount of protein ranging from 12% to 23%. The major protein components found in quinoa are globulins and albumins. Globulins make up 37% of the protein content, while albumins account for 35%. These proteins are considered high-quality and contain all the essential amino acids needed by the human body. Incorporating quinoa into one's diet can be a beneficial way to increase protein intake and improve overall nutrition (Dakhili *et al*., 2019 & Filho *et al*., 2017) [7, 11].

One of the major protein components found in quinoa is chenopodin, which is an 11S-type globulin protein. Chenopodin is an oligomeric protein with a complex quaternary structure. Studies have shown that chenopodin has various functional properties, including antioxidant, antihypertensive, and anti-inflammatory effects. Another protein found in quinoa is a 2S-type albumin that contains high levels of cysteine, arginine, and histidine. This albumin is known for its strong emulsifying and foaming properties, making it a useful ingredient in food processing (Graf *et al.*, 2015 & Filho *et al*., 2017) [12, 11].

Quinoa protein is considered a complete protein as it contains all nine essential amino acids required by the human body. In fact, quinoa protein is particularly rich in several of these essential amino acids, with levels that can surpass the recommended daily intake. For example, quinoa protein can provide over 180% of the daily requirement of histidine, as estimated by FAO/WHO/UNU (1985). Similarly, quinoa protein can supply 274% of isoleucine, 338% of lysine, 212% of methionine + cysteine, 320% of phenylalanine + tyrosine, 331% of threonine, and 228% of tryptophan. Incorporating quinoa into one's diet can, therefore, be a beneficial way to ensure adequate intake of essential amino acids (Ng & Wang 2021) [22].

Quinoa Minerals

Quinoa is a nutrient-dense grain that contains high amounts of various essential minerals in bioavailable forms. In fact, quinoa contains significantly higher levels of calcium, magnesium, iron, copper, and zinc than many other cereal grains, including wheat, barley, oats, rye, triticale, and rice. Furthermore, the process of germination can increase the mineral content of quinoa even further. Studies have shown that germination can lead to a 39.43% increase in iron, a 49.04% increase in calcium, and a 20.25% increase in zinc content. Incorporating quinoa into one's diet can be a beneficial way to increase mineral intake and improve overall nutrition (Bastidas *et al*., 2016 & Darwish *et al*., 2021) [3, 8].

Quinoa Lipids

Quinoa is a grain that has a high ratio of unsaturated to saturated fats, making it a healthy dietary choice. Its oil contains significant amounts of omega-3 and omega-6 fatty acids, which are beneficial for human health. Despite being highly unsaturated, quinoa oil is stable due to the natural presence of tocopherols, which act as antioxidants. This makes it a suitable oil for cooking and food processing. Comparatively, amaranth, buckwheat, and wheat have lower ratios of unsaturated to saturated fats and do not contain as much omega-3 and omega-6 fatty acids as quinoa. Therefore, quinoa is a superior source of healthy fats compared to these grains. Additionally, quinoa's high nutritional content makes it a popular choice for vegans, vegetarians, and health-conscious individuals. Its versatility in cooking makes it a great addition to any diet (Ng & Wang 2021) [22].

Quinoa Vitamins

Quinoa is a good source of vitamin E, which is a natural antioxidant that helps to protect the unsaturated fatty acids in its oil from oxidation. This makes it more stable compared to oils from other grains like corn, amaranth, buckwheat, and wheat. In addition to vitamin E, quinoa also contains several B vitamins, including thiamin, riboflavin, and niacin. These vitamins are essential for the proper functioning of the body's metabolism and nervous system. Incorporating quinoa into your diet can help you meet your daily nutritional requirements for these important vitamins. Overall, quinoa is a highly nutritious grain that offers many health benefits (Al-Qabba *et al*., 2020) [1].

A 100 g serving of quinoa contains sufficient amounts of vitamin B6 and folate to fulfil an adult's daily requirement for these nutrients. Furthermore, the riboflavin content in quinoa can fulfil up to 40% of an adult's daily needs for this vitamin (Ng & Wang 2021) [22]. Quinoa contains tocopherols ranging from 971-1764 µg/100 g dry weight, which varies by grain color. Its vitamin E activity value is significantly greater than that of barley and wheat (Tang & Tsao, 2017 & Vera *et al*., 2019) [35, 39].

Quinoa Carbohydrate

Quinoa starch is known for its high solubility and digestibility, making it a popular choice in many food products. Starch constitutes a significant portion of the dry matter in quinoa, ranging from 58.1% to 64.2%. The amylose content in quinoa starch is typically low, ranging from 3% to 20%, while amylopectin makes up around 90% of the starch. The amylopectin in quinoa has a relatively low degree of polymerization of 8-12, resulting in a starch crystal that is more soluble and digestible. This is because the increased number of branches on the starch surface area increases water binding and enzymatic digestion. Overall, the unique composition of quinoa starch makes it an attractive option for use in many food products. (Selma *et al*., 2020 & Srichuwong *et al*., 2017) [32, 33].

Natural polysaccharides have gained attention for their pharmacological properties, and researchers have begun investigating the biological activity of quinoa polysaccharides. Studies have shown that purified polysaccharide fractions from quinoa have demonstrated antioxidant and immunomodulatory activities, with significant effects on radical scavenging and anti-inflammatory properties (Yu *et al*., 2018 & Hu *et al*., 2017) [42, 14].

Quinoa Fiber

Quinoa has a higher dietary fiber content compared to rice and corn, with 8-13% fiber. This makes it a fiber-rich cereal option. In contrast, rice and corn have lower fiber contents. It is a crop that contains both soluble and insoluble fiber. The insoluble fiber ranges from 10% to 14% and is composed of homogalacturonans, which promote bowel regularity. The soluble fiber ranges from 1.3% to 6.1% and is mainly composed of arabinan and homogalacturonans, which slow down glucose absorption and reduce cholesterol levels. The fiber composition of quinoa can vary depending on growth conditions and genotypes, and it is essential for promoting digestive health and overall well-being (Zhu, 2020) [4].

Table 1: Nutritional content of quinoa

Nutritional composition	Compounds	Content	References
Moisture	NA	9.8 g/100 g	Pereira *et al*., 2019 [28]
Ash	NA	3.3g/100 g	Nowak *et al*., 2016 [25] Pereira *et al*., 2019 [28]
Fiber	Total dietary fiber	11.7 g/100 g	Nowak *et al*., 2016 [25]
	Crude fiber	3.3 g/100 g	
Fat	Total	5.7 (4.0-7.6) g/100 g	Nowak *et al*., 2016 [25]
	Crude fat %	4.0-7.6%	Pereira *et al*., 2019 [28]
Protein	Total	14.4 g/100 g	Repo *et al*., (2003) [29] Pereira *et al*., (2019) [28] Pathan & Siddiqui, (2022) [27]
	Albumins + globulins	45	
	Prolamins	23	
	Glutelins + insoluble	32	
	Crude protein %	9.1-15.7%	
Carbohydrate	NA	59.9 g/100 g (48.5-69.8)	Nowak *et al*., 2016 [25] Pereira *et al*., 2019 [28]
Minerals		11%	Nowak *et al*., 2016 [25] Pathan & Siddiqui, (2022) [27]
	Calcium (Ca)	63mg/100 g	
	Iron (Fe)	8.47 mg/100 g	
	Magnesium (Mg)	27.5–148.7 mg/100 g	
	Phosphorous (P)	273 mg/100 g	
	Potassium (K)	696.7–1475.0 mg/100 g	
	Sodium (Na)	11.0–31.0 mg/100 g	
	Zinc (Zn)	3.73 mg/100 g	
	Copper (Cu)	1.0–9.5 mg/100 g	
Vitamin	Tocopherols (E)	971 µg/100 g dw	Pereira *et al*., (2019) [28] Hernández 2019 [13]
	Thiamin (B1)	0.36 mg/100 g	
	Riboflavin (B2)	0.32 mg/100 g	
	Niacin (B3)	1.52 mg/100 g	
Energy	NA	420+/- 2 kcal/100 g	Pereira *et al*., 2019 [28]
Lipids	Fatty acids, SFA	0.71 g/100 g	Hernández 2019 [13]
	Fatty acids, MFA	1.61 g/100 g	
	Fatty acids, PFA	3.29 g/100 g	
Sugar	Total	2.9 g/100 g	Pereira *et al*., 2019 [28]
	Arabinose	0.62 g/100 g	
	Fructose	0.25 g/100 g	
	Glucose	0.61 g/100 g	
	Sucrose	1.4 g/100 g	

Total Polyphenol Content	NA	71.7 mg/100 g	Kim & Iida, (2023) [16]
DPPH Radical Scavenging Activity	NA	16.28~19.10 mg/mL	Kim & Iida, (2023) [16]
Organic acid	Total	732 mg/100 g dw	Pereira *et al*., (2019) [28]
	Oxalic	415 mg/100 g dw	
	Citric	317 mg/100 g dw	

Processing of quinoa

Germination

Germination is a commonly used method in domestic seed processing for enhancing the nutritional value of seeds. This process involves several steps, starting with the absorption of water by the inactive, dry seed and ending with the elongation of the embryo axis. During this process, the major storage reserves within the seed are mobilized, and this is closely linked to the growth of the seedling. The overall outcome of germination is an increase in the nutritional value of the seed due to the activation of enzymes that break down complex molecules into simpler ones that are more readily available for the plant's use (Benincasa *et al*., 2019) [4]. Germination is a cost-effective method of improving the antioxidant capacity of seeds, increasing the bioavailability of essential minerals and vitamins. It is widely used in domestic seed processing due to its simplicity and efficacy. Germination activates enzymes that release nutrients from the seed, making them more easily absorbed by the body (Nkhata *et al*., 2018) [23].

The germination of quinoa seeds has been shown to decrease protein content by 11% from 15.13 to 13.50 g/100 g. The protein loss during germination is attributed to either the breakdown of larger protein molecules into smaller peptides and amino acids or the synthesis of new proteins. However, some studies have reported contrasting results with an increase in protein content after sprouting (Padmashree *et al*., 2019 & Darwish *et al*., 2021) [45, 8]. Germination followed by oven-drying is an effective method for enhancing the phenolic content and antioxidant activity of quinoa seeds. These germinated products are a rich source of essential fatty acids, which play a crucial role in brain development, insulin sensitivity, prostaglandin metabolism, and maintaining a healthy omega-6: omega-3 fatty acid ratio. This ratio is associated with improved cardiovascular health, immunity, reduced inflammation, and better management of autoimmune diseases (Vega *et al*., 2010) [38].

Fermentation

Fermentation is a traditional food processing method that has been used for centuries to improve the nutritional and sensory quality of foods. In recent years, fermentation has gained attention as a means of enhancing the nutritional value and functional properties of quinoa. Fermentation of quinoa involves the use of microorganisms, such as lactic acid bacteria, to break down complex carbohydrates, proteins, and lipids, into simpler compounds that are more easily digested and absorbed by the body. This process also results in the synthesis of bioactive compounds such as vitamins, amino acids, and peptides, which have been shown to have numerous health benefits.

One study by (Wang *et al*., 2018) [41] investigated the effects of fermentation on the nutritional composition and sensory properties of quinoa. The study found that lactic acid fermentation of quinoa resulted in a significant increase in the content of certain essential amino acids, such as lysine and methionine, as well as a decrease in the content of antinutritional factors, such as phytic acid and tannins. The authors also reported an improvement in the protein digestibility and sensory quality of the fermented quinoa. Similarly, another study by Ticona *et al*. (2021) [36] investigated the effects of spontaneous fermentation on the nutritional and functional properties of quinoa. The study found that fermentation resulted in a significant increase in the content of free amino acids, such as glutamic acid, which is known to have umami taste and enhance the flavor of foods. The study also reported an increase in the antioxidant activity of fermented quinoa, as well as a decrease in the content of saponins, which are known to have negative health effects.

In conclusion, fermentation is a promising processing method for quinoa that has the potential to enhance its nutritional value, functional properties, and safety. Fermentation can increase the content of essential amino acids, improve protein digestibility, and decrease the content of anti-nutritional factors and saponins. Furthermore, fermentation can enhance the flavor and sensory quality of quinoa, as well as increase its antioxidant activity. Fermented quinoa also has an extended shelf-life and reduced risk of foodborne illnesses, making it a valuable food product in regions where quinoa is produced and consumed.

Malting

Malting is a traditional processing method that has been used to improve the nutritional quality of various cereal grains. A study by Vega-Gálvez *et al*. (2010) [46] investigated the effect of malting on the nutritional composition and antioxidant activity of quinoa. The study found that malting resulted in a significant increase in the content of free amino acids, soluble fiber, and phenolic compounds, which are known to have antioxidant properties. The authors also reported an increase in the protein digestibility and a decrease in the content of antinutritional factors, such as phytic acid and tannins, in the malted quinoa.

Another study by Lamothe *et al*. (2015) [18] evaluated the effect of malting on the sensory quality and nutritional composition of quinoa. The study found that malting resulted in a significant increase in the content of certain essential amino acids, such as lysine and methionine, as well as an increase in the antioxidant activity and sensory quality of quinoa. The authors suggested that malting could be a potential processing method to improve the nutritional and sensory quality of quinoa-based food products.

Roasting

Roasting is another popular processing method for quinoa, which involves heating the grains at high temperatures for a short period of time. This method has been shown to improve the sensory properties of quinoa, such as the color, aroma, and flavor, while also enhancing its nutritional quality. One study by Miranda *et al*. (2010) [21] investigated the effects of roasting on the physicochemical and nutritional properties of quinoa. The study found that roasting increased the content of phenolic compounds and antioxidant activity of quinoa, which may have potential health benefits. Additionally, the authors reported an improvement in the sensory properties of roasted quinoa, such as the nutty flavor and crunchy texture.

Another study by Lazarte *et al.* (2021) [20] evaluated the effect of roasting on the amino acid profile of quinoa. The study found that roasting significantly increased the content of essential amino acids, such as lysine, methionine, and threonine, while also reducing the content of non-essential amino acids. The authors suggested that roasted quinoa may have improved nutritional quality compared to unroasted quinoa. Overall, roasting is a simple and effective processing method for quinoa, which not only enhances its sensory properties but also improves its nutritional quality.

Dehulling or decortications

Dehulling or decortication is a common processing method for quinoa that involves removing the outer layer of the seed to obtain the edible portion. The removal of the bitter saponin coating on quinoa seeds through this process improves its taste and digestibility, making it more appealing to consumers (Ruiz *et al*., 2014) [31].

According to a study by (Vega-Gálvez *et al*., 2010) [45], dehulling quinoa significantly increases its protein content, particularly the concentration of essential amino acids such as lysine and tryptophan. Dehulling also enhances the mineral content of quinoa, particularly calcium and iron, making it a valuable source of these essential nutrients for vegetarians and vegans. Another study by (Zhihong *et al*., 2017) [43] reported that dehulling quinoa not only increases the protein and mineral content, but also reduces the concentration of anti-nutritional factors such as phytic acid and oxalates, which can impair the absorption of certain minerals in the body. Overall, dehulling or decortication is an essential processing method for quinoa, which not only improves its taste and digestibility, but also enhances its nutritional value by increasing the concentration of protein, essential amino acids, and minerals while reducing the concentration of anti-nutritional factors.

Dehydration

Dehydration is a common processing method used for quinoa to extend its shelf-life and preserve its nutritional properties. One study by (Lavanholi *et al*., 2018) [19] investigated the effects of three different dehydration methods (oven, sun, and freeze drying) on the nutritional composition and sensory properties of quinoa. The study found that all three dehydration methods resulted in a decrease in the content of certain vitamins and minerals, such as vitamin C and iron, but did not significantly affect the protein and fat content of quinoa. The authors also reported that freeze drying resulted in the highest overall quality of quinoa, followed by oven drying and sun drying.

Another study by (Vega-Gálvez *et al*., 2009) [37] investigated the effects of dehydration on the antioxidant activity of quinoa. The study found that oven drying and sun drying resulted in a significant decrease in the antioxidant activity of quinoa, while freeze drying resulted in no significant change. The authors suggested that the decrease in antioxidant activity could be due to the degradation of certain antioxidants during the dehydration process.

Sprouting

Sprouting is a traditional processing method that has gained popularity in recent years due to its potential to improve the nutritional value and digestibility of quinoa. A study by (Vega-Gálvez *et al*., 2010) [46] reported that sprouting significantly increased the content of essential amino acids, such as lysine and methionine, and improved the protein quality of quinoa. Another study by (Kim *et al*., 2022) found that sprouting also resulted in a significant increase in the antioxidant activity and total phenolic content of quinoa.

Furthermore, sprouting has been shown to decrease the content of antinutritional factors such as saponins, phytic acid, and tannins, thereby increasing the bioavailability of minerals and improving the digestibility of quinoa (Graf *et al*., 2015) [12]. In addition, sprouting has been reported to increase the content of vitamin C and carotenoids, which are important micronutrients that have antioxidant and immune-boosting properties (Mujica *et al*., 2017) [47]. Overall, sprouting is a simple and effective processing method that can significantly improve the nutritional value, bioavailability, and digestibility of quinoa.

Table 2: Different processing effects on quinoa

Processing	Effects	References
Germination	Causes a 2-fold rise in antioxidant activity after 3 days, and also increased oleic acid content while reducing linoleic acid content.	Carciochi, *et al*., (2016a) [5] Srujana *et al*., (2019) [34] Park & Morita (2007) [36]
Fermentation	Decrease in the content of ascorbic acid and tocopherol, but an improvement in the phenolic compounds and antioxidant capacity.	Carciochi, *et al*., (2016b) [6]
Malting	Effective in enriching antioxidants.	Carciochi, *et al*., (2016b) [6]
Roasting	Increase in both peak and final viscosity of the cake.	Rothschild *et al*., (2015) [30]
Dehulling or decortications	Decreasing antinutrient levels and enhancing sensory properties, this process leads to an improvement in the quality of grains.	Srujana *et al*., (2019) [34]
Dehydration	40, 50, and 80 °C increased antioxidant capacity, while vitamin E content was boosted by dehydration at 70 and 80 °C.	Miranda *et al*., (2010) [21]
Heat application	Protein structures can be significantly affected by the processes they undergo, which in turn can affect their susceptibility to digestion.	Srujana *et al*., (2019) [34]
Sprouting	Increases vitamin C content	Darwish *et al*., (2021) [8]

Conclusion

Quinoa is a promising food crop with a wide range of nutraceutical potential for improved human health and well-being. It is a rich source of protein, dietary fiber, vitamins, minerals, and antioxidants, and has been shown to have potential health benefits, such as improving lipid profiles, reducing inflammation, and managing diabetes. The various processing methods of quinoa, such as germination, fermentation, malting, roasting, dehulling or decortications, dehydration, heat application, and sprouting, can further enhance its nutritional and functional properties, making it more suitable for human consumption. These processing methods can increase the bioavailability of nutrients and reduce the content of antinutrients, resulting in improved health outcomes. Therefore, quinoa has the potential to be a valuable ingredient in the development of functional foods and nutraceutical products, promoting better health and well-being for individuals.

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