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Derleme Makale / Review Paper

The Role and Potential Sources of Sustainable Plant-Based Foods: A Look to the Future

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ABSTRACT

The food industry, influenced by environmental issues such as global warming and climate change, is undergoing significant changes towards establishing a sustainable food system. This system prioritizes reducing the adverse impacts on our natural resources while ensuring sufficient and nutritious foods. Despite animal sources being rich in nutrients, consumer concerns regarding sustainability are increasing the search for alternative sources. With growing consumer interest in sustainable and healthy choices, there is an increasing demand for plant-based food sources. Plant-based protein sources generally include seeds, legumes, nuts, and oilseeds. Plant-based proteins are not only consumed as a food but also valued for their potential for various techno-functional properties in the food industry. Plant-based foods are both good sources for proteins and high in fiber, vitamins, and minerals. This study focuses upon the impact of a developing world and increasing population on plant-based foods, their nutritional value, and potential applications.

Keywords: Plant-based food, Protein, Sustainability

Sürdürülebilir Bitki Bazlı Gıdaların Rolü ve Potansiyel Kaynakları: Geleceğe Bir Bakış

ÖZ

Küresel ısınma ve iklim değişikliği gibi çevresel sorunlardan etkilenen gıda endüstrisi, sürdürülebilir bir gıda sistemi oluşturma yolunda önemli bir değişim yaşamaktadır. Bu sistem, doğal kaynaklarımız üzerindeki olumsuz etkiyi azaltırken herkes için yeterli ve besleyici gıda sağlamayı önceliklendirmektedir. Hayvansal kaynaklar yüksek besin içeriğine sahip olmasına rağmen, sürdürülebilirlik konusundaki tüketici endişeleri alternatif kaynak arayışını arttırmaktadır. Sürdürülebilir ve sağlıklı seçimlere olan tüketici ilgisinin artmasıyla birlikte bitkisel gıda kaynaklarına olan talep artış göstermektedir. Bitkisel protein kaynakları genel olarak tohumlar, baklagiller, yağlı tohumlar ve kabuklu yemişler olarak bilinmektedir. Bu bitkisel kaynaklı proteinler gıda olarak tüketilebildiği gibi çeşitli tekno-fonksiyonel özellikleri sebebiyle gıda endüstrisinde de kullanım potansiyeline sahiptir. Bitki bazlı gıdalar sadece protein kaynağı olarak değil, aynı zamanda lif, vitaminler ve mineraller bakımından da zengin kaynaklardır. Bu çalışma, gelişen dünya ve artan popülasyonun bitki bazlı gıdalar üzerindeki etkisi, bitki bazlı gıdaların besin değeri ve potansiyel kullanım alanları üzerine odaklanmıştır.

Anahtar Kelimeler: Bitki bazlı gıda, Protein, Sürdürülebilirlik

INTRODUCTION

Products made from plant-based ingredients aim to mimic the nutritional components and sensory properties of animal-based foods [1]. Many consumers add more plant-based foods into their diets due to concerns about sustainability and the impacts of global warming on the environment and biodiversity [2, 3]. Consequently, the rise of plant-based alternatives replaces the nutrition and sensory experience of animal products address to the growing consumer demand for sustainable food options that lessen environmental impact.

Driven by sustainability concerns, the food system undergoes a paradigm shift toward providing adequate and nutritious sustenance for a growing population while minimizing the strain on finite natural resources. In this context, plant-based proteins represent an emerging trend with the potential to significantly contribute to this challenge [4]. As recent reports highlight the potential shortfall of animal-based proteins to meet the nutritional demands of a growing global population, the adoption of plant-based food sources is poised to become increasingly crucial [5].

In developed regions, plant-based meat and dairy alternatives emerge as viable substitutes for animal products, offering a pathway toward more environmentally sustainable dietary patterns. Plant-based milk alternatives have witnessed remarkable growth in recent years, capturing a significant share of the overall milk market [6]. It is predicted that by 2050, the world's population will exceed 9 billion people and the need for food, feed, and fiber will increase by 70%. In order to meet this need, it is important to investigate new plant-based resources [7]. Since animal-based foods have higher risk of diet-related metabolic disorders, it is important to explore new plant-based sources to meet this need [8].

Plant-based eating focuses on plenty of fruits, vegetables, legumes, whole grains, nuts, seeds, and healthy oils. It limits animal products like low-fat dairy, lean meat, and fish. This eating style ranges from flexitarian (eating very little meat) to pescatarian (including fish) and lacto-ovo vegetarian (including dairy and eggs) to vegan (entirely plant-based) [9].

Today, the increasing interest in plant-based foods with consumer trends has become one of the fundamental dynamics that also directs the innovation processes of the food sector. Plant-based ingredients offer a wide potential in terms of high nutritional content, functional component content such as phytochemicals, dietary fiber, antioxidants, and processability [10]. In addition, the production of these resources serves environmental sustainability goals with lower greenhouse gas emissions, less water and land use compared to animal production. When evaluated in the context of the food sector, plant-based raw materials enable the development of alternative solutions in terms of technological features such as texture, structure, and shelf life, and play a critical role especially in the development of functional foods and new generation products. In addition, the nutritional value of plant-based foods is of great importance not only for a healthy diet, but also as a production model that supports local agricultural economies and contributes to sustainability [11]. Therefore, plant-based foods should be evaluated not only with health or ethical concerns (especially sensitivity to animal welfare and treatment), but also from the perspectives of technological innovation and environmental responsibility.

NUTRITIONAL VALUE

Nutritional properties are important in the acceptance of plant-based food alternatives. There are increasing concerns regarding the nutritional profile of plant-based products, with emerging evidence that many are not nutritionally equivalent to conventional animal products. The primary motivation for the development of plant-based products is to provide consumers with tasty and nutritious alternatives to conventional animal products [12]. Nutritional composition and product health are important factors for consumers when making food choices, and there is growing concern and confusion among consumers about the nutrient density and health benefits of plant-based foods.

Fueled by factors like nutritional advantages (offering essential vitamins, minerals, and fiber, potential health benefits (e.g., reduced risk of chronic diseases), and environmental concerns (such as the impact of animal agriculture), plant-based proteins are experiencing a surge in popularity, a trend expected to continue for decades. To satisfy this growing demand, novel plant sources rich in protein and with desirable functional properties are actively being explored. Notably, plant-based foods are not just protein sources, but also treasure troves of bioactive compounds, including vitamins, phenolics, and bioactive peptides [7]. These bioactives significantly contribute to human health, further propelling the rise of plant-based protein. Plant proteins are a good source of many essential amino acids, vital macronutrients, and are sufficient to achieve complete protein nutrition.

Further research into the specific health benefits associated with these plant-based bioactives can further enhance the appeal of plant-based protein sources. While various groups have raised concerns about whether plant-based products are truly nutritious alternatives to traditional animal versions, research comparing various protein sources consistently shows that plant-based options are more widely accepted by consumers than alternatives such as seaweed or cultured meat [12, 13].

From a nutritional viewpoint, the ideal integration of proteins from diverse plant sources can provide an adequate amount of essential amino acids to meet human health needs. The use of plant-derived proteins has recently gained momentum due to their diverse edible and nonedible applications and their biodegradable nature. The use of plant proteins will be essential when animal-derived proteins are unable to meet the needs of the global population [5].

Plants are relatively more abundant and cheaper than animal proteins, however, the direct use of plant-based proteins is still limited. Plant proteins are used as animal feed to produce animal-based proteins such as meat, eggs and milk [5]. In recent years, there has been a surge in the popularity of plant-based foods like vegetables and pulses. These foods are not only a great source of protein but also brim with health-promoting phytochemicals. Studies suggest that diets rich in these plant-based options may help prevent various diseases [14].

PLANT-BASED FOODS

Recently, there has been an increased interest in plant proteins in the human diet, both economically and for their health benefits and positive impact on the environment. The 2015 Scientific Report of the Dietary Guidelines Advisory Committee recommended increasing the consumption of plant-based foods such as legumes and whole grains [15, 16]. Approximately 57% of the edible protein supply comes from plant protein sources [7]. Plant-based proteins are proteins found in sources such as legumes, grains, and nuts. The history of plant-based proteins was started with the discovery of soybeans in Asia. Soybeans are an important food source to meet the body's protein needs [17]. In addition to soybeans, many other plant protein sources have been investigated over time, such as other legumes (chickpeas, peas, faba beans, beans, okra, lupins, etc.), pseudocereals (quinoa, amaranth, and buckwheat), cereals (wheat, barley, maize, rice, sorghum, etc.), seeds (flaxseed, chia, sesame, etc.), and nuts [16, 18]. With the increase in the global population, interest in alternative protein sources is also increasing. Other plant-based protein sources include proteins obtained from agricultural industry by-products [7]. Figure 1 shows the plant-based protein sources and Table 1 shows the nutritional content of some plant-based sources.

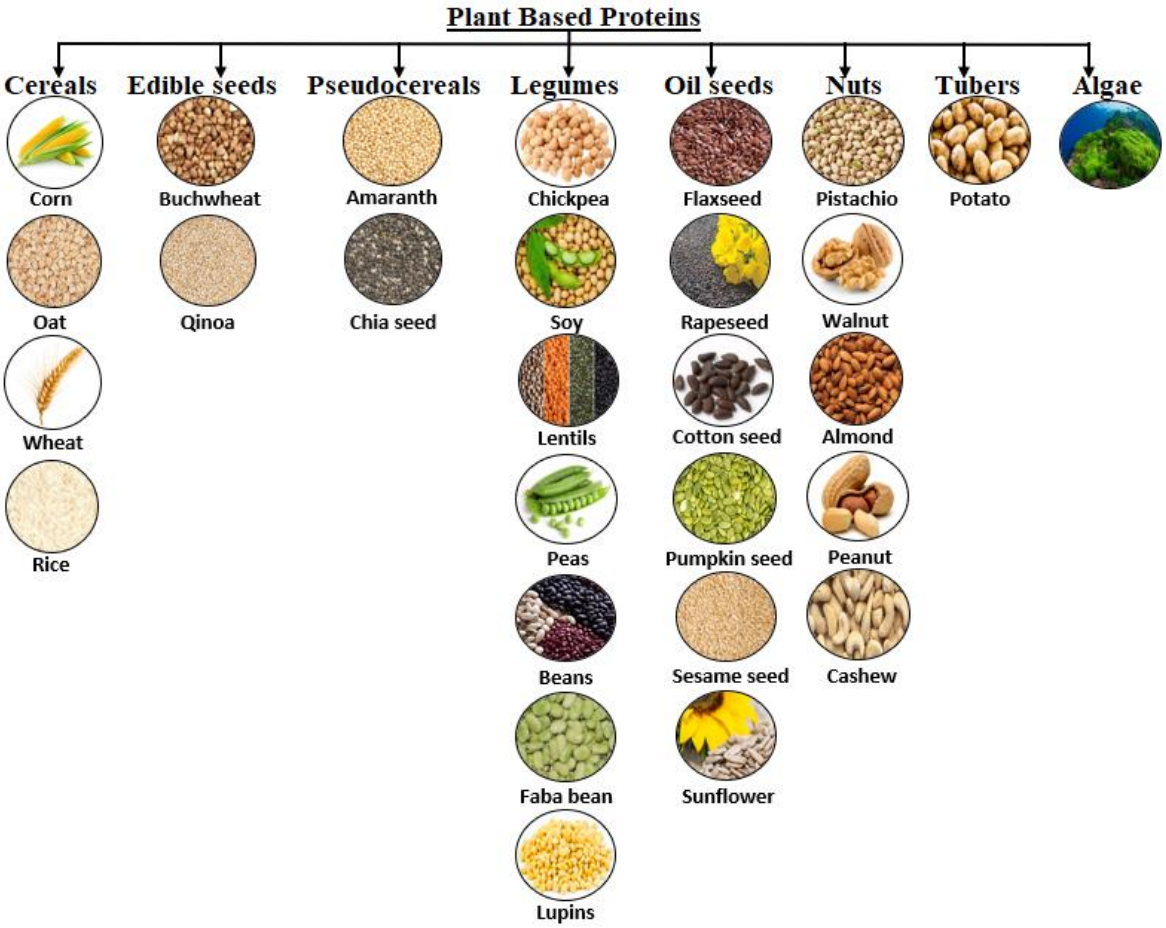

Figure 1. Plant-based proteins sources (Modified from [18])

Legumes

A diet rich in legumes has many beneficial effects on the human body. Legumes are important sources of protein, carbohydrates, fiber, energy, vitamins, and minerals for human nutrition. They are also more economical compared to proteins of animal origin [16]. Soybeans are one of the most widely known legumes in terms of nutrient content, especially protein content. They are among the oilseeds. It attracts attention with its protein content of about 40% and carbohydrate content of about 30%. Soybean proteins are especially rich in histidine, leucine, isoleucine, threonine, phenylalanine, and tryptophan amino acids [27, 28]. Moreover, its high oil content (18-24%) enables its use in the oil industry [29]. In addition to soybeans, peas are also an important source of protein

intake in the human diet. Besides its approximately 25% protein content, it is a source of 40-50% digestible starch [27]. It contains less methionine compared to soybeans [18]. It can be included in formulations of different foods to improve protein content [7]. Lupine seeds and flours are also used as vegetable protein sources [30]. They have about 35% protein content and 8-10% fat content [27]. Faba bean has about 26% protein, about 58% carbohydrate, and 15-30% dietary fiber content [31]. Chickpea contains 18-29% protein, 50-60% starch, and 4-7% lipids [32]. Legumes have a low glycemic index and generally high dietary fiber composition. With their nutrient content, they can be added to different food products such as meat [33]. Plant proteins can be added to foods as flours, isolates and concentrates [34]. The concentration, structure and type of proteins are important in determining functionality. In the literature, it is reported that the water holding capacity of protein isolates is higher compared to the flour form. This is likely the result of the higher protein content of the isolates. In addition to protein, flours also contain components that prevent water penetration such as fibers, starch granules and lipids [35]. For example, Aryee and Boye [36] reported that lentil protein isolate had a higher water holding capacity compared to the flour form. This difference was thought to be due to the smaller size of the protein isolates and lower lipid content.

Table 1. Nutritional content of some plant-based sources

Plant-based product	Moisture*	Protein**	Fat**	Ash**	Carbonhydrates**	Energy***	Total Dietary Fiber**	References
Faba bean	11.9	31.2-32.3	1.01-2.1	3.4-3.6	63.3	1685	24.5-24.7	[19],[20]
Lupin	9.5	30.5-33.02	6.8-7.3	3.8	58.3	1782	42.3-47.5	[19],[20]
Buckwheat	10	12.30-27.8	3.8-8	2-5.3	56.1-58.9	1769	7-8.4	[19], [21]
Quinoa	8.7	13	7.2	2.9	76.8	1795	9.9	[19]
Flaxseed	6.5-7.1	20-20.9	37.1-46.3	3.7	28.9-29.1	2217-2563	24.5-30.2	[19], [22], [23]
Lentil	-	29.3	-	3.8	-	-	17.7	[20]
Amaranth	11.29	13.56	7.2	2.88	65.25	1552	6.7	[24]
Rice	-	6.67	2.22	-	75.6	1489.5	2.2	[24]
Wheat	-	10.91	1.82	-	80	1523	2.2	[24]
Corn	10.21	9.42	4.74	-	74.26	1527.2	-	[24]
Almond	4.41	21.15	49.93	-	21.55	2422.54	12.5	[25]
Pistachio	-	20.2	45.3	-	27.2	2340	10.6	[26]

*: g/100 g, **: g/100 g DW, kJ/100 g DW

Cereals

Cereals are a major source of vegetable proteins, carbohydrates, and energy. Although only 41% of the world's cereals are used for human consumption, global consumption is about 480 grams per day [37]. One of the most consumed cereal types in the world is rice, but wheat, maize and barley are also widely consumed [7]. The best cereals as protein sources are wheat (8-18%) and rice (7-8%). Other protein sources include barley (7-15%), millet (6-16%), sorghum (10-11%), oats (9-16%), maize (9-12%), and rye (8-18%). Cereals are generally limiting in the amino acid lysine [37]. However, millets contain more essential amino acids (including lysine) than recommended by WHO/FAO/UNU (2007) for humans. Therefore, it is thought to enrich diets as a protein source [16]. Cereal-based proteins are often used industrially in bakery products [7]. In addition, cereal and legume mixtures can be used in combination to obtain products with appropriate levels of amino acids [16, 19, 38, 39].

Pseudocereals

Plants such as buckwheat, amaranth, and quinoa are known as pseudocereals. Unlike monocotyledonous cereals such as wheat, barley and rice, pseudocereals are dicotyledonous. They are similar in composition and function to cereals. Therefore, they are called pseudocereals [40]. With the increasing demand for protein sources in recent years, interest in pseudocereals such as quinoa has also increased [7]. Among the pseudocereals, amaranth has a protein content of about 13-16%, quinoa 12-15% and buckwheat 12-19%. The protein content of pseudocereals is high compared to maize but low compared to legumes such as soy and beans [41]. In addition to their protein content, pseudocereals are rich in fibers, vitamins, minerals, and unsaturated fatty acids. They also have a high quality essential amino acid profile [16]. The most abundant amino acids in pseudo-grains are phenylalanine and leucine. Compared to cereals, the amount of lysine in pseudocereals is not limiting [41]. Also, compared to cereals, the lysine content of quinoa and amaranth is higher than the recommended amount [16, 42]. Buckwheat, quinoa, and amaranth pseudocereals do not contain prolamin, which is toxic in celiac disease [43]. Therefore, it is used instead of wheat in individuals with celiac disease. They are important ingredients generally used in gluten-free food products [40]. They are used in baby foods as they have low allergic effects [41]. With their rich phytochemical content, they have a positive effect on human health [40].

Oil Seeds

The consumption of plant-based foods has increased, the demand for protein-rich oilseeds has also increased [7]. Approximately 85% of plant resources are used in oil production worldwide [29]. Flaxseed (18-25%), rapeseed (17-36%), cottonseed (55-60%), chia seed (19-23%), soybean (40%), sunflower seed and sesame (23-25%)

are some of the oilseeds with rich protein content [44]. Flaxseed also contains essential amino acids, fibers and phenolic compounds [7]. It contains approximately 40% fat. It is an inadequate source of lysine, tyrosine and threonine. However, it is rich in glutamic acid, arginine, aspartic acid, methionine and cysteine [29]. In addition to its protein content, chia seeds contain 30% fat and 30-34% dietary fiber. It is also rich in phenylalanine, leucine, valine, arginine and lysine, as well as glutamic acid, serine, alanine, aspartic acid, alanine and glycine [45, 46]. Oils obtained from seeds such as sunflower and rapeseed are used in the production of vegetable margarine and butter in the industry. Peanut oil is also used in vegan cheese production [33]. Desirable quality criteria such as the foamability of whipped cream, spreadability of butter, firmness of ice cream and meltability of cheese are influenced by the crystallization properties of fats. Compared to fats of animal origin, fats of vegetable origin contain more unsaturated fatty acids, and they are more viscous at ambient temperature. This problem is usually solved by increasing the degree of saturation of the oils by hydrogenation [47].

Nuts

Nuts are generally not preferred as a source of protein because of their high energy value. In fact, nuts such as walnuts, cashews, pistachios, peanuts, and almonds have high protein content. However, their limited amino acid profile reduces their protein quality [15]. Nuts such as almonds, hazelnuts, and peanuts are also plant sources known for their high protein, lipid, and fatty acid content [7, 33]. Almonds have a protein content of about 20%. It is also rich in phenylalanine, leucine, isoleucine, threonine, and histidine [30]. It was reported that the fat content varies between 420-630 mg/g [48]. Hazelnuts have an important place in human nutrition in terms of fat, carbohydrate, protein, and dietary fiber [49]. They have a fat content of approximately 59-69% [50]. The protein content of peanut varieties generally between 20-30%. At the same time, it has been reported that it is not sufficient to meet the daily intake of lysine, threonine, and valine amino acids [16, 51].

Industrial By-Products

The demand for food production increases with the increase in the global population. Therefore, there is an increase in food waste due to industrial growth [52]. Globally, approximately 1.3×10^9 tons of food are wasted annually [53, 54]. Generally, food waste is rich in proteins, carbohydrates, lipids and nutraceuticals. Effective waste management practices, disposal or treatment of these waste with commercial value are emphasized [52]. Recovery of proteins from industrial food waste is one of the sustainable alternatives to maximize resources, minimize disposal and develop different food products [16]. For example, about 3.5 billion tons of banana peel waste is generated a year. Banana peels are a rich source of dietary fiber, protein, polyunsaturated fatty acids, vitamin A, calcium, and phenolic compounds. Banana peels also contain significant levels of carbon compounds that contribute to negative climate changes [33]. There are studies in the literature where banana peel and banana pulp are included in the formulation of various foods such as pasta, extruded products, meat products, bread, cookies, and cereal bars in order to increase their nutritional value [55-58]. Another example is aquafaba. Aquafaba is a liquid derived from cooked/boiled chickpeas [33]. It is a plant-based product that has become popular as an emulsifier used to replace egg whites in bakery products. It has functional properties such as emulsifying, foaming and gelling. It has the potential to be used especially in vegan products [59]. Aquafaba is a solution containing phenolic compounds, water-soluble proteins and soluble polysaccharides. It does not contain starch and fat [33]. In the literature, there are studies such as the development of gluten-free bread, cake, and vegan mayonnaise formulations by utilizing the physicochemical properties of aquafaba [60-62].

Algae

Algae are photosynthetic microorganisms that are divided into two groups: microalgae and macroalgae. They are suitable for vegan diets and can be used as an alternative to animal protein sources. They grow rapidly and can reach high concentrations. Therefore, they have an advantage over terrestrial plants [63]. Algae are a sustainable alternative protein source with high nutrient content [64]. Microalgae are rich in carbohydrates, protein, lipids and bioactive components. Microalgae proteins are higher than animal sources such as dairy products, meat products, poultry [65]. *Chlorella*, *Dunaliella*, *Haematococcus* and *Spirulina* microalgae are approved for human consumption by the European Food and Safety Authority [63]. Algae with high protein content can be used as food supplements in capsule, tablet or powder form. In addition, algal proteins can be separated using different extraction methods and incorporated into foods such as bread, noodles, chocolate, biscuits, beer and meat products as food additives [64]. It can also be used to make fermented functional foods such as cheese, yogurt and cream [66]. Microalgae proteins have techno-functional properties such as emulsifying, high solubility, foam and gel formation [67]. Besides, polysaccharides such as agar, alginate and carrageenan are obtained from marine algae. These hydrocolloids have the ability to form gels and high viscosity solutions [66]. It was reported in a study that proteins extracted from *Chlorella vulgaris* have higher emulsifying properties compared to commercial emulsifiers [68].

POTENTIAL RISKS and DEFICIENCIES of PLANT-BASED FOODS

The growing popularity of plant-based foods is encouraging a positive transformation, especially in terms of sustainability and health [69]. However, the nutritional value and risk of deficiencies [70], food safety and risk of contamination [71], and sustainability conflicts associated with this trend need to be assessed. Adopting a vegetarian diet may result in a reduced intake of some nutrients; however, it has been reported that with proper planning, these deficiencies can be avoided. A well-planned vegetarian diet including vegetables, fruits, whole grains, legumes, nuts and seeds can provide adequate nutrition [70]. In particular, studies are being

conducted on the effects on total protein intake when animal protein intake is low and the diversity of plant protein sources is limited. While further research is needed to reveal possible variations in the bioavailability of some specific amino acids, current studies suggest that plant-based diets have no risk of clinical deficiencies in amino acid absorption [72]. It has been shown that plant-based foods generally show higher levels of contamination compared to animal-based foods [73]. This may put individuals on a vegan diet at risk of higher levels of contaminant exposure [71]. Plant-based alternatives are often presented with claims of low environmental impact. However, the extent to which these products offer sustainability benefits is still controversial and more scientific studies are needed. For example, the production of legumes is often associated with a lower environmental footprint. However, the impact of legumes in reducing Greenhouse Gas Emissions is highly dependent on the management of the agro-ecosystem used [74]. Furthermore, post-harvest processing methods also significantly impact the overall sustainability profile of the crop [75].

CONCLUSION

Proteins are essential nutrients for human nutrition and well-being. The quality, amino acid profiles, digestibility, and bioavailability of nutrients vary depending on the purity and processing of the products. There is a growing demand for plant food sources as an alternative to animal food sources due to dietary preferences (vegan, vegetarian, etc.), health impacts and concerns about sustainability. Compared to animal-based products, plant-based products produce lower greenhouse gases. Furthermore, the biological origin of plant-derived proteins and the methods used to isolate, dry and purify them affect their functional properties. Plant proteins differ chemically and physically from animal proteins. As a result, plant-based foods seem to have an important place in the future of the food sector. Developments in this area should focus on optimizations that will accelerate growth in the sector, such as the use of plant resources in new generation food products, texture and structure improvements, and the optimization of functional innovative products. In particular, the development of innovative product formulations that will meet consumer expectations and increase the acceptance of plant-based alternatives will contribute to growth in the sector. In addition, plant-based food alternatives that minimize environmental impacts, are produced with local resources, and are low-cost will be able to reach wider audiences in the future. The food sector should continue to develop innovative solutions in line with technology, sustainability, and consumer expectations in order to best evaluate the potential offered by plant-based foods and offer them to consumers. Substituting plant proteins for animal proteins is also technically complex. The techno-functional and sustainability properties of these plant proteins need to be determined. In addition, plant-based food formulations with high bioavailability and rich nutrient content should be developed. Further studies are needed to better understand the functional properties for applications in the food industry.

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