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ORIGINAL RESEARCH ARTICLE

Sustainable nutrition

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ABSTRACT

Sustainability refers to the ability to endure and persist into the future. It was initially introduced by the World Commission on Environment and Development through their 1987 report entitled "Our Common Future". When defining sustainable nutrition, The Food and Agriculture Organization of the United Nations (FAO) places importance on respecting and safeguarding biodiversity and ecosystems, as well as ensuring adequate, reliable, and nutritious food. The global population is presently experiencing rapid growth, which poses a risk of depleting nutritional resources over time. One of the primary objectives of sustainable nutrition is to preserve existing resources for future generations. Achieving this requires careful utilization of global resources. In recent years, there has been a particular focus on researching and altering dietary choices and patterns within communities. The emphasis has been on the applicability of nutrition models that exhibit low ecological, carbon, and water footprints as sustainable nutrition models. Examples of such plant-based sustainable nutrition models include the Mediterranean diet, the Double Pyramid model, the New Nordic diet, vegan and vegetarian diets, the Dietary Approaches to Stop Hypertension (DASH) diet, and the planetary health diet. Additionally, it is crucial to discover alternative food sources that resemble animal protein sources, are accessible to all, and gain widespread acceptance. Currently, the most extensively studied alternative food sources include insects, algae, and cultured meat.

Keywords: sustainable diet models; plant-based nutrition; alternative food sources; future food security; ecological footprints

1. Introduction

The rapid growth of the global population, the excessive utilization of existing resources, the greenhouse gas emissions resulting from production activities, climate change, and global warming have made sustainable nutrition a significant concern in recent years[1]. The food choices we make not only impact our health but also influence the climate and the environment. Food production, processing, and cultivation have diverse environmental effects, including energy consumption, agricultural land use, water footprint, and greenhouse gas emissions[2]. The environmental impacts of animal-based food sources outweigh those of plant-based food sources. Therefore, individuals are advised to reduce their consumption of animal-based foods and transition to plant-based alternatives to implement sustainable diet patterns[3]. Sustainable nutrition involves evaluating the environmental impacts of food throughout its life cycle. It encompasses principles such as adequate and

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balanced nutrition, seasonal consumption of fruits and vegetables, and a greater emphasis on plant-based proteins. Diet models suitable for sustainable nutrition should be easily accessible, nutritious, offer food diversity, and possess a low carbon and water footprint[2,4]. In addition to promoting health, these diets should be sustainable for environmental, economic, and social systems[5]. To maintain sustainable nutrition, it is crucial to exercise careful utilization of all resources worldwide and strive to minimize harm to the environment[2]. The objective of this review is to underscore the significance of sustainable nutrition and provide information regarding alternative food sources suitable for sustainable nutrition based on current literature.

2. Sustainability and sustainable nutrition

To comprehend the notion of sustainable nutrition, it is pertinent to initially clarify the complete meaning of sustainability. Sustainability is a term used to describe the functioning of a system or society in a way that minimizes its detrimental impact on future generations. Its objective is to strike a balance among the interconnected factors of the environment, economy, and society. It encompasses the preservation of existing natural resources and the utilization of renewable resources to meet the needs of future generations. In doing so, it strives to minimize environmental pollution and mitigate climate change. In recent times, the concept of sustainability has found application in various domains, spanning from health to the economy, politics to education. Sustainable nutrition is one of these applications.

Nature has accommodated living organisms since time immemorial. However, humans, as guests, pollute nature more than any other living being. This situation, which has been exacerbated with the advent of the Industrial Revolution, leads to increasingly adverse impacts on the environment. The insufficient availability of natural products and the detrimental effects of the haphazard use of artificial chemicals without considering their environmental harm have contributed to this situation[6]. In comparison to earlier eras, the concept of sustainability has gained greater prominence in today's world. When defining sustainability, it denotes the continuation or perpetuation of the existence of something. With the Industrial Revolution, the proliferation of mechanization in numerous domains and disparities in lifestyle have intensified the exploitation of environmental resources. Unconscious, unplanned, and unregulated consumption patterns have arisen[7].

As the concept of sustainability arises due to the uncontrolled use of natural resources and the growing population, various sustainability concepts have also emerged, including sustainable living, sustainable cities, sustainable planets, and sustainable agriculture. Sustainable nutrition is another concept among them. The concept of sustainability was initially introduced by Gussow and Clancy in 1986. In subsequent phases, the impact of sustainability on food and health concepts was examined within dietary guidelines. Studies were carried out on the environmental implications of dietary preferences[7,8].

The Food and Agriculture Organization and the World Health Organization define sustainable nutrition as follows: “Sustainable healthy diets are dietary patterns that promote all dimensions of individuals’ health and well-being; have low environmental pressure and impact; are accessible, affordable, safe, and equitable; and are culturally acceptable”[9].

In summary, sustainable nutrition can be defined as nourishment that strives to protect the ecosystem, biodiversity, quality of life for future generations, and food security[10]. Like other dietary approaches, sustainable nutrition encompasses various models.

2.1. Sustainable nutrition and diet models

Nutrition is a vital process essential for the sustenance of all individuals, even all living organisms. While not universally perceived in the same manner, there is variation in food preferences among individuals.

Sustainable nutrition models refer to dietary patterns that prioritize both individual health and minimal adverse environmental effects. Examples of such models include the Mediterranean diet, the Double Pyramid model, the New Nordic diet, vegan and vegetarian diets, the DASH diet, and the planetary health diet[11,12].

2.1.1. Mediterranean diet

The Mediterranean diet (MD) holds a prominent position among well-known dietary approaches and serves as a leading sustainable nutrition model. Until the mid-20th century, this model formed the basis of dietary habits in Mediterranean countries. However, with the advent of globalization and the adoption of Western lifestyles, its prevalence has waned over the years. The MD model encompasses essential elements such as biological diversity, local food production, nutrition, sustainability, and culture. It exhibits a low water footprint and contributes to reduced carbon emissions and ecological impacts. Primarily plant-based, it is recognized as a sustainable nutrition model[2,13,14]. The MD, adopted by various communities around the Mediterranean region, emphasizes the consumption of agricultural products. Consequently, it has acquired distinct characteristics in different societies. This dietary model includes fresh or dried vegetables and fruits, legumes, olive oil, moderate amounts of fish, dairy products, tea, whole grains, and an array of herbs and spices. It suggests moderate wine consumption alongside meals, provided it aligns with religious or cultural norms[15–18].

Sustainable diets are easily implementable dietary patterns that prioritize both individual and environmental well-being. Among these, the Mediterranean diet stands out due to its evidence-based approach and practicality.

The MD presents the most easily applicable dietary model based on scientific evidence. Its emphasis on the consumption of traditional, local, and seasonal fresh vegetables and fruits enhances accessibility[19]. It is not a restrictive diet and encompasses a diverse range of foods, contributing to both flavor and satiety. Individuals of various cultural backgrounds can readily adopt it[20]. Beyond being a mere dietary model, the Mediterranean diet represents a way of life that incorporates cultural elements, socialization, and culinary activities. It promotes communal meals, facilitates social interaction, and fosters stronger human connections. This aspect holds significant value as a moment for communication[18,20,21].

2.1.2. Double Pyramid model

The Italy Barilla Food and Nutrition Foundation introduced an innovative approach to the Mediterranean diet pyramid in 2009, incorporating an inverted pyramid that assesses the ecological consequences of food choices[4]. Although the original pyramid provides Mediterranean-style dietary recommendations, the additional pyramid categorizes foods based on their adverse environmental impacts, considering their ecological footprint[16,18]. Positioned at the top right of the pyramid are foods such as red meat, cheese, fish, and sugary products, which should be consumed sparingly due to their substantial environmental footprint. In contrast, the lower level consists of foods that should be consumed more frequently, as they have a lower environmental impact[4,16].

2.1.3. New Nordic diet

The New Nordic diet model represents one of the sustainable dietary approaches. Recognizing that societies extend beyond the Mediterranean region, experts have acknowledged the necessity for a distinct dietary model in Scandinavian countries, where unsustainable and unhealthy eating habits have become prevalent. As a result, they have developed the New Nordic diet model[22,23]. This model has gained popularity in Denmark, Finland, Iceland, Norway, and Sweden[16]. Its most recent update occurred in 2012, with the aim of establishing a sustainable Scandinavian region that prioritizes environmental preservation[5]. The New Nordic diet incorporates elements of Scandinavian culinary culture while considering the environmental and health impacts of food choices. It encourages the consumption of locally produced foods at the regional level,

including legumes, rye, oats, vegetables, fruits, a wide variety of local herbs, mushrooms, fish, and oily seeds. Furthermore, it emphasizes the avoidance of farm and game animals, processed foods, packaged meals, and sugar-sweetened products[4,5,18,22,23].

2.1.4. Vegan and vegetarian diets

This dietary model revolves around plant-based consumption. Vegetarian diets are classified according to the inclusion or exclusion of animal-derived foods. Lacto-ovo vegetarians incorporate dairy products and eggs; pescatarians include dairy products, eggs, and fish, and ovo vegetarians solely consume eggs. Semi-vegetarians, or flexitarians, limit their intake of red meat, poultry, and fish to less than once a week[5,16,18]. In a vegan diet, both primary and secondary animal sources are entirely eliminated from the diet[4]. Compared to other sustainable dietary models, the vegan diet exhibits the most significant reductions in land use and greenhouse gas emissions[18].

2.1.5. The DASH diet

This dietary model, the Dietary Approaches to Stop Hypertension, known as DASH, focuses on plant-based eating with the aim of reducing both systolic and diastolic blood pressure by limiting sodium intake. The DASH model emphasizes the consumption of whole grains, fruits, and vegetables, while also including fish, nuts, poultry, legumes, and low-fat dairy products. Red meat, saturated fat, sugar, and sugar-sweetened foods and beverages are restricted by this approach. It has proven to be highly effective in preventing or managing hypertension and various chronic diseases[20,24–27].

2.1.6. Planetary health/EAT-Lancet diet

The planetary health diet, introduced by the EAT-Lancet Commission in 2019, is the result of a nutrition-related meeting attended by representatives from 16 countries and 37 experts. This model focuses on the sustainability of both planetary and human health. Its primary objectives are to provide nourishment for the global population, prevent species extinction, and preserve natural resources. The diet emphasizes a plate divided equally between fruits and vegetables on one side and unsaturated plant oils, whole grains, plant-based protein sources, limited dairy and meat products, and starchy vegetables on the other[28,29].

2.2. Comparing diet models: A general rule of thumb

Various diet models have emerged as potential solutions to address both individual health and environmental concerns. Despite their distinct names and origins, these diet models share a common thread that underscores their environmental benefits. At the heart of these models lies a focus on plant-based foods, including vegetables, fruits, whole grains, legumes, and nuts. This emphasis on plant-centric nutrition serves as a unifying principle across the Mediterranean diet, the Double Pyramid model, the New Nordic diet, vegan and vegetarian diets, the DASH diet, and the planetary health diet. By limiting or excluding the consumption of resource-intensive animal products, particularly red meat, these diet models collectively contribute to a reduction in greenhouse gas emissions, land use, and water consumption. While it remains challenging to precisely quantify the environmental impacts of each diet due to various contextual factors, for example, a study compares the carbon footprints of a standard American diet versus the Mediterranean and vegan diets. Their findings suggest the Mediterranean diet has 2.17 kg of CO_2 equivalent and the vegan diet has 1.63 kg[30]. Although this is expected, a scenario where a vegan diet comprises avocados and tropical fruits that travel across the world and highly processed foods may alter the result.

However, a valuable general rule of thumb emerges: diets that prioritize plant-based foods and minimize animal product consumption, especially red meat, tend to offer a more environmentally sustainable approach to nourishment. By adopting these principles, individuals can contribute to both their own well-being and the

sustainability of the planet for future generations. As research continues to evolve, refining our understanding of the nuances and intricacies of these diet models will aid in further shaping sustainable dietary recommendations. To support this approach with visualization, a comparison of protein-rich food's carbon footprints is given in **Figure 1**.

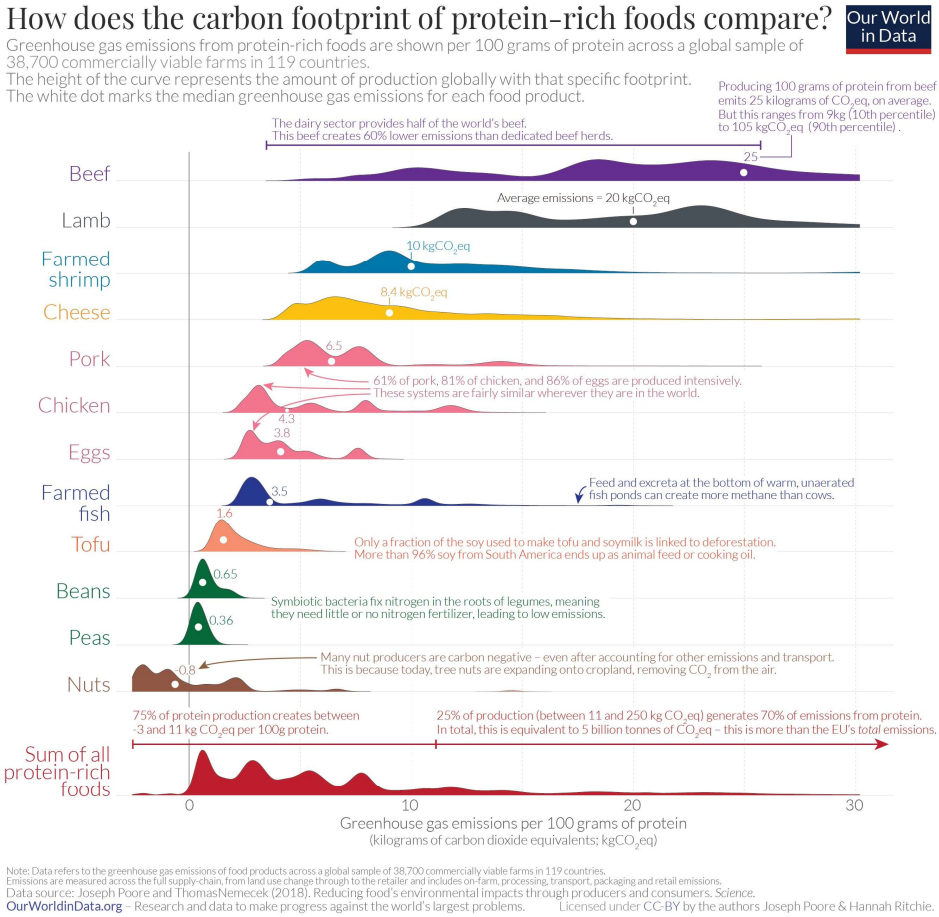

Figure 1. Carbon footprint comparison of some foods per 100 g protein[31].

2.3. Sustainable nutrition and alternate food sources

Reducing global greenhouse gas emissions is a priority for the well-being of the planet, and societies and governments are considering various measures. The food sector is responsible for 26% of global greenhouse gas emissions, with 18% from the supply chain, 24% from land use, 27% from agriculture, and 31% from fishing and livestock[32].

As sustainable nutrition models gain traction, there is a growing emphasis on exploring alternative food sources that are accessible to communities and acceptable to individuals, while also minimizing environmental impacts. Insects, algae, and cultured meat are among these alternatives.

Compared to traditional livestock and poultry, insects are considered a viable and sustainable food source due to their lower water usage, reduced greenhouse gas emissions, and minimal waste generation during production. Microalgae, with their high productivity and protein content compared to larger seaweeds, are also recognized as alternative food sources. "Cultured meat" refers to meat produced in laboratories using animal cells and tissues. It has gained significance as an alternative food option due to its potential to mitigate deforestation caused by animal agriculture, lower greenhouse gas emissions, and meet the increasing food demands of the growing human population[2,16,33,34].

2.3.1. Insects

Compared to traditional protein sources, insects are considered sustainable food sources as they can be produced using less land and energy without requiring advanced technology[35]. The Food and Agriculture Organization of the United Nations (FAO) has recognized insects as foods of the future and recommended the establishment of insect farms in a report published in May 2013[36]. In 2021, the FAO further emphasized the safety of edible insects from a food safety perspective[37]. The European Food Safety Authority (EFSA) has also acknowledged edible insects as a novel food[38].

According to FAO research, approximately 2 billion people across the globe consume around 1900 species of insects as food, with variation based on continent and place of residence[36]. Insects and insect-derived products are rich in macro and micronutrients. The nutritional content and calories of insects vary depending on their species and stage of metamorphosis, as illustrated in **Table 1**.

Table 1. Insects and their ratios of energy and nutrient components[32].

Species	Example insects	Energy (kcal/100 g)	Protein (g/100 g)	Fat (g/100 g)	Carbohydrate (g/100 g)	Minerals (g/100 g)
Coleoptera	Sand beetles, carrion beetles, ladybugs	126–574	3.7–54	3.7–52	12–34	1–2
Diptera	Flies	199–460	17.5–67	4.2–31	8.4–23	1.24–8
Hemiptera	Bed bugs, aphids, mealybugs	329–622	33–65	7–54	7–19	1–19
Hymenoptera	Bees, ants	234–593	1–81	1.3–62	5–94	0–6
Lepidoptera	Butterflies, moths	126–762	13.2–69.6	7–77	3–41	2–8
Orthoptera	Crickets, grasshoppers	117–436	13–77	2.4–25.1	16–30	2–27

Despite being a culturally dependent edible option and a sustainable alternative to traditional protein sources, insects are often perceived negatively, and seen as repulsive and harmful in many societies.

Approximately 2 billion people consume insects at various stages of their life cycle (larva, egg, pupa, or adult) primarily in Latin America, Asia, and Africa. Ants, bees, crickets, grasshoppers, and flies are among the most consumed insect species[39].

Research on insects as an alternative protein source for sustainable nutrition has experienced consistent growth in the past decade. For instance, the number of research studies on insects was less than 50 in 2010, according to Web of Science data, but it surpassed 200 in 2020 and 2021[40]. As of 2022, a search using the keyword “insect protein” yielded 197 publications, while “insect-based protein” resulted in 72 publications.

2.3.2. Algae

Algae have minimal negative impacts on terrestrial ecosystems as they naturally thrive in water sources[41]. Algae can be used in various industries, including food and beverage, cosmetics, fertilizer production, and animal feed. Organic acids, alginic acid, cellulose, and vitamin B12 can be derived from algae[42]. According to the FAO, global production of aquatic plants containing algae exceeds 30 million tons, with significant contributions from China and Indonesia[43].

Although algae consumption is observed in various societies, Far Eastern countries, particularly Japan, have been at the forefront. It is known that red and brown algae are more commonly consumed compared to green algae. Brown algae species such as Undaria, Laminaria, and Hizikia are commonly available in dried forms. However, seaweed can also be consumed fresh (in salads, etc.), cooked (in soups, dishes, sauces, etc.), or dried for nutritional purposes. Different types of algae are used as ready-to-eat food items, and algae

consumption can also be in the form of several teas. In Turkey, algae species such as Porphyra, Ulva, Laurencia, Rhodymenia, and Gelidium are available and have the potential for similar usage[42].

Among the algae, there are microalgae that are suitable for human consumption. They are rich in carbohydrates, proteins, and fatty acids and have high nutritional value. Microalgae contain minerals such as magnesium (Mg), sodium (Na), potassium (K), calcium (Ca), iron (Fe), sulfur (S), and phosphorus (P). They are also abundant in vitamin B12[33].

2.3.3. Cultured meat

Cultured meat is regarded as an alternative protein source with the potential to decrease greenhouse gas emissions from animal sources, prevent deforestation, and fulfill the rising protein demands of the growing human population[44]. Compared to traditional livestock-based meat production, cultured meat offers advantages such as reduced water, land, and soil requirements, as well as lower carbon emissions[45,46]. In 2013, Professor Mark Post created the first cultured meat, which had a production cost of $300,000[46]. The underlying premise for cultured meat stems from the fact that livestock production for food contributes to around 15% of global greenhouse gas emissions. The following charts depict the annual meat supply (**Figure 2**) and daily meat consumption (**Figure 3**) levels per person worldwide as of 2020.

The global meat supply reveals a notable disparity, with some countries having a per capita annual meat supply exceeding 100 kg, while others barely reach a tenth of that amount. A similar imbalance is evident in per capita daily meat consumption. However, the development of lab-grown meat shows promise as a significant tool to address the environmental impact of traditional meat production and rectify this inequality.

The process of cultured meat involves extracting stem cells from animals raised for food, which are then cultured and differentiated in a bioreactor under specific conditions, including an energy source and nutrients. Initially, renewable muscle cells are produced, and these cells are further transformed into larger muscle tissues, resulting in the creation of cultured meat. The widespread adoption of cultured meat is slowly progressing due to factors such as cost, uncertainties in testing and research, and extended timelines. For example, in 2013, a Dutch company conducted research to produce cultured meat hamburgers and assessed the process and cost of producing 1 kg of cultured meat. The study revealed a cost of $280,400 per kilogram. Subsequent reports from different companies indicated that the cost of 1 kg of cultured meat was $800 in 2018, $112 in 2019, and $10 in 2021[44].

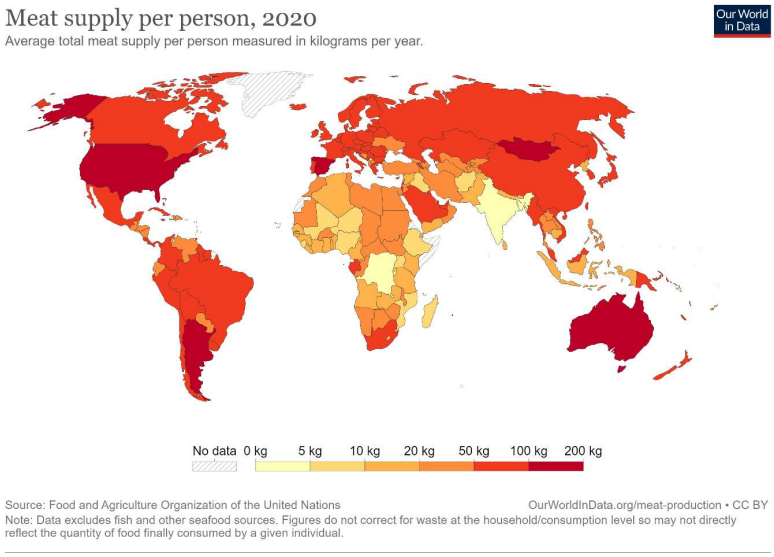

Figure 2. Annual meat supply levels kg/per person[47].

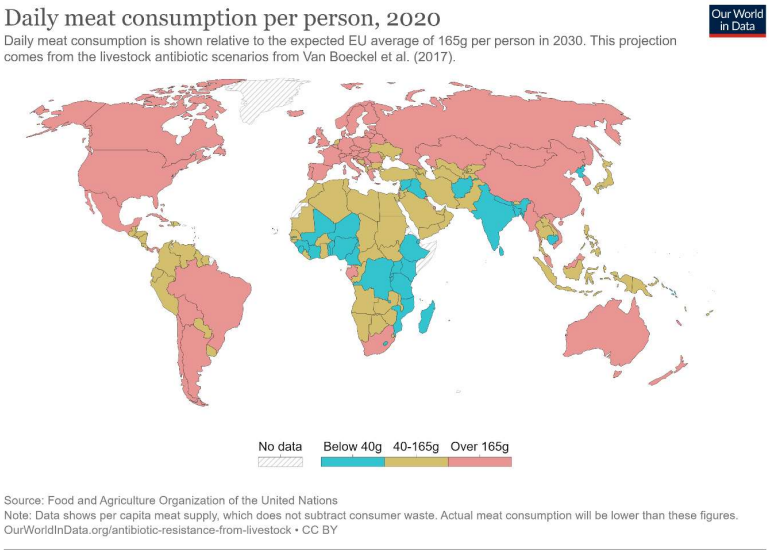

Figure 3. Daily meat consumption levels g/per person[47].

3. Conclusion

Food resources around the world are gradually depleting as the global population continues to increase. This situation poses a significant challenge for humanity in the years to come. The responsibility of the current generation is to practice sustainable nutrition, make efficient use of nature's limited resources, and leave a better world for future generations. Sustainable nutrition revolves around fruits, vegetables, whole grains, legumes, oily seeds, olives, and olive oil. Research has shown that high consumption of animal-based foods contributes to excessive greenhouse gas emissions, water footprint scores, and inefficient energy and land use. In comparison, edible insects have been found to have a lesser environmental impact than other animal protein sources. Therefore, it is crucial to embrace sustainable resources to fulfill the growing world population's increased protein requirements. Insects, algae, and cultured meat are recognized as alternative protein sources that are nutrient-rich, environmentally friendly, and offer innovative and sustainable solutions. The key step towards achieving sustainable nutrition is to pay attention to our individual and societal food preferences.

To protect our health and the planet, it is imperative to prioritize sustainable dietary patterns with a low environmental impact on our lives. Our diet should primarily consist of fresh, seasonal, plant-based foods, with a reduction in processed food consumption. Dietitians play a significant role in effectively communicating the health and environmental benefits of sustainable nutrition and actively participating in relevant studies.

To address environmental issues, consumers' individual responsibilities should be emphasized through various policies and media channels, and nutrition guidelines for sustainable diets should be developed. Educational and awareness campaigns about sustainable living should be conducted through seminars and suitable communication channels, including social media, targeting individuals of all ages.

The objective of our food systems should be to meet current and future generations' needs while considering the environment. Increasing agricultural productivity and adopting low-environmental footprint methods in food systems are crucial steps in minimizing the system's adverse impact on the environment.

Efforts must be made to explore alternative food sources for groups that are expected to face scarcity in the future. Newly developed protein sources as alternatives to animal-based proteins should be promoted through food enrichment initiatives. Although certain societies may find the consumption of these alternatives challenging, efforts should be made to increase their acceptance through various approaches.

Algae represent a significant nutritional alternative, yet this resource is currently underutilized. There should be an increase in the number of centers dedicated to researching and maximizing the benefits derived from algae, both within our country and globally.

Lastly, it is important to remember that the world belongs to all living beings, present and future.

Author contributions

Conceptualization, HP and AMG; methodology, AMG; investigation, HP and AMG; resources, HP and AMG; data curation, HP; writing—original draft preparation, HP and AMG; writing—review and editing, AMG; visualization, HP; supervision, AMG. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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