SİDAS MEDYA
Akademik Gıda®
ISSN Online: 2148-015X
http://www.academicfoodjournal.com

Akademik Gıda 16(2) (2018) 197-204, DOI: 10.24323/akademik-gida.449865

Review Paper / Derleme Makale

Possible Protein Sources for the Future

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Received (Geliş Tarihi): 28.07.2016, Accepted (Kabul Tarihi): 18.12.2017
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ABSTRACT

In parallel with the world population growth, the decrease in food sources, caused by global climate change, unplanned urbanization, unplanned industrialization and reduction of agricultural land etc., creates a high potentially risk about poor nutrition and hunger. This case has caused scientists to make researches about new food sources and alternative nutrients. Numerous processes and materials such as algae, edible insects, microbial proteins, microbial oils, *in vitro* meat, non-dairy and vegan milk and cheese, bio-fermentation technology have been proposed as alternatives by scientists. Besides being healthy of these foods, characteristics such as price, taste, shelf life will be decisive for their acceptance thereof by consumers. However, cultural, religious and social factors may be limiting on the alternative foods. Despite all, future generations will probably eat very different foods for nutrition that we consume today. In this study, it is aimed to give information about possible future alternative food sources and technologies, mainly on protein sources.

Keywords: Alternative food, Algae, *In vitro* meat, Edible insects, Microbial proteins and oil

Geleceğin Olası Protein Kaynakları

ÖZ

Dünya nüfus artışına paralel olarak, küresel iklim değişikliği, plansız kentleşme ve sanayileşme, tarımsal arazilerinin azalması gibi nedenlerle gıda kaynaklarındaki azalma yakın gelecekte yetersiz beslenme ve açlıkla ilgili yüksek potansiyel risk oluşturmaktadır. Bu durum, son zamanlarda bilim insanlarının yeni besin kaynakları ve alternatif besin maddeleri konusunda araştırmalar yapmasına neden olmuştur. Algler, yenilebilir insektler, mikrobiyal proteinler, mikrobik yağlar, *in vitro* et, süt ürünü olmayan vegan peynir ve biyo-fermantasyon teknolojisi gibi birçok proses ve materyal alternatif olarak önerilmiştir. Yenilikçi gıdaların sağlıklı olmasının yanı sıra, fiyat, lezzet ve raf ömrü gibi özellikleri tüketicilerin kabulünde belirleyici olacaktır. Bununla birlikte, kültürel, dini ve sosyal faktörler de alternatif gıdaları sınırlayıcı olabilir. Tüm bunlara rağmen, muhtemelen gelecek kuşaklar bugün tükettiğimiz besinlerden çok farklı yiyecekler yiyor olacaklardır. Bu makalede, ağırlıklı olarak protein kaynakları olmak üzere, geleceğin olası alternatif gıda kaynakları ve teknolojileri hakkında bilgi verilmesi amaçlanmıştır.

Anahtar Kelimeler: Alternatif gıdalar, Algler, *İn vitro* et, Yenilebilir insektler, Mikrobiyal protein ve yağlar

INTRODUCTION

Nutrition is one of the most fundamental human needs. People have provided their food from various animal and vegetable sources throughout the history. From time to time, the human race had to deal with famine problem in regional scale depending on various factors. However, they have succeeded in overcoming these problems with technological developments in the field of agriculture and livestock. Nowadays a large number of people are undernourished in the world for various reasons. According to the report “State of Food Insecurity in the World” published each year by UN Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD) and World Food Programme (WFP), 805 million people in the world are faced with danger of chronic malnutrition [1]. It is mentioned that one in four people in Sub-Saharan Africa attracts chronic hunger and Asia, the world's most densely populated areas, is hosting the 526 million hungry people. Gradual decrease of food sources due to reasons such as the rapid population growth, global climate change, unplanned urbanization and industrialization and progressive reduction of agricultural land is expected to confront the world a serious danger of starvation in the future. According to the United Nations Food and Agriculture Organization (FAO), the current food production must be doubled meet the food needs of the World in 2050 [2].

The danger of food shortages for the World in the coming years is at an important place on the agenda of international organizations and studies has already started while this situation has encouraged scientists to do research on alternative nutrients for people. The opinions that might be harmful to health, declared by various individuals and organizations, about genetically modified foods (GMO) produced for purposes such as to reduce losses in agricultural products and ensure increased efficiency, have created a hesitation in consumers [3-7].

It is necessary produce new uncommon food sources in order to prevent the feared shortage in the future. To make available as food the products, that cannot be used as food by humans, generating some microorganisms high volume and using this biomass as a food ingredient, obtaining proteins from microorganisms [8], development of alternative sources of protein such as *in vitro* meat [9], non-farm milk beverages [10, 11], ensuring insects and algae use as food with developing new food processing techniques [12-16], food production for human from cellulose by bio fermentation technology [16] can be shown within alternative materials and methods. In the present article, it is aimed to give information about these possible alternative sources mentioned.

MICROBIAL PROTEINS

Invisible micro-organisms play an important role in our daily lives by sometimes beneficial, sometimes harmful effects. Microorganisms, as a biological material, are made up of organic materials such as proteins, carbohydrates and oil, also like other organisms (Table 1) [17]. Using in human nutrition as a food source of the components of the chemical composition of microorganisms has attracted the attention of scientists for many years and successful works in this regard have been made [18].

Table 1. Approximate composition of main groups of microorganisms (% dry weight) [17]

Composition	Fungi	Algae	Yeast
Protein	30-45	40-60	45-55
Fat	2-8	7-20	2-6
Ash	9-14	8-10	5-10
Nucleic acid	7-10	3-8	6-12

Nutritional purposes protein derived from microorganisms, is known by the name of "Single Cell Protein (SCP)", “Microbial Food", "Yeast Protein". SCP production processes has involved work in the fields of economics, microbiology, biochemistry, genetics, chemical and process engineering, food technology, agriculture, animal nutrition, ecology, toxicology, medicine and veterinary science. Bacteria, algae, yeasts, fungi can be used for SCP production [8, 19]. Among these, yeasts such as *Candida spp*, *Saccharomyces cerevisiae*; molds such as *Aspergillus fumigatus*, *Aspergillus oryzae*, *Aspergillus niger, Penicillium cyclopium, Rhizopus chinensis*; bacteria such as *Pseudomonas fluorescens*, *Bacillus megaterium*; and algae such as *Chlorella* and *Spirulina* come in the first place because of rich protein content. These microorganisms can be produced plentiful, easily and cheaply on various substrates. Farm waste, shellfish waste, molasses, potato starch, sugar, whey, fruit pulp, beer wastes and paper industry, etc. have been evaluated for this purpose [19]. Single cell protein can be produced by two types of fermentation processes: semisolid state fermentation and submerged fermentation. After fermentation, as described in greater detail in Figure 1, the biomass is harvested and process steps are performed like washing, cell disruption, protein extraction and purification [20].

Using of microorganisms as a source of protein has many advantages and some disadvantages. Generation time of microorganisms is short, can be converted easily by biotechnological methods, can benefit from many substrate, there is no need for an arable land, the production is not dependent on seasons and weather conditions, and therefore continuous production is possible anywhere in the world. However, microbial-derived protein can increase of uric acid in the blood because of the high level of nucleic acid, uric acid accumulation in joints and may cause similar symptoms like gout, has been suggested, also perceived by the body as foreign substances can cause allergic reactions has been claimed [8, 19]. There are some uncertainties about using them as food source. There is a need for detailed researches on the acute and chronic toxicity of SCP in humans and animals, the effects on reproductive ability, teratogenicity, carcinogenicity and its lifetime effects.

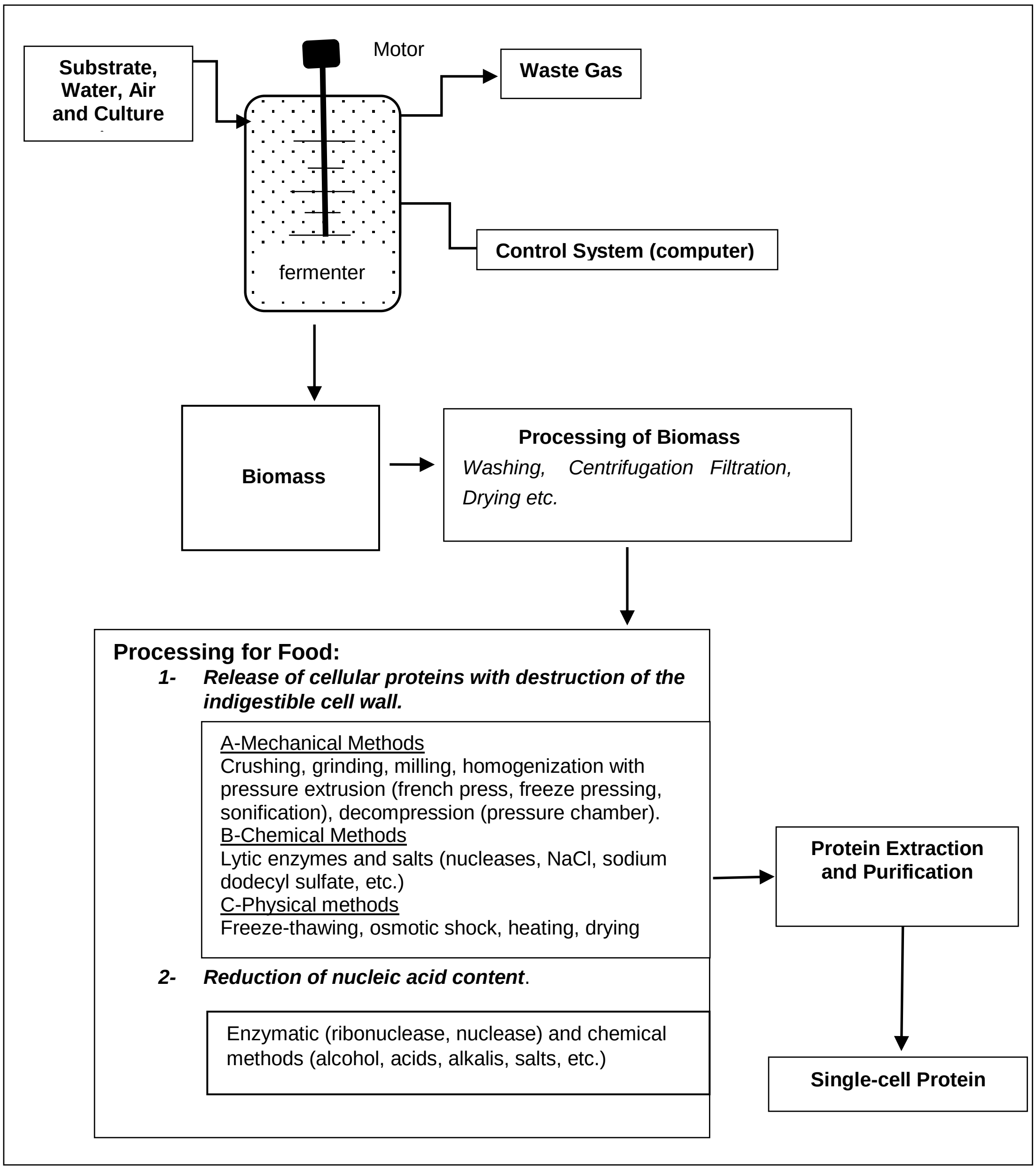

Figure 1. Single-cell protein production [20]

MICROBIAL OILS

Microorganisms are also considered as an alternative for edible fats just not protein. Microbial oils is obtained from molds, yeasts, bacteria and algae which described as oleaginous (can accumulate lipid over 20% of dry cell weight) [21, 22]. Today, studies have focused on the high value oils containing important polyunsaturated or specific fatty acids, which can use in the industry of food, feed and oleochemistry. Oleaginous yeasts are belongs to the genus typically *Candida, Cryptococcus, Lipomyces, Rhodosporidium, Rhodotorula, Rhizpus, Trichosporon* and *Yarrowia*. Many mold species like A*spergillus terreus, Claviceps purpurea, Tolyposporium, Mortierella alpina, Mortierella isabellina* can accumulate lipids [23]. Microalgae are also promising potential for the future of sustainable edible oil production [14]. For commercial production of microbial oil, are being carried out a serial processes like obtaining of biomass, centrifugation, drying, oil extraction, neutralization of crude oil, degumming, bleaching and deodorization [24, 25].

Compared with agricultural oilseed crops, the rapid growth rate of microorganisms and independent of the climate due to culture in closed systems are the most important advantage of microbial oil production. However, the cost of microbial lipids is still very high, and also food safety, sustainability, implementation aspects to product are the subject should be considered and investigate carefully before entering into food market [23].

ALGAE AS A FOOD SOURCE

Algae are usually eukaryotic organisms which can observed in different morphology from microscopic forms, unicellular and filamentous, to a few meter plants, usually live in aquatic and semi-aquatic habitat, with a cellulose cell wall, autotroph, simple structure, capable of photosynthesis [26]. Many algae have been used as food since ancient times in East Asian countries such as Japan, China. “Nori, kombua, wakame” in Japan, “ziacain, haidai” in China, “laver” in Ireland, Wales and Scotland are widely consumed red and brown algae. Additionally additives obtained from seaweed such as carrageen, agar, alginic acid and derivatives are commonly used in foods as supplement today [14, 27].

Species of particularly *Phaeophycea* and *Phodophyce* family in algae containing a high proportion of proteins, carbohydrates, vitamins and minerals have the qualifications to evaluate in human nutrition [14]. Some algae like *Porphyra spp* (Nori) can have a protein content as high as 47% of the dry weight [28]. The quality of algal proteins is high, and comparable to conventional vegetable proteins. But the protein content of algae varies according to the season and the species. A large part of the amino acids constituting their protein is generally aspartic and glutamic acids. *Laminaria japonica* (Kambu) is the original source of monosodium glutamate known as flavor enhancer. However, the bioavailability of seaweed proteins may inhibit due to the nature of the proteins in the cellular matrix. To overcome this disadvantage, physical processes which break the fibers or fermentation have been proposed [14].

Important minerals, like calcium, accumulate in higher amounts in algae compared to terrestrial plants [14].The amounts of minerals such as iron copper, magnesium and iodine are higher than many edible foodstuffs. Seaweeds comprise lipid about 2% of the dry weight and the lipid content consists of polyunsaturated fatty acids. Omega-3 and Omega-6 hold an important place in human nutrition and are found in seaweed [29, 30]. Seaweeds contain vitamins (especially E, C) and many antioxidant compounds. Also seaweeds, containing vitamin B12, is one of the few alternative plant sources for vegans and vegetarian [15]. *Gracilaria spp.* contains significant amounts of beta carotene [31].

Seaweed, compared with known vegetables, is a valuable source as dietary fiber [32]. They are large extent indigestible fiber in the intestine and create a feeling of fullness with bulking capacity, help digestion [15]. Brown seaweed alginate has been found to be beneficial to the intestinal health. It is expressed that alginates accelerate the passage of the intestinal contents from the column and thereby make protective effects against colon cancer. Alginate also reduce the absorption of heavy metals they bind metal ions [32-34].

Today, algal products are marketed as healthy food, as cosmetics or as animal feed. High production costs and technical difficulties to convert the algal material into delicious foods limit the consumption of algae yet [35].

INSECTS

Insects may be one of the sources that can meet the nutritional needs of mankind's in the future. This issue has become the agenda of world with book named "Edible Insects” published in 2013 by FAO [12].The European Union provides important support for researches about edible insects [36].

The use of insects as food in order to meet the world's food needs is not an economic necessity yet, however today eating insect (entomophagy) is in progress at the regional scale, especially in African and East Asia. It has been reported that more than 1900 of the edible insect species in these areas [12]. Globally the most widely consumed insects can be listed as beetles (*Coleoptera*, 31%), caterpillars (*Lepidoptera*, 18%), bees, wasps and ants (*Hymenoptera*, 14%), locusts and crickets (*Orthoptera*, 13%), cicadas, grasshoppers, plant pests, scale insects and true bugs (*Hemiptera*, 10%), termites (*Isoptera*, 3%), dragonflies (*Odonata*, 3%), flies (*Diptera*, 2%) and others (5%) [12].

Insects have nutritive value as a source of good energy, protein, fat, calcium and vitamins and can also be included as additives in many foods [12, 36]. They emit less greenhouse gas according to livestock and can be fed with organic waste [12, 37]. Within a short time, they can easily be grown in small areas [37, 39]. They are cold-blooded creatures, so potential of convert their feed to protein is very high. Crickets that are considered among edible insects need 12 times less feed than cattle, four times less than sheep, and half as much as pigs and broiler chickens to produce the same amount of protein [12].

Processing and storing of insects as food require the maximum observance to hygiene and sanitation rules. Besides, variety issues such as microbial safety, toxicity, the presence of inorganic compounds should be taken into. Insect farming is done on the waste products, so their potential health effects should be taken into consideration. It has been reported that some insects may cause allergic reactions [12].

Three main categories about affecting consumer acceptance of innovative food: Factors related to the product, social trust and norms and psychological factors [40, 41].There is a serious resistance on the use of insects as food in western societies. This obstacle is primarily due to cultural factors. The reasons for the attitude about the use insects as food in western society are fear, disgust and concern [41, 42]. It is a settled idea in western thought, that insects are dirty, disgusting and dangerous. Despite the increase in the literature showing the value of insects in human and animal nutrition, the idea that insects are pests, is common [12, 43, 44].

IN VITRO MEAT

In vitro meat, called tube meat, cultured meat, tube steak etc. in media, is a product that has never been part of a living animal. The first study has been launched for long-term space flight or space stations in 2002 [9].

For *in vitro* meat production, starting cells are taken by biopsy from live animals. This process occurs without interfering with the genetic sequence of cells or any genetic manipulation. Needing to very specific cells, stem cell as starting cell is a disadvantage of *in vitro* meat. These are inoculated into a culture medium, proliferate and begin to grow up. Cells called myoblast reaching enough numbers are placed on a skeleton-like structure called scaffolds are made from edible materials such as alginate, chitosan and collagen. The scaffolds are placed into a bioreactor and added growth medium. One of the most difficult task in designing an in vitro meat production system is determining the best culture medium formulation. Additionally regular contraction is a necessity for skeletal muscle. To the cells, mechanical or electrical stimuli are applied. After this stage, the cells are harvested and the *in vitro* meat is obtained [45].

The UN Food and Agriculture Organization expects world consumption of meat to double between 2000 and 2050. In the report named "Long Shadow of Livestock" [46] published by the United Nations, it is stated to conventional meat production by current methods have reached a very coercive size for environment. It is known that *in vitro* meat production is more environmentally friendly. According to a study on compared traditional meat to *in vitro* meat production carried out by Tuomisto and Mattos [47] in Europe it is estimated that cultured meat would require 7-45% less energy, 9% and 82-96% less land use and water use to produce than the same volume of pork, sheep or beef. In addition, according to this research, cultural meat production could cause 78-96% less greenhouse gas emissions. Another advantage is that only will be developed of muscle tissue for cultured meat production instead of cultivating of a whole animal.

Cultured meat has many other advantages. The ability to control precisely the amount of fat in meat and to produce steak which have not lead to heart attack with the ideal fatty acid ratio of and as a result of that the reducing of cardiovascular disease, the reduction of greenhouse gas emissions, termination of use of animals as a bioreactor for the production of food and other products and thus prevent the suffering of animals, produce meat in aseptic environments which is normally impossible at livestock, reduce the risk of diseases such as mad cow disease, swine flu, avian flu and Salmonella, meat production in the laboratory so that prevent diseases caused by animals are other positive aspects of this technology [45, 47, 48]. Compared with conventional production methods, to obtain meat, remarkably lowers time is needed for vitro system and takes several weeks instead of months (for chickens) or years (for pigs and cows) [49].These results indicate that *in vitro* meat has great potential for future, environment, health and animal welfare, although initially the *in vitro* meat began to be developed for astronauts in space.

There are difficulties to be overcome before *in vitro* meat become commercially available. Three-dimensional muscle tissue production still cannot be achieved at a sufficiently low price. When standard mammalian cell culture techniques and standard engineering techniques are developed, there will be reductions in the cost of cultured meat [50]. Also there are many difficulties in producing *in vitro* meat [51-53]. There are uncertainties about the best stem cells, the best bioreactor design and the best way to process. On the other hand, there are technological challenges such as developing a more visually appealing and delicious cells. Nowadays, there are studies about the use of 3D printers to create a real steak similar structure.

In vitro meat is colorless compared to conventional meat. It has been tried to resolve this problem by adding an amount of beet juice and saffron [52, 53]. One of the other most important issues is the adoption of consumer products [54]. Because the fat, blood or blood vessels and connective tissue are not present in the *in vitro* meat, it is composed of only muscle tissue, the lack of certain nutrients essential for health, that are found in meat vivo are likely. Absence of consumer confidence to cultured meat is the main obstacles on dissemination of cultured meat.

Despite all these disadvantages, according to Holmes and Dacey's article [55] that discussed cultured meat, that cultured meat has the potential to meet all nutritional and hedonic needs of meat eaters without the need for animals to eat and destroy the suffering of animals. For majority of people, the most appealing feature of *in vitro* meat is its moral promise for animals.

OTHER SOURCES

Nanotechnology is a new branch of science and technology with works such as measurements performed in smaller sizes than a hundred nanometers, processing, design, modeling and regulation. This technology has the potential of common use in food production although still in its early stages. ''Nano food'' is defined as food products which harvested using nanotechnology techniques. Nano foods are produced, processed, and packaged with nano-techniques or obtained by the addition of nanomaterials such as nanocapsules containing zinc or iron nanoparticles and active ingredients [56]. The applications of nano-based technology in food industry may include functional foods, nutraceuticals, bioactives, farmafoods, food safety and biosecurity (e.g. nanosensors), and nanotoxicity [57, 58]. Nanotechnology is becoming increasingly important for the food sector. But there is not enough research on the safety of these products and there are no worldwide accepted rules or regulations for nanotechnology, yet. Public perception of nanotechnology in the food industry is another determinative factor [59].

One of the studies pointed out in recent years is the production of milk and dairy products in the laboratory without livestock. These products, also named as vegan, are obtained by genetically modified yeast (*S. cerevisiae*) which expresses milk protein (casein). Process begins with the production of yeast in large bioreactors and ends up with the production of the milk protein casein. Proteins that are produced by yeast are purified. Casein is combined with water, fat and vegan sugar. Then the milk mixture is converted to vegan cheese by conventional techniques [60, 61]. The products, obtained by this method, do not contain pathogenic bacteria which can be found in the actual product, biological components such as pus, pesticide residues, feed additives, heavy metals, drug residues and hormones, and this is shown to be an important advantage [62, 63]. Also, there is not lactose that cannot digest 75% of adult people in this type of product. This process also has some disadvantages. There are some difficulties of using yeast in protein production. Yeast cell systems are less efficient compared with milk-producing animals. On the other hand, to use of genetically modified yeast may pose problems for opponents of genetically modified organisms.

A method in alternative food production is also bio-fermentation technology which still in the idea stage. In the emergence of this method was started out in the form of nutrition of some ants and ruminants [62]. Cattle meet the %80 of protein requirements by microorganisms in the rumen. In a suggested theory, selected microorganisms (bacteria or fungi) are grown with minerals and micronutrients in suitable temperature and sufficient gas mixture in water-filled silo. Then freeze-dried cellulose pellets which from grassland are added to the media kept under electronic surveillance. The proliferation of microorganisms with using cellulose is provided. Microorganisms are collected at the end of the process and nutrient elements are extracted from them. Currently, there are no research on this subject and technical barriers are not known [62, 64].

Lichens, wild mushrooms and edible wild plants have been used as food for many years especially in times of famine and as traditional food in some areas [65, 66, 67]. These are called “famine foods”, "wild plant foods” and “non-cultivated plant foods”. In the war period in Bosnia and Herzegovina, the lack of conventional food, some people stayed alive eating mushrooms and lichens [67]. Because of the danger of poisoning wild mushrooms and lichens, are still quite a few unknown food sources and not widely used in human nutrition. With studies will be done in the future on the food sources also named as a possible scarcity of food and traditional foods, there's a possibility to convert these into high value-added processed products.

CONCLUSION

Alternative food sources and high-tech food processing technology seems inevitably an obligation to put in practice in the future, because of the increasing world population, increasingly shrinking of natural habitats, approaching the unsustainable situation of the industrial farms with greenhouse gases, methane and environmental waste, global climate changes that may arise from the classic production. New research on these issues can lead to new possibilities as unconventional foods. Widespread usage of food production techniques based on high-tech may make the human race became stranger to nature and animals and also cause social, technological and economical changes. Studies are needed to foresee the socio-political changes which would be able to lead to able scientific and technological progress and take the necessary precautions; no doubt, future generations will have to consume many different foods that we eat today.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS’ CONTRIBUTIONS

This work was carried out in collaboration of all authors. Author AÜA conducted the literature research and wrote the first draft of the manuscript. Authors AÜA, SY were responsible for subsequent reviewing and scientific editing, while author AÜA was the primary responsible for final content. All authors read and approved the final manuscript. The authors declare no conflicts of interest and this research received no grant from any funding agency.

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