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Review

Mushrooms and Algae– 'Microorganisms as source Superfoods': A Review

Kiran Bala[1], Kiran Bala Negi[2], Ajaib Singh[3], Pushp Lata[4], Gaurav Kumar[5], Manisha Sengar[6], Jaya Malhotra[*7]

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Abstract

Mushrooms and algae have been consumed since ancient times because of their culinary and gastronomic attributes. Both are important dietary sources of bioactive compounds including essential minerals, vitamins, complete profile of amino acids and are valuable source of dietary fibres. They are low in calorie content because of negligible amount of fats and carbohydrates. Beyond the excellent nutrition profile of these superfoods, they also belong to the category of nutraceuticals which provide medicinal benefits along with meeting daily dietary requirements. Bioactive compounds present in them are an interest of research because of anti-cancerous, antimicrobial, antiviral, antioxidant, hypoglycemic and immunomodulatory activities. These microorganisms are easy to grow on varied substrates therefore cost effective and eco-friendly that gives a great advantage over synthetic super foods obtained from animal origin. The current review focusses on the nutritional and medicinal value with importance of mushrooms and algae as a super food. Review also discusses about the toxicity associated with mushrooms along with the current status in trends of production, cultivation and consumption of fungi and algae based foods in different countries and offers thoughts on course.

Keywords: Superfoods, nutraceuticals, therapeutic, mushrooms, Algae, bioactive compounds

Introduction

Any food item loaded with nutrients and low in calorie are termed as functional foods or super foods, although there are no fixed criteria for categorising an item as 'superfood'. However, a particular category qualifies the superfood if it is packed with fibres, vitamins, essential amino acids and minerals; must be high in antioxidant compounds; has a positive impact on health of the consumer and is easily available [1]. Mushrooms and algae have been considered as super foods, scoring high not only as a delicacy but as functional foods or nutraceuticals [2] [3]. They are known to provide health benefits beyond the daily nutritional requirements. Incorporation of super foods in daily diet can improve human health, reduce the risk of degenerative diseases such as cardiovascular diseases, diabetes, metabolic syndrome, obesity, neurological conditions and sometimes even cure an illness [1].

Edible mushrooms

Worldwide more than 3000 mushrooms have been identified as edible. Out of which 200 types are produced under controlled conditions and 60 varieties are grown widely. A dozen varieties are cultivated on commercial scale. India is home to more than 300 varieties of mushrooms [2]. Mushrooms have been a part of diet since the ancient times by the Greek, Romans and Chinese populations because of their great flavour and texture [4]. The history of consumption of mushrooms can be estimated by its presence in the food remains in dental calculi of a woman buried 18,700 years ago [5]. Mushrooms have gained worldwide popularity as a valuable food source with essential proteins (nine different essential amino acids) [Figure 1]. Mushroom is considered to be a complete, health food and suitable for all age groups. The protein value of mushrooms varies from 18.87 - 36.96% of dry weight. It is reported that a 100 g of mushrooms can meet more than 50% of the Recommended Dietary Allowance (RDA) for both men and women [6]. Mushrooms also have high moisture content 80-92% [7]. Amino sugars, sugar acids, polysaccharides, pentose, mannitol and disaccharides may be present in mushroom although soluble carbohydrates content declines post-harvesting as they are metabolised during the process [8]. Presence of cell wall in the cells of mushroom makes it an excellent source of dietary fibre. It mainly consists of chitin, beta-glucan (β-glucan), pectin, hemicelluloses and polyuronides. Edible mushrooms commonly have insignificant lipid level with higher proportion of polyunsaturated fatty acids. Mushrooms are rich in important vitamins like the B-complex, which include thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), biotin (B7) and cyanocobalamin (B12) [9]. They are also a good

[1,6,7] Department of Zoology, Deshbandhu College, University of Delhi-110019, India
[2] Swami Shradhhanand College, University of Dehli-110036, India
[3] Department of Zoology, Sri Venkateswara College, University of Delhi, Delhi, India.
[4] Department of Zoology, University of Delhi, Delhi, India
[5] Department of Physical Education, Hansraj College, University of Delhi-11007, India
[*]Corresponding Author : jmalhotra@db.du.ac.in

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source of vitamin B9, helps in preventing anaemia. Vegetables lack vitamin B12, thus for a person having vegetarian diet, mushrooms can supplement the requirement of vitamin B12. Ergo sterol, a precursor of vitamin D2, is found in all species of mushrooms. Thus, apart from being rich in B complex, mushrooms also serve as a potential reservoir of vitamin D2. Mushrooms are a rich source of potassium. They also have a generous amount of other minerals like phosphorous, copper and iron [10]. The amount of sodium and calcium is however low in mushrooms. Mushrooms also provide selenium which is accredited with

Figure 1: Illustrates the nutritional benefits of consuming mushrooms as superfoods

Medicinal values of different mushrooms

Edible mushrooms have been revered for thousands of years for their immense health benefits and have been extensively used in folk medicines. In mushrooms specific bioactive compounds such as

triterpenoids, low molecular weight proteins, glycoproteins and immune modulation compounds are responsible for improving human health in many ways. They improve immune system, boost health, lower the risk of cancer, help in blood sugar balance and protect against microbes. Although there are many varieties of mushrooms in the world but we have listed below the most commonly consumed mushrooms. The health benefits and nutrients contained in them have been emphasized along with their growth conditions.

Agaricus spp. (White button mushrooms)

It is top ranked cultivated mushroom that is well known for its edibility. This mushroom is a potent immune stimulant, inhibits cell proliferations, protects liver and lowers blood glucose and cholesterol [12]. It has high levels of antioxidants, tocopherols and phenolic compounds. Ergothioneine is specific anti-oxidant found in *Agaricus* spp. which is necessary for healthy eyes, kidneys, bone marrow, liver and skin [13].

Lentinusspp. (Shitake mushroom or Oak mushroom)

It is second most popular edible mushroom in the global market. This mushroom works against cell proliferation [13]. a lot of positive effects on human body including proper functioning of the immune system [4]. Required in trace amounts, selenium also has a role to play in production of thyroid hormones, deficiency of which can cause severe medical complications. Apart from being nutritious and low-calorie food, there is enough evidence to support their medicinal and therapeutic effects [4] [6]. Mushroom can be easily cultivated on varied nutrient medium like soil and agro waste including submerged medium [11]. Some of the popular cultivated varieties include *Agaricus bisporus*, *Pleurotus* spp. and *Lentinusedodes* [6].

It is a good source of fibres and produces an anti-tumour compound, lentinan. It grows on oak logs in forests but can be cultivated on synthesised logs made of saw dust and agricultural discard. It is used to treat for diseases like depressed immune function, environmental allergies, frequent flu and colds, bronchial inflammation, heart disease, hyperlipidaemia, hypertension, infectious diseases, diabetes, hepatitis and regulating urinary inconsistencies [12]

Pleurotusspp. (Oyster mushroom)

An increasing number of studies from different centres confirm the fact that Pleurotus spp exhibit multidirectional health promoting effects [11]. At present, oyster mushrooms are world's third most cultivated mushroom after button and shiitake mushrooms [10]. Bioactive compounds in them exhibit immune stimulatory, anti-neoplastic, antidiabetic, hepatoprotective and antioxidative properties [14]. Protein content of this species is higher and includes all the vital amino acids, limiting the sulphur-containing amino acids. It contains minerals like sodium, potassium, calcium, phosphorous, iron, zinc, copper, iodine and selenium with variety of vitamins like ascorbic acid and vitamin B complex [14].

Ganodermaspp. (Reishi, Lingzhior Oyster mushroom)

Lingzhi has been recognised as a medicinal mushroom for over 2000 years and its powerful effects have been documented in ancient scripts [14]. Its dried extract is also available commercially because of potential health benefits. It includes bioactive compounds such as polysaccharides, glycoproteins, steroids, terpenoids, phenols, nucleotides and their derivatives. It contains protein content with all the essential amino acids and is specifically rich in leucine and lysine [15].

Armillaria*spp* (Honey Mushroom)

Honey mushroom enhances immunity, fertility, bone health and mental health. The variety has low calorie content thus it serves as a good food for weight loss. It shows anti-cancer, anti-inflammatory properties. It has also been found that the compounds present in *Armillaria* improve insulin sensitivity [16]. This variety is rich in micro elements like copper, iron, zinc and selenium. Macro elements like calcium, magnesium, manganese, phosphorous, potassium and sodium are also present in cap, stipe or stalk region of the fungi. It serves as a source of vitamin D2. The mushroom grows as a root parasite of hardwoods and conifers causing intensive rot. However,

honey mushroom is extremely good to eat and grows in very large quantities during autumn.

Morchella spp. (Morels or sponge mushrooms or Gucchi)

Morel mushrooms are consumed as functional foods as having anti-oxidative, anti-inflammatory and immune-stimulatory properties. In traditional medicine, *Morchella* has been used for quick recovery of wounds in the form of antiseptic. It is also recommended for indigestion, excessive phlegm and shortness of breath [17]. This variety is rich in proteins, carbohydrates and lipids. Several fatty acids which serve as precursors to wide variety of short chain volatiles in mushrooms are also present. It also contains organic acids like citric acid, ascorbic acid, malic acid and oxalic acid [17]. This fungus grows on humus in deciduous forests.

Toxicity of Mushrooms

Although mushrooms are considered beneficial for health however many medicinal mushrooms also contain toxic substances [24]. Therefore, safety assessments of mushrooms are considered mandatory before their consumption. As per world health organization (WHO) reports, approximately 0.346 million people have died around the world since 2004 due to mushroom poisoning [25]. Many more cases are reported in different countries every year. Toxic substances found in mushrooms are: amatoxins, coprine, gyromitrin, orellanus, muscarine, ibotenic acid and psilocybin.

Amatoxins are bicyclic octapeptides and they inhibit the DNA-dependent RNA polymerase activity. This stops protein synthesis, cell necrosis and apoptosis as well [26]. Coprine is metabolized to analogue of disulfiram. Which then inhibits aldehyde dehydrogenase (ALDH) [27]. Gyromitrin gets converted to mono methyl hydrazine (MMH) by a long period of cooking. MMH then inhibits pyridoxal phosphokinase and leads to reduced production of pyridoxal 5-phosphate (vitamin B6) which can cause neurotoxic effects [28]. Orellanine inhibits the synthesis of alkaline phosphatase, leucyl aminopeptidase, γ-glutamyl transferase and adenosine triphosphates [29]. Muscarine inhibits the muscarinic receptors of nerves and muscles causing sweating, salivation, blurred vision, palpitations and respiratory failure [30]. Ibotenic acid binds to NMDA receptors which allow excess Ca2+ into the system resulting in death of nerve cells. Ca2+ also activates Ca2+/Calmodulin Kinase which phosphorylates multiple enzymes. The activated enzymes then produce reactive oxygen species which damages surrounding tissue [31]. Psilocybin reacts agonistically with serotonin (5-hydroxytryptamine) type 2A (5-HT2A) receptors to produce hallucinations [32].

Global Production Trend of Mushroom

China and Europe are the largest producers and consumer of mushroom in the world (Figure-2, 3). Countries like Netherlands, Belgium, Poland, and Lithuania are the major mushroom producers and exporter all over the world. [18]. Whereas France, UK, Germany and Russia are importing countries [19]. USA is also known as a production hub for mushroom cultivation. Major cultivation occurs in Pennsylvania State which produces *Agaricus spp*. of mushroom [20]. Other top mushroom cultivating states are California, Florida and Michigan [21]. India produces 2% of the world's whereas China contributes to 75%. The global mushroom production as per FAQ statistics was estimated around 2.18-3.41 million tons over period of 1997-2007 [50]. It was 14.35 million tonnes in 2020 and market is grown 15.25 million tonnes in 2021. Further expected to grow 24.05 million tonnes in 2028. The global impact of COVID-19 with mushroom observed a positive impact on demands across all the regions. The major growth is expected in the Asian countries. Europe is the largest market for cultivated mushrooms which makes 35% of the global market. The total mushroom production in India is approx. 0.13 million tons (2016-17), the growth of mushroom industry an average of 4.3% per annum [22, 23]. Out of the total mushroom produced, white button mushroom share is 73% followed by oyster mushroom (16%), paddy straw mushroom (7%) and milky mushroom (3%). Compared to other vegetables consumed; per capita consumption of mushrooms in India is less than 100 grams per year which is too low [24]. Despite the favourable conditions for mushroom cultivation in India the production is low. This is mainly due to lack of awareness of mushroom's nutritional value among the consumers of India. Also, government should focus on mushroom-based start-ups throughout the rural areas of India.

Figure 2: Top 20 countries that produce the most mushrooms (Source: FAQ/ 2020, Rob Cook)

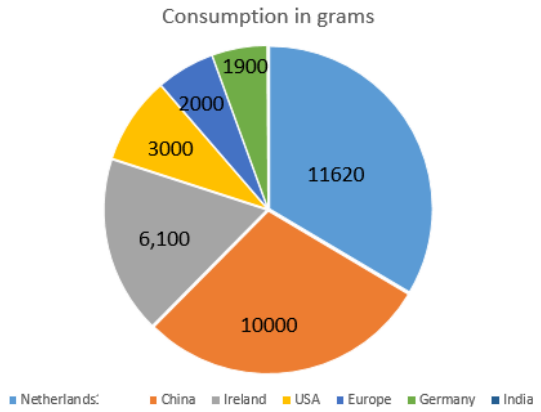

Figure 3: Data labels represent the capital consumption (Source- ICAR, Solan, India and web source)

Future scenario and mushroom production in India

Mushroom can make a valuable dietary and play an important role by food security as well as in income generation. The current scenario of mushroom production in India is encouraging with an overall increase in 5-5 folds. India has great genetic resource of edible mushrooms with diverse climatic conditions in different regions, therefore possible to cultivate several varieties. Successful mushroom cultivation for export requires well coordination between different research institute, agro-industries and wholesaler. The development of infrastructure facilities and distribution network provides the greater scope for marketing. The awareness and knowledge about the production will increase its production with a domestic population of more than one billion, India itself is a largest market for mushroom [25]. To enhance local consumption there is a need to popularising the beneficial effects of cultivated and wild collected edible mushrooms. The quality mushroom spawn and well equipped processing units are equally essential for the mushroom production. The technology can be profitably considered in rural and urban areas where land is a limiting factor and lot of agro waste is available. Mushroom cultivation not only help in recycling of organic material but also help in regenerating the employment. The government of India took many affords to encourage mushroom production. However, India lags behind many European and Asian countries and lot more needed to improve the mushroom production technologies.

Algae – Another Class of Edible Form

Alga belongs to the diverse eukaryotic photosynthetic group of microorganisms. They can be unicellular like diatoms to multicellular like the kelps. Typically, marine alga is edible and known for health benefits while fresh algae are mostly poisonous forms. Algae are consumed both as processed and unprocessed forms throughout the world and contribute a major food market commercially [34]. The direct consumption of some of the type's dates back from the ancient times. The first mention of algae as food dates back to 800 B.C. where pond weed and duck weed appeared as edible and worthy. In 1660s, Chinese used extracts of *Gracilaria* and *Gelidium* as a prime source of jelly. As of the 1880s, popularization of *Porphyra* as salad centred in China and radiated to western countries including Canada and Mexico. During the time of World War, I, when grain supply became exhausted, seaweeds were used by French soldiers to feed their horses. *Chondrus crispus* commonly called Irish moss or carrageen moss is a species of red seaweed famously known for its consumption by the Irish during the famine of 19th century [35]. Its extract was orally taken by soldiers in case of throat infections [34]. During World War II, seaweeds were consumed as food in most European countries like Ireland, Scandinavia and Scotland.

Caulerpa racemosa commonly called sea grapes are a part of traditional diet in island nations such as Fiji, Tonga and Samoa. Unlike plants, they are not seasonal and can grow on a minimal medium, they have a potential for commodity scale production which is difficult to realise with terrestrial crops [35]. They are efficient photosynthetic producers therefore can produce valuable biomass. People living across freshwater resources or coastal areas have an easy access to these seaweeds, therefore algal food derivatives are essentially included in their diet and also have cultural significance associated with them (Table 1).

Table 1: Highlights important nutraceuticals and their health benefits present in edible micro algal species [19].

NutraceuticalTypes	**Omega-3 Polyunsaturated Fatty Acids (ω-3 PUFAs)**	**Carotenoids**	**Minerals and vitamins**	**Proteins**	**Polysaccharides**	**Phenolic compounds**
	ω-3 long chain PUFAs, α-linolenic acid (ALA, C18:3 ω-3), EPA, docosapentaenoic acid (DPA, C22:5 ω-3), and DHA	β-carotene and astaxanthin	Vitamin A, B1, B2, B6, B12, C, E, nicotinate, biotin, folic acid and pantothenic acid). , α-tocopherol (Vitamin E), Cobalamin (vitamin B12) and essential minerals like Na, K, Ca, Mg, Fe, Zn.	*Spirulina* has all essential amino acids with 60 % to 70 % of protein content. Enzymes like lysozyme and various types of immunoglobulins.	Starch, glucose, galactose, rhamnose, mannose, arabinose, Nacetylglucosamide and N-acetylgalactosamine, sulphated galactanexopolysaccharide	Phenolic acids, hydroxycinnamic acids, simple phenols, coumarins, xanthones, naphthoquinones, flavonoids, stilbenes, anthraquinones, and lignins
Health benefits	Prevention and treatment of cardiovascular disorders, colon cancers, lowering hypertension, type 2 diabetes, inflammatory bowel disorders, asthma, arthritis, kidney and skin disorders (psoriasis),depression, and schizophrenia ,cystic fibrosis, Alzheimer's disease.	Antioxidants, prevents premature aging, cancers, chronic inflammatory diseases, metabolic syndrome, diabetes, CVD, gastrointestinal, liver and neurodegenerative diseases.	Effective against degenerative disorders, arteriosclerosis, heart disease, cancers and light-induced pathologies of skin and eyes	growth factors, hormones and immunomodulators	anticancer, anticoagulant, antihypercholesterolemic, immunostimulating and antioxidant properties.	antioxidant, anti-inflammatory, and antimicrobial properties, regress atherosclerotic plaques and strokes.

Commonly consumed seaweeds

Microalgae have high nutritional value, this is due to presence of long chain polyunsaturated fatty acids, phenolic compounds, volatile compounds, proteins, amino acids, peptides and vitamins in them. Marine algae have been used as food and medicine from centuries. The Omega-6 fatty acids are produced by microalgae. Nowadays approximately 200 species are in use worldwide in different sectors. Few of them used as food supplements are listed below.

***Chlorella*-** An abundant in nature, green microalga contains several health benefits like antitumor, antioxidant, anti-inflammatory, and antimicrobial properties [36]. They are high producers of lipids, proteins with dietary fibres. They are rich in lutein, α-carotene, β-carotene, ascorbic acid, α-tocopherol and β-1, 3-glucan. Leutin is highly beneficial for treatment of macular degeneration. As a nutraceutical it functions to lower blood pressure and cholesterol levels. Its effects have also been reported for constipation and diabetes [37].

***Spirullina*-**It is a cyanobacterium rich in Vitamin B, proteins (50-70%), β-carotene and phycocyanin [38]. It contains good number of fatty acids like palmitic, oleic, lauric, docosahexaenoic acid (DHA, C22:6 ω-3) and γ-linolenic acids. It is known to increase HDL levels, lower blood pressure and weight [36]. It is one of the most concentrated natural source of nutrition known it contain all amino acids.

Kelp-These are most commonly consumed types of brown alga. Several types of kelps include Kombu, Wakame and Arame. Kombu has high amount of calcium, alginate, carotene, fucoidan, chromium, germanium, iodine, laminarin, iron, magnesium, phosphorous, mannitol, phytohormones, protein, sodium, potassium, and vitamins such as A, C, D, E, K. Wakame is the rich in calcium and proteins, while Arame is rich in iron and iodine [39].

Nori- The red algae *Porphyridium* or Nori is consumed as food in Japanese dish "sushi". It is a rich source of dietary fibre which is beneficial for digestion and gastrointestinal health. The presence of sulfated polysaccharide has anti-inflammatory property [40].

Ogonori- scientifically termed as *Gracilaria*, is the source of jelly like substance agar-agar. An alternative to gelatine, vegetarian use it in jellies, custard and puddings preparation [41].

Umibodo- popular as sea grapes due to its appearance, hence sold fresh to maintain the texture and flavour. It is type of green alga, rich in fibre and essential micronutrients [42].

Hijiki- a type of brown alga that appears black on boiling and drying. It has a salty flavour and used with seasonings. Rich in dietary fibre, calcium, magnesium but some researchers have reported high content of Arsenic, therefore limited consumption is advised [42].

Food derivatives and nutritional value of algae

Apart from including it in diet, extracts of industrial use are also derived from different algal varieties. Few of them are polysaccharides, alginate, agar-agar and colloids (hydrocolloids and phycocolloids). Three major types of phycocolloids extracted commercially for food products are carrageenan [43], align [44, 45] and agar [41]. Dietary supplements from *Spirulina* and *Chlorella* extracts are available as powders, capsules and granules as they serve as a superrich source of proteins (53-63%), Vitamin B, carotenoids and iron [46]. Oil is extracted from the edible varieties that are high in mono and poly saturated fatty acids. Food cooked in this oil is rich source of omega 3 fatty acids [43].

Being termed as 'superfoods', algae are undoubtedly rich in the essential biomolecules required for healthy functioning of body. The amino acid profile of marine algae boasts of high amount of glutamic acid and aspartic acid. Amino acids like alanine and glycine are also present in marine algae that provide great flavour and aroma [47]. Small algal forms are found are rich in triacylglycerol, whereas larger forms have low lipid content, with phospholipids and glycolipids being the only major constituents. Long chain polyunsaturated fatty acids encompass a significant portion of marine algal lipids [44]. The major polysaccharide found in brown algae is alginate whose benefits includes its ability to absorb toxins, generating short chain fatty acids and decrease cholesterol uptakes. Also, alginate has the ability to scavenge toxic elements from the gut and can be used to control the weight. Other polysaccharides majorly found in brown algae are laminarin, cellulose and heteroglycan. Red algae have nutritionally important carbohydrates like floridean starch and sulphated galactans etc. [48]. Edible algae are also rich in dietary fibres. The findings have showed that these are considered to be an excellent source of vitamin C, A, vitamin B complex and vitamin E [44] [49]. They are also known to be rich in antioxidant and phenolic compounds [50].

Global production and future scopes

The global market for microalgae based food and feed supplements/ nutraceuticals is well developed and with a great potential for growth. Micro algae have been used as a food, feed and fertilizers for centuries. Commercial farming of algae has a long history especially in Asia and commercial farming of macro algae species *Chlorella* was started in the 1960s followed by *Spirulina* in 1970. China, Japan, Republic of Korea along with Philippines, USSR, Norway and Chile are leading producers of seaweeds. 80% of world's total production mainly for colloid industry is done in Asia. While for human consumption mainly produced in China, Japan, Republic of Korea and Taiwan. In India at CTFRI Mysore research is being

conducted on blue green algae, *Spirulina* as a supplement to diet.

Although the total production volumes and market of food and feed supplement derived from microalgae are still relatively small with respect to alternative sources, they have increased 5-fold since the beginning of the century. Recent years interest in bioactive peptides from marine sources is growing [50]. Microalgae are relevant sources of proteins and shown several beneficial effects on health [44]. The GFI (Good Food Institute) India recently published a strategic analysis on the potential of algal protein as an alternative protein food in India [45]. According to the research, although the algal protein industry in India is still in nascent development stages. There are lot of scope as geographical and climatic conditions are also favourable for the cultivation of microalgae and seaweeds. Its 8100 kilometre coastline assures the country to become a major production hub- not only for food applications like carrageenan, alginates, agar and oil but also growing the number of microalgae to create novel alternative food solutions.

Conclusion and future prospects

The world population is exceeding at a larger pace than the food production and by the end of 2050, the production has to be scaled by 70% to meet the increasing demand. For that reason, it is needed to find alternative sources to the traditional food sources in less time and space. Also, the recent COVID-19 crisis will leave a big gap in nutritional food availability even in the developed nations. To build up a stronger immune system, the need of balanced diet and hence incorporation of nutraceuticals is becoming mandatory. Nutraceutical is an edible, non-toxic food item that provides healthcare as well as involved in prevention and treatment of many life threatening diseases. These in general contain all the vital nutrients and certain bioactive compounds which may be used in nutritional therapy. Inclusion of mushrooms and algae in different forms along with our staple diet will be helpful in setting up equilibrium with increasing demand of food that is high in nutrition and provide therapeutic effects. Also, super foods can be the best alternative to immunity booster chemically synthesised health supplements with potentially no side effects. While a multibillion dollar industry, algae and mushrooms are projected to bring about huge opportunities to create novel meat, egg and dairy alternatives in the rising third pillar of edible products.

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