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WHAT'S NEXT ON OUR PLATES? A LOOK INTO THE NEXT GENERATION OF FOOD

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ABSTRACT

With the population steadily growing, there is a legitimate concern and increasing importance of finding sustainable and nutritious food sources. This narrative review examined next-generation foods such as edible insects, algae, and lab-grown meat. Microalgae were discussed as they represent sustainable, high-protein sources of essential fatty acids, vitamins, and minerals with a notable minimal environmental impact. Insects provide a nutrient-rich source of proteins, vitamins, and minerals, and used less resources to produce than livestock. Lab-grown meat is developed from stem cells of traditional livestock and is a more sustainable alternative to traditional meat, as it can lessen land use, water use, and zoonotic disease risks. Despite the benefits of these new foods, major barriers existing for consumer acceptance arise from the cultural, emotional, and sensory issues that are frequently cited when discussing edible insects and lab-grown meat. The public's fear of food neophobia and rejection of "unnaturalness" often lead to the reluctance to adopt new food sources. Fostering consumer goodwill requires

transparently communicating the process of novel foods, culturally appropriate marketing, and educating consumers to familiarize them with the products and build trust. This review recommended that future foods must take technological innovation with acceptable values from consumers to be successful. Making these foods accessible, affordable, and acceptable will be the pathway to achieving global goals in nutrition and sustainability.

KEYWORDS: future foods, algae, edible insects, lab-grown meat, consumer perception.

INTRODUCTION

The global population is increasing continuously, so the question arises as to how do we continue feeding everyone in a manner which is both sustainable and nutritional. Existing method of feeding the population is putting high pressure on the environment, which makes it even more necessary for us to find alternative sources of nutrition. The various solutions emerging for this problem includes meats grown in the lab, insect foods, algae products and even 3D printed meals. Edible insects are high in protein and also resources required to farm are far less than that required for livestock; however, the main challenge faced in making insects a food for future is its lack of consumer acceptance and also its selective breeding is cumbersome.[1-2] Another source for food for the future which is gaining massive attention is algae as it is a sustainable and nutritious option.[3] Recent innovation in the technologies for food also play a very crucial role in the shaping of the future of global nutrition and health.[4] The changes being made have to be very mindful in both scientific as well as social aspects because eventually it is consumer attitude which will play the major role in the success of these novel foods.[5-6] Moreover, knowing how people respond to these food products which are unfamiliar in nature will be of major help in introducing these innovations in the market.[7] In this narrative essay, we will try to look into the various aspects of future foods which includes trends in food technology, alternative protein sources, consumer acceptance and their preferences, and challenges and opportunities in the field of novel food.

Can microalgae satisfy future needs

Food should contain two types of nutrients macronutrients and micronutrients. Macronutrients consist of carbohydrates, protein and fats. According to WHO carbohydrates should be responsible for 45 to 75 percent, protein 10 to 15 percent and fat 15 to 30 percent of daily energy intake. Micronutrients consist of vitamins and minerals required in appropriate amounts in our diet to maintain good health. Need of houris to develop a food source that could provide complete nutrients and can meet sustainable needs of the future. One of the

promising contenders is algae as a food source.

Reasons why algae is a sustainable crop

Algae is a sustainable source as it can grow on salty and brackish water. Not only this but algae use carbon dioxide for its growth reducing the burden of greenhouse gases which will significantly help in reducing extreme climatic changes. Microalgae have the ability to produce greater biomass making it an ideal crop to feed growing world population. Algae have been used as a food source for thousands of years. But in recent times, interest in growing algae on a larger scale has increased—mainly because of its potential as a sustainable source of biofuel. The biofuel industry has recognized that algae could be a green and renewable way to produce energy. When it comes to producing microalgae as food or animal feed, the process can be a bit different from that used for biofuel. The end products may vary, but the basic cultivation process stays the same.[8]

Nutritional diversity of algae

Most of the crops cultivated today are rich in carbohydrates, there are very few crops which are rich in protein and essential fatty acids. That's Where algae comes in. They naturally produce large amounts of both protein and lipids. These nutrients from algae are easy to digest and offer a balanced nutritional profile. In fact, algae are already being added to various foods—like cereals, dairy, and even meat products—to boost their nutritional value.[8]

Interestingly, some algae are packed with protein. For example, species like Arthrosporic platensis (commonly known as spirulina) can have up to 70% of their dry weight made up of protein—making them a powerful and sustainable source of nutrition.[9]

Algae are also a rich source of lipids, especially essential fatty acids such as linolenic acid, docosahexaenoic acid and eicosatetraenoic acid. Traditional sources of these fatty acids in human diets are saltwater fish. But these fish are a rich source because they eat these algae which are originally rich sources of fatty acid. These algae are being genetically engineered to produce end results similar to colostrum for infants, which will significantly help to reduce the burden of malnutrition in infants.[9]

Algae are also a rich source of carotenoids which is provitamin of vitamin A. Vitamin A has various preventive benefits against eye diseases such as age-related macular degeneration and various cancers. Vitamin A is fat soluble vitamin thus it requires lipid for its absorption algae

being a rich source of both lipids and vitamin A makes the bioavailability of carotenoids even better. Dunaliella salina is an alga which is the topmost source of beta-carotene. Other good sources of carotene are Chlorella and Spirulina. Spirulina is already used quite commonly as supplement in form of capsules.[8]

Another great nutrient found in microalgae is beta-glucan which is a polysaccharide formed by beta linkages between glucose molecules. They are commonly found in the cell walls of plants, fungi, and bacteria. When humans consume beta-glucans, they work like soluble fiber, which can help reduce low density lipoprotein cholesterol and reduce the risk of heart disease. Interestingly, many green algae also produce beta-glucans, which increases the health benefits of foods made from or containing algae. This makes algae-based products even more valuable from a nutritional point of view.

Algae production on a large scale

The perfect system for growing algae shouldn't focus on making just one product. Instead, it should take advantage of all the benefits algae can offer—like producing several useful substances from the same biomass like food, fuel and natural detox for the environment reducing carbon burden. This makes it not only cost-effective but also good for the environment.

There are three main ways to grow algae: open pond systems, photobioreactors, and fermenters. Key things to consider include the availability of water (especially if one is growing freshwater algae) access to sunlight, and how much labor and energy will cost—these are major factors that affect overall expenses.[3]

One may consider it is better to cultivate marine species of algae as seawater is abundant but freshwater algae can play a dual role as they might help to clean wastewater and produce food both at once. Algae Farming doesn't just need water and carbon dioxide—it also uses key nutrients like nitrogen and phosphorus, because of this, algae could be a great way to make use of nutrient-rich wastewater to grow useful biomass. In cities, cleaning up wastewater is becoming more important. Algae can play a big role in this. When algae which use light (phototrophic algae) are used in wastewater treatment, the process becomes more energy-efficient and environmentally friendly. Not only can it reduce greenhouse gases and costs, but the oxygen produced by algae can help with further treatment steps similar to how oxygen is used in aeration tanks to treat waste water.[3]

When it comes to photobioreactors, open pond systems are generally cheaper to build and run. So, for large-scale algae production where keeping costs low is key, closed photobioreactors are often not considered as practical. Still, they can be very useful in certain situations—like when growing high-quality inoculating cultures to seed open ponds, or when producing high-value products. Closed systems are also better protected from pests and environmental fluctuations, which makes them more reliable overall.[3] Fermentation, on the other hand, is easy to scale up, relatively affordable, and a useful way to turn organic carbon sources—like dextrose or acidic acid—into biomass rich in valuable compounds such as Omega-3 fatty acids and antioxidants.

Crawling food to satisfy future demands

As the population is on the rise, the demand for food is also increasing. However, at the same time, we're losing the land needed to grow this food. Climate change is making things worse by reducing the amount of usable farmland, which could make food insecurity even more severe—especially in poorer countries. These regions are already struggling with hunger and poverty, and they're likely to be hit the hardest.[1]

Even though there has been some progress, food insecurity still exists in many parts of the world. Shortages and undernutrition are still common—especially in places like sub-Saharan Africa—due to climate change and rising prices, particularly for animal-based foods. Lack of sustainability will increase the disparity between rich and poor even more. Insects are now widely recognized around the world as a highly nutritious food.[10]

Nutritional profile of insects

Insects are packed with essential nutrients—proteins (including essential amino acids like methionine, lysine, and threonine), healthy carbohydrates(polysaccharides), fats, minerals like calcium, iron, zinc, and phosphorus, and important vitamins such as vitamin A and various-complex vitamins.[10] The outer shell of insects, called the exoskeleton, is made mostly of chitin, a natural fiber. When purified, chitin can become up to 90% dietary fiber and can be digested by humans. Fiber in diet can significantly reduce morbidity related to heart and gut.[1]

Insect Protein Content

	INSECTS	PROTEIN CONTENT
1	Caterpillars	50–60g of protein per 100g of dry weight.
2	Palm weevil grubs	23–36g of protein
3	Grasshoppers	41–91g
4	Ants	7-25g
5	Termites	35–65g per 100g

When it comes to specific nutrients silkworm pupae are especially rich in amino acids. The bamboo caterpillar and crickets also contain a wide range of amino acids and minerals. Beetles and grubs, for instance, are great sources of calcium and iron. Grasshoppers and the water bug have very high levels of phosphorus (up to 280 mg per 100g).[10] Cricket powder is especially rich in magnesium, zinc, and copper. Crickets and termites are known for their high iron and zinc content. Grasshoppers and mealworms contain more copper, magnesium, manganese, and zinc than even beef. The fat and oil content (lipids) in edible insects can vary quite a lot depending on the species, their diet, and their stage of life. The balance of omega-6 and omega-3 fatty acids in insects can be influenced by what the insects are fed, this obstacle can be tackled by insect farming. For example, mealworms contain fat types similar to those found in fish—and even healthier than those in pork or beef.[1] Honey Bee eggs, larvae, and pupae contain vitamins A, B2, and C indecent amounts. In terms of calories, insects can be energy-dense too. In fact, some insects can provide up to 776.9 kcal per 100g, which is more than what you'd get from the same amount of soybeans, maize, or beef.[10]

For insect farming to really take off, we also need clear laws and regulations—this would encourage more investment and help expand insect farming from small backyard setups to full-scale commercial operations. It would also help build a stronger global market for edible insects and their products.[1]

There’s even practical research behind this, in Kenya, for example, bread enriched with just 5% of a local termite species (Macromeres subhyaline) was found to be more nutritious and better liked in terms of taste, texture, and appearance than regular bread. It also had higher levels of vitamins and minerals—like riboflavin, niacin, folic acid, calcium, iron, and zinc—compared to normal wheat bread. The oil extracted from certain insects like Rhynchophorus phoenicisgrubs is also considered healthy because it contains a high level of good(unsaturated) fats which helps to reduce low density lipoprotein (Bad Cholesterol).[1]

Approach towards insect farming

When insects are collected from the wild for food, they can end up competing with other species, like predators or decomposers which will disrupt the balance in ecosystems. If their populations shrink, it can affect the entire food web and natural processes involving them. One big problem is overharvesting. If too many insects are harvested especially before they've reproduced — their numbers can't bounce back. This will threaten their long-term survival. If anyone predator insect species will be extinct it will affect the population of prey species which will cause imbalance in ecosystem.[10]

Another problem with wild harvesting is that various food safety concerns like i) Allergen - certain insect proteins such as arginine kinase or α-amylase are known for triggering allergic responses. ii)Pesticides -wild insects might feed on crops that have been sprayed with pesticides. These chemicals can stay in their bodies and may be harmful when eaten, various outbreak cases have been reported in areas where insects are included in diets often. iii) Pathogens- insects can carry harmful bacteria depending on how they're raised or caught. Poor hygiene during processing can lead to infections. Studies have found dangerous bacteria like Bacillus, Salmonella, and Staphylococcus in edible insects to prevent this strict hygiene and food safety practices are essential during each step of insect farming.[1] To prevent this the best way would be selective breeding and insect farming along with avoiding harvesting insects from wilderness. When we need to improve a specific insect population through breeding, we need to think about what we're aiming to achieve this is called breeding goal. We need to identify which traits for selective breeding which are most important early on which requires some understanding of the species' biology. In an insect their protein production ability, they might measure how much dry mass or protein content the insects produce, or how fast they grow. These traits usually have the highest economic value because they most directly impact profit derived from them.[2]

Cell cultured meat - In Vitro solution to quench future hunger

Lab-grown meat is created by taking stem cells from animals and growing them in nutrient-rich environments in laboratories. These cells multiply and form muscle, fat, and connective tissues—just like inside the animal's body. Although the first burger cost over $300,000 to make in 2013, costs have since dropped dramatically due to the advancements in technology. Lab-grown meat starts with collecting muscle stem cells from animals like cows, pigs, chickens, or fish. These cells are placed in a special nutrient-rich solution in a lab control

manner where they multiply, then they are moved to a bioreactor which provides a controlled environment where they grow into muscle fibers and eventually forms tissue that resembles real meat.[11]

Regular meat, especially the processed ones, often contains high levels of saturated fats which is responsible for cardiovascular diseases and strokes. Lab-grown meat, on the other hand, can be modified to have better fats like omega-3 and fewer harmful ones. Scientists can even fortify its nutritional profile to include more vitamins, minerals, and helpful compounds.[11]

Lab-grown meat doesn't require the routine use of antibiotics that are common in animal farming. This is important because overuse of antibiotics in animals has contributed to antibiotics resistance in humans which causes one of major concerns these days. Lab-grown meat is created in tightly controlled environments under the care of scientists and producers, keeping it free from exposure to outside germs and microorganisms. After Covid-19 pandemic one of major concerns is spread of zoonotic infections via food and lab grown meat might be the solution to it. For feeding the meat eating population raising livestock requires a lot of land and water. To solve this either we need to reduce the meat eating or find ways to produce it more sustainably. Since meat fills a lot of nutritional gaps in today's population lab grown meat might be solution to produce it more sustainably with less land and less water.[11]

CONSUMER ACCEPTANCE AND PREFERENCES

The foods we eat are undergoing continuous transformation. From lab-grown meat to insect protein snacks, algae snacks, and even 3D-printed meals are entering the picture. Even though these innovations include sustainability, nutritional value, and efficiency, it often fails to earn consumer acceptance. The analysis conducted by Mosikyan.[6] depicted that the huge role in acceptance of novel food and beverages is played by factors which are psychological, cultural and sensory in nature. They revealed that consumers' choices are ruled more by emotional responses like disgust or perceptions of "unnaturalness" and familiarity than by health benefits or sustainability claims. The factor which holds more value in the eyes of the general population than lab data or certification is the trust in the companies The study by Tuorila and Hartmann also shows that aversion and fear of unfamiliar or new food ingredients arises from a very early stage of life and a major role in it is played by cultural norms. This in turn results in rejection of food which are insect based or meat which are grown in lab despite having environmental advantages.[7] Emotional aspects play a very important role in this rejection

and they are further reinforced by social and generational models, this in turn makes it crucial to adopt culturally aware and mindful strategies when introducing novel/new foods.[7]

Then there is the added challenge of high-tech food systems.[12] reviewed Industry 4.0 technologies such as cultured meat, precision fermentation, additive manufacturing, and personalized nutrition and added a crucial insight: when production processes seem opaque or overly technical, consumers often consider the resulting foods "too artificial" or unreliable. They also observed that these products frequently fail to meet sensory expectations of taste, texture, aroma which means they are often rejected irrespective of their scientific merits. Now the question arises as to how we overcome these barriers? There was a repeated pattern in various studies that showed that what we need the most at the moment is transparency, familiarity and emotional connection.[6] suggests that marketing should also include the human side of foods which includes calling attention to honest producers, having a fair and ethical supply chain and also sharing real stories about companies to help people build trust and make them feel more connected. Study also advises that the fear of unfamiliar ingredients could be overcome gradually if there are interventions and programs for educating people, especially children.[7] There is also emphasis on maintenance of familiar sensory elements like taste, appearance, and texture even when food is produced using novel techniques to gain consumer trust and comfort.[12]

Table 1. talks about potential drivers of acceptance or rejection of novel and unfamiliar foods. The list illustrates the multitude of new products and motivations, but it is not exclusive.[7]

Challenges and Opportunities

As the global population is about to reach 9.7 billion within three decades one the biggest concern which arises is whether the traditional farming method will be enough to sustain the population.[5] Therefore one of the most important challenges that the future food has to face is how it can scale up the food production. The solution of this suggested by Galanakis includes advanced farming techniques like vertical farming, precision agriculture, and smart supply chains.[5] These ideas seem too futuristic but in reality, these are already starting to take place but only in developed countries, for poorer countries application of this method is still tough with major limitations being money and resources. Affordability is another big hurdle. A lot of the new food options like lab-grown meat, plant-based alternatives, or protein from insects are still more expensive than the usual stuff we buy at the grocery store. Hussain and Bekhit explain that these foods can be way more efficient and environmentally friendly to

produce, but the technology behind them is still new and costly.[4] Until prices come down, most people might not be able or willing to choose them over cheaper, traditional options like beef or chicken. Another field which needs to be addressed is nutrition because not all future or sustainable food is nutritious. Some of these novel foods/alternatives do not have the required vitamins, minerals, or complete protein. Furthermore, Hussain and Bekhit in their study has mentioned that we have to be mindful of nutrient gaps in these new foods and make sure that it meets our health needs especially in areas where malnutrition is highly prevalent.[4] However, the biggest challenge is still to make people accept these new/novel foods because food like bugs and lab grown meat often sound appealing. Same was found in a review by Hassoun A. and team which showed that people are often reluctant in accepting these technologies even more when they are not aware of the process which is used to make food or where the food is coming from.[12] This in turn shows that it's not always about what's on the label but also about trust, familiarity and often culture. Hassoun and team in the review also mentions that activities like storytelling, better and honest labelling, and real-life experiences like school food programs can be very helpful in building trust and interest.[12]

Table 1: Factors Influencing Acceptance and Rejection of Novel and Unfamiliar Foods.

Type of food	Definition	Acceptance	Rejection
Ethnic	Unfamiliar locally, known and 'safety tested' in another culture	Variety seeking Increased availability	Unfamiliar (weird) sensory properties Uncertainty Food neophobia
Nutritionally modified	Contains often more fiber or less fat, sodium, or sucrose than a conventional food	Health, nutrition and well-being	Sensory properties may differ from regular
Functional	Evidence based beneficial effect due to special ingredients	Health, nutrition and well-being	Price Perceived uselessness
Free from	An ingredient unfit for a part of population has been omitted (e.g., lactose, gluten, palm oil)	The absence of unhealthy or unfit ingredient	Sensory properties may differ from regular
Vegetarian and vegan	Free from meat and other animal- based material (different levels exist, fully free = vegan)	Meat avoidance Environmental concerns Moral views Health, nutrition and wellbeing Ethical value	Attached to meat Perceived inadequacy of nutritional value

Organic	Produced in traditional farming conditions without fertilizers or herbicides/pesticides	Naturalness Health, nutrition and well-being Ethical value	Price Quality defects
Plant based meat replacers	Products replacing the meat component from a dish or meal	Source of protein Ethical value	Attached to meat Sensory expectations hard to meet
Insect	Product containing whole or bruised insects	Source of protein Curiosity	Disgust Food neophobia
Artificial meat	Meat produced from stem cells without a living animal body	Sensory properties similar to meat Ethical value	Disgust Unnaturalness
Genetically modified (GMO)	Contains, consists of, or produced from genetically modified material	Price Improved quality	Unnaturalness Food technology neophobia
3D-printed	Computer-assisted design combined with 3D food printer -> products in complex patterns and shapes	Personalized nutrition	Disgust Unnaturalness Food technology neophobia

CONCLUSION

Eventually, the future/novel foods are not just about innovations and newer ingredients, it's more about the global people. The motive for creating this food is to make it more accessible, healthy and also trusted by the people. Along with the technology and the science which we have got the main focus should be on gaining trust of people and bringing everyone along for the ride. In the end, for a food innovation to be successful what is most required is the combination of scientific meticulousness with empathic connection. Ultimately, it's about making the innovation feel like food which can be both trusted and enjoyed rather than making it feel like a tech experiment. Easiest way to achieve it is by making smart choices, being culturally sensitive, good and empathetic communication, and better education.

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