

CAN WE NOURISH HUMANS WITHOUT SACRIFICING THE EARTH?

Nida Tariq^{1*}, Mariyam Anwar Ur Rehman², Abida Liaquat³, Wajid Hussain⁴ and Moatar Badar⁵

1. University of the Punjab, Lahore, Pakistan
2. Department of Food Science and Technology, University of the Punjab, Lahore, Pakistan
3. Department of Nutritional Sciences, Government College Women University Faisalabad, Pakistan
4. Department of Agriculture and Food Technology, Karakoram International University Gilgit, Pakistan
5. Institute of Food and Nutrition, Department of Human Nutrition and Dietetics, PMAS Arid Agriculture University Rawalpindi, Pakistan

*Corresponding Author: L1nidatariq@gmail.com

ABSTRACT

As the population grows and the world advances in technology, the demand for better nutrition also increases. In the race to provide enough nutritious food for people around the globe, the impact of food production on climate change and vice versa cannot be ignored. Therefore, this paper discusses recent innovative technologies for sustainable food systems, including cellular agriculture, regenerative agriculture, vertical farming, the planetary health diet, food waste mitigation, edible insects, and microalgae. It also briefly discusses the use of CRISPR in more resilient crops and AI in precision agriculture. Structural barriers, i.e., scarcity of resources, lack of regulation, lack of functional compatibility with natural products, and consumer acceptance, are outlined. It is possible to move toward feeding a growing population while reducing environmental damage, but there is unlikely to be one technology that completely solves the problem. The future will require a compatible combination of these technologies where they genuinely offer advantages.

Keywords: Food Security, Climate Change, Sustainability, Food Production, Agriculture

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Introduction

It is estimated that there will be a 50-60 percent increase in total global food demand between 2019 and 2050. As food demand increases with the increasing population [1, 24], growing food costs our Earth too. A single meal that a person eats involves several global systems behind it: water, soil, agriculture, energy, and human health. It involves greenhouse gas emissions, deforestation, biodiversity loss, and the use of energy resources, which all lead to climate change, and climate change in turn affects the production of food. It clearly shows the influence of both on each other [25]. It is the need of the hour to devise a system that provides sufficient, affordable, and wholesome food without compromising Mother Earth and nature in the long run. By protecting food, the climate can also be protected, and vice versa[2]. Utilizing food waste to produce value-added products, food preservation, shelf-life extension, alternative proteins, and sustainable packaging are among the solutions[3]. Precision fermentation is also playing a leading role in this regard[4]. Other popular ways include wise eating habits, cellular and regenerative agriculture, micro-algae, CRISPR, and AI technologies.

Since these technologies are emerging, they have their own limitations and future concerns, such as consumer acceptance from food safety and halal perspectives. Also, not all foods produced through these technologies are as functional as natural products[4].

RISING FOOD DEMAND

As food demand increases with the increasing population, the story is no longer just about numbers; it is about people. By 2050, nearly nine out of every ten humans on Earth will live in the developing world, the very places where a desire for meat, milk, and eggs is set to rise the fastest as families climb out of poverty and dream of fuller tables. It is a poignant contradiction that even today, more than three billion people, almost half of humanity, are unable to access a wholesome diet at all[5].

CLIMATE CHANGE AND FOOD PRODUCTION

Food production and climate change influence each other. Agricultural production and livestock farming evidently emit greenhouse gases such as methane, nitrous oxide, and carbon dioxide, which are the top reasons for climate change nowadays[2]. Food choices have a bigger impact on the climate than it appears. By the year 2100, food consumption alone could contribute nearly 1°C of additional global warming, with around three-fourths related to methane-emitting foods, such as beef, other ruminant meat, dairy, and rice[7].

The question lies not in simply growing more food but in providing affordable and nutritious food without wiping out nature, eradicating trees from our surroundings, depleting the water table, and emitting more greenhouse gases[2]. Better food production, wise eating choices, and minimal waste generation can prevent more than 55% of this problem[7].

FOOD CHOICES

There are risks associated with the quantities, proportions, variety, or combination of different foods, drinks, and nutrients in a person's diet. From a health perspective, however, this is more linked to the consequences of poor eating habits (obesity, diabetes, etc.). Thus, these issues have little to do with climate change and its effects on food, although it is evident that eating habits play a part in climate change regarding environmental sustainability [6, 30, 31].

The EAT-Lancet/Planetary Health Diet recommends eating more vegetables, fruits, whole grains, beans, peas, soy, nuts, and less red/processed meat and excessive animal products [29, 32]. At present, this diet is not being followed very closely. However, it is estimated that premature deaths could be prevented by following this diet [8]. A flexitarian shift could also reduce greenhouse gas emissions, making it easier to achieve the 1.5°C climate goal. This means the dependence on technologies to remove CO₂ from the Earth's atmosphere would be reduced [9].

One of the three vital instruments that could prevent over half of food-related warming is waste reduction[7]. Reducing food waste is not just a theoretical idea; countries have already shown that large-scale reductions are possible. UNEP Food Waste Index Report 2024 shows that the UK reduced food waste by about 18% through cooperation between government and businesses, voluntary commitments, better practices, food redistribution, and public campaigns. It also shows that Japan substantially reduced food waste through measures such as requiring large food businesses to report waste, setting reduction targets, converting suitable food waste to animal feed, and running public awareness campaigns. The challenge is to implement proven measures consistently across more countries and households, businesses, and retailers.

CELLULAR AGRICULTURE

The most trending solution for sustainable food production right now is **precision fermentation**, especially the newest frontier often called "food from air": using engineered microbes to brew real proteins (casein, whey, lactoferrin, mycoprotein) in bioreactors instead of raising animals, with some processes even feeding on CO₂ and hydrogen. Thus, the need for crops from land, large amounts of water, and animal agriculture is eliminated. In comparison with traditional livestock production, using this technology provides proteins with up to 97% less carbon dioxide emissions and up to 99.7% reduced water use[11]. Animal-free protein like vegan soy products that feel like meat can be provided by precision fermentation[4].

Cultivated meat, another angle of cellular agriculture, involves real animal meat grown from cells in bioreactors, which means no slaughter and no feedlot. The US gave the first-ever federal approvals to UPSIDE Foods and Good Meat in June 2023[14]. Compared to the crops required for chicken

production, cultivated meat requires about one-third the crops to produce almost the same amount of meat [13].

Cellular agriculture has genuine potential to reduce the environmental burden of livestock production, but it substantially depends on powering it with low-carbon energy and managing the additional demand for certain materials such as tellurium, which could become a limiting factor, particularly for solar-powered scenarios. Moreover, cellular agriculture has limitations in compatibility with existing food systems and real-world execution. Companies producing food using these techniques need to go through safety and regulatory checks, which can prolong their practical implementation. Some people may be hesitant to eat ingredients made by genetically modified microorganisms[12].

EDIBLE INSECTS: TINY FARMS, HUGE YIELDS

Insects are the efficiency champions of the protein world, emitting up to 100 times fewer greenhouse gases relative to conventional livestock. They also use 50-90% less water and land while providing protein levels of 30-85%, usually more micronutrient-rich than fish or other meat. The market is already moving as it is expected to reach \$2 billion by 2030[15]. The real obstacle in this regard is cultural, not technical. Fragmented food safety rules and consumer hesitation still hold back the cricket burger[16].

MICROALGAE: THE PROTEIN FARM THAT NEEDS NO SOIL

Microalgae such as Spirulina and Chlorella, composed of all essential amino acids, comprise up to 70% protein by dry weight. Another advantage is their cultivation on infertile land besides recycling wastewater and even capturing greenhouse gases[17]. Dairy alternatives and 3D-printed snacks are being produced using these beneficial protein farms. They can genuinely improve food security and nutrition. However, production costs are high, and regulations for their use lag behind the science[18].

VERTICAL FARMING: SKYSCRAPERS THAT GROW DINNER

Compared to traditional fields, vertical farms grow crops indoors in stacked layers. Farmers can carefully control light, temperature, water, and nutrients. So, crops can be grown year-round with much less dependence on weather and soil. The technology is leading the way in many regions across the world. Cutting-edge work uses dynamic lighting that reacts to changing electricity prices throughout the day, making it a cost-efficient practice without compromising crop yield. It is still not a complete solution to the high energy demands of vertical farming[19].

REGENERATIVE AGRICULTURE: HEALING THE SOIL THAT FEEDS US

Rather than escaping the farm, this movement rebuilds it. Regenerative practices benefit by boosting biodiversity, replenishing soil health, climate regulation, and sequestering carbon. And it does not affect farmer profits or yield gains. Thus, regenerative agriculture practices can mitigate global warming[20]. The new twist is “regenerative agrivoltaics”, pairing solar panels with regenerative farming so the same land produces both food and clean energy at the same time[21].

Regenerative Agrivoltaics

Practices				
Benefits				
Challenges				

CRISPR CLIMATE-RESILIENT AND FORTIFIED CROPS

Crops like rice and maize, which make up a major proportion of everyday diets, are being advanced by CRISPR. This technology leads to desirable characteristics such as drought tolerance, higher yield, and biofortification in these crops via prime and base editing. This is the “grow more on the same land” strategy, and it pairs naturally with agroecology, giving higher yields while enhancing climate adaptation at the same time. However, it still faces challenges such as field validation; ethical, regulatory, and ecological concerns; and access to the technology[22, 26].

AI AND PRECISION AGRICULTURE

Data-driven farming that applies exactly the right input at the right place. Artificial intelligence (AI) is used for crop and soil monitoring, climate prediction, fertilizer tailoring, and smart irrigation. The goal of precision

agriculture is to raise crop yields while causing the least harm to the environment by using data analytics and satellite imagery. Moreover, AI enables more accurate predictions of soil conditions and better decision-making processes. Some of the major tools in this regard are: Blockchain and GIS for Supply Chain Optimization; CNNs, Drones, and Robots for disease and weed detection and removal; Machine Learning, Vision Systems for detecting and managing pest populations; Decision Support Systems for efficient resource management; Data Integration Systems for Integrated Crop Management; Autonomous Farming Vehicles for planting, spraying, and harvesting [27].

The major challenges are data collection, data ownership, and data privacy, along with the huge cost of implementing the AI-based setup. Farmers in all areas cannot afford the technology, and rural areas also lack reliable internet and infrastructure [28, 33].

CONCLUSION

All the solutions discussed above have their own trade-offs: vertical farms need cheap electricity, regenerative agriculture needs rigorous carbon accounting, CRISPR has its own ethical and regulatory concerns, cultivated meat needs cheap clean energy, and dietary shift needs consumer adoption. All these remain stubborn bottlenecks. Consumers and buyers still prefer taste, price, and health over sustainability while purchasing items. There is a gap in scalability and commercialization because the regulatory framework and industrialization are lagging behind science.

Circular use of food by-products, better policies, infrastructure, and global cooperation are some of the recommended measures. However, no single breakthrough will feed 10 billion people on Earth. The real answer is a blend, and that blend is already being built, i.e., hybrid products. The realistic solution is to redesign the food system using multiple complementary approaches that make food production more resource-efficient, nutritious, affordable, and climate-resilient. A more practical and acceptable approach is: future foods will comprise plant proteins in combination with mycelial ingredients or cellular agriculture to balance cost, taste, and sustainability, along with AI-driven formulation optimization.

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