NOVEL BIOTECHNOLOGY APPROACHES FOR HUMAN FOOD

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Abstract
The bioeconomy of the future promoted by the European Commission and OECD relies on new technologies, among them, modern biotechnologies (such as synthetic biology, nanobiotechnology or cellular agriculture) highly dependent on artificial intelligence. The fast advancement of artificial intelligence requires the examining of the potential impact of modern approaches used to obtain human food. Proponents argue that these technologies are needed to increase food production, while reducing the environmental impact of the agricultural sector. Opponents argue that these modern biotechnology-related approaches will have unintended consequences, such as impacts on human health and unforeseen environmental health issues. They also bring forth the negative or even destructive impact on traditional farming systems, increasing global inequity at both individual and national levels. The speed at which modern agro-food biotechnologies advance is dangerously outpacing the institutional control reaction. There are deep concerns that fully appropriate national and internationally-agreed control structures for those technologies (especially at the nano-level) are missing or not fully functional. This paper offers a synopsis of the research done on the use of modern biotechnology for producing and processing human food.

Keywords: *modern biotechnology, biological engineering, human food, agriculture.*

Clasificare JEL: *Q57, Q10*

1. Introduction

The bioeconomy of the future promoted by the European Commission (2018) and OECD (2009) relies on new technologies, among them, modern biotechnologies (synthetic biology, nanobiotechnology or cellular agriculture etc.). Modern biotechnology for agriculture and food uses technology in biology to obtain new organisms or products. An example is genetic engineering which alters the genetic structure of plants, animals, and microorganisms. Cellular agriculture comprises the technologies to produce agricultural products out of mammalian cells and microorganisms (Rischer et al., 2020). It became widely known after 2013 when the first lab-grown burger (O'Riordan et al., 2017) was publicly tasted. In 2024, GFI estimates the global amount of funding for alternative proteins to be more than half billon US dollars with the highest contribution from China, India, and the United States (GFI, 2024).

The recently started transition to a digitalized society based on a bioeconomy was the focus of authors' research in the past years: moving from the analysis of the socioeconomic metabolism, the evolution of agriculture towards Ag 3.0/Ag 4.0, and of the green and blue economies, towards the methods and indicators used to assess the impact of these changes. As a natural follow-up, the interest for the environmental impact of the advancement of artificial intelligence (AI) calls for the analysis of the modern approaches used to obtain human food. To study the environmental impact, this paper offers a necessary synopsis of the research done on the use of modern biotechnology (including synthetic biology or biological engineering, cellular agriculture and nanobiotechnology) for producing and processing human food.

The next sections discuss some novel approaches to obtaining human food using modern biotechnology and the associated risks and ethical concerns. The last section concludes.

2. Modern approaches to human food

The United States is the most active promoter of biotechnology for agriculture and foods as the world's leading cultivator of genetically engineered crops. According to the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA), in 2024, biotechnology plantings as a percentage of total crop plantings in the United States were about 94% for corn, 96% for cotton and 96% for soybeans (USDA, NASS Data).

In the European Union, as of January 2025, "there are no applications of synthetic biology in animals envisaged for the EU market" (EFSA) while in the field of plant biotechnology there are several public-private partnerships (PPPs). One such relationship is the Circular Bio-based Europe Joint Undertaking (CBE JU), "a partnership between the European Union and the Bio-based Industries Consortium (BIC) that funds projects advancing competitive circular bio-based industries in Europe" (Circular Bio-based Europe).

The increasing access to and versatility of artificial intelligence recently opened new ways (e.g. through modern biotechnology) for producing and processing one of the main sources of subsistence for the human body, namely food. Artificial intelligence is vital for modern biotechnology.

The European Council (2025) clearly differentiates between the Established genetic modification (GMO) techniques and New genomic techniques (NGT). GMO alters the genetic material "in a way that does not occur naturally by crossing or natural recombination, sometimes with foreign DNA (transgenic reeding or transgenesis)". NGT modify the genome "at a selected targeted location (targeted mutagenenis) or a sequence from the same species or a closely related species is inserted (cisgenesis)." Some examples of precise gene editing for fruits are provided, among others, by Silvestri et al. (2024) and Ninama et al. (2024), for fish by Lal et al. (2024) and for tomatoes by Baranov et al. (2024) and Ninama et al. (2024).

Synthetic biology or biological engineering is an interdisciplinary field that projects and produces biological elements and systems (parts of DNA, genes, etc.). To accomplish this, artificial intelligence is key. Synthetic biology developed very fast in the past twenty years. It started, in the United States, with producing vegan burgers with meat flavor and synthetic collagen "grown" in the laboratory.

The novel approaches related to human food include, among many other uses: 1) industrial food biotechnology used for food additives and food processing aids through selection and improvement of microbes (Awulachew, 2021); 2) engineering using artificial intelligence food enzymes and metabolic microbes (Amore and Philip, 2023); and 3) improving the nutritional value of modern-foods through novel fermentation and enzyme technological processes, protein engineering, genetic engineering, metabolic engineering, bioengineering, quorum sensing and nanobiotechnology (Yaradoddi et al., 2024).

The industrial food biotechnology used for food additives and food processing aids through selection and improvement of microbes is discussed in detail by Awulachew (2021). Biotechnology is used to "transform perishable raw ingredients or inedible raw food materials into more palatable foods, useful shelf stable with long shelf life and potable beverages" (Maryam et al. 2017 cited in Awulachew 2021, p. 73)

AI is vital to food biotechnology for the engineering of food enzymes and of metabolic microbes. Amore and Philip (2023, p. 1) discuss some specific sectors of food biotechnology: development of new process-aid enzymes; precision fermentation; food safety and toxicity; food microbiology; and the study of the interplay between food and gut microbiome. Yaradoddi et al. (2024) recently edited a book on current biotechnological advances and approaches to improving the nutritional value of modern-foods such as: novel fermentation and enzyme technological processes, protein engineering, genetic engineering, metabolic engineering, bioengineering, nanobiotechnology, and quorum sensing.

The nanoscale science and engineering works at the level of one billionth of a meter. Just to give an idea about the meaning of the nano-realm, the already classical comparison with the thickness of a paper sheet is useful: 100000 nanometers (NNI). At the nanolevel, due to quantum effects, materials have physical, chemical, and biological properties different from those at atomic or molecular scale. Nanomaterials can be specifically engineered to have certain properties and can be inorganic, organic-based, and a combination of those two (Duran et al, 2013). In food science, the European Union defines nanomaterials as novel foods (meaning “not produced or used before 1997”) in Article 3(2)(f) of the Regulation (EU) 2015/2283.

In food industry, nanoscale applications can be found in processing, packaging, functional food development, and other areas (Singh et al., 2017; Vieira et al., 2024; Ahmad et al., 2025; Shweta et al., 2025). For example, in food processing, nanoscale ingredients can be found as:

> “food additives and carriers for smart delivery of nutrients; anticaking agents to improve nutritional value of food; gelating agents to improve the consistency of food and to prevent the lump formation; to improve the food texture and nanocapsules and nanocarriers; to protect aroma, flavor and other ingredients in food” (Primožič et al. 2021, p. 3).

3. Risks and ethical concerns related to agro-food biotechnology

Modern biotechnology technologies (including plant genome editing, cellular agriculture, and nanobiotechnologies) used for agro-food purposes bring unknown (only recently started to be documented) risks for human, animal, and plant health, for ecosystems and environment as a whole. Also, the techno-corporate dominance (through patents and entry barriers) associated with the unnatural organisms and products (Mahoney, 2022; Wood et al., 2023; Munawar et al., 2024) brings along a negative or even destructive impact on traditional farming systems. The potential impact is even wider (multidimensional) if one looks at the traditional way for food production as a building block of our civilization; it increases global inequity at both individual and national levels (Wood et al., 2023).

With respect to modern biotechnology applied in agriculture, in the view of United States Department of Agriculture (USDA FAQs), three of the main risks relate to plant proximity, unknown environmental effects on other organisms and new proteins’ toxicity and allergic responses. Plant proximity refers to biotech crops located in fields close enough to other cultures of similar species allowing the interaction through pollination. Many details regarding the risks for human health associated with genetically modified plants and the negative environmental impact are presented by Ghimire et al. (2023).

There is an increasing hype regarding milk and dairy replacements that can be obtained either from plant proteins or through cellular agriculture. The challenges associated with the hazards related to this new type of agriculture are complex. A thorough review of the potential toxicological challenges for humans related to the cellular replacement of dairy production is carefully presented by Fytsilis et al. (2024). Also extremely important and far-reaching are the side-effects of replacing real dairy products with those cell-generated (Wood et al. 2023). There are other roles livestock play in our societal arrangements that would be gone: products from hides, wool, manure, serum, blood, and fats, pulling or hauling loads, ecosystem services, life-style basic element including cultural-related roles.

The nanomaterials for agro-food industries are also worrisome given the negative effects at the cell-level such as cytotoxicity (Verstrepen et al., 2004; Vetter and Schlievert, 2005; Gayathri et al., 2024; Duran et al., 2025). Also, nanoparticles (e.g. nanofertilizers and nanopesticides) can genetically interact with cells at a sub-cellular level in plants and in humans or animals by penetrating their skin and induce toxicity or oxidative stress (Wang and Irudayaraj, 2008; Duran et al., 2025; Rodriguez-Seijo et al., 2025).

Already, in the modern lifestyle, unknowingly, through the most common actions associated with living—breathing, ingestion, and the skin—are ways for humans to assimilate nanomaterials (Duran et al., 2025). The largely used nanoemulsion technique brings to healthy organisms toxic compounds that allow confounding the receptors of immune cells and generate cellular damage (Pradhan et al., 2015; Gayathri et al., 2024). A detailed discussion of the toxicity associated with those inorganic (Ag, Fe_2O_3, TiO_2, SiO_2, and ZnO) and organic (lipid, protein, and carbohydrate) nanoparticles used most often in food industries is offered by de Oliveira Mallia et al. (2022).

Associated with these risks, are many ethical questions related to agro-food biotechnology. Agro-food biotech issues connect environmental sustainability, food security, and individual food choices with human health (Varzakas and Antoniadou, 2024), while cellular agriculture brings ethical animal welfare concerns raised about their use for scientific purposes in the process of obtaining dairy replacements (Fytsilis et al., 2024). The new frenzy of genetic tests used to obtain a person's ancestry from a DNA sample is an example that brings up profound concerns about the potentiality of personal information, including food preferences, to be misused. International consensus for regulation is necessary since the bio- domain does not respect national boundaries and the subsequent unintended consequences cannot be accurately assessed as scale and duration; things are getting even more complicated if one considers the existence of multiple value systems regarding life/death (Chui et al., 2023).

The speed at which modern agro-food biotechnologies advance is dangerously outpacing the institutional control reaction. There are deep concerns that fully appropriate national and internationally-agreed control structures for those technologies (especially at the nano-level) are missing or not fully functional; even the US, as the world's leading promoter of modern agro-food biotechnology is lagging (Kendig et al., 2024; Rodriguez-Seijo et al., 2025). As for now, various countries have adopted some regulatory measures for nanotechnology obtained agricultural products (an extensive presentation in Kumari et al., 2023).

4. Conclusions

Modern biotechnology-related approaches to producing human food supposedly have many advantages, however due to their recent development there are also unknown effects on plant, animal, and human health (such as new proteins' toxicity and allergic responses), the environment, and the civilization as we know it which may also raise ethical concerns. As time moves on, biotechnological approaches will only continue, getting more sophisticated. These improvements will, hopefully, lead to greater productivity and less greenhouse gas emissions, but could also increase the risk of environmental catastrophe and human health crises. Therefore, understanding all aspects of the biotechnology movement are important, so a completely informed decision can be made that benefits all aspects of society. More conclusions will be drawn in future work.

5. Acknowledgement

This work was supported by the Institute for Economic Forecasting of the Romanian Academy, Romania as part of its research program through the studies *Aspects of the environmental impact in the context of the transition to a digital bioeconomic society* (*Aspecte ale impactului de mediu în contextul tranziției spre o societate bioeconomică digitală*) and *The impact of biotechnologies in the transition to a digital bioeconomic society* (*Impactul biotehnologiilor în tranziția spre o societate bioeconomică digitală*).

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