Agrifood side-streams as source of macro and micronutrients pool for biotechnology applications

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Keywords: food waste, side-streams, food system, sustainability, greenhouse gas emission, green chemistry, cellular agriculture, cultivated meat, macronutrients, circular economy, culture medium, biotechnology

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Over the past few years, the rate of global population expansion has markedly risen. As of 2019, the Earth harbored 7.7 billion inhabitants, and projections suggest a surge to 10 billion by the year 2050, as indicated by the United Nations in 2019 (Facchini, 2022). This demographic challenge is exacerbated by the intensifying environmental crisis, with the food system contributing to 26% of global greenhouse gas (GHG) emissions, ranking as the second-largest producer (Poore, 2018). Notably, 31% of GHG emissions within the food sector originate from livestock and fisheries (Ritchie, 2019). Conventional intensive livestock practices further compound environmental and health issues, including the depletion of vital resources (e.g., land and water), spillover, and biodiversity loss. Consequently, the challenge extends beyond the mere production and delivery of protein to the growing population; it necessitates a sustainable approach. While several different new production technologies are currently tested as possible complementary solutions (e.g., cellular agriculture) to the traditional ones, we know from the Waste Framework Directive (2008/98/EC) that above 58 million tons of fresh mass were wasted in 2021. In navigating this complex landscape, the identification of emergent biotechnologies offers promise in minimizing the environmental impact of food production. Simultaneously, addressing the environmental repercussions of food waste from agri-food and large-scale retail trade (GDO) remains imperative. Within this context, the integration of the circular economy concept into emergent biotechnological research emerges as a viable strategy. This integration not only has the potential to mitigate greenhouse gas emissions from food waste but also facilitates the advancement of sustainable technologies by creating value in side-streams and by-products.

1. THE BIOTECHNOLOGY REVOLUTION IN SUSTAINABLE FOOD PRODUCTION

The multidisciplinary field of biotechnology introduces technical possibilities that can be of help in large-scale production of sustainable foods. Among these innovations, cellular agriculture stands out for its focus on producing animal tissues and products through cell culture, eliminating the need for traditional animal breeding. Moreover, the advantages linked to cell culture production are also related to the minimization of the environmental impact coming from animal protein production and resource depletion (e.g., land and water use). Despite these advantages, it is imperative to acknowledge that cellular agriculture is still in its nascent stages, presenting various technical challenges that demand further research to pave the way for feasible and scalable large-scale production.

2. THE CHALLENGES OF LARGE-SCALE PRODUCTION IN CELLULAR AGRICULTURE

The cellular agriculture protocol for animal protein production requires four steps:

- Cell isolation
- Proliferation
- Differentiation
- Packaging

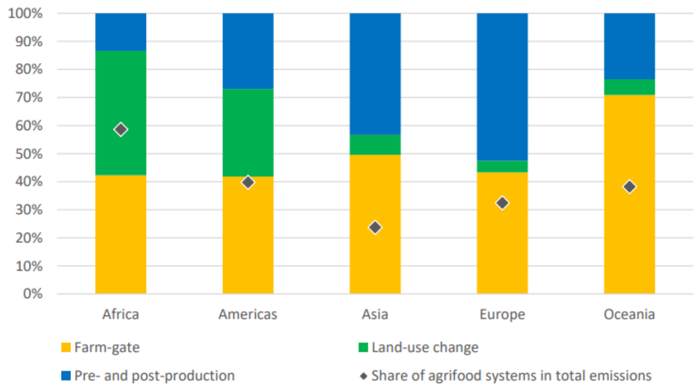
Each of these steps poses several technical challenges (e.g., maximization of cell density, cell banking) that need to be solved to make large-scale production possible. Specifically, the proliferation and differentiation phases require the production of cell-culture media that includes all the necessary components to maximize protein production. Indeed, the cells isolated need to grow in specific cell-culture media that contains all the necessary components to make it possible for the cells to grow and divide, being therefore strictly necessary. Currently, the media used contains around 52 components, 8 of whom are considered essential to grow stem cells (Garrison, 2022). So far, some of the necessary components (e.g., Fetal Bovine Serum, Fibroblasts Growth Factor-2) have been isolated from animals, therefore still including the animal in the whole process of cellular agriculture production. Moreover, some of these components (e.g., growth factors) are very expensive, making difficult the transition from proof-of-concept (POC) to large-scale production.

At present, the scientific community is researching the possibility of identifying cheaper and alternative ingredients for formulating cell-culture media for cellular agriculture production.

3. THE CIRCULAR ECONOMY CONCEPT

The circular economy concept represents a developmental framework that aims at minimizing the adverse effects of human actions through the application of principles linked to "3R": reduce, reuse, recycle (Li, 2010). Its goal is to sustain the optimal utility and value of products, components, and materials consistently (Ellen McArthur Foundation, 2015b). This concept can be applied to minimize, for instance, the environmental impact deriving from greenhouse gas emissions (GHG) coming from agri-food sector. Indeed, in Europe more than 50% of the total agrifood emissions come from pre- and post-production, as estimated by the Food and Agriculture Organization (FAO) (FAO, 2022) and shown in **Figure 1**.

Figure 1.Regional agrifood system emissions and share in total emissions (2020).



4. AGRI-FOOD WASTE FOR THE CELLULAR AGRICULTURE SUPPLY CHAIN

The necessity of identifying new sustainable technologies for food production (e.g., animal protein) and the urgency in reducing the anthropogenic emissions due to food waste are part of the intricate complexity of the food system, which require a system thinking approach. In doing so, I am focusing on the connection between animal protein production and food waste and loss. Specifically, my focus centers on repurposing side-streams from agri-food industries for biotechnological applications, with an emphasis on characterizing various raw materials (e.g., apple pomace) to identify key biopolymers. The biopolymers selected will eventually be used to formulate a plant-based medium for cellular agriculture applications. Furthermore, the ingredients sourced from each side-stream undergo extraction processes, utilizing both traditional and green chemistry methods, thereby embedding sustainability into the extraction phase.

The novelty of this research lies in its potential to contribute to creating a new supply chain for cellular agriculture, leveraging the reutilization of side-streams to be used to produce sustainable animal protein. Importantly, the identification and extraction of components from diverse side-streams confer intrinsic value to previously wasted raw materials, introducing purpose and financial value. This approach not only contributes to environmental sustainability but also reduces the ecological footprint associated with biomolecule production by circumventing the use of traditional solvents and technologies.

5. ACKNOWLEDGMENTS

This abstract is part of the project NODES which has received funding from the MUR – M4C2 1.5 of PNRR funded by the European Union - NextGenerationEU (Grant agreement no. ECS00000036)

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