FACT SHEET

Biomass Fermentation: tapping into the protein potential of microorganisms

Mycelium-based chicken analog.
Images provided by Meati Foods.

gfi / Brazil

Credits

Authors

Marina Sucha Heidemann
Isabela de Oliveira Pereira
Bruna Leal Maske
Stéphanie Massaki
Maria Clara Manzoki
Germano Glufke Reis

Review

Amanda Leitolis
Cristiana Ambiel
Carlos Ricardo Soccol
Susan Grace Karp

Design

Fabio Cardoso

International Cataloging in Publication - CIP

H465 Heidemann, Marina Sucha et al.
Biomass fermentation: tapping into the protein potential of microorganisms: fact sheet / Marina Sucha Heidemann, Isabela de Oliveira Pereira, Bruna Leal Maske, Stéphanie Massaki, Maria Clara Manzoki and Germano Glufke Reis. – São Paulo: Tikibooks; The Good Food Institute Brazil, 2025.
E-BooK: PDF, 14 p.; IL; Color

ISBN 978-85-66241-21-1

1. Foods. 2. Food Production Chain. 3. Food Technology. 4. Innovation. 5. Fermentation. 6. Biomass Fermentation. 7. Microorganism. 8. Alternative Proteins. 9. Food Products Analogous to Conventional Animal-Based Foods. I. Title. II. Tapping into the protein potential of microorganisms. III. Fact sheet. IV. Heidemann, Marina Sucha. V. Pereira, Isabela de Oliveira. VI. Maske, Bruna Leal. VII. Massaki, Stéphanie. VIII. Manzoki, Maria Clara. IX. Reis, Germano Glufke. X. IFC/Brazil.

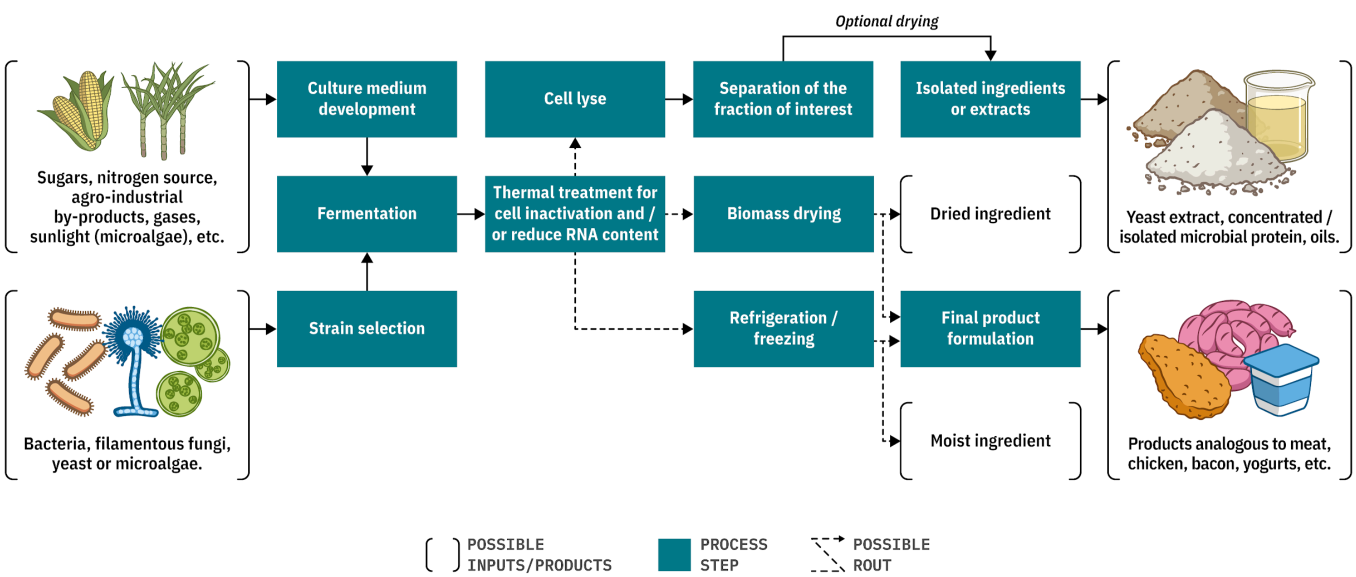
CDU 664 **CDD 664**

Cataloging prepared by Regina Simão Paulino – CRB 6/1154

Biomass fermentation is a process in which microorganisms—such as bacteria, yeasts, microalgae and fungi—multiply in large quantities, generating cell biomass. This process is performed inside controlled tanks, the bioreactors, which create a favorable setting for microbial growth. Depending on the microorganism chosen for the fermentation process, the biomass can be composed of cells that have high protein content (single-cell protein) or high oil content (single-cell oil) (Campos-Valdez et al., 2023).

Biomass fermentation enables the production of different products mimicking conventional animal-based products: meat analogs (Meati, Bosque Foods, Quorn), seafood analogs (Aqua Cultured Foods), yogurts (Nature's Fynd), or even protein ingredients to be used in various food formulations (Typcal, Done Properly).

Graphical summary. *Potential pathways, raw materials, and alternative protein products obtained through the application of biomass fermentation technology as detailed in this fact sheet.*



1. Potential of microorganisms as a protein source

Biomass fermentation represents a notable technology within the alternative protein sector. The biomass ingredient can be utilized as a primary constituent in novel product formulations, necessitating minimal processing. Application of this technology is feasible in business-to-business (B2B) models to supply a diverse array of animal-component-free ingredients to the food industry. Examples include mycelium-based protein flour and ingredients already used by the industry, such as nutritional yeast, yeast extract and fermented extracts. In addition, B2C (business-to-consumer) business models are also possible. In this case, final products such as mycelium-based burgers or seafood analogs are sold directly to consumers.

In 2022, US$406 million was invested in the biomass fermentation sector, and currently, 70 startup companies globally are engaged in the development of alternative products through biomass fermentation.	Between 2013 and 2023, US$4.1 billion was invested in fermentation to produce alternative proteins worldwide[1]. In 2022, the biomass fermentation sector was responsible for US$406 million in investment[2]. Currently, approximately 70 *startups* develop alternative protein products by biomass fermentation worldwide[1]. In Brazil, examples include the companies Typical, Tekohá, and Hyph. *Source: Good Food Institute (2023) and Alternative Protein Company... (2024).*

Microorganisms can contain up to 75% protein in their composition	Although the utilization of mycelium has been emphasized, it is important to note that yeasts, bacteria, and microalgae also constitute viable and prospective sources of protein[1]. For example, spirulina microalgae contain up to 65% protein in their composition[2]. Once processed, the resulting protein powder can be added to food products, increasing their nutritional value. Some bacteria species, such as *Bacillus subtilis* and *Corynebacterium glutamicum,* can reach about 70% protein on a dry basis, and some microalgae, such as *Aphanizomenon flos-aquae,* can reach 75%[3]. *Source: 1- Bratosin, Darjan and Vodnar (2021); 2- Alfadhly et al. (2022); 3- Ritala et al. (2017) apud Silva, Taniwaki and Sá (2022).*

The utilization of microbial biomass to create meat analogs can enhance their organoleptic properties	For example, mushroom species contain glutamic acid, one of the main elements responsible for the umami flavor*, and are used to give a rich and satisfying taste sensation[1]. Yeast extract contributes to umami flavor profiles due to its elevated concentration of flavor precursors, containing non-volatile molecules such as reducing sugars, amino acids, nucleotides, peptides, lipids, and thiamine, many of which possess gustatory activity[2]. *Source: 1- Singh et al. (2023); 2- Kale, Mishra and Annapure (2022).* **Umami constitutes the fifth fundamental taste perceived by the human gustatory system, complementing sweet, salty, bitter, and sour. It enhances salivation, extends the flavor profile of comestibles, and potentially reduces sodium content in culinary preparations.*

Mycelium can be used to mimic meat fibers and texture in analog products	Mycelium is the name given to the structure that constitutes the biomass of filamentous fungi, composed of branched filament structures that resemble meat fibers and are rich in proteins[1]. Therefore, mycelium can be used as the main ingredient in meat analog products because it has interesting texture and neutral flavor characteristics, depending on the species used. In addition, the product's structure can remain intact after cooking, making it possible to cut it, as in animal-based products[2]. Thus, it is possible to obtain meats analogous to beef (Adamo Foods), pork (Bosque Foods), chicken (Meati), fish (Esencia Foods) and seafood (Aqua Cultured Foods). *Source: 1- Holt et al. (2023); 2- Ahmad et al. (2022).*

Biomass fermentation products have high nutritional value	Biomass fermentation can provide foods with high nutritional value[1]. In general, microbial biomass is rich in proteins and fibers and has low fat content. It is also rich in minerals and vitamins. The nutritional profile differs depending on the microorganism used in the process and the product's formulation. For example, yeasts have high amounts of oligosaccharides and beta-glucan, which are known for their prebiotic properties, promoting intestinal health[2]. Another important aspect is that some microbial protein sources provide all the essential amino acids for the human diet, just like conventional meat [3]. *Source: 1- Bratosin, Darjan and Vodnar (2021); 2- Rai, Pandey, and Sahoo (2019); 3- Saeed et al. (2023).*

Biomass fermentation is also an alternative to produce oils	Single-cell oil species can also play a crucial role in the alternative protein industry, and can be used in microbial-based products, plant-based analogs, and cultivated meat. Microbial oils may be similar to plant oils, depending on the fatty acid profile, and may also be a more sustainable and efficient production alternative. *Source: Stellner et al. (2023).*

Microbial protein production can significantly reduce the environmental impact and cost of ingredient production when compared with conventional protein production	Technical-economic analyses (TEA) demonstrate that an ingredient made from *Fusarium venenatum* biomass can be produced for values ranging from US$ 3.55/kg (US$ 29.56/kg of protein)[1] to US$ 5.04/kg (US$ 40.04/kg of protein)[2], indicating that this alternative already competes economically with the price of beef cuts, especially when examining costs based on protein content. The studies also reinforce that potential reductions in cost to reach price parity with cheaper products, such as chicken, can be achieved through advances in specific parameters of the microorganism, such as protein content and growth speed. Regarding process impacts, life cycle assessment (LCA) results demonstrated significant sustainability benefits of mycoprotein* produced with lignocellulosic substrate, with greenhouse gas emissions of less than 14% of emissions from beef protein production[2]. Additionally, diversifying feedstocks, such as lignocellulosic residues or gases (gas fermentation) as substrates, can provide even lower environmental impacts. A bacterial protein produced from H_2, O_2 and CO_2 gases, for example, provides 53 to 100% less environmental impact than animal-based food proteins[3]. --- *Source: 1- Risner et al. (2023); 2- Upcraft et al. (2021); 3-Järviö et al. (2021).* *Term that defines the protein derived from fungi, originating from the Greek term "myco" meaning fungus.*

Microbial biomass can also be used as an input in the cultivated meat value chain	Beyond the role of adding flavor, protein content, and texture to final products, the utilization of fungi as edible scaffolds –three-dimensional structures used to support cell adhesion and growth– has been investigated to improve cultivated meat structure[1,2]. Furthermore, fungi and microalgae biomass may be employed in the production of culture medium constituents, as a protein source, or as a source of amino acid-rich hydrolysates. --- *Source: 1- Wang et al. (2024); 2- Ogawa et al. (2022); 3-Nakazawa et al. (2018); 3- Combe et al. (2024).*

2. Why is biomass fermentation promising in Brazil?

Brazil possesses a distinctive advantage through its mature production chain for fermentation-derived bioproducts, complemented by substantial feedstock production. The country leads the global sugarcane production and achieved a record in sugar production, reaching more than 46 million tons (Brasil Deve Atingir..., 2024). Sugarcane is one of the most promising biomass resources in the bioeconomy, as it is a source of fermentable sugars and lignocellulosic biomass that can be converted into a wide variety of products (Karp et al., 2022).

A total of 86% of Brazilian researchers work in studies involving the use of industrial and/or agro-industrial wastes as components of the culture medium[1]	In addition to the wide availability of traditional fermentable substrates such as cane sugar, the use of agro-industrial by-products and wastes as a source of carbon and nitrogen for fermentation-derived protein production provides an opportunity to reduce the costs and environmental impacts of the processes. Brazil produces billions of tons of these materials annually, which motivates the work of several researchers in alternatives for valuing these by-products. *Source: 1- survey conducted by The Good Food Institute Brasil*

Opportunity for a growing national market: Addition of mycelium in formulations of plant-based analogs can improve quality parameters of these products[1]	The results of a study that evaluated the production of plant-based low-moisture meat analog incorporating mycelium into pea protein isolate using extrusion[1], for example, demonstrated that the addition of up to 30% of mycelium has minimal effect on the structure, but improves quality parameters (water solubility index, water and oil absorption capacity, water holding capacity, expansion rate, etc.), leading to the formation of a fibrous meat analog food product. Mycelium-based ingredients may be an option for the industry that has not yet managed to deliver the desired balance between taste, price, convenience, and health promotion, as found in the research on Brazilian consumers and the plant-based market[2]. *Source: 1- Mandliya et al. (2022); 2- Lupetti and Casseli (2024).*

Scientific production: exploring microbial biodiversity and the diversity of Brazilian feedstocks	Brazilian researchers are engaged in isolating new strains of microorganisms with high protein contents of proteins, lipids and micronutrients, such as vitamins, minerals and bioactive compounds, using agro-industrial wastes. This trend is supported by recent Brazilian scientific publications[1,2,3,4], which highlight yeast, microalgae and mycelium as promising sources of nutritious biomass. Some projects of the BIOMAS program, an initiative of GFI Brazil, investigate this potential, such us "Amazonian fungi as a potentially healthy and sustainable alternative for the development of meat analog food products,"[5] "Bioconversion of by-products of the nut agroindustry in the Amazon into *plant-fungi-based* protein,"[6] and "Development of flour ingredient from babassu by-products after hydrolysis and fermentation process to formulate meat analog products"[7]. The scientific production on the theme also includes review articles on microbial protein potential as a sustainable alternative to meat, using agro-industrial wastes[8] and advances in bioprospecting lipid-producing microorganisms[9] (single-cell oil). *Source: 1- Bitencourt et al. (2022); 2- Pessoa et al. (2023); 3- Fratelli et al. (2023); 4- Pesquisadores do INCT... (2024) ; 5- Bicas (2022); 6- Sales-Campos (2022); 7- Carvalho Netto (2022); 8- Alves et al. (2023); 9- Soccol et al. (2022).*

The similarity between the equipment utilized in the brewing industry and that required for biomass fermentation presents an opportunity for equipment retrofitting* and the enhancement of food manufacturing capacity in Brazil	Compared with precision fermentation, biomass fermentation is a technology with lower complexity and cost. The equipment required for this technology is similar to that used in the brewing industry, including fermenters, temperature control systems, agitators or aeration systems, filtration systems, and drying and final processing equipment. This may be a significant opportunity for the Brazilian market since the country has large fermentation industries that cover food, beverages, and ethanol production. Seasonality in some of these industries may result in operation below full capacity during some periods of the year, suggesting an opportunity for biomass fermentation production, providing profits and driving sustainable development in the food sector. *Source: Fermentation Manufacturing Capacity... (2024).* **It refers to updating, modernizing, or adapting equipment to implement new features.*

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GFI Brazil Team

Alexandre Cabral
Executive Vice President

Alysson Soares
Public Policy Specialist

Ana Carolina Rossettini
Development and Strategy Manager

Amanda Leitolis, Ph.D.
Science and Technology Specialist

Ana Paula Rossettini
Human Resources Analyst

Bruno Filgueira
Corporate Engagement Analyst

Camila Nascimento
Operations and Finance Analyst

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Cristiana Ambiel, MS.
Director of Science and Technology

Fabio Cardoso
Communication Analyst

Gabriela Garcia, MS.
Public Policy Analyst

Gabriel Mesquita
Corporate Engagement ESG Analyst

Graziele Karatay, Ph.D.
Science and Technology Specialist

Guilherme de Oliveira
Corporate Engagement
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Julia Cadete
Operations Analyst

Karine Seibel
Operations Manager

Lorena Pinho, Ph.D.
Science and Technology Analyst

Luciana Fontinelle, Ph.D.
Science and Technology Specialist

Luiz Ribeiro
Communication Analyst

Lívia Brito, MS.
Communication Analyst

Manuel Netto
Public Policy Analyst

Mariana Bernal, MS.
Public Policy Analyst

Mariana Demarco, Ph.D.
Science and Technology Analyst

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Executive Assistant

Raquel Casselli
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