Mycelium as Food

When will it be approved as a Novel Food?

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Abstract

Edible mushrooms have been consumed by humans for centuries, yet there is a regulatory distinction between the fruiting body and the mycelium. While the fruiting bodies of well-known species like champignons or oyster mushrooms are considered food, the associated mycelium is classified as a "novel food" and can only be brought to market after safety assessment and approval. This article explains why that is, what constitutes a novel food, and how the market is currently developing.

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Introduction

Mushrooms have been a part of the human diet for centuries. Their edibility or toxicity have been extensively tested by our species through trial and error. The best candidates for human consumption have been selected over time and are now cultivated in racks or on substrate blocks in conditioned climate chambers to ensure a continuous supply. A supply in significant quantities: According to the German Federal Statistical Office, approximately 78,000 tons of mushrooms were harvested in Germany last year [1]. Today, every well-stocked supermarket offers not only white and brown button mushrooms *(Agaricus bisporus)* but also king oyster mushrooms *(Pleurotus eryngii)*, oyster mushrooms *(Pleurotus ostreatus)*, or shiitake *(Lentinula edodes)*.
Technological advancements now allow for the cultivation of not only the fruiting bodies but also the mycelium, the normally hidden "root network" of mushrooms, found in the soil or tree bark. If provided with an adequate nutrient medium, the mycelium can be multiplied under sterile conditions in liquid culture without forming fruiting bodies (◆ Figure 1). This offers several advantages in the context of climate change and the growing world population:
The area required for production is used more efficiently, similar to a vertical farming approach. Since fermenters can be set up and operated under the same conditions anywhere in the world, the production process is location-independent. No pesticides or antibiotics are needed in sterilized nutrition media to suppress the growth of competing species. Independence from weather and season provides production security, even during extreme weather events. Additionally, the production time for submerged mycelium cultivation is significantly shorter than the cultivation time needed until fruiting bodies can be harvested.

The Novel Food Regulation

According to EU Regulation 2015/2283, foods are considered novel if they were not consumed to a significant degree in the European Union prior May 15, 1997, and fall into one of ten specified categories [3]. This includes foods consisting of or isolated from or produced from fungal cell cultures. These products must be evaluated regarding their safety to protect the population before they can be placed on the market. Specifically, this means that the fruiting bodies of button mushrooms, oyster mushrooms, or shiitake are not considered novel foods and are therefore not affected by this regulation; however, the mycelium of these edible mushrooms is, and a separate authorization is required.
The path to an authorized novel food leads through the EFSA (European Food Safety Authority), which, upon receipt of a valid application from the European Commission, conducts

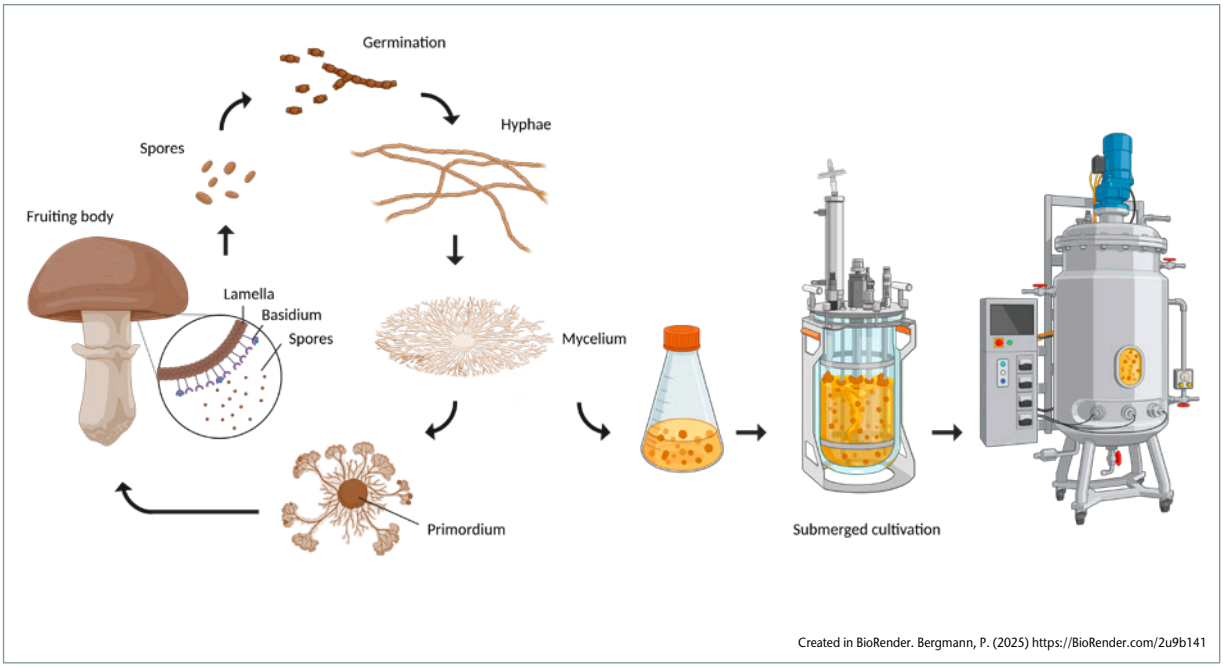

Fig. 1: **The life cycle of a basidiomycete and the biotechnological utilization of mycelium** [2]

a scientific evaluation. A maximum processing time of nine months is stipulated. In practice, however, the procedures often take much longer due to missing data and the associated need for further documentation. Authorized novel foods are included in the Union list [4]. Next to the house cricket *(Acheta domesticus)* or Antarctic krill *(Euphausia superba)*, for example, some products from mushrooms can already be found there (◆ Table 1).

The safety assessment for microorganisms can be accelerated through a QPS status (Qualified Presumption of Safety), which is granted based on the state of knowledge about the taxonomic identity and the associated low potential safety concerns. However, filamentous fungi, both ascomycetes and basidiomycetes, have been excluded from QPS evaluations [6].

Fruiting body vs. mycelium

Are the fruiting bodies and mycelium of, for example, button mushrooms so different that one must be extensively evaluated as a novel food, while the other does not?

The mycelium represents the vegetative part of the fungus and consists of a network of hyphae that absorb nutrients from the environment. In contrast, fruiting bodies are the reproductive structures that develop from the mycelium under suitable conditions and are responsible for the production and dissemination of spores (◆ Figure 1). Due to their different biological roles, the molecular composition of mycelium and fruiting bodies can differ significantly, even if the genetic information is the same. These differences can be observed in the gene expression profile, as described for shiitake, truffles, and the bay bolete [7–9]. Depending on environmental conditions and the phase of differentiation, various genes are up- or down-regulated, leading to different metabolite concentrations in the cells. For example, higher fat contents were found in fermentatively produced truffle mycelium compared to the fruiting body, while the fatty acid composition was nearly identical [10]. It should not be overlooked that the natural variations in the composition of mushrooms are generally significant. Mushrooms are known and appreciated for their high adaptability to various substrates, and even different generations of the same species show noticeable differences [11, 12].

Since environmental or cultivation conditions (light, temperature, nutrition medium, etc.) have a significant influence on the composition of the fruiting body and mycelium, not only the final product or the production strain is considered in the novel food approval, but the entire production process. Therefore, there is no generally valid approval.

In terms of meat alternatives, biotechnologically produced mushroom mycelium could complement the product range: The biomass already has a fibrous texture due to filamentous growth, similar to muscle fibers. Unlike products of plant origin, it does not necessarily have to be extruded or textured in a complex manner. Isolated mycoprotein could be used analogously to plant protein in the broad range of vegetarian and vegan food products.

Species	Product	Status	
Button Mushroom *(Agaricus bisporus)*	fruiting body	food, not novel	✓
	fruiting body enriched with Selenium und Cobalamin (Vitamin B_{12})	food, not novel	✓
	fruiting body, treated with UV light post-harvest to increase Vitamin D_2 contents	approved novel food	✓
Almond Portobello *(Agaricus blazei)*	fruiting body	food, not novel	✓
	dehydrated mycelium powder	novel food, not yet approved	✗
Shiitake *(Lentinula edodes)*	fruiting body	food, not novel	✓
	aqueous extract of the mycelium of *L. edodes*, cultivated in submerged fermentation	approved novel food	✓
	pea and rice protein fermented with mycelium[a]	approved novel food	✓
	dehydrated mycelium powder	novel food, not yet approved	✗
Oyster Mushroom *(Pleurotus ostreatus)*	fruiting body	food, not novel	✓
	beta-glucan	food, not novel	✓
	mycelium and dehydrated mycelium powder	novel food, not yet approved	✗
Stout Camphor Fungus *(Antrodia camphorata)*	freeze-dried mycelium from solid-state fermentation for dietary supplements	approved novel food	✓
Tinder Fungus *(Fomes fomentarius)*	chitin-glucan complex from cell walls of fruiting bodies for dietary supplements	approved novel food	✓
Vitamin-D_2-Mushroom-Powder[a]	mushrooms treated with UV light after harvest, dried and grounded	approved novel food	✓

Tab. 1: **Basidiomycetes as food and their status regarding the Novel Food Regulation**
Excerpts from the Union List of Novel Foods (EU Regulation 2017/2470 [4]) and the online accessible Novel Food Status Catalog [5]
[a] subject to data protection and may only be marketed in the EU by the applicant until it expires or with their consent

It should be considered that many edible mushrooms can cause intolerances (e.g., stomach pain, digestive problems) when consumed raw or contain the (easily destructible) toxin agaritin. To what extent possible intolerances also apply to the mycelium of these edible mushrooms remains to be clarified by reliable studies. For the submerged cultivated mycelium of the button mushroom, lower contents of agaritin are reported compared to the fruiting body [13, 14]. However, thermal treatment before consumption is always advisable.

From a nutritional perspective, mushrooms generally come off well: They consist mostly of water (85–95% of the fresh weight) and usually contain few simple carbohydrates (sugars) or fat, but many dietary fibers and a lot of protein. Depending on the species, growth conditions, and other factors (see above), they contain between 9–43% protein based on the dry mass [15]. There are few directly comparative data on mycelium and fruiting bodies, as the fruiting bodies are often cultivated under different conditions than the mycelium in liquid culture. The nutrient composition can vary significantly depending on the species, substrate, and cultivation conditions. The protein quality of "Quorn", the currently only meat substitute product from submerged cultivated (mold) mycelium on the European market, was rated 0.99 out of 1 in the Protein Digestibility Corrected Amino Acid Score (corrected amino acid score based on fecal digestibility of dietary protein) and thus performs better than soy (0.91) or beef (0.92) [16, 17]. The total carbohydrate content ranges from 34–72%, with chitin and glucans from the cell walls making up the largest share as dietary fibers. The fat content is given as 1–8%, with linoleic acid, α-linolenic acid, palmitic acid, and oleic acid being the most frequently occurring fatty acids [18, 19]. The cell membranes naturally contain ergosterol, which can be converted to vitamin D_2 under UV-B radiation. Button mushrooms treated with this method are already approved as novel foods (◆ Table 1).

Research in the NewFoodSystems innovation cluster

Another advantage that basidiomycetes bring is their ability to grow on a wide variety of side streams from the agricultural and food industries. As important decomposers in the forest, they possess enzymes that can break down lignin, a substance that is difficult to degrade in lignified plant cell walls. Whether it's bran, spent grains, pomace, press cake, or whey, many side streams of food quality can be used as substrates for fermentation. Mycelium as food can therefore help avoid waste and support the goal of a circular economy in the sense of sustainability. Within the NewFoodSystems innovation cluster, the project "LacOat4Fungi", funded by the German Federal Ministry of Research, Technology and Space (*Bundesministerium für Forschung, Technologie und Raumfahrt*, BMFTR), addresses this issue. The project partners include Milei GmbH, the Fraunhofer Institute for Process Engineering and Packaging IVV, Albert Handtmann Maschinenfabrik GmbH & Co. KG, Albert Handtmann Armaturenfabrik GmbH & Co. KG, and Justus Liebig University Giessen. The goal of the project is to produce new food systems based on biotechnologically produced mycelium. For the production of these foods, unlike many other vegan and vegetarian products with similarities to animal-derived products, no crops such as peas or soybeans need to be cultivated. Instead, two existing but so far little used side streams from the food industry are used as substrates for fermentation: oat okara from oat drink production and a whey concentrate that accumulates during cheese production.

Since the start of the project in November 2023, 56 edible mushrooms have already been monitored, and their growth on the side streams has been characterized. Suitable mushroom-substrate combinations have been identified, and pilot-scale production is now on the horizon. After cultivation, the insoluble and soluble fractions of the mycelium are isolated. These are then to be used, depending on their properties and texture, for the development of alternative meat and dairy products.

How is the current market situation?

Several start-ups have been working on the cultivation of mycelium for some time. German examples include Infinite Roots from Hamburg, Kynda Biotech from Jelmstorf near Uelzen, and Nosh.bio from Berlin.

Whether the mycelium obtained by fermentation can be marketed as food must be clarified on a case-by-case basis. According to a press release from the Lower Saxony Ministry of Food, Agriculture and Consumer Protection, the mycelium produced by Kynda Biotech is not considered a novel food and therefore does not require approval [20]. The production strain remains a secret, so it can only be speculated that it might be the mold *Fusarium venenatum*; the only mycelium currently available on the European market that does not require approval under the Novel Food Regulation despite being produced in liquid culture. It has been sold since 1985 in the UK under the name "Quorn" and thus predates the cutoff date of May 15, 1997, by 12 years.

Meanwhile, the *Handelsblatt* reports that competitor Infinite Roots submitted an application for approval to EFSA for its product two years ago [21]. However, they are not listed among the ongoing applications that can be viewed on the website of the European Commission [22]. However, there is a hit with the American counterpart of the EFSA, the FDA (U.S. Food and Drug Administration). The application for GRAS status (Generally Recognized as Safe) for the mycelium of the lung oyster *(Pleurotus pulmonarius)* is still under review [23].

The American GRAS status can be considered equivalent to the European QPS status and was recently granted to the mycelium of the red bread mold *(Neurospora crassa)* produced by The Better Meat Co. [24]. The ascomycete is now allowed to be used in meat, fish, and dairy analogs in the USA. Nosh.bio also works with a mold: "Koji" *(Aspergillus oryzae)*, which is also used in the fermentation of soybeans to produce soy sauce, for example [25]. The submerged cultivated biomass is approved in both the USA and the EU. Recently, a product similar to fresh cheese was introduced into the German retail market, based on "Koji protein" and developed by the Berlin start-up Formo.

The mycelium of molds is already on the rise, while the mycelium of basidiomycetes, which are valued as food, is still waiting for its safety assessments. It will take some time before mycelium and fruiting bodies of the well-known edible mushrooms can be found side by side in the local supermarket. Nevertheless, the authors of this article appreciate that our legislator prioritizes consumer protection and food safety and are willing to wait for EFSA's evaluations.

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For more information, visit
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Disclosure on Conflicts of Interest and the use of AI
The authors declare that there is no conflict of interest and that no AI applications were used in the creation of the manuscript.

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