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A Comprehensive Review on the Sanitary, Nutritional, and Functional Quality of Edible Mushrooms and Innovations for Food Quality Enhancement

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Edible mushrooms are increasingly recognized as valuable food resources with significant nutritional, functional, and sanitary attributes, alongside emerging innovations to enhance their food quality and safety. This review synthesizes current knowledge on microbial and chemical contamination risks in edible mushrooms, highlighting prevalent bacterial pathogens, fungal contaminants, and bioaccumulated heavy metals and pesticides. Variability in contamination levels across species and ecological zones underscores the need for targeted hygienic practices, environmental monitoring, and regulatory oversight. Innovations such as hygienic cultivation and harvesting techniques, smart packaging with controlled atmosphere storage, advanced post-harvest treatments, and cutting-edge analytical technologies are transforming mushroom production, improving shelf life, and ensuring food safety compliance. Despite these advances, challenges remain in post-harvest conservation, standardization of indigenous species' valorization, and integration of mushrooms into novel food products like fortified flours, functional beverages, and nutrient-enriched pastries. Addressing these challenges through multidisciplinary research, capacity building, and policy support is essential to unlock the full potential of edible mushrooms as sustainable, functional foods that contribute to improved nutrition and public health in Africa and globally.

Introduction

Mushrooms are ubiquitous organisms that grow in a wide variety of natural environments across the globe. Accurately assessing the diversity of these fungi proves to be challenging due to their vast variability (Yorou & Codjia, 2017; Ganguly *et al.,* 2022). Globally, the estimated number of fungal species ranges from 3.5 to 6 million, yet only 14% of this fungal heritage has been identified (Yorou & Codjia, 2017). These organisms, distinct from plants and animals, play a vital role in maintaining ecosystem balance. They primarily belong to the phyla Basidiomycota and Ascomycota (Ganguly *et al.,* 2022).

Human use of fungal resources dates back to the Stone Age and spans various domains, including food (with distinctions between edible and non-edible varieties) and pharmacology. Initially foraged, some mushroom species have been domesticated and cultivated to enhance their availability for both food and medicinal purposes. For example, the Shiitake mushroom (*Lentinus edodes*) has been cultivated for over 1,000 years in Japan and China, while the common button mushroom (*Agaricus bisporus*) has been cultivated since the 18th century in Europe and from the 1980s in North America. According to Wang & Zhao (2023), China boasts more than a hundred domesticated edible species and over sixty commercially cultivable species, including *Lentinus edodes*, *Auricularia auricula*, *Pleurotus ostreatus*, *Flammulina velutipes*, *Pleurotus eryngii*, *and Agaricus bisporus.*

Africa also has a rich diversity of edible mushrooms. In West Africa, for instance, over 160 edible species have been identified (Kesel *et al.,* 2024). However, the popular consumption of mushrooms in Africa remains a challenge. Urban culinary habits are gradually shifting towards Western lifestyles, and as a result, traditional mushroom-based diets are declining with each generation. This situation is further compounded by limited knowledge and the prevalent mistrust surrounding mushrooms. However, in rural areas, mushrooms continue to hold significant importance, with local populations relying heavily on them. Therefore, raising awareness, particularly among urban populations, is crucial to giving mushrooms a more prominent place in human nutrition (Ba *et al.,* 2014).

According to Wang & Zhao (2023), the composition of mushrooms (flavoring compounds, nutrients, bioactive substances, and potential allergens) positions them as potential sources for producing meat analogs. Rangel-Vargas *et al.,* (2021) highlight studies showing that mushrooms can replace meat, flour, and salt, and help reduce the use of phosphates, nitrites, and synthetic antioxidants. However, attention must be paid to the interactions between properties and the technologies used in processing.

In Benin, mushrooms are a part of local gastronomy, particularly during the rainy season when they are abundant (De Kesel *et al.,* 2002). These fungi are commonly used in sauces and can replace fish or meat in various dishes. The bakery sector is another promising area for agro-food innovation. Products such as biscuits and cakes are popular, flavorful, durable, and offer opportunities for nutritional enrichment (minerals, vitamins, proteins). The incorporation of edible mushrooms into such products could significantly advance this sector (Salehi, 2019).

This review aims to contribute to the valorization of edible mushrooms. After providing an overview of edible mushrooms, their sanitary, nutritional, and bioactive qualities, as well as their uses, the paper will explore innovations in the development of agro-food products, highlighting both challenges and opportunities.

Materials and Methods

This review is based on a comprehensive analysis of scientific articles, and relevant publications concerning the sanitary, functional, and nutritional quality of edible mushrooms, with a focus on innovations in food quality enhancement. A search of academic databases such as PubMed, ScienceDirect, Google Scholar, and Scopus was conducted using keywords like "edible mushrooms," "sanitary quality," "functional properties," "nutritional value," "food quality enhancement," and "innovations in mushroom applications." Studies published between 2000 and 2024 were included to ensure a balance of foundational knowledge and recent advancements. The inclusion criteria focused on research that addressed the quality attributes of edible mushrooms, technological innovations for improving food quality, and their applications in food products such as meat analogs, bakery items, and fortification. Exclusion criteria involved studies unrelated to edible mushrooms or lacking relevant data. Extracted data were categorized into themes such as sanitary quality, functional properties, nutritional value, and innovations in food quality enhancement. Special emphasis was placed on recent developments in using mushrooms to enhance food products, such as improvements in sensory properties, shelf-life, and nutritional content. The selected studies were critically evaluated to identify gaps in knowledge, challenges in applying mushrooms in food systems, and opportunities for future research. The findings were then synthesized to provide a comprehensive understanding of the benefits of edible mushrooms, offering insights into their potential role in improving food quality and addressing global food security and health challenges.

Result and Discussion

Diversity and edibility of mushrooms

Edible mushrooms constitute a taxonomically and ecologically diverse group of macrofungi with significant nutritional, medicinal, and economic relevance. Their edibility and usage vary widely across regions and cultures, and they are broadly classified into two categories based on their mode of acquisition: wild-harvested and cultivated mushrooms (Sharma, 2019, Tripathi *et al.,* 2017).

Wild mushrooms are foraged from natural ecosystems such as forests, woodlands, and savannahs. They include species like *Boletus edulis* (porcini), *Cantharellus cibarius* (chanterelle), *Morchella spp.* (morels), and *Termitomyces spp.*, which are highly prized for their unique organoleptic properties and high market value (Stojanova *et al.,* 2017; Novakovic *et al.,* 2020). While wild mushrooms contribute significantly to seasonal diets and local economies, their collection carries inherent risks due to the morphological similarity of edible and toxic species, highlighting the importance of taxonomic knowledge and safe foraging practices (Imaobong *et al.,* 2025).

In contrast, cultivated mushrooms are produced under controlled environmental conditions that allow for standardized quality, predictable yields, and year-round availability. Globally dominant cultivated species include *Agaricus bisporus* (button, cremini, portobello), *Lentinula edodes* (shiitake), *Pleurotus spp.* (oyster mushrooms), and *Flammulina velutipes* (enoki). The development of novel substrates, improved spawn production, and optimized growth parameters has expanded the range of cultivable species, supporting both smallholder livelihoods and industrial-scale operations Chang and Wasser, 2017; Mleczek *et al.,* 2020).

The global consumption patterns of edible mushrooms reflect both cultural preferences and local biodiversity. In East Asia, mushrooms such as shiitake and wood ear (*Auricularia spp.*) are deeply integrated into traditional cuisine and medicine (Tabuchi *et al.,* 2021). In Europe, especially in Central and Eastern regions, wild mushrooms are culturally significant and frequently featured in gastronomy (Procházka *et al.,* 2023). In sub-Saharan Africa, species like *Termitomyces* are essential protein sources and are commonly sold in informal markets during the rainy season (Ndifon, 2022). These consumption practices underscore the interplay between ecological availability and cultural adaptation.

Mushrooms also hold considerable ethnobotanical significance, serving as both nutritional resources and medicinal agents in various traditional systems. Their culinary value is closely tied to their umami-rich flavor, textural complexity, and versatility in food preparation. Furthermore, traditional knowledge surrounding the identification, harvesting, and preparation of mushrooms constitutes an important component of intangible cultural heritage, particularly in Indigenous and rural communities (Hayat *et al.,* 2024; Jiang *et al.,* 2023).

Nutritional value of edible mushrooms

Edible mushrooms are recognized for their well-balanced nutritional profile, comprising both macronutrients and micronutrients that are essential for human health. Although technically fungi, they are often categorized as vegetables in dietary contexts due to their culinary uses and nutrient composition (Yao *et al.,* 2020). The edible part, known as the fruiting body or sporocarp, is the primary source of these nutrients.

Macronutrient content

Mushrooms are particularly valued for their high-quality protein content, which typically ranges from 15% to 35% on a dry weight basis, depending on species and cultivation conditions. They contain essential amino acids such as lysine, leucine, and methionine, which are often deficient in cereal-based diets. This makes mushrooms a strategic dietary supplement, especially in regions with protein-energy malnutrition or in plant-based diets (Wang & Zhao, 2023; Dimopoulou *et al.,* 2022).

In addition to proteins, mushrooms are a notable source of complex carbohydrates, primarily in the form of dietary fibers such as β-glucans, chitin, and mannans. These fibers support gut health by modulating the microbiota, improving intestinal transit, and contributing to satiety (Yu *et al.,* 2020).

Although mushrooms contain relatively low levels of lipids, the small quantities present are mostly unsaturated fatty acids, contributing positively to cardiovascular health. Their fat content is generally below 5% of dry matter, making them a naturally low-fat, heart-friendly food.

Micronutrient Profile

From a micronutrient perspective, edible mushrooms are rich in B-complex vitamins, notably riboflavin (B_2), niacin (B_3), and pantothenic acid (B_5), all of which play critical roles in energy metabolism and neurological function. Furthermore, they are among the rare plant-derived sources of vitamin D, particularly vitamin D_2, which can be synthesized when mushrooms are exposed to ultraviolet (UV) light during cultivation or post-harvest handling (Yao *et al.,* 2020). UV-treated species such as *Agaricus bisporus* and *Pleurotus ostreatus* can provide substantial contributions to daily vitamin D requirements, supporting bone and immune health. Mushrooms also supply important minerals including potassium, phosphorus, selenium, and iron. Potassium is essential for maintaining normal blood pressure, while selenium acts as a powerful antioxidant involved in DNA repair and immune defense. The relatively low content of antinutritional factors in mushrooms improves the bioavailability of these micronutrients compared to many plant foods (Kokkoris *et al.,* 2019).

Energy Value

Mushrooms are naturally low in energy, with a caloric density of approximately 20 to 35 kcal per 100 g of fresh weight. This makes them particularly suitable for weight management and energy-restricted diets, as they offer satiety and nutritional density without contributing excess calories (Singh, 2023).

Comparison with other food sources

When compared to other food groups, mushrooms occupy a unique nutritional niche. While they do not rival animal-sourced foods in total protein concentration, their amino acid profile is often more balanced than that of cereals and many vegetables. Their fiber content rivals or exceeds that of common vegetables, and their micronutrient richness, especially in terms of B vitamins and trace elements, enhances their role as a functional food. Importantly, mushrooms can bridge nutritional gaps in vegetarian and vegan diets by providing vitamin D and bioavailable minerals typically scarce in plant-based sources.

Functional properties and bioactive compounds

Edible mushrooms are increasingly valued not only for their nutritional attributes but also for their broad spectrum of functional properties, largely attributable to a rich diversity of bioactive secondary metabolites. These include polysaccharides, phenolic compounds, and terpenoids, all of which contribute significantly to the health-promoting potential of mushrooms and have generated considerable interest for their use in nutraceuticals and functional foods (Kumar *et al.,* 2021; Fitsum *et al.,* 2025). Mushrooms have been scientifically validated as a rich source of medicinal bioactive molecules (Loni *et al.,* 2025).

Among these compounds, polysaccharides particularly β-glucans located in the fungal cell walls are the most extensively studied. β-(1→3), (1→6)-D-glucans are known to exert potent immunomodulatory and antitumor activities, primarily through interactions with immune effector cells such as macrophages and natural killer cells. In parallel, mushrooms are rich in phenolic compounds such as gallic acid, caffeic acid, and flavonoids, which exhibit strong antioxidant properties by scavenging reactive oxygen species (ROS), thereby mitigating oxidative stress and cellular damage (Flores *et al.,* 2024; Vetter, 2023). Terpenoids, abundantly found in species such as *Ganoderma lucidum*, *Cordyceps militaris*, and *Lentinula edodes*, further enhance the therapeutic profile of edible mushrooms. These metabolites possess notable anti-inflammatory, antiviral, and hepatoprotective properties, and have demonstrated selective cytotoxicity against various cancer cell lines. The synergistic action between polysaccharides, phenolics, and terpenoids underpins the multifunctional bioactivity observed in many mushroom extracts (Ahmad *et al.,* 2023, Paisansak *et al.,* 2021, Jafari *et al.,* 2023).

An expanding body of literature supports the physiological relevance of these compounds. Antioxidant activity, driven primarily by phenolics and polysaccharide-protein complexes, confers protection to lipids, proteins, and nucleic acids against oxidative degradation. Additionally, immunomodulatory effects are well-established, with certain mushroom-derived compounds, such as lentinan from *Lentinula edodes* and polysaccharide-K (PSK) from *Coriolus versicolor*, already employed as adjuvant therapies in oncology in various countries (Joseph *et al.,* 2018; Tomasz, 2023; Sánchez-García *et al.,* 2023).

Furthermore, the antitumor capabilities of mushrooms involve mechanisms such as apoptosis induction, angiogenesis inhibition, and interference with oncogenic pathways. Their anti-inflammatory actions are also compelling, as evidenced by their ability to downregulate key pro-inflammatory mediators like TNF-α, IL-6, and COX-2. These multifunctional effects support the integration of mushrooms into dietary strategies targeting chronic inflammation, metabolic syndromes, and immune dysregulation (Nandi *et al.,* 2024).

The significance of these functional attributes is reflected in the growing development of mushroom-based nutraceuticals and functional foods. Mushroom extracts are increasingly incorporated into capsules, powders, teas, and health beverages, while also being added to conventional food matrices such as snacks and meat substitutes. This trend aligns with the global push toward natural, plant-derived bioactives in preventive health management (Elkhateeb *et al.,* 2019; Kumar *et al.,* 2021; Fitsum *et al.,* 2025).

Notably, Table 2 highlights a range of bioactive compounds identified in different mushroom species, along with their associated health benefits and ethnobotanical uses across various cultures. For instance, *Agaricus bisporus* contains flavonoids and lectins with anti-inflammatory and insulin-regulating effects, while *Ganoderma lucidum* is rich in triterpenoids and β-glucans known for their immunomodulatory, antitumor, and antiviral properties. Mushrooms such as *Flammulina velutipes*, *Pleurotus ostreatus*, and *Lentinula edodes* exhibit multifunctional activities, including antioxidant, antimicrobial, and hypolipidemic effects (Bhambri *et al.,* 2022; Shamim *et al.,* 2023; Chugh *et al.,* 2022).

Despite these promising attributes, challenges remain in standardizing the extraction and quantification of bioactives, ensuring reproducibility of therapeutic outcomes, and conducting rigorous clinical validation. Nevertheless, edible mushrooms represent a unique reservoir of functional compounds with vast potential to contribute to dietary and therapeutic interventions aimed at improving human health (Fitsum *et al.,* 2025).

Sanitary quality and microbial risks

The sanitary quality of edible mushrooms is a vital concern in ensuring consumer safety, particularly due to their high moisture content and porous structure, which make them susceptible to microbial and chemical contamination. From cultivation through to post-harvest handling and marketing, mushrooms encounter multiple sources of potential hazards, including environmental pollutants, unsanitary handling practices, and inadequate storage conditions (Meng *et al.,* 2024).

Microbial Contamination

Microbiological safety assessments of edible mushrooms have become increasingly important, especially in regions such as Benin where consumption and commercialization are growing. Several studies have investigated bacterial, fungal, and parasitic contaminants in both cultivated and wild mushroom species. These assessments, often conducted across diverse ecological zones, aim to identify the presence and prevalence of harmful microorganisms and to develop appropriate mitigation strategies to ensure food safety (Schill *et al.,* 2021; Zhang *et al.,* 2018; Venturini *et al.,* 2011; Chen *et al.,* 2018).

Bacterial contaminants such as *Escherichia coli*, *Salmonella spp.*, *Listeria monocytogenes*, and *Staphylococcus aureus* have been frequently detected, alongside fungal contaminants like *Aspergillus*, *Penicillium*, and *Fusarium*, which can produce mycotoxins. Yeasts, though less pathogenic, contribute to spoilage and reduced shelf life (Zhang *et al.,* 2018; Venturini *et al.,* 2011; Chen *et al.,* 2018, Zhang). These microbial hazards are often linked to the use of contaminated water, poor hygiene during harvesting, and inadequate storage infrastructure.

Comparative analyses of microbial loads across mushroom species and growing environments in Benin have revealed significant variability. For instance, wild mushrooms collected in forested zones often exhibit higher contamination levels compared to those cultivated under controlled conditions. This species- and environment-specific variability is critical for developing evidence-based hygienic protocols and targeted risk management strategies. Such knowledge informs both producers and regulators in prioritizing interventions and establishing microbiological criteria specific to local contexts.

Chemical Contaminants

In addition to microbial risks, chemical contamination has emerged as a significant food safety concern. Edible mushrooms are known bioaccumulators of heavy metals, pesticide residues, and other chemical pollutants, which may originate from their growing environment, substrate composition, agricultural inputs, or atmospheric deposition. In Benin, recent studies have documented the presence of these contaminants in mushroom species from various agroecological zones. Numerous mushroom species have the ability to bioremediate, which is the process by which they degrade environmental contaminants like plastics, pesticides, and heavy metals. This capacity to purify polluted environments is especially crucial in a time when industrial operations and agricultural methods are speeding up environmental deterioration. Mushrooms, particularly those containing ligninolytic enzymes, break down organic waste and organic pollutants (Kumar and Chandra, 2020; Kim, 2021).

The occurrence of heavy metals such as cadmium, lead, arsenic, and mercury has been linked to environmental exposure from industrial activities, pesticide use, and traffic-related pollution. Research has also detected pesticide residues in both wild and cultivated mushrooms. For example, Le *et al.,* (2021) reported traces of agrochemical residues, while Ronda *et al.,* (2022) highlighted the strong bioaccumulation capacity of macrofungi for both nutrients and metal elements. Gałgowska & Pietrzak-Fiećko (2021b) also confirmed the accumulation of pesticide residues in edible mushrooms, underscoring the significance of monitoring environmental inputs in mushroom production systems.

The health implications of chronic exposure to such contaminants are considerable. Bioaccumulated toxins may induce oxidative stress, organ damage, neurotoxicity, endocrine disruption, and increased cancer risk. Understanding the mechanisms of accumulation is therefore crucial. Factors influencing uptake include the mycelial structure (with high surface area for absorption), species-specific genetic traits, the physicochemical properties of the contaminants, and competitive interactions with other elements (Kokkoris *et al.,* 2019). Ivanić *et al.,* (2021) further emphasized the influence of environmental parameters—such as substrate composition, temperature, humidity, soil pH, and organic matter—on the degree of contaminant accumulation.

Regulatory and Public Health Considerations

International sanitary standards, such as those established by the Codex Alimentarius, EFSA, and FDA, set microbiological and chemical thresholds for fresh and processed mushrooms. These include limits on total viable bacterial counts, coliforms, *Salmonella*, *Listeria monocytogenes*, as well as heavy metals and pesticide residues. However, in many low- and middle-income countries, including Benin, the enforcement of these standards remains limited due to infrastructural and institutional challenges (EFSA BIOHA *et al.,* 2024; FAO & WHO, 2023; Committee on the Review of the Use of Scientific Criteria and Performance Standards for Safe Food, National Research Council, 2003).

To ensure the safety of mushrooms across the value chain, the implementation of Good Agricultural Practices (GAP), Good Hygienic Practices (GHP), and Hazard Analysis and Critical Control Points (HACCP) is essential. Additionally, ongoing microbiological and chemical surveillance, particularly within informal markets and wild mushroom collections, is vital for public health protection (EFSA BIOHA *et al.,* 2024; FAO & WHO, 2023)

Ultimately, safeguarding the sanitary quality of edible mushrooms requires a multidisciplinary approach combining microbiological assessments, chemical monitoring, risk communication, and effective regulatory enforcement. These measures are critical for supporting consumer safety, strengthening local food systems, and promoting sustainable mushroom production in Benin and beyond.

Innovations for quality enhancement

Improving the quality and safety of edible mushrooms is a critical priority for producers, researchers, and policymakers. Innovations spanning cultivation, post-harvest processing, packaging, and analytical technologies are being increasingly adopted to address microbial and chemical risks, prolong shelf life, and preserve nutritional and functional properties. These interventions not only meet growing consumer demands for safe, high-quality foods but also align with international food safety standards. Effective methods such as High-Pressure Processing (HPP), freeze-drying, nuclear magnetic resonance (NMR), imaging technology, spectroscopy, and advanced packaging technologies have been introduced (Verma *et al.,* 2022). By implementing suitable postharvest processing and preservation methods, it is possible to maintain the sensory characteristics and nutritional value of mushrooms effectively (Dawadi *et al.,* 2022; Kumar *et al.,* 2021).

Hygienic cultivation and harvesting techniques

One of the most effective strategies for enhancing mushroom quality is the adoption of hygienic cultivation and harvesting practices. This includes the use of sterilized substrates, controlled environment farming, filtered irrigation water, and clean handling equipment. Implementing Good Agricultural Practices (GAP) and Good Hygienic Practices (GHP) at all stages from spawn production to harvesting significantly reduces the risk of microbial contamination. Training producers in these methods, particularly in smallholder and informal sectors, is vital to improving overall product quality and ensuring food safety compliance (Chang and Wasser, 2017; Mayans *et al.,* 2021).

Smart packaging and controlled atmosphere storage

Advances in smart packaging technologies are transforming the way mushrooms are stored and transported. Smart packaging systems incorporate indicators and sensors that monitor freshness, temperature, humidity, and gas composition, enabling real-time tracking of product quality. Modified Atmosphere Packaging (MAP), which adjusts oxygen and carbon dioxide levels around the product, is especially effective in slowing down microbial growth and enzymatic spoilage. These innovations extend shelf life, reduce post-harvest losses, and ensure mushrooms reach consumers in optimal condition (Sangeeta *et al.,* 2024). Smart packaging technologies encompass various functions, including antibacterial action, humidity regulation, and gas control. These functions enable the packaging to automatically adjust its internal environment according to the specific requirements of different fruits and vegetables, thereby slowing the growth of bacteria and mold, prolonging freshness, and retaining nutritional content. Despite its advantages, the widespread adoption of smart packaging technology faces several challenges, including high costs, limited material diversity and reliability, lack of standardization, and consumer acceptance. However, as technology matures, costs decrease, and degradable smart packaging materials are developed, smart packaging is expected to play a more prominent role in fruit and vegetable preservation. Future developments are likely to focus on material innovation, deeper integration of IoT and big data, and the promotion of environmentally sustainable packaging solutions, all of which will drive the fruit and vegetable preservation industry toward greater efficiency, intelligence, and sustainability (Du *et al.,* 2025, Vanderroost *et al.,* 2014).

Post-harvest treatments

Post-harvest treatments play a critical role in stabilizing mushrooms and preventing spoilage. Dehydration, particularly freeze-drying and hot air drying, reduces moisture content and microbial activity while preserving nutritional value. Gamma irradiation is another emerging technique that inactivates pathogens and extends shelf life without leaving harmful residues. Additionally, biopreservation methods, such as the use of lactic acid bacteria or natural antimicrobial compounds, are gaining traction as eco-friendly alternatives to synthetic preservatives (Dawadi *et al.,* 2022).

Recent analytical technologies

Analytical innovations are enhancing the detection, monitoring, and traceability of quality attributes in mushrooms. Biosensors portable, rapid, and sensitive devices are increasingly used for on-site detection of microbial pathogens, pesticide residues, and heavy metals. Biosensors, which integrate biological components such as enzymes, DNA, RNA, antigens, living cells, or antibodies with electronic sensing elements like conductance, intensity, electromagnetic radiation phase, electric current, mass, viscosity, electric potential, temperature, and impedance. These tools support early intervention and quality assurance in real time. Furthermore, traceability technologies such as blockchain, RFID (Radio-Frequency Identification), and QR code systems offer transparent tracking of mushroom production and distribution chains. These tools are crucial for building consumer trust, ensuring regulatory compliance, and facilitating recalls in case of food safety breaches (Inês *et al.,* 2025; Dhal & Kar, 2025; Odobašić *et al.,* 2019; Najeeb *et al.,* 2017; Thakur & Ragavan, 2013).

Challenges and future perspectives

Despite the growing recognition of edible mushrooms as valuable contributors to human nutrition, health, and economic development, several challenges hinder their optimal exploitation. Addressing these constraints and investing in targeted research are essential steps toward fully harnessing the potential of mushrooms for food security, sustainable nutrition, and public health.

A major challenge in the mushroom value chain lies in the perishability of fresh mushrooms due to their high moisture content and metabolic activity (Castellanos-Reyes *et al.,* 2021). Inadequate storage infrastructure, lack of access to cold chain systems, and limited use of preservation technologies in many regions including Benin lead to significant post-harvest losses. Additionally, the absence of standardized processing methods, such as drying protocols, packaging norms, and preservation strategies, affects product quality, safety, and market competitiveness. These limitations highlight the need for improved conservation technologies and investment in local processing capacity.

The current scientific landscape reveals important gaps in the standardization of cultivation and processing techniques, particularly for indigenous mushroom species. Many local varieties, though consumed traditionally, remain underexplored in terms of nutritional composition, bioactive potential, and functional applications. Research is needed to characterize these species, establish cultivation protocols, and develop safety and quality standards. Such efforts would facilitate the integration of native mushrooms into formal food systems and promote their use in functional products and nutraceuticals. Furthermore, systematic toxicological assessments are essential to ensure safe consumption.

Mushrooms hold promising potential for diversifying diets and contributing to sustainable nutrition. Their incorporation into composite flours for infant feeding, functional beverages, fortified pastries, and even the maturation of alcoholic drinks presents opportunities for product innovation aligned with modern consumer trends. These applications could significantly improve the nutritional density of widely consumed foods and support efforts to combat micronutrient deficiencies. In particular, the development of mushroom-enriched formulations tailored for vulnerable populations such as children, pregnant women, and the elderly offers valuable prospects for improving public health outcomes. To realize these potentials, multi-sectoral collaboration involving researchers, producers, processors, regulators, and policymakers is essential. Strengthening training programs, enhancing research infrastructure, and supporting market development through quality assurance systems will be key to positioning mushrooms as strategic resources for food sovereignty and health promotion in sub-Saharan Africa and beyond.

Table.1 Proximate Composition and Energy Value of Selected Edible Mushrooms from Various Sources

Name	Moisture (g/100 g)	Ash (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Dietary Fiber (g/100 g)	Carbohydrates (g/100 g)	Polysaccharides (g/100 g)	Energy (kJ/100 g)	Reference
***A. aegerita* (dry)**	—	—	23.1	2.3	—	56.1	—	1304	Wang & Zhao (2023)
Agaric	13.93	3.98	11.06	0.46	57.6	12.97	6.76	886	Yu et al. (2020)
Agaricus bisporus	—	—	38.7	3.3	—	31.6	—	1317	Wang & Zhao (2023)
***Agaricus bisporus* (%)**	81.79	7.12	29.29	—	24.56	20.57	—	—	El-Ramady et al. (2022)
***Agaricus bisporus* (%)**	—	9.3	25.1	1.4	2.9	52.7	—	1424	Dimopoulou et al. (2022)
***Auricularia auricula* (fresh)**	—	—	1.5	0.2	—	6.0	—	135	Wang & Zhao (2023)
***Auricularia auricula* (dry)**	—	—	12.1	1.5	—	65.6	—	1376	Wang & Zhao (2023)
Boletus	12.16	7.04	23.99	1.95	31.0	23.86	4.94	1134	Yu et al. (2020)

***Boletus edulis* (%)**	—	6.4	21.9 ± 0.2	2.6	9.9	59.2	—	1453	Dimopoulou et al. (2022)
***Cantharellus cibarius* (%)**	—	13.2	19.9	2.2	12.4	43.5	—	1257	Dimopoulou et al. (2022)
***Coprinus comatus* (%)**	—	10.5	14.2	0.9	12.3	53.8	—	1260	Dimopoulou et al. (2022)
Cordyceps militaris	10.60	5.23	25.41	1.70	20.8	36.26	6.39	1278	Yu et al. (2020)
Cordyceps militaris	12.78	4.84	25.52	1.73	21.1	34.03	5.40	1245	Yu et al. (2020)
***Cordyceps militaris* (%)**	—	4.4	23.1	0.4	11.9	49.3	—	1341	Dimopoulou et al. (2022)
Flammulina velutipes	—	6.33	18.42	—	7.81	56.37	—	—	El-Ramady et al. (2022)
***Flammulina velutipes* (fresh)**	—	—	2.4	0.4	—	6.0	—	158	Wang & Zhao (2023)
***Ganoderma lucidum* (%)**	—	2.8	19.2	2.1	11.3	57.8	—	1276	Dimopoulou et al. (2022)
Ganoderma lucidum	15.51	3.85	9.31	0.59	70.2	0.54	2.11	751	Yu et al. (2020)
Grifola frondosa	12.41	5.19	15.60	2.91	36.2	27.69	6.24	1133	Yu et al. (2020)
***Grifola frondosa* (%)**	83.06	7.0	21.1	—	10.1	58.8	—	—	El-Ramady et al. (2022)
***Grifola frondosa* (%)**	—	1.5	13.8	2.6	11.4	52.7	—	1453	Dimopoulou et al. (2022)
***Lentinula edodes* (%)**	—	6.1	20.7	1.3	3.8	31.9	—	1260	Dimopoulou et al. (2022)
Lentinus edodes	11.59	1.27	23.29	1.06	33.6	29.19	5.14	1200	Yu et al. (2020)
***Lentinus edodes* (fresh)**	—	—	2.2	0.3	—	5.2	—	137	Wang & Zhao (2023)
***Lentinus edodes* (dry)**	—	—	20.0	1.2	—	61.7	—	1433	Wang & Zhao (2023)
Pleurotus eryngii	—	—	1.3	0.1	—	8.3	—	167	Wang & Zhao (2023)
Pleurotus eryngii	9.16	6.40	19.15	0.56	27.5	37.23	6.85	1199	Yu et al. (2020)
***Pleurotus florida* (%)**	87.05	7.40	34.56	—	11.41	31.59	—	—	El-Ramady et al. (2022)
Pleurotus ostreatus	—	—	1.9	0.3	—	4.6	—	122	Wang & Zhao (2023)
***Pleurotus ostreatus* (%)**	85.05	7.05	30.92	—	12.10	31.40	—	—	El-Ramady et al. (2022)
***Russula delica* (%)**	—	17.92	26.25	—	15.42	34.88	—	—	El-Ramady et al. (2022)
Shiitake (*Lentinus edodes*)	15.38	3.81	17.95	0.94	32.1	29.82	6.35	1104	Yu et al. (2020)

Tricholoma	13.77	5.40	36.87	1.86	16.5	25.60	3.43	1263	Yu et al. (2020)
Tricholoma giganteum	—	5.0	16.1	NR	4.5	70.1	NR	NR	El-Ramady et al. (2022)
Volvariella volvacea	—	—	2.7	0.2	—	4.3	—	126	Wang & Zhao (2023)
***Volvariella volvacea* (%)**	—	12.6	30.1	—	11.9	50.9	—	—	El-Ramady et al. (2022)
Volvariella volvacea	10.24	10.08	28.10	1.19	20.7	29.69	5.83	1192	Yu et al. (2020)
***Agaricus bisporus* (brown)**	—	—	2.50	0.10	0.60	4.30	—	920	Zhou et al. (2024)
***Agaricus bisporus* (white)**	—	—	3.09	0.34	1.00	3.26	—	920	Zhou et al. (2024)
***Agaricus bisporus* (Portobello)**	—	—	2.11	0.35	1.30	3.87	—	920	Zhou et al. (2024)
Cantharellus cibarius	—	—	1.49	0.53	3.80	6.86	—	1338	Zhou et al. (2024)
Flammulina velutipes	—	—	2.66	0.29	2.70	7.81	—	1548	Zhou et al. (2024)
Grifola frondosa	—	—	1.94	0.19	2.70	6.97	—	1297	Zhou et al. (2024)
Morchella esculenta	—	—	3.12	0.57	2.80	5.10	—	1297	Zhou et al. (2024)
Pleurotus ostreatus	—	—	3.31	0.41	2.30	6.09	—	1380	Zhou et al. (2024)
Lentinula edodes	—	—	2.24	0.49	2.50	6.79	—	1422	Zhou et al. (2024)

Table.2 Microbiological results from selected studies on mushrooms

Type of Mushroom	Origin / Sampling Location	Microorganisms Analyzed	Analysis Methods	Main Results	Compliance with Standards	References
Agaricales, Agaricomycotina, Cantharellales, Boletales, Pezizomycotina	Online purchases and supermarkets, Austria	Mesophilic aerobic bacteria, coliforms, yeasts, molds, Salmonella, Bacillus cereus	(ISO-6887-1, 2017); (ISO-4833, 2003); (ISO-21528-2-, 2017); (ISO-7932, 2004); (ISO-11290-1, 2017); in-house	High coliform load (5.4 log CFU/g), Absence of Salmonella	17 samples (27.9% of total) non-compliant; Agaricales: compliant	(Ludewig *et al.,* 2024)
Agaricus bisporus	Various stores in Florence, sold in Tuscany	Mesophilic aerobic microorganisms and Enterobacteriaceae	UNI EN ISO (ISO-4833-1, 2013) and (ISO-21528-2-, 2004)	Aerobic bacteria: detected at T0 and T1, all samples, > "acceptable" thresholds of DGRT 55/98 decree for raw foods. Enterobacteriaceae: present in 100% of samples, > acceptable values in 90% at T0, 95% at T1. Higher loads at T1	Not compliant for raw consumption; proper cooking can protect consumers	(Donzellini *et al.,* 2018)
Agaricus bisporus	Whole and sliced mushrooms stored at 12°C (post-harvest), Penn State University, USA	Listeria monocytogenes, Salmonella sp.	(Martin & Beelman, 1996), MOX agar (Listeria) or XLD agar (Salmonella)	No significant growth of L. monocytogenes and Salmonella spp. in whole fresh mushrooms; significant growth in sliced mushrooms	-	(Chikthimmah, 2006)
Agaricus bisporus	Mushrooms packed in two polymer films (perforated and non-perforated PVC), stored at 17°C and 25°C, Spain	Mesophilic aerobic flora, Pseudomonas spp., fecal coliforms, Escherichia coli, anaerobic spores, Staphylococcus aureus	(ICMSF, 1978); (King *et al.,* 1954); (Freed *et al.,* 1982)	No growth of S. aureus at 17°C, slight growth with non-perforated film at 25°C after 1 day; no enterotoxin detected	-	(Gonzalez-Fandos *et al.,* 2000)
Various species (including *Agaricus bisporus*, *Auricularia*, *Lentinula*, etc.)	Markets and supermarkets of Zaragoza (Spain)	Mesophilic aerobic microorganisms, Enterobacteriaceae, lactic acid bacteria, total and thermotolerant coliforms, E. coli, yeasts and molds, Listeria monocytogenes, Salmonella spp., S. aureus, Yersinia enterocolitica	Multiple ISO standards (see French version)	Auricularia: highest microbial load (9.4 log CFU/g); Calocybe gambosa (40%), Hygrophorus limacinus (40%), Tuber indicum (100%): presence of Listeria; Pseudomonas dominant (3.7–9.3 log CFU/g); L. monocytogenes and Y. enterocolitica detected; E. coli O157:H7 and Salmonella spp. not detected	Cultivated mushrooms: excellent safety; Wild mushrooms: sometimes contaminated with Listeria	(Venturini *et al.,* 2011)
***Agrocybe cylindracea, Amanita cecilae, Boletus reticulatus*, etc.**	Various regions of Anatolia (Turkey)	E. coli O157:H7, L. monocytogenes, yeasts & molds, total aerobic mesophiles, total coliforms, lactic acid bacteria, Salmonella spp., S. aureus, Clostridium	(Venturini *et al.,* 2011); (Brennan & Gormley, 1998); (Ajis *et al.,* 2017); (Chen *et al.,* 2018)	Edible wild mushrooms considered acceptable		(Ergönül *et al.,* 2018)

		botulinum				
Flammulina velutipes, Pleurotus ostreatus, P. eryngii, A. bisporus	Various commercial sources in Korea	Total mesophilic aerobic bacteria (TMAB), psychrophilic aerobic bacteria (TPAB), E. coli/coliforms (EC), yeasts/molds (YM)	Petrifilm count plates	F. velutipes: highest microbial load and levels of psychrophiles and coliforms; P. eryngii: lowest load; P. ostreatus & A. bisporus: highest yeast/mold loads; 32/200 samples positive for Listeria spp., mostly F. velutipes & P. ostreatus	Mostly acceptable; F. velutipes shows potential microbiological risks	(Meng *et al.,* 2024)
Kalaharituber pfeilii	Local market, Namibia	Mesophilic aerobic flora, coliforms, yeasts and molds, Salmonella	(Maturin & Peeler, 2001); (Feng *et al.,* 2002); (AOAC International, 2016)	Highest mesophilic aerobic count: 7.3 ± 0.1 CFU/g; Salmonella absent	Mostly compliant	(Hainghumbi *et al.,* 2022)
Lactarius spp.	Local market, Muğla province, Turkey	Total mesophilic aerobic bacteria, lactic acid bacteria, total yeasts, total molds, S. aureus, total and fecal coliforms	(FDA-BAM, 2020); (ISO-15214, 1998); (FDA-BAM, 2019)	High microbial load; E. coli biotype I detected in 35% of samples; Enterobacter aerogenes in 1 sample	Not compliant	(Öncül & Çiftçi, 2023)
Lentinula edodes	Dried (online); Fresh (local market); Sliced and powdered (Virginia, USA)	Mesophilic flora, yeasts and molds, Bacillus spp., enterotoxigenic strains, total coliforms and E. coli	(Kim *et al.,* 2015)	Online purchases less contaminated than local fresh; absence of E. coli, Salmonella and L. monocytogenes in all samples	-	(Kim *et al.,* 2016)
Lentinula edodes	Cultivated on logs in a commercial farm (Artigas, Uruguay); in sealed 20x30 cm bags of two PE types (60 µm thick) and PP (40 µm thick)	Lactic acid bacteria, aerobic bacteria, yeasts & molds, Salmonella spp., Listeria spp.	MRS, Petrifilm plates, UNIQUETM diagnostic kits	No Salmonella spp. or L. monocytogenes in 25 g; Modified atmosphere: slight variations in mesophilic and lactic bacteria; major differences in yeasts/molds depending on film	Technologies safe for mushroom preservation	(Parentelli *et al.,* 2007)
P. ostreatus, P. eryngii, L. edodes	Retail sale in Austria (from Poland, Germany, Austria, South Korea)	Mesophilic aerobic bacteria (AMC), Enterobacteriaceae (EB), Pseudomonadaceae (PS), lactic acid bacteria (LAB), yeasts, molds, presumptive Bacillus cereus, Salmonella spp., L. monocytogenes	Multiple ISO methods (see French version)	Most abundant: Pseudomonas fluorescens (58.4%) and potential pathogen Ewingella americana (28.3%); Salmonella spp., L. monocytogenes, B. cereus: not detected	Overall good microbial quality, both fresh and after storage; Increase in AMC especially in Korean-origin Pleurotus spp.	(Schill *et al.,* 2021)
Pleurotus sajor-caju	Mushrooms stored for 12 days at 4 °C and 25 °C, Malaysia	Mesophilic aerobic flora, yeasts and molds, *Escherichia coli*, *Bacillus cereus*, and *Listeria monocytogenes*	-	Reduction of mesophilic aerobic flora from the 6th day due to food packaging containing less oxygen than normal air	-	(Suhaili *et al.,* 2021)

Table.3 Comparison of heavy metal concentrations in mushrooms across studies (mg/kg dry weight)

Types of mushrooms	Samples origins	Method	Paramètres (mg/kg)											Références
			Cd	Pb	Hg*	As	Co	Ni	Cr	Cu	Fe	Mn	Zn	
Pleurotus ostreatus	Chilla Forest Colony Inde	CP-MS/A of fungiD	0.06±0.02	-	-	-	-	-	0. 81±0.14	14.10±1.20	29.76±1.53	9.33±0.20	13.56±0.62	(Širić *et al.,* 2022)
Boletus badius	northeastern part of Poland	FGAAS	0.615±0.020	0.243±0.013	-	-	-	-	-	-	-	-	-	(Gałgowska & Pietrzak-Fiećko, 2021a))
Boletus edulis	northeastern part of Poland	FGAAS	2.151±0.066	0.301±0.017	-	-	-	-	-	-	-	-	-	(Gałgowska & Pietrzak-Fiećko, 2021a))
Cantharellus cibarius	northeastern part of Poland	FGAAS	0.370±0.024	0.424±0.021	-	-	-	-	-	-	-	-	-	(Gałgowska & Pietrzak-Fiećko, 2021a))
Kalaharituber pfeilii	Ondangwa in Oshana region, Namibie	ICP	0.53±0.07	-	-	-	-	-	4.59±0.3	-	241.34±11.1	1.98±0.1	85.57±4.8	(Hainghumbi *et al.,* 2022)
Lactarius deliceus	Tokat, Turkey	AAS	2.84±0.22	1.96±0.15	-	-	0.46±0.02	1.73±0.14	0.87±0.05	31.4±2.8	288±21	36.5±2.3	82±7	(Tüzen, 2003)
Boletus edulis	East Black Sea region of Turkey	FAAS-MD et GFAAS-MD	1.1±0.1	-	-	-	-	-	-	20.1±2.2	764±65	96.3±7.4	158±14	(Tuzen *et al.,* 2007)
Lactarius volemus	Reiek forest, Mamit District, Mizoram, Inde	AAS	0.61±0.00	0.33±0.03	-	-	-	0.19±0.00	-	-	-	7.75±0.02	-	(Thachunglura *et al.,* 2024)
Vascellum pratense	Reiek forest, Mamit District, Mizoram, Inde	AAS	0.75±0.01	0.85±0.03	-	-	-	0.44±0.01	-	-	-	13.14±0.05	-	(Thachunglura *et al.,* 2024)
Lactarius deliciosus	Eskisehir, Turkey	(ICP-OES)	0.47±0.03	0.42±0.23	-	-	2.46±0.07	-	4.24±0.01	10.60±0.01	146±0	16.80±0.22	69.80±0.04	Yamaç *et al.,* (2007)
Boletus chrysente	Eskisehir, Turkey	(ICP-OES)	0.34±0.00	0.98±0.15	-	-	5.96±0.21	-	1.95±0.06	15.70±0.18	143±2	45.40±0.64	59.80±0.10	Yamaç *et al.,* (2007)

ron														
Pleurotus Djamor	Chilla Forest Colony Inde	AAS	0.05±0.01	-	-	-	-	-	0.73±0.05	12.08±0.08	30.20±0.86	8.14±0.15	14.09±0.40	(Širić *et al.*, 2022)
Pleurotus ostreatus	Chhandi Devi Forest, Inde	AAS	0.10±0.03	-	-	-	-	-	0.57±0.07	17.90±1.04	25.01±3.17	10.36±1.10	18.64±1.56	(Širić *et al.*, 2022)
Pleurotus Djamor	Chhandi Devi Forest, Inde	AAS	0.07±0.02	-	-	-	-	-	0.42±0.08	15.05±0.49	23.19±2.02	8.99±0.72	16.03±1.10	(Širić *et al.*, 2022)
Pleurotus ostreatus	Bheemgoda Barrage Forest, Inde	AAS	0.11±0.03	-	-	-	-	-	0.75±0.09	14.43±0.32	30.86±1.38	7.80±0.43	19.70±0.98	(Širić *et al.*, 2022)
Pleurotus Djamor	Bheemgoda Barrage Forest, Inde	AAS	0.09±0.01	-	-	-	-	-	0.38±0.02	15.09±0.75	27.74±0.84	8.64±0.27	13.50±2.15	(Širić *et al.*, 2022)
Ganoderma lucidum	South Korean market	CP-MS/AD	0.11±0.1	0.08±0.1	0.01±0.01	0.03±0.03	-	-	-	-	-	-	-	(An *et al.*, 2020)
Phellinus linteus	South Korean market	CP-MS/AD	0.68±1.0	0.54±0.9	0.01±0.02	0.11±0.1	-	-	-	-	-	-	-	(An *et al.*, 2020)
Umbilicaria esculenta	South Korean market	CP-MS/AD	0.47±0.5	12.3±7.0	0.06±0.04	2.79±1.6	-	-	-	-	-	-	-	(An *et al.*, 2020)
Trametes versicolor	South Korean market	CP-MS/AD	0.33±0.14	0.54±0.4	0.006±0.005	0.14±0.1	-	-	-	-	-	-	-	(An *et al.*, 2020)
Agaricus blazei	South Korean market	CP-MS/AD	5.8±5.4	0.40±0.4	0.21±0.28	3.9±3.84	-	-	-	-	-	-	-	(An *et al.*, 2020)
Hericium erinaciium	South Korean market	CP-MS/AD	0.12±0.1	0.03±0.02	0.002±0.004	0.06±0.05	-	-	-	-	-	-	-	(An *et al.*, 2020)
Lactarius glyciosmus	Fatsa, Black Sea Region (Turquie)	ICP-MS	0.16±0.01	0.21±0.01	-	-	0.24±0.01	23.3±0.57	2.63±0.10	29.7±0.22	241±12	18.3±0.42	49.9±0.29	(Türkmen & Budur, 2018)
Lactarius glyciosmus	Ulubey, Black Sea Region (Turquie)	ICP-MS	0.28±0.01	0.15±0.00	-	-	0.01±0.00	24.2±0.20	2.29±0.09	47.0±0.04	97.2±3.58	4.61±0.13	80.5±1.02	(Türkmen & Budur, 2018)
Cantharellus cibarius	Çaka, Black Sea Region (Turquie)	ICP-MS	0.64±0.01	0.72±0.01	-	-	0.22±0.01	22.7±0.29	1.07±0.23	56.4±0.84	454± 20.7	28.5±0.92	116±3.03	(Türkmen & Budur, 2018)
Lactarius glyciosmus	Ünye, Black Sea Region (Turquie)	ICP-MS	0.13±0.01	0.29±0.02	-	-	0.33±0.06	12.7±6.06	6.26±3.69	17.5±1.65	299±38.4	37.2±1.36	34.4±1.07	(Türkmen & Budur, 2018)

Cantharellus cibarius	Kumru, Black Sea Region (Turquie)	ICP-MS	0.80±0.02	0.34±0.00	-	-	0.16± 0.02	18.1±2.72	2.78±0.65	64.6 ±0.42	273±10.1	14.3±0.82	109±0.93	(Türkmen & Budur, 2018)
Lactarius glyciosmus	Gölköy, Black Sea Region (Turquie)	ICP-MS	0.14±0.01	1.42±0.02	-	-	0.24±0.02	22.8±0.02	2.35±0.09	48.4 ±0.45	125±5.37	27.0±0.34	69.5±1.24	(Türkmen & Budur, 2018)
Cantharellus cibarius	Okçu, Black Sea Region (Turquie)	ICP-MS	0.20±0.01	0.91±0.06	-	-	0.55±0.02	20.1±2.03	1.34±0.69	39.3±0.21	484±15.4	33.0±0.11	58.7±1.22	(Türkmen & Budur, 2018)
Polyporus squamosus	Tandır, Black Sea Region (Turquie)	ICP-MS	0.61±0.01	1.10±0.03	-	-	0.42±0.01	22.0±0.59	1.84±0.22	47.7±0.40	314±6.45	34.1±0.22	225±1.70	(Türkmen & Budur, 2018)
Lactarius salmonicolor	Boztekke, Black Sea Region (Turquie)	ICP-MS	0.14±0.03	0.66±0.02	-	-	0.65±0.03	23.2±0.22	1.55± 0.17	37.8±0.82	1149±84.9	46.2±1.43	57.5±1.58	(Türkmen & Budur, 2018)
Psathyrella candolleana	Greater Athens area, Grèce	AAS	-	5.17±1.39	-	-	-	14.55±0.57	0.68±0.37	45.88±4.43	344.95±51.72	13.67±2.07	92.76±7.96	(Kokkoris *et al.,* 2019)
Volvopluteus gloiocephalus	Greater Athens area, Grèce	AAS	-	8.43±1.35	-	-	-	16.92±2.79	0.89±0.42	39.54±4.26	385.28±79.23	27.29±2.74	77.93±2.44	(Kokkoris *et al.,* 2019)
Agaricus bisporus	Greater Athens area, Grèce	AAS	-	4.23±1.26	-	-	-	9.13±0.95	0	65.81±13.22	371.97±106.64	35.88±2.89	80.54±11.11	(Kokkoris *et al.,* 2019)
Agaricus bitorquis	Greater Athens area, Grèce	AAS	-	2.80±0.64	-	-	-	13.41±4.43	0.69±0.69	64.81±12.11	493.44±182.18	40.58±5.22	68.90±4.26	(Kokkoris *et al.,* 2019)
Agaricus gennadii	Greater Athens area, Grèce	AAS	-	4.12±0.57	-	-	-	10.93±4.7	0.82±0.82	21.75±9.05	736.83±212.74	43.93±5.47	76.25±8.83	(Kokkoris *et al.,* 2019)

*mercury analyzer (Milestone, Sorisole, Italy) without pretreatment, ICP: Inductively coupled plasma Spectrometer; AAS: atomic absorption spectrometry; FAAS: flame atomic absorption spectrometry; GFAAS: graphite furnace atomic absorption spectrometry; ICP-MS: Inductively coupled plasma mass spectrometry; ICP-OES: Inductively Coupled Plasma - Optical Emission Spectrometry

Table.4 Pesticide residues in selected mushroom species

Type of Mushroom	Origin / Sampling Location	Pesticides Analyzed	Analysis Methods	Main Results	Compliance with Standards	References
Agrocybe aegerita	Fujian Province, China	Clothianidin, Diflubenzuron, Chlorbenzuron, Pyridaben	UPLC-MS/MS	214.22 (μg/kg), 680.12 (μg/kg), 719.33 (μg/kg), 200.31 (μg/kg)	No risk	(Yao *et al.,* 2024)
Agaricus bisporus	Jinshan District, Shanghai, China	Cyromazine (CA), Melamine (MEL)	UPLC-MS/MS	Fruiting body shows higher accumulation capacity for MEL compared to CA	Health risk from ingesting CA and MEL residues in the fruiting body is negligible for humans	(Zhao *et al.,* 2018)
Boletus edulis*, *Imleria badia*, and *Cantharellus cibarius	Northeastern Poland	Organochlorine insecticides: DDT, DDE, DDD, and γ-HCH	GC-ECD	Positive for these compounds at low levels; *C. cibarius* more effective at accumulating contaminants = decreased food appeal compared to the other two species	Consumption of these mushrooms poses no notable health risk	(Gałgowska & Pietrzak-Fiećko, 2017)
Tremella fuciformis	Fujian Province, China	44 pesticides tested including: profenofos, fenitrothion, diazinon, malathion, acephate, phoxim, methamidophos, dichlorvos, omethoate, trichlorfon, dimethoate, chlorpyrifos, cypermethrin, etc.	GC-MS/MS, HPLC-MS/MS	13 pesticides detected: acephate, methamidophos, phoxim, chlorpyrifos, cypermethrin, carbofuran, isoprocarb, imidacloprid, acetamiprid, propargite, pyridaben, chlorbenzuron, and avermectin. Top 8 most detected: Carbofuran, Acetamiprid, Imidacloprid, Propargite, Avermectin, Pyridaben, Methamidophos, Phoxim	Exceeded MRLs for Methamidophos, Carbofuran, Phoxim, and Avermectin. Highest risk: Carbofuran	(Yao *et al.,* 2020)

Figure.1 Research Strategy for Assessing the Sanitary, Functional, and Nutritional Quality of Edible Mushrooms

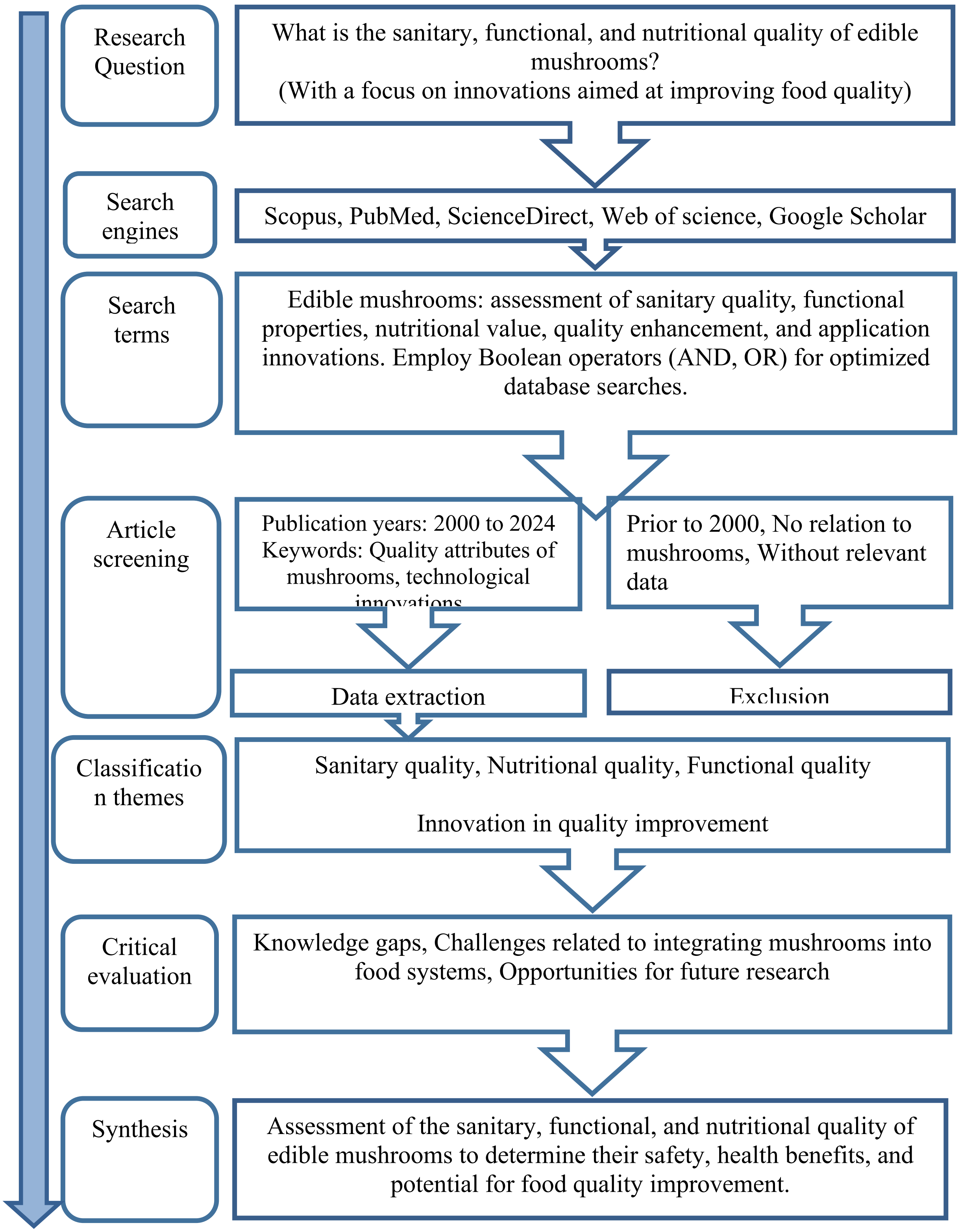
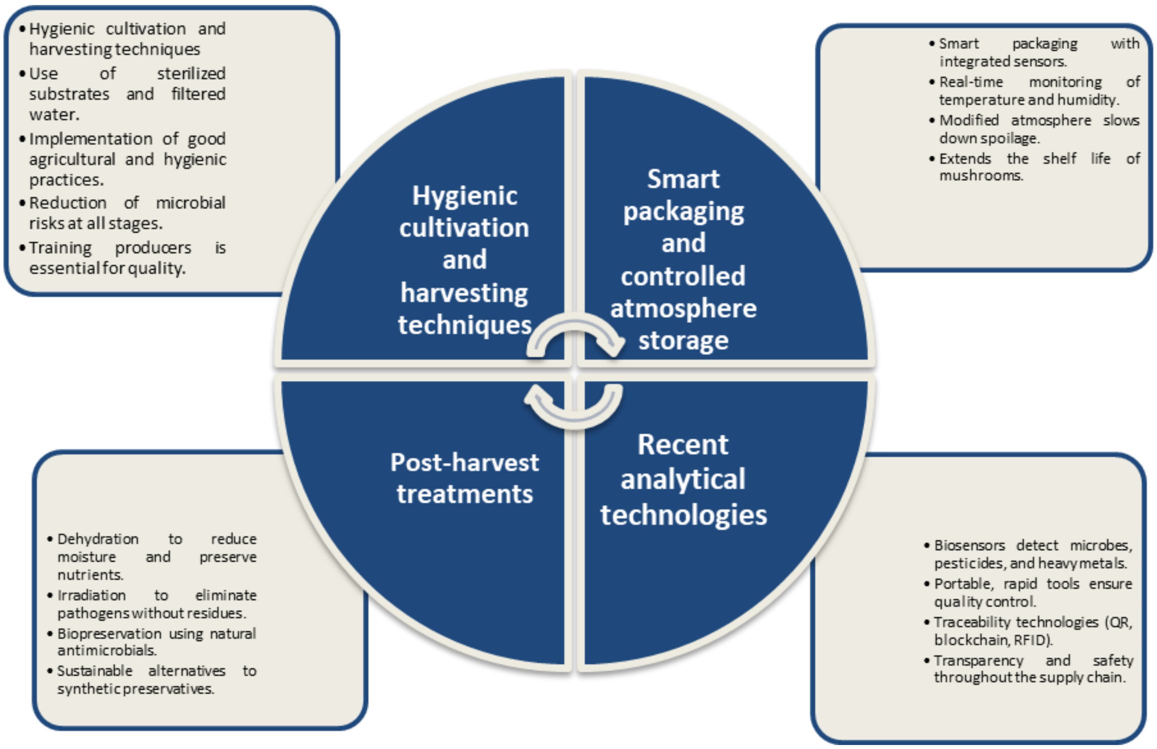


Figure.2 Key innovations for enhancing mushroom quality and safety



In conclusion, Edible mushrooms represent an invaluable resource at the intersection of nutrition, health, and sustainable agriculture. This review has highlighted their rich nutritional profile, diverse bioactive compounds, and functional properties that contribute to antioxidant, immunomodulatory, and therapeutic effects. However, ensuring their safety and quality remains a pressing concern, with microbial and chemical contamination posing significant risks, particularly in regions with limited regulatory oversight and post-harvest infrastructure.

To fully harness the potential of mushrooms in food systems, coordinated efforts are needed. Researchers should prioritize the standardization of analytical methods, the valorization of underutilized local species, and the exploration of novel applications in functional foods and nutraceuticals. Producers must adopt hygienic cultivation and post-harvest practices, integrate preservation innovations such as smart packaging and biopreservation, and engage in sustainable sourcing. Policymakers are urged to strengthen food safety regulations, support training and infrastructure development, and promote investment in mushroom research and commercialization.

Author Contributions

Mawutin Justine Bérénice Houssou-Goe: Investigation, formal analysis, writing—original draft. Comlan Kintomagnimessè Célestin Tchekessi: Validation, methodology, writing—reviewing. Tétédé Rodrigue Christian Konfo:—Formal analysis, writing—review and editing. Cécilia Sêna Ahondokpe: Investigation, writing—reviewing. Yaya Alain Koudoro: Resources, investigation writing—reviewing. Chimène Agrippine Rodogune Yelouassi: Validation, formal analysis, writing—reviewing. Marius Eric Badoussi: Conceptualization, methodology, data curation, supervision, writing—reviewing the final version of the manuscript. Déley Sylvain Dabade: Investigation, formal analysis, writing—original draft. Farid Abdel Kader Baba-Moussa: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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