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Morchella esculenta Fr. – A Growing Gold of Mountains, its Nutritive Value and Cultivation

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Abstract

Morchella esculenta Fr., known as Guchi in India, is an edible mushroom from the Ascomycota group. It is nutritious, economically and scientifically valuable. Traditional cultures have long used this mushroom both as food and as a remedy for various health issues. This mushroom is rich in carbohydrates, proteins, fiber, vitamins, minerals, and aromatic compounds. Its unique taste, flavor, and texture make it a popular ingredient in recipes around the world. In addition, *Morchella esculenta* has several medicinal properties, such as antioxidant, antitumor, antimicrobial, and anti-inflammatory effects, and it is used to aid digestion, act as a body tonic, soothe the skin, and help heal wounds. Research on morel cultivation spans over a century, with China leading the way in large-scale outdoor cultivation. The life cycle of the mushroom involves two main stages: the formation of sclerotia and the production of conidia. Cultivating these mushrooms involves making the spawn, introducing it to a growing medium, adding extra nutrients, managing the fruiting phase, and finally harvesting. The application of exogenous nutrition bags facilitates robust mycelial development. Naturally, *Morchella esculenta* thrives in cold, hilly regions and is commonly found near hardwood and coniferous trees in a saprobic or mycorrhizal association. Its peak growing season is from March to July, and it is native to the Kullu District in Himachal Pradesh, located in the western Himalayas.

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Introduction

Morchella esculenta (Morel) is one of the wild species that is significant and economically valuable hence recognized as "growing gold of mountains".[1] It is one of the most extensive and profitable international commerce networks now globally significant.[2] It is believed that in 2023, the market size of the India mushroom was USD 1.18 billion and from 2024 to

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2030, the compound annual growth rate (CAGR) is expected to grow at 12.7% from 2024 to 2030. The rising demand for a protein-rich diet among the growing vegan population is anticipated to have a major impact on the market. Mushroom is referred to as a superfood due to its high nutrient content. Selenium, vitamin D, glutathione, and ergothioneine are important nutrients found in large quantity in mushrooms. These nutrients help prevent or lessen chronic diseases like dementia, cancer, and heart disease by lowering oxidative stress.[3] In India, the demand for spawns is about 8000-10000 tons per annum based on the production statistics.[4] With an annual yield of 487 thousand tonnes, or 2% of the global total, India was one of the leading producers of mushrooms in the world as of 2020.[3] More than 300 types of wild mushrooms can be found in India. The FAO Statistics-2022 ranking of the world's mushroom output (in tonnes) was evaluated i.e. China (5,150,000)> Italy (785,000)> USA (388,450) > Netherlands (307,000)> Poland (220,000) and India (29992).[5] However, India consumes fewer than 50 grams of mushrooms per person, compared to nearly a kilogramme in other nations.

This usually occurs in thick coniferous forests (2500–3500 msl) with loamy soil that is rich in humus from March to July.[1,6] It is commonly found in a saprobic or mycorrhizal relationship with coniferous trees and hardwood.[7] Morels can be found in a variety of habitats and conditions, including cold soils, dead trees, and disturbed soil. Additionally, they have adapted to survive in a range of environments, including dunes, river bottoms, and abandoned mines.[8-10] Although they are uncommon in warmer temperatures, morels can be found in all temperate and boreal forests in the Northern Hemisphere as well as some Mediterranean and subtropical areas.[11] The woodlands of Jammu and Kashmir and Himachal Pradesh in India are home to this mushroom, which is indigenous to the Kullu District.

The scientific classification of this mushroom is: Fungi>Ascomycota>Pezizomycetes>Pezizales>*Morchella*ceae>*Morchella>esculenta/ conica/ deliciosa/ angusticeps/ arassipes/ hybrida=semilibera*. *Morchella esculenta, M. conica, M. deliciosa, M. angusticeps, M. arassipes* and *M. hybrid (M. semilibera)* are reported from India.[12] Because of its distinctive flavour and high nutritional content, *M. esculenta* is a pricey commodity.[13] Fruit bodies start as grayish sponges, expand to yellowish sponges with pits and ridges on white stems: pitted caps, 2-10 cm tall, 7 cm broad, fuse to stem. The crown can be yellow to tan, pale brown to greyish brown, or pale brownish cream.[14,15]

This versatile ingredient, rich in vitamins, minerals, proteins, carbohydrates, fibers, and aromatic compounds, is used in various recipes worldwide due to its unique flavor, and texture, and antioxidant, anticancer, antibacterial, and anti-inflammatory are among its many pharmacological characteristics. When used improperly, it can cause numerous negative effects and be toxic if consumed uncooked. This mushroom's extracts show promise as treatments for diabetes, heart disease, and cancer[16] and colon cancer, one of the cancers that kill people.[17]

Nutritive Value

The edible fruiting body of *M. esculenta* contains many active compounds, including organic acids, carotenoids, tocopherols, and phenolic compounds. In the carotenoids, lycopene and β-carotene are present. The tocopherols include δ-, α-, and γ-tocopherol, while the phenolic compounds comprise protocatechuic acid, p-coumaric acid, and p-hydroxybenzoic acid. Additionally, organic acids such as citric, oxalic, fumaric, quinic, and malic acid are found in this mushroom.

This mushroom is both tasty and nutritious. It is rich in protein, carbohydrates, and vitamins—especially those in the B-complex—with smaller amounts of vitamins A, C, and D. It also supplies essential minerals like calcium, iron, copper, zinc, magnesium, manganese, sodium, phosphorus, potassium, and selenium. With few calories and low fat,[18,19] its composition is approximately 38% carbohydrates, 32.7% protein, 17.6% fiber, 9.7% ash, and 2.0% fat. Moreover, it has been reported to contain around 195 mg/g of iron, 98.9 mg/g of zinc, 62.6 mg/g of copper, 54.7 mg/g of manganese, 23.5 mg/g of potassium, 3.49 mg/g of phosphorus, 1.82 mg/g of magnesium, 0.85 mg/g of calcium, and 0.18 mg/g of sodium.[20,21] Previous studies have also detected various aromatic compounds such as phenols, alcohols, acids, esters, aldehydes, ketones, and terpenes in *M. esculenta*. The main aromatic substances identified include alcohol (15.55%), carbamic acid (11.37%), phenol (50.88%), and esters.[22] Additionally, proteins derived

from the mycelium of *M. esculenta* can serve as a useful protein supplement, similar to the proteins found in the fruiting body.[23] Due to its high protein content, this mushroom is easier to digest compared to many other vegetables.

Furthermore, *M. esculenta* is believed to help treat conditions such as hepatitis B, colds, stomach aches, and headaches. It may also lower cholesterol levels, ease sleep problems and fatigue, regulate blood sugar, and provide an effective remedy for anemia.[24-31]

Historical Developments

The first documented instance of outdoor cultivation dates back to 1882 in France, where *M. esculenta* was cultivated alongside Jerusalem artichokes.[32] Subsequent advancements were achieved through patents issued between 1986 and 1989, which optimized sclerotia-based inoculation and regulated environmental parameters such as humidity and temperature.[33,34] Despite initial success, attempts at indoor cultivation were abandoned in 2008 due to contamination and yield inconsistencies.[35] Innovations such as ectomycorrhizal symbiosis[36] and controlled soilless systems[37] have since been introduced. Notably, large-scale field cultivation in China has seen significant expansion, with yields reaching 7620 Kg/ha and over 1600 hectares cultivated by 2016.[38] The artificial cultivation of morels has grown rapidly, with China leading advancements in field soil culture since 2012, achieving significant scale and yield. However, challenges like yield instability, genetic variability, and contamination have driven interest in cultivating morel mycelia as an alternative.[39]

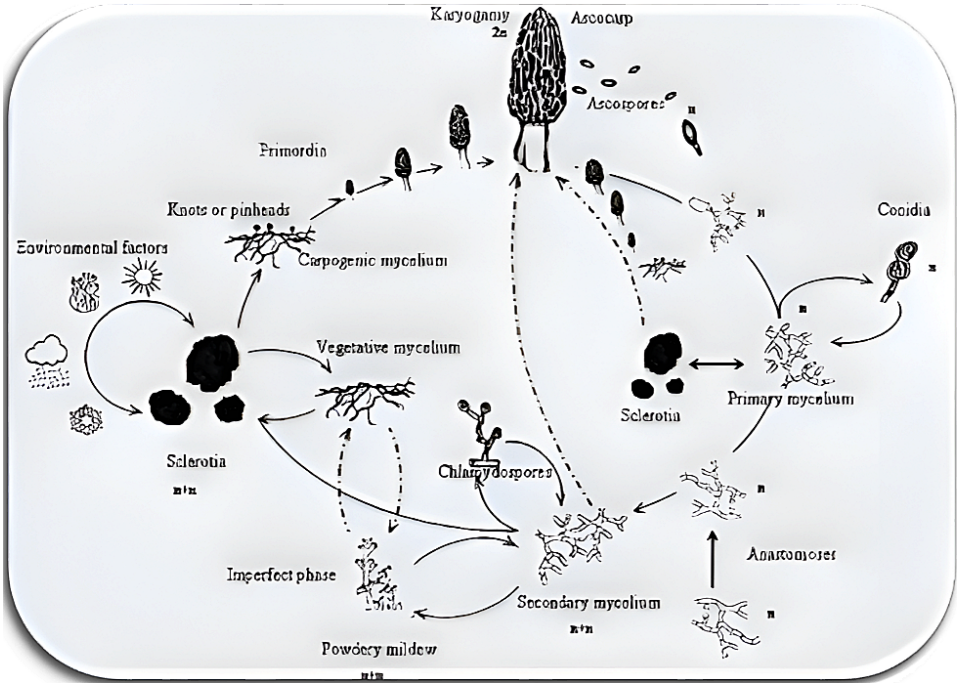

Fig. 1: Genus *Morchella* spp. theoretical life cycle[43]

Life Cycle

Morel mushrooms, members of the ascomycetes, reproduce through both sexual and asexual means. In the sexual phase, the fruiting body or ascocarp, houses numerous sac-like structures known as asci, each usually containing eight spores. A thorough understanding of these reproductive processes is essential for the successful artificial cultivation of morels.[40] Key stages in their life cycle include forming sclerotia and producing conidia. (Fig.-1) illustrates the asexual reproduction of *Morchella esculenta* via conidia, drawing parallels with powdery mildew and emphasizing recombination and propagation mechanisms that enhance resilience under stressful conditions. Additionally, the ascospores that are released give rise to the primary mycelium, which

can subsequently develop sclerotia to survive under adverse conditions.[40] In spring, sclerotia can germinate in two ways: myceliogenically, leading to the formation of a new primary mycelium, or carpogenically, resulting in the development of a fruiting body. Moreover, when one primary mycelium meets a compatible counterpart, their hyphae merge to form a heterokaryon containing paired nuclei. In morels, the sclerotia are actually pseudosclerotia, formed through the repeated branching and expansion of terminal hyphae. These hyphae may be either primary (homokaryotic) or secondary (heterokaryotic).[41] Conidia in *Morchella esculenta* function as asexual spores, aiding both mating and colony expansion. Acting as gametes and propagules, they are influenced by environmental factors like air, nutrients, and moisture. Their formation is crucial for the its reproduction and cultivation.[42]

The growth substrates along with the nutritional composition affects the both mycelial characteristics and sclerotia formation.[44,45] While the trophic strategies of *Morchella* vary, available evidence suggests that the genus comprises facultative mycorrhizal, saprophytic, as well as strictly mycorrhizal species. However, these findings do not indicate that an ectomycorrhizal association is essential for the morel life cycle or for ascocarp production.[46]

In China, growers assess the quality of morel spawns by evaluating the amount of sclerotia produced. Due to the rapid senescence of morel strains, which results in a loss of vigor and viability, it becomes necessary to continually reselect strains from spore cultures.[46] Successful outdoor cultivation requires an exogenous nutrient supply, although the mechanism by which these nutrients affect growth remains unclear. A transition from a nutrient-rich to a nutrient-poor environment prompts the fungus to shift into its sexual growth phase, during which ascocarps are formed.[47]

Most morel cultivators in China are of the opinion that exogenous nutrient bags provide the essential nourishment required for mycelial growth.[48] Providing exogenous nutrients involves considerable labor and expense, including the preparation, sterilization, and incorporation of the nutrient into the mushroom bed. Consequently, focusing on the mechanization of this nutrient supply—or exploring alternative cultivation methods based on its underlying mechanisms—represents a promising direction for improvement.[39,48]

Properties and the Applications of *Morchella esculenta*

Overview and Toxicity

Morchella esculenta is valued for its culinary and medicinal uses, benefiting conditions like cardiovascular diseases, diabetes, cancer, and obesity. However, improper preparation can cause neurotoxic effects, such as ataxia and visual disturbances, which are neutralized by adequate cooking.[12,49]

Medicinal and Nutritional Benefits

Rich in polysaccharides, proteins, vitamins, and trace elements, *M. esculenta* provides significant health benefits. Its bioactive compounds, including phenolics, offer antioxidant, anti-inflammation and antitumor effects.[50,51] *M. esculenta* is rich in the essential amino acids, wherein glutamic acid being the most predominant.[27]

Antioxidant Properties

M. esculenta has potent antioxidant activity through phenolic compounds, tocopherols, and organic acids, which reduce oxidative stress.[52] Serbian samples show strong DPPH radical scavenging and polysaccharides from fermentation scavenge superoxide and hydroxyl radicals.[53] (MEPs) *M. esculenta* polysaccharides enhance antioxidant enzyme activities, reduce lipid peroxidation by decreasing (MDA) Malondialdehyde levels, and also activate the AKT/Nrf2 signalling pathway, enhancing protective proteins like HO-1 to help protect against oxidative damage.[54,55] They also mitigate nephrotoxicity and liver damage induced by oxidative stress.[56]

Antimicrobial Potential

M. esculenta exhibits a lot of antimicrobial activity against bacteria, especially those which are already resistant to antibiotics such as the *Salmonella* and *Staphylococcus aureus*. Badshah *et al*. and Kalyoncu *et al*. affirmed sesquiterpenes and steroids among the active principles hence corroborating its traditional use to infection control are proven effector compounds.[57,58] However, it is not the only evidence that the plant is effective in controlling these infections microbiologically. Additionally, *M. esculenta*

has been found to inhibit the growth of *E. coli* and exhibits effectiveness against both Gram-positive bacteria and also the Gram-negative bacteria which is supported by scientific evidence such as that mentioned by.[59,60]

Fig. 2: *Morchella esculenta* benefits

***Morchella esculenta* benefits**

Uses as Pharmaceuticals

Morchella species contain diverse bioactive and nutritional compounds and are valued by traditional hilly societies for their healthcare applications.[13,52,61-63] *M. esculenta* has been traditionally employed to alleviate excessive phlegm, aid digestion, and support heart health,[64] stomach aches, wound healing,[65] and also function as a emollient and laxative.[31] Additionally, it alleviates type 2 diabetes in mice by improving gut function, glucose tolerance, and reducing inflammation.[66]

Anti-inflammation Effects

The methanol extract derived from the entire plant exhibits anti-inflammatory properties and aids in pain reduction. It inhibits both acute and chronic inflammation.[26,28] Sulfated MEPs protect against inflammation by inhibiting NF-κB activation.[67] The active compound, (EOYA) (E)-Octadec-11-En-9-Ynoic Acid, interacts with proteins such as NR1I2, PTGS1, and PTGS2, regulating prostaglandin biosynthesis through the arachidonic acid pathway.[68]

Antitumor Activity

Antitumor activities are exhibited by polysaccharides derived from *M. esculenta*. These polysaccharides induce cell cycle arrest, apoptosis and autophagy in cancer cells, including the HT-29 human colon cancer cells.[69,70] In *M. esculenta*, the mycelia contain chemicals that have the potential to regulate the progression of cancer at several stages or to operate at the same stage concurrently. The extracted polysaccharide from the *M. esculenta* fruiting bodies

has shown immunological stimulatory action.[20] Furthermore, MEPs enhance immune function, stimulate macrophages, and mitigate chemotherapy side effects.[71]

Immuno-Modulatory Activities

Active immunostimulatory properties are exhibited by the galactomannan polysaccharide that was isolated from *M. esculenta*.[24] MEPs activate macrophage function by binding to TLR4 receptors and stimulating signalling pathways like NF-κB, JNK, and Akt, which boosts phagocytosis and cytokine production.[67] Acetylated MEP modulates macrophage immune activation by promoting IκBα degradation and activating NF-κB and MAPK pathways, enhancing viability and nitric oxide production.[55]

Hypolipidemic and Hypoglycemic Activity

Several MEPs show strong hypolipidemic and hypoglycemic effects. An acidic polysaccharide from *M. esculenta* reduces blood glucose and promotes insulin secretion in diabetic rats. MEPs also exhibit anti-atherosclerotic effects by lowering serum total and LDL cholesterol, and triglycerides via the AMPKα signaling pathway.[72] Carboxymethyl FB-MEP enhances cholesterol-lowering by upregulating CYP7A1 and LDL-R expression and downregulating HMG-CoA in the liver. Both FB-MEP treatment and carboxymethylated FB-MEP reduce serum TC and TG, while increasing HDL-C, indicating significant lipid-lowering activity.[73] The benefits of *Morchella esculenta* have been depicted in brief in the Fig.-2.

Cultivation of *Morchella Esculenta*

Morchella esculenta is a saprotrophic fungus that predominantly colonizes humus-rich forest floors, where it forms dense mycelial networks under adequate nutrient availability. Ascocarps emerge post-precipitation, favoring ecosystems dominated by tree species such as *Cedrus deodara* and *Pinus wallichiana*, alongside medicinal flora including Angelica glauca and *Dactylorhiza hatagirea*. Harvesting occurs during the peak season from April to June.[13,74] Due to the impracticality of traditional cultivation methods, submerged fermentation has been explored as an alternative.[75]

Cultivation Techniques

Three main systems include Ower's indoor cultivation (focused on sclerotia production and fruiting induction), Yunnan's stump wood bionic cultivation (utilizing wood nutrients but limited by forest resource use), and field cultivation in China (using nutrient bags to enhance stability and yield).[76]

Spawn Production

The production of high-quality spawn is fundamental to successful cultivation. Cultures are typically initiated from healthy fruit bodies or commercially obtained isolates and propagated on (PDA) potato dextrose agar supplemented with humus. Common substrates include wheat, wheat bran, sawdust, and gypsum, with a recommended composition of wheat (46%), husk (20%), and humus (4%).[77] Approximately 4500 spawn bags (14–28 cm) are required per hectare, incurring costs between $7620 and $10,880.

Spawning

Optimal spawning conditions necessitate loose, aerated soil with a maintained humidity of 50–70%. Spawning typically occurs between October and December when local temperatures are below 20°C. Spawn is sown in 15 cm-deep beds, covered with a 3–5 cm layer of casing soil. Protective measures such as mulching and canopy installation ensure stability in temperature and moisture levels.[78]

Exogenous Nutrition

The application of exogenous nutrition bags, containing substrates like wheat and sawdust, facilitates robust mycelial development. These bags are placed at 50 cm intervals and deplete within 40–45 days, effectively supporting ascocarp formation.[79,80]

Fruiting Management

Critical environmental parameters include soil moisture (>50%) and air humidity (85–90%). Flooding practices have been shown to stimulate primordium differentiation by promoting interactions with beneficial soil microbiota. Optimal fruiting temperatures range from 6–10°C, with diurnal variations enhancing primordium initiation. Pest management relies on biological control methods to mitigate competitive fungi and insect infestations.[76,81]

Artificial Cultivation

Morchella species were artificially cultivated in 2012, began in Sichuan of China. It has since

grown to yields of up to 15,000 kg per hectare. It's success relies on good quality spawn and selection of suitable species and also prevention from uncontrollable species like *M. angusticeps*. Despite continuous cropping leading to variation in the properties of soils and crop diseases in some regions, challenges for food security such as erratic yields and reduced production are still prevalent. Therefore, the crop rotation, soil alterations and disease resistant strains are being investigated for improved sustainability.[38] Although morel cultivation is profitable, environmental variability and limited knowledge about the most suitable conditions for growth still hinder its development.[76,82]

Harvesting and Market Significance

Ascocarps, measuring 10–15 cm, are harvested upon maturity and subsequently dried for commercial distribution. In India, *M. esculenta* fetches premium prices, ranging from ₹14,000 to ₹15,000/Kg, largely driven by its short harvesting window and high demand. However, overharvesting has led to significant population declines in natural habitats, emphasizing the need for sustainable harvesting practices.[30,83]

Sustainable Farming

To address soil health and production concerns, sustainable morel farming in continuous cropping settings emphasizes disinfection of the soil, rotations of the crop, intercropping, deep ploughing of the soil, breeding, and microbial inoculants. Soil disinfection methods like solarization and fumigation are also effective.[84]

Genesis of Morel Mushrooms Continuous Cropping Obstacles

Soil's Physicochemical Properties Modifications

Morchella spp. is a saprotrophic fungus that effectively breakdown complicated molecules into simpler ones by secreting various enzymes.[85] This action leads to a rise in nutrient levels in the soil.[85,86] Thus, continuous morel cropping causes the soil to accumulate nutrients, which makes it unsuitable for fruiting and lowers the yields of primordium and fruiting bodies.[87]

Soil Microbial Population Alterations

Morchella operates as a highly invasive species that quickly controls the soil. The competition for nutrients and space with the native soil microbial communities leads to the alteration of the native resident fungal communities.[84]

Soil-borne Disease

High amounts of fungal infections of morel mushrooms are seen in the soil bed during the fruiting body stage of continuous cropping.[88] Consequently, the production of morel mushrooms d ecreases, and soil-borne diseases become more prevalent.[89] Potential morel mushroom pathogens that were found in high concentrations include *Gibberella, Microidium, Trichoderma, Penicillium, Sarocladium and Streptomyces*. In addition to these, the Aspergillus and Fusarium were found in low concentrations.[87,90]

Allelopathy and Autotoxicity

The phenolic acid extracts from the soils show allelopathic effects, which promote the growth of harmful fungus while simultaneously suppressing the growth of morel mushrooms.[89] The production of endogenous organic acids by *Ganoderma lucidum* results in stress, which in turn triggers autotoxicity feedback and cropping hurdles.[91]

Strategies for Growing Morels Sustainably in Continuous Cropping Environments

Deep Ploughing

Deep ploughing helps in decreasing physicochemical properties by nutrient-deficient deeper layers of soil to the surface. It also helps in the restoration of microbial diversity in the soil.[89]

Crop Rotation and Intercropping

The yield and quality of the morel mushroom's fruit body were enhanced when it was rotated with rice.[92] Water has a high heat conductivity, irrigating the soil with enough water raises its temperature. Consequently, this aids in clearing the soil of autotoxic and allelopathic compounds.[93-95] By improving the annual yield per unit of land area and facilitating more effective land use, intercropping eventually boosts economic benefits.[94]

Soil Disinfection

Physical disinfection techniques include radiation sterilization, steam disinfection, microwave therapy, and solarisation.[96] Greenhouse Thermal pasteurization, a type of solarisation that raises the temperature and aids in the removal of harmful microbes, is used by farmers in China.[97]

Breeding of Morel Mushrooms

By using monokaryotic hybridization, new Morel mushroom isolates are produced which improves the variety by increasing yield and quality.[97,98]

Microbial Inoculants

Many microbes inoculants are used as biofertilizers to perform specific functions, as biopesticides for the management of various diseases, and in bioremediation of various contaminants.[99,100]

Competitive Landscape and Mushroom Cultivation Market Share Analysis

The mushroom cultivation industry is characterized by a competitive landscape that provides insights into various market players. Key aspects include company profiles, financial performance, revenue generation, market potential, research and develop-ment investments, expansion strategies, global presence, production facilities, manufacturing capacities, strengths and weaknesses, product launches, product range, and market dominance in different applications. The information presented focuses specifically on companies engaged in the mushroom farming sector.[3,30,83]

Several Key Participants Involved in the Mushroom Farming Industry Include

1. Monaghan Group (Ireland)
2. Costa (India), Bonduelle (France)
3. Walsh Mushrooms Group (Ireland)
4. Monterey Mushrooms (U.S.)
5. Mycelia (Belgium)
6. Cargill, Incorporated (U.S.)
7. Smithy Mushrooms Ltd. (U.K.)
8. Myco Terra Farm (Belgium)
9. Rheinische Pilz Zentrale GmbH (Germany)
10. Lambert Spawn (U.S.)
11. Italspwan (Italy)
12. The Greenyard (Belgium)
13. Mushroom SAS (Italy)
14. Heereco (Netherlands)
15. Hirano Mushroom LLC (Kosovo)
16. Bluff City Fungi (U.S.)
17. Fujishukin Co. Ltd. (Japan)
18. Smithy Mushrooms (U.K.)

Conclusion

Due to its high market value, the morel mushroom plays a crucial role in a country's economy. Morel mushrooms, belonging to the genus *Morchella*, are globally distributed and hold significant social and economic importance. These mushrooms are highly valued as edible fungi, with substantial harvests occurring when certain species fruit abundantly, particularly in the first year following a fire. However, despite their widespread use, limited research has quantified post-fire morel mushroom abundance. *M. esculenta* contains functional polysaccharides beneficial to human health. Scientific advancements are essential for improving its cultivation and ensuring the availability of viable propagules. A collaborative approach involving mycologists is necessary to identify suitable microcultures for field applications, while agronomists and ecologists must investigate resource management mechanisms. Comprehensive research is required in systematic, ecological, physiological, and genetic aspects of morel mushrooms. Detailed studies on their lifecycle, including spore formation, dispersal, and germination, are essential. Additionally, analysis of the soil's physicochemical properties beneath the fruiting bodies is crucial to understanding the optimal conditions for spore germination. Determining the ideal factors for sclerotia formation, growth, and maturation, as well as their regulation, is vital. Furthermore, proper identification and documentation of plant species associated with *Morchella* fruiting bodies will enhance understanding of their ecological interactions.

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Author Contributions

- **Saroj Belbase and Jiwan Paudel:** the conceptualization, literature search and wrote the original draft.
- **Shradha Subba:** analysis, review, and editing and revised the manuscript.
- **Surush Das:** review and editing of the final manuscript
- **Shrvan Kumar:** the critical insights and supervision of the overall writing

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