

# Developments in Mushroom Production: Advancing Sustainable Livelihood Security: A Review

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## Abstract

Mushroom cultivation represents a vital biotechnological innovation that converts agricultural waste into a high-quality food source, addressing both waste management and nutritional security. This review explores the fundamental biology and ecological role of fungi, the nutritional and medicinal benefits of edible mushrooms, and the detailed, multi-step process of their cultivation, focusing specifically on *Agaricus bisporus* (white button mushroom). The study highlights mushroom farming as a sustainable and economically viable agribusiness, particularly in regions like Jammu and Kashmir, where temperate climates and local waste resources create a favorable environment for year-round production. The detailed production technology is a scientifically managed process encompassing compost preparation, a critical step that transforms raw agro-waste into a selective growth medium; spawn preparation and spawning, which involves inoculating the compost with pure fungal mycelium; casing, where a protective layer is added to stimulate fruiting; and finally, fruiting and harvesting, which requires precise environmental control for optimal yield. The review emphasizes the importance of utilizing innovations like region-specific composting methods and maintaining strict hygiene to ensure successful, high-quality production. Ultimately, mushroom cultivation is presented not just as a farming technique, but as a powerful tool for promoting sustainable livelihoods, creating employment, and enhancing public health. Production challenges include a lack of proper infrastructure like shade-net houses, high costs of raw materials, unavailability of quality spawn, and sensitivity to extreme weather. Marketing challenges are marked by poor market access, high transportation costs, and a lack of cold storage, leading to significant post-harvest losses and reduced profitability. Strategic issues facing initial projects often involve suboptimal compost quality, inconsistent yields, and high production costs due to a reliance on expensive, non-local inputs and machinery. Despite these hurdles, the economic analysis reveals a highly feasible and profitable model. With a modest initial fixed investment of approximately ₹1.47 lakh, an operation can generate a net annual profit of nearly ₹1.5 lakh, achieving a strong benefit-cost ratio of 1.90. This demonstrates that mushroom cultivation is a low-risk, scalable, and sustainable venture that provides substantial income and supports rural employment, particularly for women and youth. The study concludes that with targeted support for training, infrastructure, and market linkages, this model can become a powerful tool for economic empowerment and diversification in the agricultural sector.

**Key words:** Edible mushroom, Production technology, Sustainable livelihood, Improved cultivation, Medicinal uses, Agri-venture

A mushroom is the visible, fruiting body of a fungus and plays a vital role in the fungal reproductive cycle. Although commonly perceived as independent organisms, mushrooms are actually just a small part of a larger fungal network, much like fruit is to a tree [1]. Their primary biological function is to produce and release microscopic spores, which under suitable conditions such as the right moisture, temperature, and nutrients can grow into new fungi. These spores are dispersed through wind, water, animals, or insects, aiding in the colonization of new environments. Structurally, a mushroom includes a cap (pileus) that protects the spore-bearing surface, gills or pores where spores are formed, a stalk (stipe) that elevates the cap for efficient spore release, and sometimes remnants like the volva and annulus, which help in species identification. Hidden beneath the ground is the mycelium, the true body of the fungus,

consisting of thread-like hyphae that absorb nutrients, break down organic matter, and sustain the fruiting body. Mycelium can persist underground for years, producing mushrooms only when conditions are favorable [2]. Ecologically, mushrooms are crucial decomposers, breaking down dead organic matter, forming symbiotic (mycorrhizal) relationships with plants, or acting as parasites. Mushrooms belong mainly to the Basidiomycetes (like white button and shiitake) and Ascomycetes (like morels and truffles), although only a small fraction of known fungi actually produce visible mushrooms [3]. Their significance extends to culinary, medicinal, and industrial uses; they are valued not only for their rich taste and nutrition but also for bioactive compounds with antiviral, anticancer, and immune-enhancing properties. Mushrooms are the reproductive arms of fungi, supported by a vast and complex

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underground mycelial network, and play essential roles in nature and human life through their ecological functions and diverse applications [4-5]. The cultivation of edible mushrooms represents a valuable biotechnological innovation, offering a sustainable method to convert lignocellulosic agro-wastes like straw, sawdust, corn cobs, and other farm residues into high-

quality edible proteins. This process not only addresses waste management concerns but also contributes significantly to nutritional security. Mushroom cultivation is gaining global recognition as an efficient and eco-friendly agribusiness, particularly suited to regions with specific climatic and agricultural profiles [6].



Fig 1 Indoor cultivation of button mushrooms in polythene bags



Fig 2 Inspection of button mushroom cultivation in a controlled growing room



Fig 3 Button mushrooms ready for harvesting

In the context of Jammu and Kashmir, particularly the Kashmir Valley, mushroom cultivation presents a viable and scalable economic opportunity. The region's temperate climatic conditions are highly favorable for year-round mushroom

farming [7]. Unlike many agricultural activities, mushroom production does not heavily depend on external inputs like electricity, making it both cost-effective and accessible in rural and remote areas. Moreover, mushroom cultivation is

inherently a low-cost, eco-friendly technology that primarily utilizes locally available farm waste as raw material, thereby reducing environmental pollution and creating a circular agricultural system. Its indoor and labour-intensive nature also makes it ideal for employment generation, especially for unemployed youth, women, and socio-economically weaker sections of society [8].

#### *Nutritional and medicinal value*

Edible mushrooms are highly valued not only for their taste and texture but also for their nutritional and medicinal benefits. Often referred to as “vegetable meat”, mushrooms are rich in proteins, essential amino acids, vitamins (especially B-complex), and minerals like potassium, iron, and selenium [9]. Their low carbohydrate and fat content makes them an ideal component of low-calorie diets, particularly recommended for heart patients and those managing obesity. Additionally, mushrooms are free from starch, which makes them suitable for diabetic patients. Certain compounds in mushrooms, such as beta-glucans and other polysaccharides, have been found to exhibit anti-tumour, antioxidant, and immunomodulatory properties, placing them in the category of functional foods or nutraceuticals [10]. Their cholesterol-reducing capabilities further enhance their appeal among health-conscious consumers.

#### *Biodiversity and commercial production*

Globally, there are an estimated 2,000 species of macrofungi recognized as edible mushrooms. However, only about 80 species have been cultivated experimentally, with 40 species under economic cultivation, and just 20 grown commercially. Out of these, a mere five species are produced on a large industrial scale [11]. The most widely cultivated mushroom worldwide is the white button mushroom (*Agaricus bisporus*), accounting for over 40% of the global mushroom production, which stands at approximately 4 million metric tonnes. Other commercially important species include oyster mushrooms (*Pleurotus spp.*), shiitake (*Lentinula edodes*), enoki (*Flammulina velutipes*), and paddy straw mushroom (*Volvariella volvacea*). Mushroom cultivation is a powerful tool for promoting sustainable livelihoods, environmental conservation, and public health [12]. In regions like Jammu and Kashmir, it holds particular promise as a year-round, low-cost agribusiness that integrates seamlessly with local agro-climatic conditions. Its potential to address food and nutritional deficiencies, create employment, and contribute to medicinal product development makes it an essential component of future agri-biotech strategies [13].

#### *Production technology*

The production procedure of button mushroom (*Agaricus bisporus*) involves a series of well-structured and scientifically managed steps to ensure optimal growth and yield [14]. Here is an elaboration of each step involved in the process:

- i. Preparation of the compost
- ii. Preparation of spawn
- iii. Spawning
- iv. Spawn running
- v. Casing
- vi. Fruiting

#### *Compost preparation for improved mushroom cultivation*

Compost preparation is a critical and foundational process in mushroom cultivation, particularly for white button mushrooms (*Agaricus bisporus*), where it directly influences

mycelial growth, crop yield, disease resistance, and overall crop success. The compost functions not only as a growth medium but also as a biologically active system that must meet the physiological and nutritional needs of the mushroom mycelium. Effective compost is selectively decomposed organic matter that retains moisture, offers good aeration, and supports an active microbial population capable of converting raw organic residues into bioavailable nutrients. The central goal is to create a stable, pest-free, and nutrient-dense substrate that selectively supports the growth of mushroom mycelium over competing organisms [15].

The substrate base for compost is generally composed of carbon-rich materials such as wheat straw, paddy straw, corn stalks, or in some regions, sugarcane bagasse, which provide structure, improve porosity, and hold moisture essential features for microbial respiration and heat retention. These bulk materials are finely chopped (typically 5–8 cm in length) to increase surface area and enhance microbial degradation. Nitrogen-rich supplements including chicken manure, poultry litter, cattle dung, urea, and ammonium salts are added to fuel microbial activity. These are further enhanced with carbohydrate sources such as wheat bran, rice bran, molasses, or fruit concentrates that energize microbes and accelerate the decomposition process. The balance between carbon and nitrogen is critical; an initial C:N ratio of 25–30:1 is targeted, which narrows down to an optimal 16–20:1 by the end of composting, ensuring adequate nitrogen availability without ammonia toxicity [16].

To optimize the chemical and physical properties of the compost, mineral additives like gypsum (usually at 2% of dry weight) and calcium carbonate are included. These serve multiple purposes: they buffer the pH, improve the friability and structure of the compost, and assist in microbial enzymatic functions. Water plays an indispensable role throughout the process, with moisture levels maintained between 65–75%, promoting thermophilic microbial activity and regulating the internal temperature of compost piles, which can naturally rise to 65–70°C. This temperature range is vital for partial sterilization, ammonia volatilization, and suppression of weed molds and pathogens [17].

*There are two principal composting methods:* the Long Method of Composting (LMC) and the Short Method of Composting (SMC). The Long Method is a traditional technique requiring 35–40 days, where compost is prepared on open floors and turned every 2–3 days without a formal pasteurization phase. While cost-effective and simple, it lacks the microbial selectivity and hygiene control of modern methods. On the other hand, the Short Method, which spans 22–26 days, is widely preferred in commercial farming due to its improved control over microbial dynamics and pest suppression. SMC involves Phase I, where raw materials are mixed, wetted, and heaped outdoors or in semi-covered sheds; frequent turnings ensure uniform heating and aeration. This is followed by Phase II, where the compost is pasteurized in bulk chambers or low-cost pasteurization to kill pathogens and convert residual ammonia into microbial biomass. Gypsum is usually added during the final turnings, and the compost is considered ready for spawning once it has cooled to around 25°C [18].

*Compost quality is influenced by four main factors:* (1) the nature and quality of raw materials, (2) the selection and proportion of organic and inorganic supplements, (3) composting technique and management practices (e.g., frequency of turning, water application, pile size), and (4)

environmental conditions such as ambient temperature and humidity. Traditional compost recipes have evolved with time. For example, older methods used mule dung in combination with straw, but today, synthetic composts using poultry manure and agro-wastes are widely used due to better consistency and nutrient balance. In regions like Kashmir, research institutions such as SKUAST-Kashmir have designed tailored composting solutions, including SK-3A and SK-3B formulations, which use locally available materials like linseed straw, maize straw, and fallen leaves of apple, chinar, or poplar. These formulas not only reduce cost but also promote sustainability and resource recycling in mushroom farming [19]. To ensure success, several key operational practices must be adhered to during composting. Regular turning and aeration are essential to ensure uniform microbial activity and prevent anaerobic pockets. Water must be added strategically during turnings to compensate for evaporation and microbial consumption. The pile size should be optimized too large restricts oxygen flow; too small loses heat rapidly. Finer straw decomposes more effectively but can compact easily, so the amount of poultry manure added must be adjusted to avoid a dense, airless substrate. During pasteurization, careful monitoring of internal compost temperatures (52–58°C for 6–8 hours) ensures that harmful microbes are eliminated and the compost matures adequately for mushroom spawning [20]. Compost preparation is a sophisticated blend of microbiology, agronomy, and engineering. Whether through the long or short method, the focus remains on transforming raw, fibrous agricultural waste into a selective, fertile medium that provides the physical structure and biochemical environment required for mushroom development. Innovations like region-specific composting strategies by SKUAST-Kashmir are instrumental in democratizing mushroom farming, making it accessible even to small-scale rural growers. Properly prepared compost not only boosts productivity and sustainability but also forms the very bedrock of successful, high-quality mushroom cultivation [21].

#### *Significance of compost in mushroom cultivation*

Compost serves as the foundational substrate for mushroom cultivation, providing essential nutrients and a conducive environment for mycelial growth. The quality of compost directly influences the health of the mycelium, disease resistance, and overall yield. A well-prepared compost ensures optimal moisture retention, aeration, and a balanced nutrient profile, which are crucial for the successful cultivation of mushrooms [22].

#### *Substrate composition and C:N ratio*

The primary ingredients in compost preparation include carbon-rich materials like wheat straw, paddy straw, and corn stalks, which serve as bulking agents. These are combined with nitrogen-rich additives such as chicken manure, poultry litter, and occasionally urea. Carbohydrate supplements like molasses and wheat or rice bran are added to accelerate microbial activity. The carbon-to-nitrogen (C:N) ratio is a critical parameter; it typically starts at 25–30:1 and narrows to 16–20:1 as composting progresses, with an optimal final ratio around 17:1 [23].

#### *Role of gypsum and pH management*

Gypsum (calcium sulfate) is commonly added during compost preparation to buffer pH levels and improve the structural integrity of the substrate. It aids in reducing ammonia toxicity and enhances the physical properties of the compost, promoting better mycelial colonization. Maintaining an

appropriate pH level is essential, as it influences nutrient availability and microbial activity within the compost [24].

#### *Moisture content and temperature regulation*

Water is a vital component in compost preparation, ensuring microbial survival and optimal temperature regulation. Moisture levels are typically maintained between 65–75% to facilitate microbial activity and heat generation. Temperature control is equally important; internal compost temperatures can reach up to 70°C, which helps in partial sterilization, eliminating pathogens and undesirable microorganisms [25].

#### *Preparation of compost for button mushroom cultivation*

Compost serves as the essential growth substrate for button mushrooms (*Agaricus bisporus*), created through microbial decomposition of organic materials such as wheat straw, sugarcane bagasse, and rice bran. Compost preparation ensures the breakdown of complex organics into a nutrient-rich medium, maintaining an ideal C:N ratio of 25–30:1 during the initial phase, which should drop to 16–17:1 by the end. For 1 kg of button mushroom, around 220 g of raw materials are needed, and for 1 ton of compost, supplementation with 6.6 kg nitrogen, 2.0 kg phosphate, and 5.0 kg potassium is recommended [26].

#### *Short method of composting (22–26 days)*

This method is widely adopted for its efficiency and better control over quality. It requires a clean, cemented floor under shade or in open air with protection from rain. The process begins by chopping paddy straw into 20–30 cm pieces, soaking and layering it, and mixing it with fertilizers (like urea, MOP, and superphosphate), wheat bran, and molasses. The mixture is stacked (5 ft × 5 ft) and subjected to periodic turnings:

Day 2: First turning and watering

Day 4: Second turning and gypsum addition

Day 12: Third turning; compost turns dark brown with ammonia odor

The compost is then pasteurized at 60°C for 4 hours to eliminate pests and pathogens and convert residual ammonia into microbial protein. Final compost is dark brown, ammonia-free, has 70% moisture, pH around 7.5, and a pleasant earthy smell, with temperature reducing to 25°C before use [27].

#### *Long method of composting (35–40 days)*

Used in regions lacking pasteurization facilities, this method relies on extended natural microbial activity. The first turning is done on Day 6, with subsequent turnings on:

Day 10: Second turning and gypsum addition

Day 17, 20, 23: Fourth to sixth turnings

Day 26: Seventh turning with 125 g Benzene Hexachloride (10%) to control pests

Day 28: Eighth turning, with ammonia smell as the key indicator for readiness

More turnings may be needed if ammonia smell persists. Like the short method, final compost should be friable, dark brown, ammonia-free, and suitable for spawn inoculation.

Efficient compost preparation is both an art and science, integrating principles of microbial ecology, agronomic science, and resource management. Whether employing traditional long methods or more rapid short methods, the ultimate goal remains the same: to produce a selective, well-conditioned substrate that supports healthy mycelial colonization and maximizes mushroom yield. Innovations by local research institutions, like

SKUAST-K, offer cost-effective, sustainable solutions tailored to regional materials and small-scale growers, promoting better productivity and resource utilization in mushroom cultivation [28].

### *Spawning*

Spawning is the process of inoculating the compost with mushroom spawn, which is essentially mycelium grown on a carrier material like grains [29].

### *Spawn run*

- After mixing the spawn into the compost, it is left undisturbed for 12–15 days to allow the mycelium to colonize the substrate.
- Temperature during spawn run: 20–28 °C.
- The compost is usually covered with a layer of newspaper or plastic to retain moisture and warmth.

### *Preparation of spawn in button mushroom cultivation*

The spawn, considered the "seed" of mushrooms, is developed from pure cultures of selected high-yielding mushroom strains. Spawn preparation is a critical step, as it directly influences yield, texture, flavor, and overall crop health [30]. The process begins with the isolation of fungal mycelium, which can be achieved using three key methods:

#### *Spore print method*

Spores are collected by placing a sterilized mushroom cap on a clean surface. After 24–48 hours, the spores drop in a pattern replicating the gill structure. These spores are then used to initiate culture development [31].

#### *Tissue culture method*

A small section of the mushroom's pileus is sterilized and placed on a nutrient medium in Petri dishes. Incubated at 25±1°C, pure mycelial growth appears within 6–12 days, from which uncontaminated plates are selected [32].

#### *Sub-culturing*

Pure cultures from the previous steps are periodically transferred aseptically to fresh media to maintain vitality and prevent contamination. These become the foundation for future spawn production.

#### *Mother spawn and commercial spawn preparation*

The mother spawn is prepared using sterilized grains (wheat, sorghum, or rye) as substrate. The grains are first boiled, dried, and then mixed with gypsum and chalk (to maintain grain separation and control pH). These are filled into bottles, sterilized (2–3 hours in an autoclave), and inoculated with mycelium from the pure culture. The bottles are incubated at 24–26°C and shaken after a week to promote uniform colonization. After 14 days, the fully colonized mother spawn can be used to inoculate many commercial spawn units [33].

Commercial spawn is produced by inoculating sterilized grain bags or bottles using mycelium from mother spawn, under aseptic conditions (usually in front of HEPA filters). These are also incubated at 24–26°C for around two weeks [34].

#### *Qualities of good spawn*

- Uniform mycelial coating on grains
- Strand-like mycelial growth (not fluffy or cottony)
- White appearance when young, turning brown with maturity
- Absence of slimy texture (bacterial contamination)
- No green or black mold (fungal contamination)

This spawn is finally used to inoculate compost beds, ensuring the foundation for successful fruiting in button mushroom cultivation.

### *Spawn production technology in mushroom cultivation*

Spawn refers to the vegetative growth of mushroom mycelium, usually propagated on a sterilized grain medium such as wheat, sorghum, or millet grains. Wheat grains are most commonly used due to their easy availability and rich nutrient content.

#### *High-quality spawn is:*

- Pure (free from contamination)
- Vigorous (fast-growing and healthy)
- Prepared under sterile conditions in well-equipped laboratories

Spawn is not typically produced on farms due to the need for controlled, sterile lab environments, and is generally obtained from authorized spawn production units or research institutions.

Once the compost has been adequately prepared through either the long or short method, the next critical phase in mushroom cultivation is spawning the process of introducing mushroom mycelium (spawn) into the compost. This phase is pivotal, as the quality and purity of the spawn directly influence the yield, disease resistance, and overall success of the crop.

#### *Spawn production (Lab process)*

The production of mushroom spawn in a laboratory setting involves several crucial steps, beginning with the selection and preparation of grains. First, suitable grains are meticulously cleaned and then boiled until they achieve a soft, but not mushy, consistency. Following this, they are carefully dried to attain a surface moisture content of approximately 50–55%, which is optimal for mycelial growth [35]. To further enhance the substrate, the boiled grains are then blended with a small amount of calcium carbonate and gypsum; these additives serve to adjust the pH to an ideal range and prevent the grains from clumping together during subsequent processes. The next critical stage is sterilization, where the prepared grain mix is meticulously filled into heat-resistant glass bottles or specialized polypropylene bags. These containers are then subjected to autoclaving at a high temperature of 121°C for a duration of 1 to 2 hours. This rigorous sterilization process is essential to eliminate any potential contaminants, such as bacteria, molds, or other fungi, that could compete with or inhibit the desired mushroom mycelium. Once the grains are fully sterilized, the process moves to inoculation with pure mycelium [36]. This delicate step is performed under strictly aseptic conditions within a laminar airflow chamber to prevent any airborne contamination. Here, the sterilized grains are carefully inoculated with a pure culture of mushroom mycelium that has been previously grown on agar media. After inoculation, the bags or bottles are sealed and then incubated at a controlled temperature of 22–25°C [37]. During this incubation period, which typically spans 10–14 days, the mycelium actively colonizes the grain substrate, growing and spreading throughout until the entire mass is fully permeated with a dense network of fungal hyphae, forming what is known as spawn. Finally, the storage and use phase dictates that the fully colonized spawn should ideally be used immediately for mushroom cultivation. However, if immediate use is not feasible, it can be stored for short periods at a cool temperature of 2–4°C. It is generally observed that fresh spawn exhibits superior performance compared to spawn that has been stored

for extended durations, highlighting the importance of timely utilization for optimal cultivation results [38].

#### *Spawning techniques (In-farm application)*

Following the successful production of high-quality spawn, the next critical step in mushroom cultivation, known as spawning, involves introducing this spawn into the prepared compost. The typical application rate for spawn is 0.5% of the compost's weight, though increasing this percentage can accelerate the colonization process [39]. The choice of spawning method is often dictated by various factors, including ambient environmental conditions, the texture of the compost, and the type of container being used. Through spawning, recognized as the most prevalent technique, involves thoroughly mixing the spawn evenly throughout the entire compost mass, which promotes uniform mycelial colonization. In contrast, top layer spawning entails spreading the spawn exclusively on the surface of the filled compost, subsequently covering it with a thin layer of additional compost; this method proves particularly advantageous when the compost exhibits a slightly higher moisture content than ideal. Double layer spawning introduces spawn in two distinct stages: once when the containers or beds are half-filled with compost, and again upon full filling, a technique that significantly encourages faster vertical colonization within the substrate [40]. For shake-up spawning, the spawn is initially incorporated and left undisturbed for approximately one week, after which the compost is agitated or mixed before being returned to its containers; this method can be immediately or shortly followed by casing. Lastly, spot spawning involves inserting small quantities of spawn grains into evenly spaced holes created across the compost surface, a technique that ensures excellent contact between the mycelium and the compost, proving especially beneficial when dealing with dense substrates [41].

#### *Environmental conditions for spawn run*

The spawn-run is the colonization phase, where the mycelium spreads throughout the compost before fruiting begins. This phase lasts about 10–15 days under optimal conditions:

*Compost temperature:* 24°C is ideal for mycelial growth.

*Room temperature:* 22–25°C for stable ambient conditions.

*Relative humidity:* High (80–90%) to prevent drying of compost.

*Carbon dioxide:* Levels up to 2% are beneficial; can be maintained by minimizing ventilation.

*Moisture maintenance:* If needed, water is sprayed lightly on paper or newspaper sheets covering the beds to avoid disturbing the compost.

Using freshly prepared spawn (immediately after mycelium colonization in the lab) is preferable, as it grows faster compared to spawn stored under refrigeration.

Spawn production and spawning are essential technical components of mushroom cultivation. While compost provides the physical and nutritional base, spawn acts as the biological starter, determining how effectively the mycelium will colonize the medium. High-quality spawn, careful spawning techniques, and proper environmental conditions during the spawn-run ensure rapid, uniform colonization, ultimately leading to healthy, productive mushroom crops. In integrated mushroom

farming systems, using certified lab-produced spawn and following best practices during spawning can significantly boost both yield and profitability [42].

#### *Casing*

Once the mushroom spawn has thoroughly colonized the compost, a crucial step in mushroom cultivation is the application of a casing layer on top of the substrate. The primary purpose of casing is to provide a specific micro-environment that triggers the formation of primordia, which are the tiny, nascent mushroom buds, thus initiating the fruiting phase. Beyond this, the casing layer is essential for retaining optimal moisture levels within the substrate and facilitating proper gas exchange, both vital for healthy mushroom development. It's important to note that the casing itself does not serve as a nutritional source for the mushrooms but rather plays a significant role in managing water balance and fostering a beneficial microflora. The casing material typically consists of a blend, often including peat soil, garden soil, sand, or spent compost. Regardless of the specific composition, an ideal casing material should possess a pH between 7.0 and 7.5, exhibit good porosity to allow for aeration, and demonstrate a high water-holding capacity. Before application, the casing material undergoes sterilization, usually through pasteurization or heat treatment, or sometimes chemical treatment with agents like formaldehyde. This critical step eliminates competing organisms and pathogens that could otherwise contaminate the mushroom crop and significantly reduce yield [43].

#### *Casing technology in mushroom cultivation*

Casing is a vital step in button mushroom cultivation that marks the transition from vegetative growth to the reproductive stage, enabling the development of mushroom fruit bodies or sporophores. This technique involves applying a biologically inert, porous, and moisture-retentive material over fully colonized compost roughly 10–14 days after spawning, with an ideal casing depth of 3.8 to 5.0 cm. The primary purpose of the casing layer is multifaceted: it stimulates fruiting by creating a microenvironment that induces pinhead formation, acts as a reservoir for moisture essential for fruit body development, offers physical support to ensure the upright and uniform growth of mushrooms, and facilitates proper gas exchange by buffering changes in CO<sub>2</sub> and O<sub>2</sub> levels. A good casing material must have high water-holding capacity, excellent aeration, structural stability, a neutral to slightly alkaline pH (7.0–7.5), and be free from pests, diseases, or undecomposed organic matter. Common casing mixtures include soil:peat (2:1 or 3:1), soil:sand (2:1), and well-rotted cow dung with light soil (3:1), each tailored to enhance moisture retention, aeration, and microbial activity [44–45]. An important biological component of effective casing is the presence of *Pseudomonas putida*, a beneficial bacterium that contributes significantly to fruiting by interacting with the mycelium, potentially releasing iron to promote development, and aiding in pinhead initiation. Using soil from barren or fallow land helps minimize contamination from previous crops [46–47]. Thus, proper casing is not merely a physical layer but a critical biological interface that directly influences the success of mushroom fruiting.

#### *Sterilization and pasteurization of casing material*

Proper casing is essential for successful mushroom cultivation, serving as a critical layer that supports fruiting and gas exchange. To ensure the casing material is safe and effective, it must be treated to eliminate harmful microbes. There are three primary methods for this: steam pasteurization, which uses steam at 60°C for five hours to kill pathogens while

preserving beneficial organisms; chemical sterilization, a method using a 2% formalin solution that's sprayed onto the casing material and left for 48 hours before being stirred daily for a week to dissipate fumes; and solarization, an eco-friendly option where the casing is spread thinly, covered with plastic, and exposed to direct sunlight for 30 days [48]. After treatment, the casing should be applied uniformly over the compost to prevent issues like irregular mycelium growth and poor pin formation. This is followed by the case-running phase, which lasts 5–8 days, where the mycelium grows into the casing layer under specific environmental conditions, including temperatures between 22–25°C, 85–90% humidity and elevated CO<sub>2</sub> levels [49-50]. Ultimately, casing is a biological interface that is more than just a cover; it's vital for water retention, stimulating fruiting, and providing microbial support, all of which are crucial for a healthy, high-yielding mushroom crop.

### Cropping and harvesting

Cropping and harvesting represent the culmination of the mushroom cultivation process and require precise environmental management to ensure optimal yield and quality. Once the casing layer is applied and the mycelium has thoroughly colonized it, fruiting begins within 2–3 weeks, provided that the environmental conditions are carefully regulated [51]. During the spawn run, a temperature of 20–28°C is maintained, whereas fruiting necessitates a drop to 12–18°C. Humidity levels must be sustained between 85–90%, and proper ventilation is essential to expel excess CO<sub>2</sub> and ensure adequate oxygen, both of which are vital for the formation of firm and healthy mushroom caps. Harvesting is ideally conducted when the mushroom caps are fully developed but before the veil breaks and exposes the gills, ensuring peak freshness and market value. Mushrooms are harvested by gently twisting them from the base, taking care not to damage nearby pins, which are potential future harvests. Success during this stage also depends on several critical factors: the use of high-quality, contaminant-free spawn guarantees vigorous growth; strict hygiene and sanitation in tools, composting areas, and among workers help prevent contamination; and consistent pest and pathogen control is necessary to combat common threats like green mold (*Trichoderma*), mites, and flies [52]. Furthermore, batch scheduling allows for staggered bed

production, facilitating a continuous and steady output. Thus, cropping and harvesting in mushroom farming is a delicate balance of scientific precision and practical skill, essential for making the enterprise both productive and sustainable [53].

### Initiation of cropping (Fruiting induction)

Fruiting induction begins approximately 10–15 days after casing, once the mycelium starts to emerge on the surface of the casing layer, by carefully modifying environmental conditions to stimulate mushroom formation. Key parameters include lowering the temperature to 16–18°C, reducing relative humidity to around 70–80%, and maintaining carbon dioxide (CO<sub>2</sub>) levels below 1000 ppm these changes encourage pinning and the subsequent development of fruit bodies (Table 1). Adequate fresh air exchange is crucial to expel excess CO<sub>2</sub> and ensure sufficient oxygen, while diffused, indirect light aids in mushroom orientation, though not essential for growth [54]. Fine misting is used to keep the casing moist, especially in dry weather, but excessive humidity can lead to malformed mushrooms due to CO<sub>2</sub> buildup. Mushrooms appear in periodic flushes rather than continuously, with the first flush emerging about three weeks post-casing, followed by subsequent flushes every 6–8 days. Typically, a crop cycle yields 4–5 flushes, with the first flush producing the highest yield. Each mushroom takes about 7–8 days to grow from a pinhead to a harvestable stage [55]. Watering during cropping must be carefully managed using fine mist sprays to maintain casing moisture without causing compaction or disrupting gas exchange. Harvesting is performed when the cap is fully developed but still closed, using either the twisting method (gently twisting and pulling) or the cutting method (using a sharp knife when surrounded by pins). Post-harvest, the cavity left by the harvested mushroom should be filled with sterilized casing soil, leveled, and gently patted down to maintain the microenvironment and reduce contamination risk. High hygiene standards during harvesting are critical to preventing disease and sustaining productive flushes throughout the crop cycle [56].

Fine misting of water is essential to keep casing moist, especially in dry weather. Excess humidity may cause CO<sub>2</sub> buildup, promoting poor mushroom formation and malformed caps.

Table 1 Optimal environmental parameters for mushroom cultivation

Parameter	Optimal range	Purpose
Temperature	16–18°C	Induces pinning and fruiting
Humidity	70–80%	Maintains casing moisture, supports mushroom development
Carbon dioxide (CO <sub>2</sub> )	≤ 1000 ppm	Lower CO <sub>2</sub> encourages fruit body formation
Air exchange	Fresh air circulation	Prevents CO <sub>2</sub> buildup and ensures oxygen supply
Light	Diffused, indirect	Not essential for photosynthesis but helps orientation of mushrooms

### Fruiting and flush pattern

In button mushroom cultivation, fruiting follows a distinct flush pattern rather than occurring continuously, with the first flush typically appearing around three weeks after casing. Subsequent flushes emerge at intervals of 6–8 days, influenced by environmental factors such as temperature, humidity, and ventilation. A complete cropping cycle usually consists of 4–5 flushes, with the first flush yielding the highest quantity and each following flush progressively producing less. Each mushroom takes approximately 7–8 days to develop from a pinhead to a fully mature, harvestable button [57]. Proper watering during cropping is essential to maintain casing moisture without disrupting the microenvironment fine mist sprays are ideal, particularly in dry climates, while heavy

watering should be avoided as it can cause surface compaction and hinder oxygen penetration. Mushrooms should be harvested when the caps are fully formed but still closed, just before the veil breaks [58]. Two primary harvesting techniques are used: the twisting method, which involves gently twisting and pulling the mushroom to avoid damage, and the cutting method, suitable when surrounded by delicate pinheads, using a sharp knife to minimize disturbance. After harvesting, it is important to refill the empty holes with sterilized casing soil, level the surface, and gently firm it to prepare for the next flush while maintaining cleanliness. Strict hygiene during harvesting minimizes the risk of pest and disease introduction, ensuring sustained yield and healthy crop development throughout the flush cycle [59].

Table 2 Cropping duration and systems

Cultivation system	Typical duration	Flushes	Notes
Tray system	6-7 weeks	4-5	Common in homes and small farms
Shelf system	6-8 weeks	4-5	Tiered composting allows efficient use of space
Bag system	6-8 weeks	4-5	Widely adopted due to low cost and flexibility

*Cropping in Kashmir context*

In Kashmir, mushroom cropping is predominantly practiced as an indoor activity within residential homes, often in non-environmentally controlled rooms where growers rely on natural seasonal temperature fluctuations instead of artificial climate regulation. This low-cost approach makes mushroom cultivation particularly feasible and appealing to small-scale and rural farmers. A variety of cultivation containers are employed, with 10 kg capacity polythene bags being the most common due to their affordability and ease of use (Table 2). Other containers include wooden or plastic trays, aluminum trays, used fruit boxes, old cement bags, and traditional peeled willow baskets lined with polythene, reflecting the region's adaptability and resourcefulness [60]. For successful cropping and harvesting, several practices are vital: maintaining evenly moist but not overly saturated casing soil, ensuring proper air circulation especially during flush periods, harvesting

mushrooms at the optimal stage before the veil breaks to preserve quality and shelf-life, and refilling harvest holes with sterilized casing soil to sustain subsequent flushes. Cleanliness within cropping rooms is crucial to prevent pest infestations and the spread of diseases. In essence, cropping and harvesting in Kashmir combine scientific understanding with practical, locally adapted techniques. The outcome of this final stage directly influences the total yield, quality, and profitability of mushroom production. With disciplined crop management, even small-scale growers in the region can achieve multiple, high-quality flushes from a single compost cycle, making mushroom farming a sustainable and accessible livelihood option [61-62].

*Diseases of button mushroom*

These compete with mushroom mycelium, affecting spawn-run and fruiting.

Table 3 Weed fungi (Competitor moulds)

Disease	Causal agent	Symptoms	Causes and Control
Green mould	<i>Trichoderma viride</i>	Green patches on compost, delayed pinhead formation	Improper pasteurization, high humidity
False truffle disease	<i>Pseudobalsamia microspora</i>	Brain-like structures in casing soil, fused mushroom caps	Poor ventilation, high temp (>22°C)
Brown plaster mould	<i>Papulaspora byssina</i>	White to brown powdery patches on casing	Wet compost, excessive moisture
Inky caps	<i>Coprinus spp.</i>	Long stalks, thin caps, liquefies into black mass	Under-composting, ammonia presence
Cinnamon mould	<i>Peziza spp.</i>	Dark brown gelatinous cup-like structures	Use of peat in casing material

The provided (Table 3) details several weed fungi, also known as competitor moulds, that negatively impact mushroom cultivation. It categorizes five diseases: Green mould, caused by *Trichoderma viride*, presents as green patches on compost, leading to delayed mushroom formation. This is often caused by improper pasteurization and high humidity. False truffle disease, caused by *Pseudobalsamia microspora*, is characterized by brain-like structures in the casing soil and fused mushroom caps, often resulting from poor ventilation and

high temperatures above 22°C [63]. Brown plaster mould, caused by *Papulaspora byssina*, appears as white to brown powdery patches on the casing, typically due to wet compost and excessive moisture. Inky caps (*Coprinus spp.*) are identified by long stalks and thin caps that eventually liquefy into a black mass, a symptom of under-composting and the presence of ammonia. Lastly, Cinnamon mould (*Peziza spp.*) forms dark brown, gelatinous, cup-like structures, and its occurrence is linked to the use of peat in the casing material [64].

Table 4 Parasitic moulds (True pathogens)

Disease	Causal agent	Symptoms	Causes and Control
Wet bubble disease	<i>Mycogone perniciosa</i>	Brown rot, foul-smelling soft masses, malformed fruit bodies	Poor hygiene, contaminated casing
Dry bubble disease	<i>Verticillium fungicola</i>	Deformed mushrooms, cap pimples, grey spots	Airborne spores, fly vectors, contaminated casing
Cobweb disease	<i>Cladobotryum dendroides</i>	Cobweb-like mycelium turns pink/red, affects all stages	High humidity, spread by air/contact

The provided (Table 4) details three significant parasitic moulds, or true pathogens, that affect mushroom crops. Wet bubble disease, caused by *Mycogone perniciosa*, is characterized by brown rot and foul-smelling, soft masses that deform the mushroom's fruit bodies. This disease is typically a result of poor hygiene and contaminated casing material. Dry bubble disease, caused by *Verticillium fungicola*, presents with deformed mushrooms, cap pimples, and grey spots [65]. Its spread is mainly through airborne spores, fly vectors, and contaminated casing. Lastly, cobweb disease, caused by *Cladobotryum dendroides*, is easily identified by its distinctive

cobweb-like mycelium that eventually turns pink or red and can affect mushrooms at all stages of development. High humidity and spread through air or direct contact are the primary factors contributing to this disease. Each of these pathogens has distinct symptoms and is managed through improved sanitation and environmental controls [66].

*Wet bubble disease*

Wet bubble disease (WBD), primarily caused by *Hypomyces perniciosis* (formerly *Mycogone perniciosa*), is emerging as a significant global threat to the commercial

cultivation of *Agaricus bisporus* (white button mushroom). This study evaluated the efficacy of selected chemical fungicides—chlorothalonil, metrafenone, and prochloraz-Mn and *Bacillus*-based biocontrol agents (*Bacillus subtilis* and *Bacillus amyloliquefaciens* strains) in controlling WBD under artificial inoculation at varying disease pressures. Six controlled trials were conducted with three different conidial inoculum rates, simulating low, moderate, and high disease conditions [67].

Treatments were assessed for their impact on disease incidence, yield, and biological efficiency. Chemical fungicides demonstrated superior effectiveness, particularly prochloraz-Mn, which significantly reduced disease incidence across all inoculum levels, especially during the first two flushes. In contrast, metrafenone was less effective under high disease pressure, suggesting limited utility in severe outbreaks. The *Bacillus*-based products showed minimal control over WBD at the tested dosages and timing, with effectiveness consistently below 20% and statistically comparable to untreated, inoculated controls. These findings underscore the continued reliance on chemical fungicides for managing WBD, particularly under conditions of high pathogen load. However, the limited efficacy of *Bacillus* treatments highlights the need for further research into optimized biocontrol application strategies or the development of alternative, sustainable management practices [68].

The disease cycle is perpetuated by the pathogen's survival as resistant spores in contaminated casing material, which is the main source of inoculum. Effective management relies on a multi-pronged integrated pest management (IPM) approach, prioritizing strict sanitation and hygiene to prevent initial outbreaks. This includes using pasteurized casing, disinfecting all equipment, and immediately removing infected mushrooms. While prochloraz-Mn is the most effective

chemical fungicide, its use is restricted in some regions due to environmental and food safety concerns, and rotating fungicides is crucial to prevent resistance. Biological control agents like *Bacillus subtilis* offer some promise by competing with the pathogen for nutrients but are often ineffective under high disease pressure. Ultimately, the best defense against WBD combines rigorous preventive measures with targeted chemical or biological controls to protect mushroom crops and maintain profitability [69].



Fig 4 Wet bubble disease

Table 5 Effectiveness and impact of different fungicides on mushroom diseases

Fungicide	Active ingredient	Effectiveness	Impact
Prochloraz-Mn	Prochloraz (46% WP)	★★★★☆	Most effective, especially in early flushes
Chlorothalonil	50% SC	★★★★☆	Moderate effectiveness; contact fungicide
Metrafenone	50% SC	★★☆☆☆	Less effective under heavy inoculum

Table 6 Common insect pests and nematodes of mushroom crops

Pest type	Examples	Damage symptoms
Flies	Phorid ( <i>Megaselia halterata</i> ), Sciarid ( <i>Lycoriella mali</i> ), Gall midges	Larvae tunnel into mushrooms, eat mycelium and buds
Beetles	Black ( <i>Sacphisoma nigrofaceatum</i> ), Brown ( <i>S. pictum</i> )	Scrape mushroom tissue, transmit bacterial diseases
Springtails	<i>Lepidocyrtus cyaneus</i> , <i>Isotoma simplex</i>	Feed on mycelium and buds
Nematodes	<i>Ditylenchus myceliophagus</i> , <i>Aphelenchoides spp.</i>	Inhibit mycelial growth, cause patchy yield
Mites	<i>Tarsonemus myceliophagus</i> , <i>Tyrophagus longior</i>	Eat spawn, transmit diseases

#### Insect pests and vectors

The provided data in (Table 6) comprehensively details the common pests of mushroom crops, categorizing them into five distinct groups based on their type, specific examples, and the damage they cause. The most prevalent pests include flies like phorids and sciarids, whose larvae are particularly destructive, tunneling into the mushroom tissue and feeding on mycelium and buds, which significantly reduces crop yield. Similarly, beetles, such as the black and brown varieties, not only scrape mushroom tissue but also serve as vectors for bacterial diseases [70]. Springtails and nematodes are also major threats; springtails feed on mycelium and buds, while nematodes like *Ditylenchus myceliophagus* inhibit mycelial growth, resulting in patchy, uneven yields. Lastly, mites,

including *Tarsonemus myceliophagus* and *Tyrophagus longior*, cause damage by consuming the spawn and are capable of transmitting diseases, further jeopardizing the health and productivity of the mushroom farm [71]. The information highlights how these diverse pests inflict damage through direct consumption, growth inhibition, and disease transmission, underscoring the need for effective pest management strategies in mushroom cultivation.

#### Production challenges

Button mushroom cultivation faces several production challenges that significantly impact yield and sustainability. A major issue is the lack of shade-net houses, which are crucial for regulating temperature and humidity, especially in regions

with extreme climates. The unavailability of quality spawn often forces growers to rely on inferior or contaminated material, reducing productivity. High costs of essential raw materials like wheat straw, gypsum, and fertilizers further increase the financial burden on small-scale farmers. Excessive summer temperatures hinder mycelial growth and fruiting, while heavy monsoon rains can lead to compost spoilage, increased contamination, and pest outbreaks. Additionally, a shortage of trained labor affects proper composting, spawning, and disease management. Compounding these issues is the lack of initial capital, which limits investment in infrastructure and technology, restricting expansion and the adoption of modern cultivation practices [72].

#### Marketing challenges

The marketing of button mushrooms is hindered by several key challenges that affect both producers and consumers. Poor market access and inadequate facilities make it difficult for growers to reach larger consumer bases, especially in remote areas. High transportation costs further increase the price of the product, reducing its competitiveness in the market. The lack of well-established wholesale market networks limits opportunities for bulk sales, forcing farmers to sell at local markets at lower prices. The absence of cold storage or preservation facilities results in rapid spoilage, leading to post-harvest losses and reduced shelf life, further decreasing profitability. Additionally, minimal promotion or advertisement for mushrooms means that potential consumers may be unaware of their availability or benefits, limiting overall market demand and growth [73].

#### Strategic issues with initial projects

Initial mushroom cultivation projects often face strategic challenges that can hinder their success. One significant issue is the use of poor-quality paddy straw-based compost, which compromises the growth of mushrooms and results in suboptimal yields. Another challenge is the difficulty in sourcing high-quality spawn and casing material, which are essential for successful mushroom cultivation but can be hard to find locally, leading to reliance on expensive or inconsistent supplies. The high cost and limited availability of specialized

machinery required for efficient production further strain the budgets of new ventures. Inconsistent yields and crop failures are also common, often due to the lack of experience or inadequate cultivation techniques. Finally, high production costs are exacerbated by the lack of localized solutions, such as locally sourced raw materials and equipment, which forces producers to rely on expensive imports, increasing the overall cost of production [74].

#### Economics of mushroom cultivation

The economics of button mushroom cultivation on a small-scale using polythene bag technology demonstrates how a relatively modest investment can generate a steady income with good returns. This model is especially suited for small or marginal farmers, women entrepreneurs, and agri-startups.

The economics of button mushroom cultivation using polythene bag technology presents a profitable and sustainable agro-enterprise, particularly well-suited for small and marginal farmers, women entrepreneurs, and agri-startups. This low-cost model requires minimal space and investment, making it accessible and easy to implement even in backyard setups or small sheds. With an initial investment of ₹25,000–₹40,000, cultivators can harvest 250–300 kg of mushrooms per cycle, yielding a net profit of ₹15,000–₹20,000 every 8–10 weeks, and potential annual earnings of up to ₹1 lakh or more [75]. The polythene bag method offers efficient space usage, manageable growing conditions, and scalability, while government support through training and subsidies enhances feasibility. Despite challenges such as perishability and market access, solutions like value addition, training programs, and digital marketing platforms make this model a viable path to income diversification and rural entrepreneurship. Let's break down and discuss each component in detail:

##### A. Non-recurring expenses (Fixed capital cost)

These are one-time investments necessary to set up the infrastructure.

##### B. Recurring expenditure

These are operational costs per crop cycle, including materials and labor.

Table 7 Estimated fixed costs for setting up a commercial mushroom growing unit

Component	Cost (Rs)	Discussion
1. Growing room construction (Size: 34' × 18' × 9.5', 750 bag capacity) @ Rs 200/sq ft	1,22,400	This cost is for a basic growing room without insulation. A larger or insulated room would increase the cost but might allow better environmental control.
2. Scrap wooden shelves	20,000	Shelving is used to stack the bags vertically, maximizing space utilization. Scrap wood makes this affordable.
3. Miscellaneous costs	5,000	Includes costs like basic tools, sanitation units, or minor construction items.
<b>Total fixed cost</b>	<b>1,47,400</b>	<b>A modest capital investment for entering commercial mushroom cultivation.</b>

Table 8 Estimated recurring costs for one crop cycle of mushroom cultivation

Input	Quantity and rate	Cost (Rs)	Remarks
Wheat straw	45 q @ Rs 120/q	6,400	Primary carbon source for compost.
Chicken manure	33 q @ Rs 50/q	1,650	Provides nitrogen and microbes for composting.
Rice bran	6 q @ Rs 500/q	3,000	Nutrient supplement.
Maize grain	57 kg @ Rs 10/kg	570	Additional nutrition.
Linseed meal	50 kg @ Rs 12/kg	960	Protein supplement.
Urea	57 kg @ Rs 6/kg	342	Nitrogen boost.
Potash	23 kg @ Rs 5/kg	115	Supports mycelial growth.
Gypsum	169 kg @ Rs 4/kg	676	Maintains compost pH and structure.

Casing soil	Lump sum	5,000	Important for fruiting phase.
Polythene bags	15 kg @ Rs 100/kg	1,500	Used to hold the substrate.
Fuel charges	-	1,000	May include heating/boiling compost.
Electricity	-	2,000	For lighting, ventilation, temperature control.
Labor (3 months)	-	6,000	Wages for preparation, maintenance, harvesting.
Miscellaneous	-	3,000	Unforeseen costs, packaging, maintenance.
Total recurring cost (per crop)		32,213	

### C. Fixed cost depreciation + Interest

To realistically estimate profitability, capital cost depreciation (10%) and interest (15%) are considered.

Table 9 Depreciation and interest on fixed costs in mushroom cultivation

Component	Amount (Rs)
Depreciation + Interest on fixed cost	₹36,850

### D. Annual recurring expenses

Since 4 crops are taken annually, recurring expenses are multiplied:

$$4 \text{ crops/year} \times ₹32,213 \text{ per crop} = ₹1,28,852$$

### E. Total annual expenses

$$C + D = ₹36,850 + ₹1,28,852 = ₹1,65,702$$

### F. Production and income

Table 10 Estimated annual mushroom yield and income

Yield per bag	1.75 kg
Bags per crop	750
Total per crop	1,312.5 kg
Total (4 crops/year)	5,250 kg
Selling Price	₹60/kg
Total annual income	₹ 3,15,000

### G. Net profit

$$\text{Income} - \text{Expenses} = ₹3,15,000 - ₹1,65,702 = ₹1,49,298$$

### H. Benefit - Cost ratio (B:C)

$$\text{B:C Ratio} = \text{Total Income} / \text{Total Expenses} = 3,15,000 / 1,65,702 \approx 1.90$$

The document says 1:1.11, which might be a typo or calculated differently (possibly comparing profit to cost rather than income to cost).

Correct interpretation suggests every ₹1 invested returns ₹1.90.

The provided discussion highlights the significant advantages and implications of the mushroom farming model, emphasizing its viability for various economic and social contexts. The model's feasibility is a key strength, making it accessible for small-scale farmers who have limited land and capital. This low barrier to entry allows a broader range of

individuals to participate in the agricultural sector. In terms of profitability, the model is highly promising, with a potential annual profit of approximately Rs 1.5 lakh [76]. This strong financial return, combined with minimal land requirements, makes the venture an attractive and lucrative option. The concept also demonstrates strong scalability, suggesting that with the right environmental controls and skill development, the operation can be expanded to generate even higher incomes. The enterprise is characterized by its low-risk nature when compared to traditional crops, as mushrooms require less water, space, and time to grow, making it a more resilient and sustainable agricultural option [77]. Finally, the model has positive social implications by supporting rural employment, particularly for women and youth, due to its reliance on manual labor and low level of mechanization. This makes it an ideal fit for community-based development and empowerment initiatives [78].

## CONCLUSION

This study demonstrates that mushroom cultivation is a highly feasible, profitable, and low-risk agricultural enterprise with significant socioeconomic benefits. It offers a sustainable solution for converting agricultural waste into a valuable food source, thereby promoting both waste management and nutritional security. The model is particularly well-suited for regions like Jammu and Kashmir due to favorable climatic conditions and minimal reliance on external inputs. The entire process from compost preparation to spawning, casing, and harvesting is a sophisticated blend of microbiology and agronomy, with each step being crucial for a successful yield. Innovations from institutions like SKUAST-Kashmir, which have developed region-specific composting formulas, further enhance the model's accessibility and cost-effectiveness for small-scale and rural farmers. Furthermore, the cultivation of mushrooms provides a vital source of rural employment, especially for women and youth, due to its low-mechanization and labour-intensive nature. The nutritional and medicinal value of mushrooms, which are rich in proteins, vitamins, and bioactive compounds, makes this venture beneficial for public health. By implementing robust production technologies and integrated management practices, this model serves as a powerful tool for promoting sustainable livelihoods, environmental conservation, and public health, positioning it as an essential component of future agricultural and biotechnological strategies.

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