Current Journal of Applied Science and Technology

Volume 42, Issue 44, Page 19-37, 2023; Article no.CJAST.109304
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Revolutionizing Mushroom Cultivation: A Comprehensive Review of Hydroponics in Fungiculture

Preeti Kaur [a] and Pooja Kapoor [a*]

[a] University Institute of Agricultural Sciences, Chandigarh University (CU), Mohali, Punjab, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2023/v42i444280

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/109304

Review Article

Received: 18/09/2023
Accepted: 23/11/2023
Published: 27/11/2023

ABSTRACT

With the introduction of hydroponics, a cutting-edge technique that is completely changing conventional procedures, the long-standing practice of mushroom growing has changed to suit modern difficulties. Traditionally cultivated in natural substrates, mushrooms are currently flourishing in hydroponic systems, which substitute nutrient-rich water solutions for soil. This change brings about an evolution in the mushroom industry and satisfies the growing need for sustainable agriculture methods. The advantages of hydroponic mushroom culture are unmatched; they include better nutrient control, year-round output, space efficiency, and pest and disease control. Growers can customize fertilizer levels and create ideal growing conditions for a variety of mushroom species thanks to the accuracy of hydroponic systems. Hydroponics overcomes seasonal limitations to guarantee steady mushroom production, satisfying the rising need for fresh produce that is acquired locally. Its layout maximizes available space, which is especially beneficial for urban farming. usage of land. Because hydroponics is an environmentally benign method, there is less chance of soil-borne illnesses and pests, which means less need for chemical treatments. This method creates a regulated, pollution-free atmosphere that promotes improved mushroom quality and consistency. In

**Corresponding author: E-mail: pooja.agri@cumail.in;*

addition, hydroponic mushroom farming reduces nutrient leakage and uses less water, which is in line with the global trend toward ecologically friendly farming methods. To sum up, the application of hydroponics to the growth of mushrooms represents a revolutionary advancement in mycology. Improved sustainability, production, and profit for mushroom growers are among the benefits that follow. Hydroponics is a viable solution that could revolutionize the mushroom business and make a substantial contribution towards achieving greater sustainability in agriculture as demand for mushrooms develops**.**

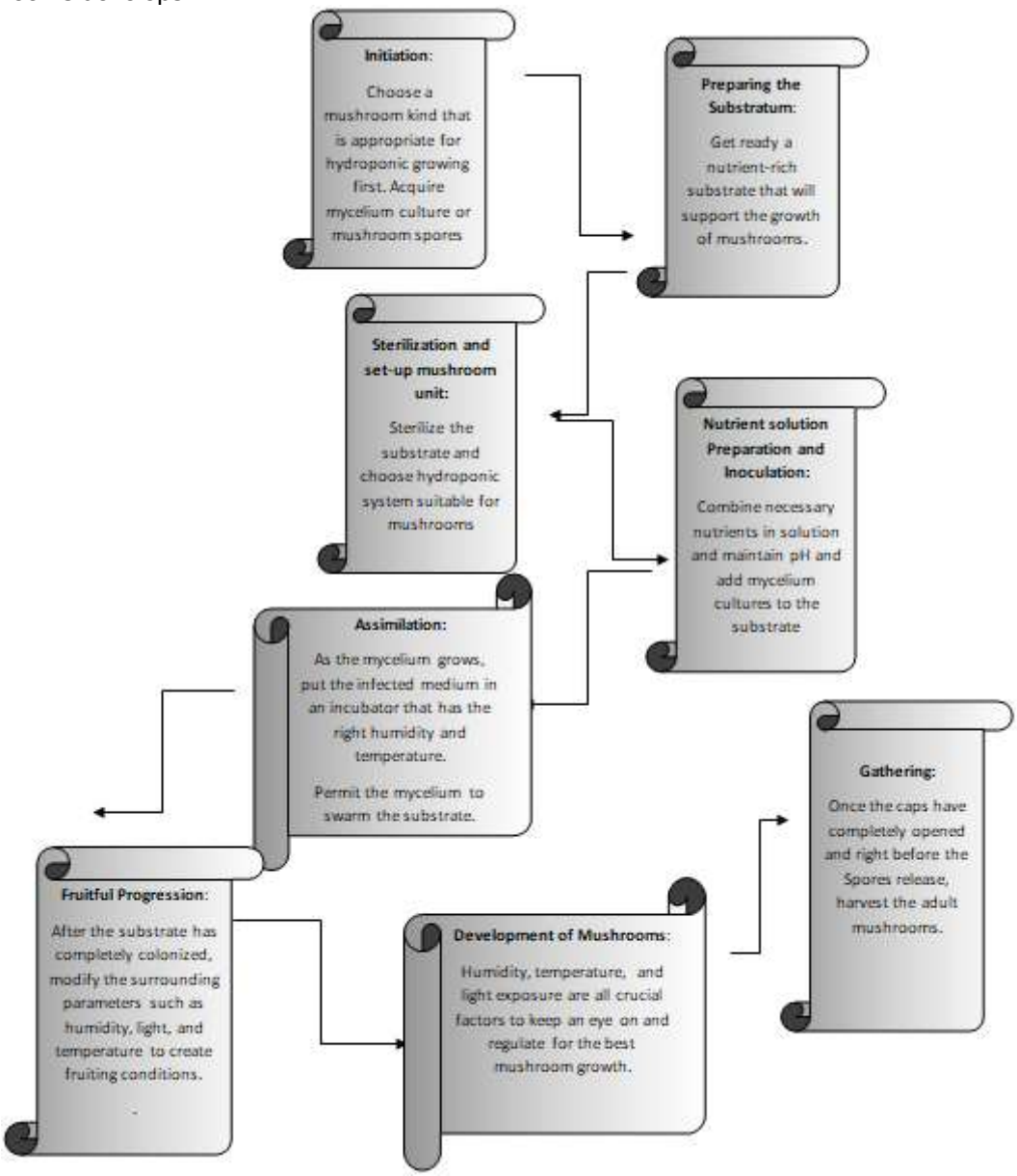

Chart 1. Graphical abstract

Keywords: Agriculture; hydroponics; mushroom cultivation; sustainability; urban farming.

1. INTRODUCTION

Mushroom cultivation has a rich history dating back centuries, offering a valuable source of nutrition, income, and even medicinal benefits. Traditionally, mushrooms have been cultivated using organic substrates such as straw, wood chips, or compost, which provide the necessary nutrients for their growth. However, in the face of increasing demand for mushrooms and the

urgent need for sustainable agricultural practices, there is a growing interest in exploring innovative cultivation techniques [38] Mushrooms can be grown as fungi using hydroponics. When you grow mushrooms hydroponically, we substitute water and growing media for soil in the cultivation process Mushrooms grown hydroponically grow quickly and tastes excellent. Mushrooms produced hydroponically look different and are of higher quality [26] Hydroponics, well-known for its soilless cultivation methods, offers efficient resource utilization and the potential for year-round production. It involves growing plants in nutrient-rich water solutions, eliminating the need for traditional soil. The introduction of hydroponics in mushroom cultivation represents a significant shift in the industry, bringing numerous advantages and addressing various challenges associated with conventional mushroom farming [12]. Improved Nutrient Control: Hydroponic systems enable precise control over nutrient delivery, allowing mushroom growers to tailor nutrient levels to the specific requirements of different mushroom species. This fine-tuned approach ensures optimal growth conditions for various strains, potentially leading to increased yields and quality. Year-Round Production: Hydroponic mushroom cultivation breaks free from the constraints of traditional seasonal farming. By controlling environmental factors such as temperature and humidity, growers can produce mushrooms consistently throughout the year, meeting the rising demand for fresh, locally grown produce. Space-Efficiency: The vertical stacking potential of hydroponic systems maximizes space utilization, making it an ideal solution for urban farming or in areas with limited available land. This spatial efficiency opens up new opportunities for mushroom farming in densely populated regions. Disease and Pest Management: Hydroponic mushroom cultivation reduces the risk of soil-borne diseases and pests, which can be devastating to traditional mushroom farms [3]. This eco-friendly approach minimizes the need for chemical pesticides and fungicides, contributing to safer and more sustainable farming practices. Enhanced Quality and Consistency: Hydroponics fosters uniform mushroom growth, leading to a consistent and high-quality product. The controlled environment ensures that mushrooms are free from contaminants, resulting in optimal texture and flavour. Reduced Environmental Impact: Hydroponic mushroom cultivation conserves water and reduces the leaching of nutrients into the environment, aligning with the increasing demand for environmentally responsible agricultural practices Conclusion, the introduction of hydroponics in mushroom cultivation represents a transformative development in the field of mycology. This innovative approach offers a multitude of advantages, including improved nutrient control, year-round production, space-efficiency, disease management, quality consistency, and reduced environmental impact [18]. Mushroom growers can harness the knowledge and techniques developed in hydroponics to enhance the sustainability, productivity, and profitability of their operations [27]. As the demand for mushrooms continues to rise, the integration of hydroponics stands as a promising solution that could redefine the mushroom industry and contribute to a more sustainable future for agriculture [5].

2. IMPORTANCE OF MUSHROOM FARMING

The historical significance of mushrooms in various cultures around the world is truly remarkable. From the Greek belief that mushrooms conferred strength in combat to the Romans viewing them as a divine dietary supplement, mushrooms have held a special place in the human diet for millennia. In Chinese tradition, mushrooms were considered an elixir of vitality, emphasizing their importance in promoting health and long life One of the key reasons for the enduring importance of mushrooms is their exceptional nutritional value. Mushrooms are a remarkable food source as they are low in calories, carbohydrates, fat, and sodium while being cholesterol-free [40]. In addition to these attributes, mushrooms provide a wealth of essential nutrients, including fibre, proteins, riboflavin, folic acid, potassium, selenium, and niacin. This nutritional profile makes mushrooms a valuable addition to a balanced diet, enhancing overall well-being and helping to prevent various health issues [26]. Mushrooms also hold a prominent place in culinary traditions worldwide. Their versatility in various cuisines has contributed to their enduring popularity. Whether sautéed, grilled, added to soups, or used in vegetarian dishes, mushrooms offer a unique flavour and texture that can elevate the dining experience. Mushrooms are not just a culinary delight; they have a rich history in traditional medicine and have been valued for their therapeutic qualities. These fungi have been associated with the treatment and prevention of various illnesses, including hypertension, Parkinson's and Alzheimer's diseases, and even

a reduced risk of stroke [4]. Their anti-tumoral properties are noteworthy, potentially reducing the risk of tumour growth and metastasis. Beyond these health benefits, mushrooms are also a source of bioactive compounds, boasting antimicrobial, immune-boosting, and cholesterol-lowering properties [34]. In recent years, mushroom extracts and supplements have gained popularity due to their potential to boost human health [4]. These products harness the bioactive chemicals found in mushrooms to provide a convenient way to incorporate their health benefits into one's daily routine**.** In conclusion, the enduring significance of mushrooms in human culture is rooted in their rich history, remarkable culinary attributes, and the wealth of health benefits they offer [37]. As we continue to explore the potential of mushrooms in modern science and nutrition, their role in promoting health and well-being remains as vital as ever, reminding us that this ancient dietary treasure is truly a gift from nature [46].

2.1 Mushroom Therapeutic Value

Ancient and Modern Medicine: Asia has a long history of using mushrooms in traditional medical practices. Their therapeutic potential in fields like immunological regulation, cancer treatment, and cardiovascular health has been highlighted by recent study [31]. Support for the Immune System: According to research by [49], polysaccharides present in mushrooms, like as beta-glucans, have been demonstrated to improve the immune system's performance as well as it prevents the action of free radicals in body resulting in delay of aging process [41]. Effects on Cancer: Studies has shown that specific mushroom chemicals have cancer-preventive characteristics, making certain mushroom extracts having potential as cancer treatment adjuncts [33]. Table 1 symbolizes the biochemical compounds and therapeutic properties of different mushroom species.

2.2 Mushroom Nutritional Value

Superfood that is packed with nutrients: Mushrooms are a great source of vitamins (including vitamin D and B vitamins), minerals (such selenium and potash), and dietary fibre [46].They are the perfect supplement to a balanced diet because they are generally extremely low in calories and fat [30].Protein Content: Some types of mushrooms, including shiitake & oyster mushrooms, are high in high-quality protein and can be used as a substitute for meat in vegetarian and vegan diets Mushrooms provide bioactive substances with antioxidant qualities, such as polysaccharides and phenolic compounds, which may lower the risk of developing chronic diseases [22].

2.3 Food Security

Since mushrooms may be farmed all year long, they help to ensure the availability of a steady supply of wholesome food [6]. Sustainable Agriculture: Because it uses agricultural wastes as substrates, such as straw and wood waste, mushroom cultivation is regarded as an environmentally benign agricultural technique. This promotes the principles of the circular economy and lessens the detrimental effects of trash disposal [43]. Moreover, spent mushroom substrates can be used as organic fertilizers. In order to release nutrients and improve soil health, mushrooms breakdown complex organic compounds, which helps with carbon sequestration. This aids in reducing climate change. Recycling of farm residues

It solves unemployment problems: This firm serves as low investment high profitable plan solving [44].

3. REQUIREMENT OF HYDROPONIC MUSHROOM FARMING

Mushrooms are a staple in many different cuisines all over the world because of their distinctive flavours and nutritional advantages. Traditional mushroom farming techniques confront difficulties due to availability of land, depletion of resources, and environmental issues as demand for mushroom continues to expand worldwide [26].

Traditional mushroom production frequently results in destruction and resource depletion because it depends on substrate such chipped wood, straw, and compost. On the other hand, rich in nutrients liquids or mediums like coir are used in hydroponic mushroom cultivation, which uses less energy and has a smaller impact on the environment [35].

In controlled circumstances, hydroponic mushroom cultivation provides year-round production, eliminating reliance on seasonal influences. This meets market demands and minimizes price changes by ensuring a steady and predictable supply of mushrooms [19].

Pests and illnesses that can destroy crops are a risk in traditional mushroom growing. The

Table 1. Biochemical compounds and therapeutic properties of different mushroom species According to research work conducted by [47] [39] [24] [51] and [31]

Mushroom species	Biochemical compounds	Therapeutic properties	Reference
Ganoderma spp.	Beta glucan	Lowers cholesterol levels Enhances antibiotic properties Strengthens immune system	[39,31]
Agaricus bisporous	Lectins	Lowers the risk of diabetes	[47]
Flammulina spp.	Ergothioneine Proflamin	Antioxidant Inhibits tumour growth	[51]
Pleurotus ostreatus	Beta glucans, ergestrol	Possess antioxidant properties Lowers risk of cancer	[52]
Hericium erinaceus	Polysaccharides	stimulation of nerve development Improving Cognitive Function	[24]
Cordyceps sinensis	Cordycepin, adenosine, polysaccharides	Anti-inflammatory properties Inhibits tumour growth	[51]

Justification: The information regarding the bioactive substances found in these mushroom and the possible health benefits they may have, backed by references to scientific papers, justifies the table 1.

- *Nutritional composition of mushrooms fulfils the day today requirement of mankind mushrooms is one of the best sources of vitamin B [4]. Mushrooms are a great source of protein comprising of about 30 percent protein by dry weight. According to the reports mushrooms as feed are very much beneficial for vegetarian because they contain similar essential amino acid which are found in animal proteins [53].*
- *Heavy metals and other environmental toxins can be concentrated and absorbed by mushrooms in a special way. This procedure, called bioremediation, can assist in cleaning up polluted soil and water. Myco-remediation, a branch of bioremediation that employs fungi, has demonstrated promise in the fight against pollution.*

- requirement for chemical interventions and the risk of infestation are decreased by hydroponic systems as well as improved control over environmental factors
- A closed-loop applications recirculation system is used in hydroponic mushroom growing, which uses less water than conventional culture techniques. This responds to the growing issue of lack of water and supports sustainable agricultural methods [50].

Urban settings and places with little space are ideal for hydroponic mushroom gardening. Mushrooms can be grown near to urban centres thanks to vertical agriculture and compact hydroponic systems, which maximize the use of available land [50].

4. CONDITIONS REQUIRED FOR HYDROPONICS MUSHROOM FARMING

The conditions required for hydroponic mushroom farming are as follows: The production of mushrooms in a without soil system under carefully controlled circumstances is known as hydroponic gardening. The prerequisites for a prosperous hydroponic mushroom cultivation, as indicated in the data you supplied and grounded in existing understanding, encompass:

Temperature and humidity: For germination, keep the temperature between 24-27°C for growth, keep it between 27-29°C [26]. During the growing phase, humidity should be maintained at 90% or below [2]. Water Quality: Make sure the water you use is clean and cold. Humidity is ideal for mushroom growth, and clean water is necessary to avoid contamination. Light: Mushrooms need light to begin the fruiting process, even though they don't need as much light for photosynthesis as some other plants do. Cool-white, 12-hour light-cycle LED or low-intensity fluorescent lights can be to encourage the growth of mushrooms. A disease-free aqueous nutrition media should be used. It is imperative to supply the appropriate range of nutrients free of any pathogenic microorganisms that might outcompete the mycelium. As the procedure progresses, keep the surroundings sanitary [26]. Sanitation: To avoid contamination, keep your workspace tidy and sanitize all of your tools. For pathogen-free air, using disinfectants such as isopropyl alcohol (IPA) and HEPA filters can be helpful. Air exchange: To keep oxygen levels stable and stop carbon dioxide from building up, efficient air exchange is required. Ventilation systems and fans can aid in maintaining the flow of fresh air. Use a hydroponic system made specifically for growing mushrooms, such as one that is set up with a

system of drips or nutrient film approach. These devices guarantee that the developing substrate receives the right amount of water and nutrients. pH Level: Modify the nutrition solution's pH level to get it within the ideal range for the particular variety of mushroom. For most mushrooms, a pH level range ranging from 6.0 to 7.5 is ideal. Selecting the Right Substrate: Pick enriched sawdust, coconut coir, or straw as your substrate. The choice of substrate can have a big impact on the availability of nutrients, productivity, and growth of mushrooms. Sanitary Conditions: Strict sanitation protocols are necessary to avoid contamination by bacteria or competing fungus that could impede the growth of mushrooms [2]. Timely Harvesting: To guarantee the best possible quality, flavour and size, harvest mushrooms right before the cap completely opens. In comparison to traditional approaches, researches shows that hydroponic gardens for mushroom growth are more sustainable and effective, yielding higher yields with less water demand. It is crucial to adjust the growing circumstances to the particular needs of the mushroom species you are cultivating because different mushroom species may require different settings.

4.1 Growing Media and Nutrients in Mushroom Farming

The growing media required for growing mushrooms hydroponically should be:

- Porous: The growing media should be porous that means it should contain pores or voids so that it can facilitate maximum root development without any hindrance [32].
- Stable structural integrity: the growing medium should possess stable structural integrity to support the anchorage of plant from the medium without interfering in the process of water and nutrient absorbability [32].
- Substrates used: Suitable ecofriendly as well as economically feasible substrates for growing such as saw dust [8] wood fibre [25] and coco coir [28] should be used.
- Pathogen free: The growing media should be properly sterilized
- Durability: The growing media should be durable as the breakdown of substrate can create fumes that may harm the plants or can lead to clogging of the set up
- Good aeration and drainage: Growing media should have good aeration as well as drainage facility so that there would be no water logging within the facility [36].
- There is a need of nutrient solution with no cation exchange ability resulting in the shifting of all the conditions in the facility such as pH, oxygen nutrient contents at a high pace.
- Depending on solution pH, some of the nutrients may precipitate &therefore, plants cannot avail them. So, regular adjustment of solution pH, buffering the solution and use of chelates are essential in fact to improve the nutrient uptake by the mycelium sometimes substances also known by the name of additives is utilized for example rhizobacteria azotobacter can be used for better supply of oxygen.

5. NUTRIENT REQUIREMENTS FOR HYDROPONIC MUSHROOM FARMING

Compared to conventional soil-based approaches, hydroponic mushroom production has the potential to boost yield, reduce the incidence of disease, and improve resource utilization. The hydroponic fertilizer solution is crucial in supplying the vital ingredients required for mushrooms growth and development (Table 2).

To achieve maximum development and maximize production, hydroponic mushroom farming relies heavily on the combination of nutrient solutions. Nutrient management in this novel growing technique an innovative method that enables environmental control and resource efficiency is hydroponic mushroom production. The material that mushrooms grow on, or the substrate, is crucial to this process. The hydroponic mushroom farming process can be considerably impacted by the substrate chosen in terms of productivity, quality, and general sustainability (table 3).

5.1 Impact on Yield Sustainability and Quality of Mushroom by Chosen Substrates

According to research, the substrate you choose has a big impact on how much mushrooms you get. Straw and sawdust are examples of substrates high in lignocellulosic materials that can support mycelial growth and fruiting, according to studies. Contrarily, coir-based substrates may have slightly lower yields but

benefit from being uniform and simple to handle [32]. Resource utilization and environmental impact are both taken into account when thinking about sustainability Due to their renewable nature and use of waste materials, materials like coconut coir and agricultural wastes are frequently seen as sustainable. Coir can be more environmentally friendly in some situations because it is a renewable and easily accessible resource, although its environmental impact might vary based on transport distances and growing methods [23]. Sustainable evaluations must to take a carbon footprint of material manufacture and transportation into account The sensory qualities and textures of mushrooms can be influenced by the substrate choices. For instance, mushrooms grown on coir-based substrates could have a distinct texture from those grown on straw-based substrates [6]. The substrate's nutritional value may have an impact on the nutritional value of the mushrooms that are harvested. Contrarily, coir-based substrates often result in mushrooms with paler hues and more sensitive textures, which might be preferable for some culinary uses. The best materials that work in synergy to create the most ideal substrate are in a combination of coco coir and vermiculite Coco Coir is coconut fibre extracted from coconut husk coir is completely renewable and organic, and it provides ideal rooting medium to speed up germination. Vermiculite is the most ideal growing substrate for mushroom farming hydroponically. This compound contains both magnesium and potassium. Due to its excellent water retention capacity moderate level of oxygenation inert chemical nature as well as effective chelation capacity to promote better plant growth. There are many substrates available for growing mushrooms hydroponically but from the wide sight, the selection of suitable growing media is also basically based on growers financial and technical implications.

6. LIFE CYCLE OF MUSHROOM

Mushroom Life cycle is depicted in Fig 1.

Mycelium Growth and Spawning: The web of thread-like structures known as hyphae that make up mycelium growth is the first stage of the life cycle of a mushroom. The breakdown and uptake of nutrients are handled by the mycelium. In conventional mushroom culture, sawdust or straw are common substrates on which mycelium is cultivated. By utilizing fertilizer-enriched substrates or liquid nutrient solutions, hydroponic systems provide an alternative Mycelium must

Table 2. Nutrient requirements for hydroponic systems according to researchers conducted by [12]

NITROGEN	Nitrogen(N) Nitrogen is necessary for the development of all vegetative processes, including mycelial growth. A robust mushroom output is ensured by sufficient nitrogen, which encourages lush, vigorous mycelium. Smaller bodies and inadequate mycelial growth can result from a lack of nitrogen [20].
PHOSPHORUS	Phosphorus (P): Phosphorus is essential for nucleic acid synthesis and energy transmission, both of which are necessary for the growth of mushrooms. It aids in the growth of robust, well shape fruiting bodies.
POTASSIUM	Potassium (K): In order to keep the osmotic equilibrium in mushroom cells, potassium is essential. It improves the growth of fruiting bodies, expanding the size and general excellence of the mushroom
CALCIUM	Calcium (Ca): Calcium is necessary for the development and integrity of cell walls. It guarantees the structural integrity of mushroom tissues and aids in the prevention of illnesses like bitter pit [15].
MAGNESIUM	Magnesium (Mg): Magnesium helps mycelial development and nutrition intake by activating enzymes and aiding in photosynthesis.
SULPHUR	Sulphur (S): Sulphur plays a role in the creation of proteins and amino acids, which affects the flavour and aroma of mushrooms. It is crucial to the general quality of the mushrooms that are gathered.
MICRONUTRIENTS	Micronutrients: Micronutrients play a role in a number of metabolic processes and enzymatic activation, ensuring that the mushroom mycelium undergoes the proper biochemical reactions.

Justification: Each nutrient's unique significance in the growth and development of mushrooms is explained in the table 2, which also serves to justify its inclusion. The cited sources support the information and highlight how important these nutrients are to getting the best possible yields and quality from mushrooms.

Table 3. The salient features, advantages, and factors for substrate uses in mushroom production

Substrate	Properties and benefits	Observation and Remarks
Coconut Coir	Superior ability to hold water Sufficient oxygenation for the growth of mycelium	Fit for growing mushrooms hydroponically Regular production of high-quality mushrooms
Moist Peat	Retains moisture Can be used alone or in substrate blends	pH level buffering
Straw	Inexpensive	Often combined with coir or peat moss
Wood-Based Composition	Used for species like oyster and shiitake mushrooms Provides unique textures and flavours	Optimize yield and quality by controlling particle size. Requires regulation of moisture content.

Justification: This table provides a quick summary of the salient features, advantages, and factors to take into account for each substrate used in mushroom production. Every one of these substances has a unique set of benefits and works well with various mushroom varieties and growing techniques. The type of substrate used can affect the final product's qualities and features.

be introduced to a flowering substrate in the next step this changeover can be accomplished in hydroponic systems by moving the substrate that has been inoculated with mycelium to trays or containers that provide the necessary environmental controls, like humidity and temperature control [54].

Pinning and Fruiting: This is the phase where the formation of small pinhead mushrooms occurs. This step can be facilitated by hydroponic systems, which offer exact environmental controls over temperature, light, and humidity all of which are essential for uniform and ideal pinning. When mature mushrooms are created, the phase of the fungus life cycle known as blossoming is the most awaited. Maintaining a steady and regulated atmosphere helps maximize the fruiting stage in hydroponic systems. Hydroponics can be used with mushroom fruiting chambers that have air exchange and misting systems installed [35].

Harvesting: Because the hydroponic system maintains a controlled environment that guarantees constant growth, harvesting mushrooms is relatively simple. To optimize quality and productivity, mushrooms should be harvested at the ideal stage of maturation in hydroponic systems, waste management and hygienic practices are crucial to preventing contamination and enabling the subsequent cultivation cycle.

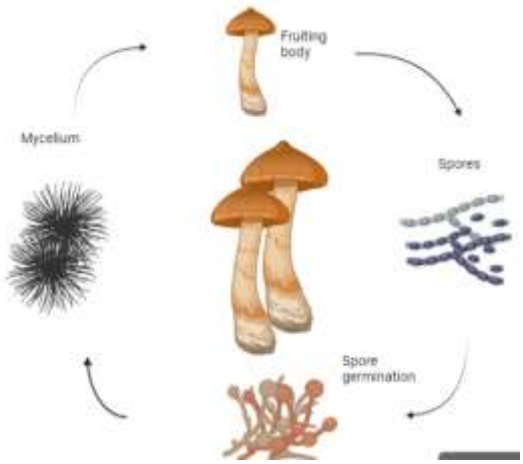

Fig. 1. Mushroom life Cycle

7. ADVANTAGES OF HYDROPONIC MUSHROOM FARMING

Hydroponic systems aid in water conservation it uses up to approximately 90 percent less water than any other indigenous soil-based agriculture which is much more beneficial in areas which experience much adverse water scarcity [45]. Efficient use of land is also possible as hydroponic systems can be set up vertically as well as horizontally. Compared to conventional production techniques, hydroponic mushroom farming takes less area. In example, vertical farming enables higher-density mushroom production in constrained spaces [35]. Urban farming and places with little agricultural land can notably benefit from this space efficiency. While implementing hydroponic technique in mushroom cultivation, year-round production can also be ensured as it can also be performed indoors in controlled conditions excluding the fear of seasonal variations [21] Higher yields can also be obtained when compared to traditional techniques, hydroponic systems can dramatically boost mushroom yield. Hydroponics regulated environment encourages quicker development and higher yields. Mushroom growth in hydroponic systems is also more nutritious and vigorous due to a lack of soil-borne illnesses. The hydroponic systems are maintained in a controlled environment as well as the operations are automatically operated as a result there is less need of labour [13]. Implementation of hydroponics tactics in mushroom farming is beneficial in saving water and other kind of artificial sprayers are also not needed as a result stagnant water is never a concern. This technique implementation is very much beneficial for the areas facing extreme abiotic stresses. Hydroponic mushroom farming results in emission of lesser greenhouse emissions. Hydroponics technology reduce malnutrition and maintains an effectual as well as fruitful use of the resources offered by nature [26].

8. METHODS TO GROW MUSHROOMS HYDROPONICALLY

Populating substrate with mushroom spores
Use of mushroom growing kit
Populating substrate with mushroom spores

8.1 Maintain Disease Free Environment

.

Substrate selection: For hydroponic mushroom production to be successful, the substrate must be chosen carefully. Materials like straw, saw dust, or a mixture of natural substances can be customized to give vital nutrients and morphology for ideal growth based on the mushroom species [44].

Popular substrate choices are equal proportion of vermiculite and perlite [2] and vermiculite mixed with brown rice flour. Vermiculite is a naturally occurring mineral that is a deep brown colour and functions as a sponge to collect nutrients that the mycelium will consume. Vermiculite is frequently mixed with water and brown rice flour (BRF) to create a dense block. BRF is nothing more than powdered brown rice. Almond flour can be utilized in its stead. A combination of the straw, coconut fibre, and vermiculite can be used as a substrate to encourage the development of mycelial colonies and flowering in hydroponic gardens, this mixture offers the ideal ratio of water and nutrients retention required for mushroom growth

- **Inoculation:** The procedure of inoculating the substrate involves dispersing mushroom spawn or spores.
Spores should be either:

1. Purchased online
2. Fresh spores gathered from produce
3. Liquid mycelium culture obtained from a culture bank
4. Commonly used immunization techniques include liquid culture and spore syringes. Liquid culture inoculation, according to research produces a more consistent mycelial dispersal in hydroponic systems, increasing total crop output. The spores should be cultured in petri-dish marking mycelium growth.

Make careful to employ aseptic procedures to avoid contamination. You can purchase superior spores or spawns from reliable vendors, based on the kind of mushroom and your preferences.

- **Sterilization:** Before inoculation, the substrate must be sterilized or pasteurized to limit competition from undesirable microbes. While pasteurization selectively decreases competing microbes while maintaining beneficial microbes like mushroom mycelium, sterilization entails the full eradication of all microorganisms [11].

- **Incubation:** Keep the temperature and humidity at the levels recommended for your particular mushroom species during incubation. During this time, mycelium is going to invade the substrate and lay the groundwork for subsequent mushroom growth.

- **Fruiting conditions:** By changing the environmental factors, move from the flowering stage to the fruiting stage. To encourage the growth of mushrooms, regulate the temperature, humidity, and exposure to light (if necessary).

- **Harvesting:** When the mushrooms are the right size, typically when the caps fully open, we should harvest them. To prevent contaminating the crop or harming the mycelium, proper harvesting methods are crucial. If necessary, keep up the flowering conditions for several harvests.

8.2 Hydroponic Mushroom Growing Kit

- Hydroponic mushroom cultivation is a unique and efficient way to grow mushrooms indoors using a mushroom growing kit (Fig 2) while most mushrooms are typically grown in substrate or soil, hydroponic mushroom growing allows for precise control over the growing conditions and can result in faster growth and higher yields Here are the steps to grow hydroponic mushrooms using a mushroom growing kit.

8.3 Steps

- **Prepare the workspace:** Make sure the work area is sterilized and clean to reduce the possibility of contamination. Before touching the mushroom kit, make sure to fully wash your hands. It's imperative that you have everything you need before you begin. A hydro mushroom growing kit typically includes instructions, fungus produce offspring, growing media, and a culture room. Some kits could come with extra devices and a humidity tent. Following the comprehensive instructions that come with your kit is essential. To open the mushroom growing kit, refer to the instructions that come with it. This usually entails taking off any packing and revealing the mycelium, which is the root system of the mushroom.

- **Hydration is required:** Most mushroom growing kits require hydration before they can produce mushrooms. Follow the kit's instructions for watering [26]. Typically, you'll need to use a spray bottle to mist the mycelium or soak it in water for a specified amount of time. Be careful not to overhydrate, as this can lead to issues like Mold growth. Mushrooms require high maintain humidity by either placing the kit in a plastic bag or using a humidity tent. Mist the inside of the bag or tent regularly to keep the environment humid Depending on the mushroom variety and growing conditions we should start to see small mushroom pins forming within a few weeks [41]. As they grow, they will mature into full sized mushrooms. Some mushroom species require light to initiate fruiting Provide indirect or low intensity light and temperature should be maintained within the desired range of particular mushroom species.

- **Inoculation:** When the medium is prepared, mycelium or spores from mushrooms will be added to it. As work by researchers like [2] upon the development of mycorrhizal fungi has shown, colonization effectiveness depends on adhering to the injection directions in the kit controlling humidity and temperature for mycelium to grow, the proper temperature and humidity must be maintained [6].

- **Harvest:** When the mushrooms are at their largest and right before the caps open, harvest them. Slice a mushroom at the centre of the stem using a sharp knife or pair of scissors. A few mushroom growing kits have the potential to yield several mushroom flushes. For more harvests, follow the directions included with the package. If there are no more flushes, you can dispose of the spent kit by following the directions on the package or by composting it for future harvests. You can dispose of the used kit according to the directions or compost it if there will be no further flushes. If your kit is made to be reused, clean and keep it carefully till it's time to use it anew. Follow the cleaning recommendations provided by the manufacturer [26].

9. SUITABLE FEATURES AND TYPES OF MUSHROOMS TO GROW ON HYDROPONICS

Features that make mushrooms more suitable to hydroponics are as follows:

Biological Features: Some types of mushrooms have biological traits that make them suitable for hydroponic cultivation Adaptive Mycelium: According to [29]

Mushroom growing kit (available online or at garden
Clean, sanitized workspace
Water
Spray bottle
Plastic bags or humidity tent (optional)
Light source (if needed)

List 1. Materials and Equipment required

Fig. 2. Hydroponic Mushroom growing kit

mushrooms with adaptable mycelial development, like *Pleurotus ostreatus* (also known as the oyster mushroom), may efficiently colonize and take nutrients from hydroponic substrates. Effective Nutrient Uptake: Certain mushrooms, such as *Agaricus bisporus* (white button mushroom), have effective nutrient uptake mechanisms that allow them to flourish in hydroponic solutions containing nutrients [35].

Tolerance for the environment: Temperature and Humidity Tolerance: Some types of mushrooms, such as *Hericium erinaceus* (the lion's mane mushroom) and *Lentinula edodes* (the shiitake mushroom), may thrive in the regulated settings of hydroponic farms.

Characteristics of growth: Rapid Growth: Hydroponic systems are well-suited to quickly developing species as Pleurotus spp. and *Hypsizygus tessellatus* (brown beech mushroom), which provide quicker turnaround times for harvest Species with minimum substrate needs, such as Auricularia spp. (wood ear mushrooms), are appropriate for hydroponics using rich in nutrients solutions.

Quality and Yield: Pleurotus species, particularly *P. ostreatus*, have produced astounding yield in hydroponic systems, which makes them commercially desirable. Qualities: When cultivated hydroponically, some species, including *H. erinaceus*, preserve exceptional quality qualities with distinctive flavours and textures [10].

Development and research: Established Protocols: Some mushroom species have hydroponic growing methods that are well-established, making it easier for them to be used in research and business scenario.

Mushrooms suitable for Hydroponic farming are:

Button (*Agaricus bisporus*): Growing Conditions: White button mushrooms grow well in hydroponic systems since they can tolerate a range of temperatures and substrates [2]. They are well renowned for producing abundant yields, which makes them a popular option for hydroponic gardener. Market Demand: White mushroom varieties are in high demand from consumers and are frequently used in cooking.

Oyster (*Pleurotus ostreatus*): Growth Requirements: The *Pleurotus ostreatus* and *Pleurotus eryngii* oyster mushrooms grow best in hydroponic environments with high

Table 4. Advantages and Disadvantages of using hydroponic mushroom growing kit according to researches by [26]

ADVANTAGES	DISADVANTAGES
Hydroponic mushroom growing kit is user friendly	It halts the creativity and knowledge of the user that they can get from traditional mushroom growing practices
Hydroponic mushroom growing kit is low maintenance	Environmental concerns
Hydroponic mushroom growing kits are space efficient	Yields of mushroom is low as compared to traditional methods
Hydroponic mushrooms growing via kit show quicker growth	Limited varieties of mushrooms can be grown via mushroom growing kit
Precise control over temperature humidity and lightning	Cost of setup is high

Justification A fair summary of the benefits and drawbacks of utilizing hydro mushroom growing kits is given in the table 4. Potential users should consider these advantages and disadvantages to see if a kit like this fits in with their mushroom growing objectives, tastes, and available resources [26] is cited as additional material, lending support to the assertions stated in the table.

humidity and comfortable temperatures) They have a great output potential and quick growth, which makes hydroponic farming viable [29] Market Demand: Gourmet and healthy markets are big fans of oyster mushrooms.

Shitake (*lentinula edodes)*: The shiitake mushroom can be effectively grown hydroponically with appropriate temperature and humidity management [14]. Yield Potential: Despite the fact that they may develop more slowly than certain other species, and they have a significant market presence and the potential for greater revenues Shiitake mushrooms are in high demand due to their distinctive flavour and possible benefits for health.

Lion's mane mushroom (*Hericium erinaceus*) : Lion's mane mushrooms grow best in hydroponic systems since they need high humidity and regulated temperature. Due to their distinctive look and possible benefits for cognitive health, they present an attractive market opportunity with an opportunity for premium pricing Market Demand: Gourmet and nutritious food industries are seeing an increase in demand for lion's mane mushrooms [17].

10. TYPES OF HYDROPONIC SYSTEMS FOR MUSHROOM GROWTH

NFT Technique: The NFT system allows a continuous layer of water and nutrients to pass over the foundation of plant roots. The NFT systems, mushrooms require a growing medium that is based on carbon. With a few modifications, the NFT system can accommodate the required mushroom substrate. The nutrient film method (NFT) uses a slanted tank so that water can pass over the roots of the plant in a shallow flow. On the other hand, while employing the deep flow method (DFT) [1], the roots are completely submerged in the solution. The nutrient film technique (NFT) is the most widely utilized hydroponic system. This method involves placing plants in channels with a nutrient solution They are constantly pumped with solution [7]. When the nutritional solutions approach the point of no return of the channel, they go back to the beginning of the system. This makes it a recirculation system, yet unlike Deep water culture technique, the plants' roots are not completely submerged, which is the main justification for referring to this method as NFT's. Efficient Nutritional Delivery: NFT systems are excellent in supplying nutrient-rich water to the vascular system of the mycelium of mushrooms through a thin layer. This specific feed delivery encourages growth and could increase production because of their recognized area-efficient design, NFT systems are suitable for growers with limited space, such as those who grow mushrooms indoors or in cities. Kinds of Mushroom Compatibility: Particularly some types of mushrooms those with complicated dietary needs or deep roots could not fare well with NFT systems. Proper maintenance of the flow of minerals is essential to prevent nutrient stoppage or uneven distribution, which can cause crop loss or delayed development.

DWC Method: The raft method, often referred to as the floating system or the deep-water culture method, involves circulating nutrient-rich water

through lengthy channels at a depth of approximately 20 cm, with rafts (typically made of polystyrene) floating on top.Net pots are used to sustain plants inside the openings in the rafts. The plant roots dangle in the full of nutrients, oxygenated water, where they take up a lot of nutrients and oxygen to support the fast development circumstances. An air stone delivers nutrient-rich water and air straight to the roots. A traditional example of this type of system is the hydroponic bucket system. Plants are arranged in net pots with roots suspended in nutritional fluid, allowing them to grow rapidly into substantial masses. As algae and moulds can grow quickly in the reservoir, it is imperative to monitor the oxygen and nutrient concentrations, salinity, and pH [7]. Larger fruit-producing plants, such as tomatoes and cucumbers, thrive in this setup and operate well. Similar to underneath drip irrigation systems in traditional agriculture, growing hydroponically cultivation techniques centred around the NFT and deep-water culture with rafts that float fundamentally stop contact among the water source as well as the aerial parts of the plants, thus decreasing the possibility of threat related to the close association of leaves or fruit with pathogenic irrigation water [11]

High Nutritional Uptake: DWC enables mushroom mycelium to absorb nutrients effectively, supporting a strong development Disease danger Decreased: DWC separates mushrooms from the soil, lowering the danger of infections transmitted through the soil and promoting Management of Oxygenation: To prevent fungal suffocation in DWC systems, oxygen levels must be carefully watched. Costs on a Commercial Scale: For large-scale commercial operations, initial setup and maintenance expenses may be less cost-effective.

Aeroponics: For those with limited room, aeroponics offers an alternative method of growing plants. An enclosed air, water, and nutrient environment that promotes quick plant development without soil and media while using little water and sunlight is known as an aeroponic system. It is a very successful and efficient method of growing plants because it uses 95% less water than conventional farming techniques and takes up less space that even the most advanced hydroponic system [16] and minerals, which may contribute to the plants' increased health and nutritional value. The biomass of the suspended aeroponic plants is accelerated because they receive all of the oxygen that is accessible and carbondioxideThe increased metabolic yield of aerial components from the aeroponic treatment suggested that other crop types should also be taken into consideration for this production strategy, not just root crops [41] The best possible oxygenation is given to mushroom mycelium through aeroponic systems, which promotes growth. Healthier Mushrooms: The absence of soil reduces the likelihood of soil-borne diseases, resulting in a lower risk of disease. Complexity of Misting System: For efficient nutrient delivery, aeroponics requires a well-designed misting system. Learning Curve: Growing mushrooms in aeroponic systems requires growers to go through a learning curve.

Irrigation by Drip: Because drip irrigation has the potential to increase crop yields and water use efficiency, it is a cutting-edge and innovative technique for providing freshwater to plants that has achieved widespread support in the agricultural industry. By effectively supplying irrigation water straight to the plant's root zone in the soil, drip irrigation reduces traditional losses including soil erosion, runoff, and deep percolation. Together with irrigation water, it also facilitates the use of herbicides, fertilizers, and other water-soluble chemicals, which produces better-quality and higher-yielding food. Many of the issues in dry land agriculture are thought to have an answer in drip irrigation systems, which also increase the productivity of irrigated agriculture [55]. According to [56], drip systems are for white button mushrooms (*Agaricus bisporus*) and provide for precise nutrient dosage. The two main concerns are ensuring uniform nutrient distribution and avoiding blockage.

Wick Technologies: This is the most basic hydroponic system; it doesn't need a pump, aerators, or electricity [42]. Plants are set up on absorbent media such as vermiculite, coco coir, or perlite, with a nylon wick extending from the roots of the plants into a nutrient solution reservoir. Plants receive water or fertilizer solutions by capillary action. This technique is effective for small plants, spices, and herbs Wick systems are affordable and easy to use, making them suitable for beginners. According to [35], they can be applied to a variety of mushroom species, including oyster mushrooms Wick systems may not be able to adequately feed nutrients to dense or big substrates [41].

11. COMPARISION OF DIFFERENT HYDROPONIC SYSTEMS

Hydroponic mushroom farming can be experimental, and it may require some trial and error to achieve optimal conditions for your specific setup and mushroom species. Keep detailed records of your growing conditions and results to fine-tune your process and improve your yield over time The type of mushroom, the volume of output, and the resources available should all be taken into account when choosing a hydroponic system NFT and DWC can handle a range of mushrooms and are appropriate for larger-scale cultivation. Although it offers fine control, aeroponics might be more appropriate for specialized markets For, some species, drip irrigation is both flexible and economical. Wick systems are user-friendly for beginners, but they could have scaling issues.

11.1 Pests and Illnesses Associated with Hydroponically Mushroom Farming

11.1.1 Common Illnesses

- Verticillium wilt is a fungal disease affecting *Agaricus bisporus* (white button mushroom), and it is brought on *by Verticillium dahliae*[35]. The disease can be prevented by choosing strains that are resistant to it and by following thorough sanitation procedures.
- *Pseudomonas tolaasii* causes microbial blotch, which results in flaws and poor quality in mushrooms. IPM tactics incorporate the use of sterilized water and good hygiene.
- Trichoderma spp. also infections in hydroponic systems can obstruct mycelial growth and result in green mould.

11.1.2 Typical Pests

- Common Mushroom Pests: Spider Mites and Mushroom Mites: These pests can damage mushroom spores and fruiting bodies. Control measures include early detection and the use of predatory mites [10].
- Fungus Gnats: These insects can negatively affect mushroom development and spread diseases. Effective integrated pest management (IPM) techniques involve the use of nematodes and yellow sticky traps.
- Sciarid Flies (Bradysia spp.): These common pests lay eggs in the growing medium, and their larvae can harm mushroom mycelium and caps.

11.1.3 Pest Management (IPM) Strategies

- Ensure a clean and hygienic environment to prevent the entry of diseases and pests into the hydroponic system. Employ beneficial microorganisms like Trichoderma species for biological control to reduce harmful fungi. Monitor and manage sciarid fly populations using pheromone traps Introduce predatory mites like *Neoseiulus californicus* to control pest mites. Implement quarantine measures for incoming materials to prevent the spread of infections.
- Modify cultural practices, such as soil formulation and watering regimens, to create less hospitable environments for diseases and pests.

12. ECONOMIC VIABILITY OF HYDROPONIC MUSHROOM FARMS

- Economic Viability: Growing mushrooms hydroponically can need a substantial upfront expenditure. It is still difficult to ensure economic viability through competitive markets and effective resource usage [58] Prospective Routes and Fields of Study:
- There exist a number of promising fields of study and future initiatives that warrant consideration in order to address these obstacles and enhance the long-term viability and effectiveness of hydroponic mushroom farming. Nutrient Optimization: To precisely address the nutritional needs of different mushroom species, research can concentrate on creating cutting-edge nutrients and delivery methods, potentially including smart technology [9]. Water Treatments and Recycling: Hydroponic mushroom cultivation can have a positive environmental impact while improving water quality thanks to technological advancements in water treatment, such as enhanced filtration and disease control techniques [57]. Biological Disease Control: Researching natural predators and beneficial bacteria as biological control agents may provide eco-friendly ways to manage pests and diseases in hydro mushroom farms. Nutrient Optimization: To precisely address the nutritional needs of different mushroom species, research can

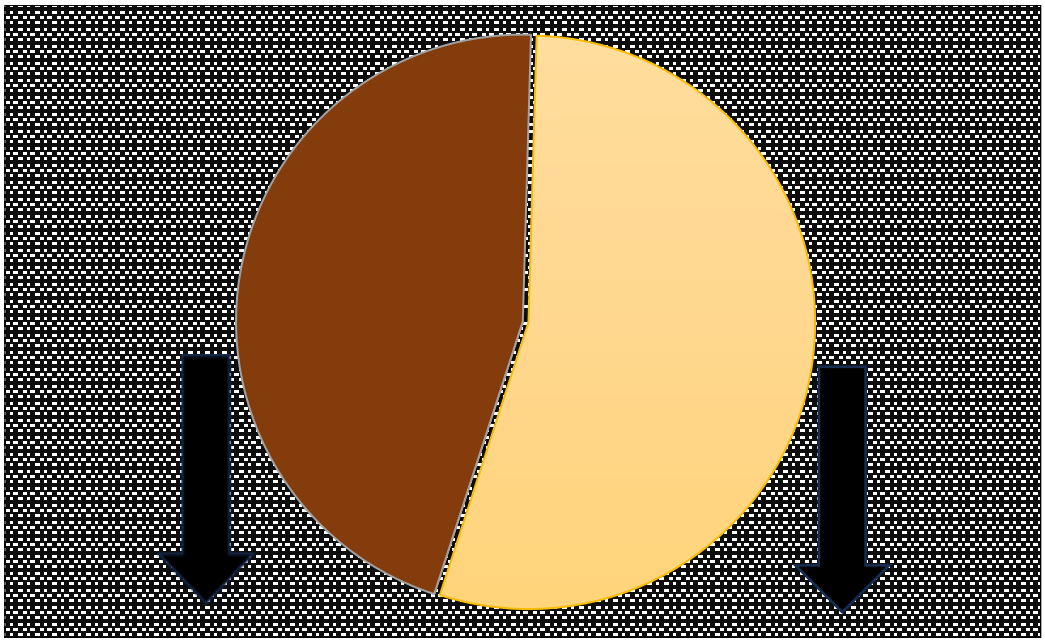

Fig. 3. Chart represents a survey conducted earlier in 2023 by [50] on how familiar the responders feel towards the adoption of hydroponic farming https://www.ijfmr.com/

concentrate on creating cutting-edge nutrients and delivery methods, potentially including smart technology [9]. Water treatments and Recycling: Hydroponic mushroom cultivation can have a positive environmental impact while improving water quality thanks to technological advancements in water treatment, such as enhanced filtration and disease control techniques [57]. Biological Disease Control: Researching natural predators and beneficial bacteria as biological control agents may provide eco-friendly ways to manage pests and diseases in hydro mushroom farms. Energy-efficient technologies: It is possible to lower energy expenses and maintain or even increase mushroom harvests by creating and putting into practice resource-efficient structures, such as LED lighting and better climate control techniques [48]. Market diversification: Hydroponic mushroom farming can become more financially viable by looking into niche markets and added value mushroom products. Gourmet mushrooms, medical mushrooms, or specialty goods like materials derived from mycelium may be involved. Researches can concentrate on developing sustainability indicators, such as resource-use efficiency measurements and carbon footprint evaluations, for hydroponic mushroom growing [48].

13. CONCLUSION AND FUTURE OF HYDROPONICS IN MUSHROOM FARMING

- Hydroponic mushroom cultivation has a bright future ahead of it, with a number of interesting possibilities:
- Environmental friendliness: Hydroponics supports the global push for environmentally friendly farming. Its small environmental impact, effective use of resources, and ability to adapt to urban environments make it a viable option for mushroom cultivation.
- Food Security: By offering a consistent supply of mushrooms that are high in protein, hydroponic mushroom gardening can improve food security. This technology can be applied in a wide range of geographical settings, including metropolitan areas and areas with a limited supply of arable land.
- Research and innovation: As technology develops, the incorporation of automation and fine-tuned control mechanisms holds the promise of further enhancing hydroponic mushroom growing. Genetics, fungal behaviour, and custom nutrition formulation research may open up new vistas of productivity and quality.

- As a result of its year-round production, superior disease management, increased yields, and resource efficiency, hydroponics has a chance of completely transform the mushroom farming industry. The transformational impact on farming, environmental responsibility, and food safety cannot be overestimated, notwithstanding the difficulties. Collaboration between academics, farmers, and regulators will be essential moving ahead to realize every potential of hydroponic mushroom growing.

How ever every coin has two sides that is hydroponics also possess some challenges-

- To achieve the best possible mushroom growth, hydroponic systems call for careful management of nutrient solutions, including macro- and micronutrients. Poor yields and product quality can result from variations in nutrient formulation It can be difficult to choose appropriate substrates for hydroponic mushroom production and to ensure that they are properly sterilized. According to [35], improper substrate preparation can lead to contamination and lower crop yields. Controlling the correct temperature and humidity conditions inside a hydroponic mushroom farm can be difficult and energy-consuming. The development of mushrooms may be impacted by variations in several variables [48]. Disease and Pest Management: Diseases and pests can still affect hydroponic mushroom systems. To stop infestations and keep crops healthy, efficient management strategies are required.

- **Interpretation:** 40.4% of respondents stated they were NOT FAMILIAR with the use of hydroponics and had never cultivated plants, compared to 59.6% of respondents who felt they were familiar with the practice.

- **Analysis:** Because hydroponic farming gives exact control over the growth environment, it is a very effective way to cultivate plants. The plants get precisely the proper amount of nutrients when nutrient-rich water is used, and neither water nor fertilizer are wasted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

.

1. Atherton HR, Li, P. Hydroponic Cultivation of Medicinal Plants—Plant Organs and Hydroponic Systems: Techniques and Trends. Horticulturae. 2023;9(3):349. Available:https://doi.org/10.3390/horticulturae9030349
2. Bechara MA, Heinemann PH, Walker PN and Romaine CP. Agaricus bisporus mushroom cultivation in hydroponic systems. Transactions of the ASABE. 2006;49(3):825-832.
3. Biswas Sand Das R. Hydroponics: A Promising Modern Intervention in Agriculture. 2022;4(1), 334-338.
4. Breene WM. Nutritional and medicinal value of specialty mushrooms. Journal of Food Protection. 1990;53:883-894. DOI: 10.4315/0362-028X-53.10.883
5. Caputo S. History, Techniques Technologies of Soil-Less Cultivation. Small Scale Soil-less Urban Agriculture in Europe. 2022;45-86. Available:http://dx.doi.org/10.1007/978-3-030-99962-9_4
6. Chang ST and Miles PG. Mushrooms: Cultivation, nutritional value, medicinal effect, and environmental impact (2nd ed.). CRC Press; 2005.
7. Domingues DS, Takahashi HW, Camara CAP and Nixdorf SL. Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. Computers and Electronics in Agriculture. 2012;84: 53-61.
8. Dorais M, Caron J, Bégin G, Gosselin A, Gaudreau L, Ménard C. Equipment Performance for Determining Water Needs of Tomato Plants Grown in Sawdust-Based Substrates and Rockwool. Acta Horticulture. 2005;691:293-304. Available:http://dx.doi.org/10.17660/ActaHortic.2005.691.34
9. Dos Santos JD, da Silva ALL, da Luz Costa J, Scheidt GN, Novak AC, Sydney EB and Social, C. R. Development of a vinasse nutritive solution for hydroponics. Journal of environmental management. 2013;114:8-12.
10. Friedman M. Chemistry, Nutrition, and Health-Promoting Properties of *Hericium*

erinaceus (Lion's Mane) Mushroom Fruiting Bodies and Mycelia and Their Bioactive Compounds. Journal of Agricultural and Food Chemistry. 2015;63(32):7108–7123.
Available:https://doi.org/10.1021/acs.jafc.5b02914

11. Gurtler JB, Gibson KE. Irrigation water and contamination of fresh produce with bacterial foodborne pathogens. Curr. Opin. Food Sci. 2022;47:100889
12. Jain A, Kumari N, Jha VK. Hydroponic system: Hope and hype. In Recent Advances in Chemical Sciences and Biotechnology. 2019;144-149.
13. Jovicich E, Cantliffe DJ, Stoffella PJ. Spanish pepper trellis system and high plant density can increase fruit yield, fruit quality and reduce labor in a hydroponic, passive-ventilated greenhouse. Acta Horticulturae. 2003;614:255-262.
Available:http://dx.doi.org/10.17660/ActaHortic.2003.614.37
14. Khan S, Mirza, Hammadtariqmirza, Khan, Muhammad. Studies on Shiitake mushroom (Lentinula edodes (Berk.) Pegler); 2020.
15. Koyyalamudi S, Rao S, Jeong SC, Song CH, Cho KY, Pang G. Vitamin D2 formation and bioavailability from Agaricus bisporus button mushrooms treated with ultraviolet irradiation. Journal of Agricultural and Food Chemistry, 2009;57(8):3351-3355.
16. Kumari,R, Kum R. Aeroponics: A Review on Modern Agriculture Technology. Indian Farmer. 2019;6(4):286-292.
17. Lai PL, Naidu M, Sabaratnam V, Wong KH, David RP, Kuppusamy UR, Abdullah N, Malek SN. Neurotrophic properties of the Lion's mane medicinal mushroom, Hericium erinaceus (Higher Basidiomycetes) from Malaysia. International journal of medicinal mushrooms. 2013;15(6):539–554.
18. Macwan J, Pandya D, Pandya H, Mankad A. Review on Soilless Method of Cultivation: Hydroponics. Int. J. Recent Sci. Res. 2020;11:37122–37127.
19. Malik A, Iqbal K, Aziem S, Mahato P, Negi AK. A review on the science of growing crops without soil (Soilless culture)–A novel alternative for growing crops. International Journal of Agriculture and Crop Sciences, 2014;7(11):833-842.
20. Mandapaka M, Murthy ANG, Shanker AK. Nitrogen Nutrition in Crops and Its Importance in Crop Quality. In A. K. Shanker (Ed.), The Indian Nitrogen Assessment. 2017; 175-186.
DOI: 10.1016/B978-0-12-811836-8.00012-4
21. Manzocco L, Foschia M, Tomasi N, Maifreni M, Costa LD, Marino M, Cortella G, Cesco S. Influence of hydroponic and soil cultivation on quality and shelf life of ready-to-eat lamb's lettuce (*Valerianella locusta L. Laterr*). Journal of the Science Food and Agriculture. 2011;91(8):1373-138.
Available:https://doi.org/10.1002/jsfa.4313
22. Mattila P, Könkö K, Eurola M, Pihlava JM, Astola J, Vahteristo L, Piironen V. Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. Journal of Agricultural and Food Chemistry. 2002;49(5):2343-2348.
DOI: 10.1021/jf001525d
23. Miles PG, Chang ST. Mushrooms: Cultivation, Nutritional Value, Medicinal Effect, and Environmental Impact (2nd ed.). CRC Press; 2004.
Available:https://doi.org/10.1201/9780203492086
24. Mohammed ASA, Naveed M, Jost N. Polysaccharides: Classification, Chemical Properties, and Future Perspective Applications in Fields of Pharmacology and Biological Medicine (A Review of Current Applications and Upcoming Potentialities). Journal of Polymers and the Environment. 2021;29(8):2359–2371.
Available:https://doi.org/10.1007/s10924-021-02052-2
25. Muro J, Irigoyen I, Samitier P, Mazuela P, Salas MC, Soler J, Urrestarazu M. Wood fiber as growing media in hydroponic crop. Acta Horticulturae. 2005;697:179-185.
Available:https://doi.org/10.17660/ActaHortic.2005.697.22
26. Naushad M, Prasad N. Hydroponics Mushroom Fastest and Soilless Method. VigyanVarta, 2023;4(5):114-117.
27. Nguyen NT, McInturf SA, Mendoza-Cózatl DG. Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements. Journal of Visualized Experiments, 2016;113:54317.
Available:https://doi.org/10.3791/54317
28. Noguera P, Abad M, Noguera V, Puchades R, Maquiera A. Coconut coir waste, a new and viable ecologically friendly peat

substitute. Acta Horticulturae, 2000;517:279-286.
Available:http://dx.doi.org/10.17660/ActaHortic.2000.517.34

29. Nongthombam Jenita, Kumar, Adesh, Patidar, Sumeet. A Review On Study Of Growth And Cultivation Of Oyster Mushroom. Plant Cell Biotechnology and Molecular Biology. 2021;22.55-65.
30. Nozzi V, Graber A, Schmautz Z, Mathis A, Junge R. Nutrient management in aquaponics: Comparison of three approaches for cultivating lettuce, mint, and mushroom herb. Agronomy. 2018;8(3):27.
Available:https://doi.org/10.3390/agronomy8030027
31. Paterson RR. Ganoderma - A therapeutic fungal biofactory. Phytochemistry. 2006;67(18):1985-2001.
Available:https://doi.org/10.1016/j.phytochem.2006.07.004
32. Patil ST, Kadam US, Mane MS, Mahale DM, Dhekale JS. Hydroponic Growth Media (Substrate): A Review. International Research Journal of Pure and Applied Chemistry, 2020;21(23):106–113.
Available:https://doi.org/10.9734/irjpac/2020/v21i2330307
33. Puttaraju NG, Venkateshaiah SU, Dharmesh SM, Urs SMN, Somasundaram R. Antioxidant activity of indigenous edible mushrooms. Journal of Agricultural and Food Chemistry, 2006;54(26):9764-9772.
DOI: 10.1021/jf0615707
34. Reis FS, Martins A, Vasconcelos MH, Morales P, Ferreira ICFR. Functional foods based on extracts or compounds derived from mushrooms. Trends in Food Science & Technology, 2017;66:48-62.
Available:https://doi.org/10.1016/j.tifs.2017.05.010.
35. Royse DJ. A Global Perspective on the High Five: Agaricus, Pleurotus, Lentinula, Auricularia & Flammulina. Proceedings of the International Conference on Mushroom Biology and Mushroom Products. 2014;22:3-16.
36. Sánchez C. Cultivation of Pleurotus ostreatus and Other Edible Mushrooms. Applied Microbiology and Biotechnology. 2010;85(5):1321-1337.
Available:https://doi.org/10.1007/s00253-009-2343-7
37. Sardare MD, Admane SV. Review on Plant Without Soil - Hydroponics, 2013;2(3):299-304.
38. Seerat Jan, Zahida Rashid, Tanveer Ahmad Ahngar, Sadaf Iqbal, M. Abbass Naikoo, Shabina Majeed, Tauseef Ahmad Bhat Razia Gul and Insha Nazir. Hydroponics – A Review. Int.J.Curr.Microbiol. App.Sci. 2020;9(08):1779-1787.
DOI:https://doi.org/10.20546/ijcmas.2020.908.206
39. Sengül M, Ufuk S. Therapeutic and Functional Properties of Beta-Glucan and Its Effects on Health. Eurasian Journal of Food Science and Technology. 2022;6(1):29-41.
40. Sharma K. International Journal of Food Processing Technology. 2015;5(12):9-12.
Available:http://dx.doi.org/10.15379/2408-9826.2018.05.02.02
41. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation, 2019;17:364-371.
42. Shrestha A and Dunn B. Hydroponics. Oklahoma Cooperative Extension Services; 2013.
43. Stamets P. Growing Gourmet and Medicinal Mushrooms. 3rd Edition, Ten Speed Press, Berkeley; 2000.
44. Stamets P. Mycelium running: How mushrooms can help save the world. Ten Speed Press; 2005.
45. Thakur K, Sood A, Chaudhary J, Kumar S, Dwivedi A. Hydroponics: Future of Indian Farming. Journal of Agricultural Innovation. 2023;2:25-28.
46. Valverde ME, Hernández-Pérez T, Paredes-López O. Edible mushrooms: Improving health and promoting quality life. International Journal of Microbiology, 2015:376387.
DOI: 10.1155/2015/376387
47. Van Damme EJM. 35 years in plant lectin research: a journey from basic science to applications in agriculture and medicine. Glycoconjugate journal, 2022;39(1):83–97.
Available:https://doi.org/10.1007/s10719-021-10015-x
48. Velazquez-Gonzalez RS, Garcia-Garcia AL, Ventura-Zapata E, Barceinas-Sanchez JDO, Sosa-Savedra JC. A review on hydroponics and the technologies

associated for medium- and small-scale operations. agriculture. 2022;12(5):646. Available:https://doi.org/10.3390/agriculture12050646

49. Vetvicka V, Vetvickova J. Glucans and cancer: Comparison of commercially available β-glucans. Oncology Letters, 2019;39(7):3975. Available:https://doi.org/10.21873/anticanres.12355
50. Vyshnavi, Asha S, Sanjana Agarwal, Harshit Dubey, Chinmay Jain L. A study on hydroponic farming. International Journal for Multidisciplinary Research (IJFMR), 2023;5(2):2582-2160. Available:https://doi.org/10.36948/ijfmr.2023.v05i02.2286
51. Wasser S. Medicinal mushrooms as a source of antitumor and immunomodulating polysaccharides. Applied Microbiology and Biotechnology, 2002;60:258–274.
52. Wasser SP, Weis AL. Therapeutic effects of substances occurring in higher Basidiomycetes mushrooms: A modern perspective. Critical Reviews in Immunology, 1999;19(1):65-96.
53. Wasser SP, Weis AL. International journal of medicinial mushrooms, 1999;1(2):121-130.
54. Woo SL, Di Benedetto P, Senatore M, Abadi K, Gigante S, Soriente I, Ferraioli S, Scala F and Lorito M. Identification and characterization of Trichoderma species aggressive to Pleurotus in Italy. Mycologia, 2004;30(4):469-470.
55. Yang P, Wu L, Cheng M, Fan J, Li S, Wang H, Qian L. Review on drip irrigation: impact on crop yield, quality, and water productivity in China. Water. 2023;15(9):1733. Available:https://doi.org/10.3390/w15091733
56. Zengliang Liu, Shengjin Wu, Xuefeng Chen, Wenlong Zhang, Shuangyun Zhou and Xiaoguo Wang. The complete mitochondrial genome of the edible mushroom pleurotus giganteus (Agaricales, Pleurotus) and insights into its phylogeny. Mitochondrial DNA Part B, 2022;7(7):1313-1315. DOI: 10.1080/23802359.2022.2096418
57. Zhang H, Asutosh A, Hu W. Implementing vertical farming at university scale to promote sustainable communities: a feasibility analysis. Sustainability. 2018;10(12):4429.
58. Zimmermann M, Fischer M. Impact Assessment of water and nutrient reuse in hydroponic systems using bayesian belief networks. Journal of Water Reuse and Desalination, 2020;10(4):431–442. Available:https://doi.org/10.2166/wrd.2020.026

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/109304