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Mushrooms for tomorrow: Soil health, nutrition, and sustainability combined

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Abstract

Mushroom cultivation has become a rapidly increasing global trend over the last few years. Historically, mushrooms were only consumed by individuals residing in rural farming areas, and thus not a valuable product. Since the introduction of mushroom farms, farmers have been able to earn a viable income through their production. The role of mushrooms has become integral to the quality and quantity of food consumed, as well as maintaining a healthy lifestyle. Nutritionally, mushrooms are an excellent source and continue to increase in demand as a food product; additionally, many people view them as medicinal in regard to their health benefits.

Mushrooms differ from traditional crops because they are grown indoors and do not require large growing areas (spaces). Moreover, mushroom crops are relatively quick to be harvested. On the other hand, if farmers wish to be proficient at producing mushrooms, the environment must be carefully monitored and managed to ensure optimal growing conditions. Specifically, temperature, humidity, moisture level, light, ventilation, and carbon dioxide all directly impact a farmer's ability to produce mushrooms successfully.

Technology advancements have made the management of mushroom production much easier. The use of technology, called modern agriculture, provides mushroom farmers with additional tools for producing mushrooms through innovative methods such as Artificial Intelligence, Data Analytics, Internet of Things, and Cloud Computing. In addition to these technologies connecting the globe, they will continue to enhance how we farm.

Keywords: Mushroom cultivation, edible mushroom, fungal biotechnology, indoor farming, controlled environment agriculture

Introduction

The phylum known as Basidiomycetes includes mushrooms as part of this diverse taxon; along with ascomycetes, these species comprise what is referred to as the Dikarya kingdom, more commonly known as 'higher fungi' (De Mattos-Shipley and colleagues 2016) ^[35]. Mushrooms are one of the top choices of food for supplementation to cereal foods. The value of mushrooms lies in their tremendous nutritional content, making them an extremely popular tonic, medicinal and addition to diet worldwide. They have been found to be rich sources for protein (35%), crude fibre (19%), vitamins, carbohydrates and minerals (Thakur 2020) ^[36]. Mushroom cultivation has also contributed to generating income, particularly among unemployed youth within the farming community, women and self-help groups (SHGs) from urban and rural areas due to their high yield per square foot of land and short time frame, as well as their cost-effective method of production (Dey and colleagues 2020) ^[37]. In addition, mushroom cultivation is also an attractive option for landless and marginal farmers as it does not take up much space. Vertical farming, which is a form of advanced farming, has been developed to make maximum use of the available land area. Farmers use innovative methods to produce mushrooms more efficiently in vertical columns than through traditional farming practices where crops are grown on horizontal rows across the ground. The role of mushroom farming in achieving sustainable

development goals is shown in Fig. 1. Achieving these goals by 2030 is a big challenge. We need smart ways to make it happen.

Mushroom farming is directly linked to some of these goals. For example it helps with

- Zero Hunger
- Responsible Consumption and Production
- Climate Action

Mushroom farming also helps with goals like

- Water and sanitation
- Sustainable cities and communities
- Life on Earth
- Partnerships for the goals

So mushroom farming is really important, for achieving these goals by 2030. Mushrooms can help us get

India produces an amount of waste from farms about 620 million tons, which is really good for growing mushrooms. People in India have not used this waste to grow mushrooms as much as they could. Some people have written about this like Thakur in 2020 Kamthan and Tiwari in 2017 Grimm and Wösten in 2018 and Raman and his team in 2018 ^[36, 40, 41, 42].



Fig 1: Mushroom cultivation and Sustainable Development Goals

India is a place to grow mushrooms because it has a lot of cheap waste from farms, good roads and buildings smart people and a big population in rural areas including many small farmers. All these good things mean that growing mushrooms in India could become a business that people can do at home or even a big company. Mushroom farming in India has a lot of mushroom cultivation, in India could really take off.

We review how mushroom farming can help with sustainability and food security. We also review how soil health affects mushroom farming.

Open residue burning is widely practiced across Asia including countries such as the Philippines, Thailand, Indonesia, Taiwan, Pakistan, Nepal, and India as a quick method for managing crop waste, with similar practices also observed in the United States. However, this approach has serious environmental and public health consequences, contributing to air pollution, respiratory illnesses, and global warming. In this context, mushroom cultivation presents a sustainable and practical alternative for utilizing agricultural residues. By converting crop waste into valuable food products, mushroom farming not only supports effective waste management but also enhances farmers' livelihoods.

Despite its growing importance, there remains a need for deeper understanding of mushroom production systems, their nutritional benefits, and their environmental impacts. Equally important is the relationship between soil health and mushroom cultivation, as soil fertility influences the quality of substrates and the availability of essential nutrients required for optimal growth. This review therefore explores the role of mushroom farming in promoting environmental sustainability, improving food and nutritional security, and supporting sustainable agricultural practices. It also examines how soil health and fertility contribute to efficient and cost-effective mushroom production. Overall, mushroom cultivation holds significant potential as an eco-friendly solution that aligns agricultural productivity with environmental conservation and human well-being.

Keywords

Sustainable agriculture, Circular bioeconomy, Sustainable Development Goals (SDGs), Crop residue management,

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Agro-waste utilization, Mushroom cultivation, Soil health, Nutritional security

2. Mushroom characteristics and nutritional value

Mushrooms are the parts that grow above the ground. They are mostly part of the Basidiomycetes group. Mushrooms also team up with ascomycetes to form the Dikarya group. One big difference between mushrooms and plants is that mushrooms do not have chlorophyll. This means mushrooms cannot make their food like plants do. Instead mushrooms get their nutrients from matter.

There are lots of types of mushrooms. Some mushrooms are safe to eat, like the ones with gills and puffballs. If you look around the world you will find around 12,000 species of mushrooms. About 2,000 of these mushrooms are edible. Only a small number, about 35 are grown commercially. Mushrooms come in all sorts of shapes and sizes. You have got some mushrooms that have a cap and a stem. Other mushrooms are shaped like cups. Are jelly-like. Some mushrooms even look like coral.

Mushrooms can be edible. This means they are safe to eat and are actually pretty good for you. Then there are mushrooms that have special healing properties. You have to be careful. Some mushrooms are poisonous. This means they are toxic and can hurt you. Mushrooms are really good for you because they have a lot of protein, carbs, vitamins and minerals. Mushrooms are also high in fiber. They are low in fat. This is a bonus.

If you are a vegetarian mushrooms are an option. Mushrooms have protein than a lot of grains. They also have some important amino acids. These amino acids are good for your body. The fat that mushrooms do have is mostly the kind. This is fat. Unsaturated fat is great for your heart health. So all mushrooms are a pretty great food to add to your diet. Mushrooms are a source of carbs. These carbs include sugars and fiber. These are really good for your gut. Mushrooms also have lots of vitamins. These vitamins are like the B- ones. Mushrooms have minerals such as potassium and copper. The potassium in mushrooms helps keep your blood pressure in check. Since mushrooms are low in sodium this is a bonus too.

Mushrooms have properties. These properties come from

things like polysaccharides and antioxidants. These things help keep us healthy. They fight off viruses reduce inflammation and even help to prevent cancer. For example the **Ganoderma lucidum** mushroom is really good at helping to lower blood pressure and cholesterol levels. Mushrooms have antioxidants that protect our cells from getting damaged. This can reduce the risk of getting sick. Overall mushrooms are pretty amazing. This is because of all the things they can do for our bodies.

Mushrooms are really good for you. They can make a difference in your health. Mushrooms have got some fat. They also have lots of high-quality protein and important nutrients. Your body needs these nutrients. So adding mushrooms to your meals can be a way to make sure you are eating a balanced diet. Mushrooms are a food to eat. They are good, for your health. You should try to eat mushrooms.

Keywords: Fungal diversity, Basidiomycetes, Edible mushrooms, Nutritional value, Amino acids, Bioactive compounds, Antioxidant activity, Medicinal mushrooms

3. Mushroom production: current status, challenges, and prospects

- Growing mushrooms helps areas in India in many ways like boosting the economy improving nutrition and keeping people healthy. The United Nations Development Program started a project in 1974 to grow button mushrooms in Himachal Pradesh. Now the Directorate of Mushroom Research is in charge of it.
- Over the 30 years mushroom production has increased a lot from 3.1 million tonnes in 1990 to 42.8 million tonnes in 2020.
- China produces the mushrooms in the world making more than 73% of the worlds supply.
- Many countries, 100 are now growing different types of mushrooms.

Some popular mushrooms grown around the world are

- *A. Bisporus*
- *L. Edodes*
- *Pleurotus spp.*
- *Auricularia auricula-judae*
- *V. Volvacea*
- *Flammulina velutipes*

A big challenge for mushroom farmers is keeping a supply to certain markets. Some initial problems they face include

- choosing the mushroom to grow
- finding a reliable supplier of mushroom spawn
- setting up a growing system
- figuring out how to supply different markets

The mushroom industry also faces many obstacles, such as

- Mushrooms don't last long
- Packaging and storage issues
- Rising costs of raw materials
- Unstable prices
- Lack of good marketing channels

- Poor spawn quality
- Inadequate policies
- Limited techniques for processing after harvest
- Long preparation time for compost
- Quality control and certification
- Lack of transportation
- Limited knowledge about financial help
- Not enough scientific research on mushroom farming

Mushrooms can be grown using agricultural waste, which is available almost everywhere. This waste has to-degrade components but mushroom growing works well with it.

Farm waste, like rice and wheat straw is a source for growing mushrooms. The rice and wheat cropping system is very important for food security. It is grown on 13.5 million hectares in Asia with South Asia accounting for 57% of this area. However managing rice straw is harder than wheat straw due to a lack of recycling technologies and high silica content. Burning crop residue is an environmental concern causing health problems and global warming. Using rice straw to grow mushrooms is a way to prevent burning it. Mushrooms, like *A. Bisporus*, *V. Volvacea* and *Pleurotus* species can be grown using paddy straw.

3.2 Types of agricultural waste

Agricultural waste is broken down into two main types (Mande *et al.*, 2005) ^[38]. Crop residues come from the land while wood and industrial processing waste comprise agricultural waste, providing a valuable source of biomass.

Crop residues, such as grasses, stalks, stems, leaves, roots, branches, haulms, and twigs, represent the residual biomass generated by the main crop after it has been harvested in the field or on farm. The processing of crops into food and other products generates many different types of waste; these include culls, rinds, seeds, pits, pulp, press cakes, marc, malts, hops, and many other residual products resulting from large-scale food production (Philippoussis, 2009) ^[39].

3.3 Physico-chemical composition of substrates

Agro-based residues are really varied. They do not dissolve in water. They are made up of cellulose and hemicellulose and lignin. Agro-based residues also have some things like pectin and starch and other polysaccharides.

Agro-based residues have a lot of good things like nutrients. These nutrients include things like nitrogen and phosphorus and potassium and calcium and magnesium and sulfur. Agro-based residues also have some nutrients like manganese and iron and zinc and copper and boron and molybdenum. The amounts of these nutrients in Agro-based residues are about 0.5 to 1.5 percent nitrogen and 0.15 to 0.2 percent phosphorus and 1 percent potassium and 1 percent calcium and 0.5 percent magnesium and 0.2 percent sulfur. Agro-based residues also have 30 milligrams of manganese per kilogram and 100 milligrams of iron per kilogram and 30 milligrams of zinc per kilogram and 5 milligrams of copper per kilogram and 20 milligrams of boron per kilogram and 1 milligram of molybdenum, per kilogram.

3.4 Preparation of substrate

Mycelium can grow on straw that has been treated with water. Other types of moulds on the straw can stop it from growing by making poisonous compounds. These moulds

compete with the mycelium during the spawn run. To help the mycelium grow people have found ways to kill the microorganisms that are in the straw.

The method used to get the straw ready for the mycelium to grow depends on the type of mushroom that is being grown. There are two ways to prepare the straw.

(I) One way is to use straw that has been composted. This straw is made by fermenting and pasteurizing it. This method is used to grow mushrooms like *A. Bisporus* or *A. Subrufescens* Peck, well as *P. Ostreatus*, *Pleurotus sajor-caju* and *Pleurotus cystidiosus*.

(II) The other way is to use straw that has not been composted. This straw is made ready by using steam or chemicals to sterilize it before the mycelium is added. Mushrooms, like *L. Edodes*, *Auricularia* sp., *F. Velutipes*, *Pleurotus eryngii*, *Agrocybe aegerita* and *V. Volvacea* are grown on this type of straw.

3.5 Preparation of compost

- The preparation of compost happens in two steps Phase I and Phase II composting.
- During Phase I people take wheat or rice straw and other things. They get them really wet. They need to absorb a lot of water 75 percent.
- After that they use these things to build a big pile that has a lot of air in it.
- They break the pile after two days. Add water to the dry parts.
- Then they build the pile again. This helps to make the compost really hot. It all gets mixed together.
- After they have turned the four times they usually do Phase II composting in a big tunnel where it gets really hot.
- There are two parts to Phase II one is called conditioning. The other is pasteurization.
- In the conditioning part they heat the compost to a temperature that is just right for certain tiny living things to grow.

This temperature is between 45 and 52 degrees Celsius.

- While this is happening, a lot of the smelling part of the compost gets trapped or it gets eaten by tiny living things. If there is much of this bad smelling part it goes up into the air. The next part is pasteurization, which's, like a cleaning step.
- It helps to kill the tiny living things that can make people sick.
- To do this they heat the compost to 59 degrees Celsius for a hours, usually four to six hours. This makes sure the compost is safe to use.

4. Decomposition of substrates and nutrient utilization by mushroom

- Mushroom species can break down residues whether they are in their natural state or have been composted. Mushroom species can do this. They are different when it comes to making the enzymes needed to break down lignocellulosic residues. This means they are different in their ability to grow and produce fruit on substrates.
- The main sources of carbohydrates in plant residues are cellulose and hemicellulose. These are often covered in

lignin, which creates a barrier around them. Lignocellulose is a compact material that does not dissolve in water.

- So there are two types of enzymes that help break down lignocellulose: the hydrolytic system and the oxidative system. The hydrolytic system releases enzymes that break down cellulose and hemicellulose. The oxidative system releases enzymes that break down lignin.
- Laccase is an enzyme that can oxidize phenols. This makes it very good at breaking down units in lignin. It also plays a role in helping morel fungi use plant litter in the soil.

The type of substrate used to grow mushrooms and the type of mushroom species can affect the type of enzymes released by the mushrooms. *Morchella importuna* is a type of mushroom that lives in the soil. It can use decomposed plant litter in the soil as a source of carbon. Mushrooms have genes that encode enzymes that can help turn waste into useful nutrients. The laccase-like multicopper oxidase genes are important for breaking down plant litter in the soil. The black morel species *M. Importuna* SCYDJ1-A1 has two of these genes called *MiLacA*. *Milacb*. *MiLacA* can act like laccase and polyphenol oxidase. This means it is involved in breaking down matter. *Morchella importuna* can break down residues. *Morchella importuna* is good, at using decomposed plant litter in the soil. *Morchella importuna* has genes that help it break down waste.

5. Interlinking soil health with substrate production for mushroom farming

5.1 Soil health, substrate production and mushroom farming: Mushroom production requires a lot of nitrogen and other nutrients to start the fermentation process. The problem is that the raw ingredients used for mushroom production do not have enough of these nutrients. For example straw has an amount of nitrogen but it is not enough to meet the nitrogen requirements.

So to solve this problem additional ingredients are added to the mixture used for mushroom production. This is called mushroom supplementation. It is a way to add nutrients to the ingredients used for growing mushrooms. Researchers like Carrasco and his team found that adding nutrients like horse dung, chicken manure or cow manure can really improve mushroom production and quality.

When it comes to growing mushrooms the environment plays a role. This includes the soil, which's a critical component. However the soil has not received attention even though its health is very important for producing good quality mushroom.

Soil health is very important for crop production. It affects the quality of the crops including the nutrients they contain. It is hard to understand how soil health affects the nutritional quality of crops because it involves many complicated processes.

The organic matter in the soil plays a role in maintaining its health. This in turn affects the yield and quality of crops. If the soil has than 1.1% organic carbon the crop yield can decrease by around 20%.

Morchella mushrooms are different from edible fungi because they are grown directly in the soil. However growing *Morchella* mushrooms can be challenging due to

productivity and failure to produce fruiting bodies. This can be caused by factors, including poor mushroom spawn, bad field management and soil-borne pathogens.

One of the pathogens that affect *Morchella* mushrooms is *Paecilomyces penicillatus*. The success of *Morchella* mushroom cultivation depends on the diversity of soil populations. A healthy soil environment with the composition of soil microbiota is necessary for optimal yields. This means having a reduced number of soil-borne pathogens, which's beneficial for growing *Morchella* mushrooms in soil. Mushroom production requires a soil environment and *Morchella* mushrooms are no exception. The soil health is critical, for *Morchella* mushroom cultivation. It is essential to maintain a healthy soil environment to achieve good quality and high yields of *Morchella* mushrooms.

5.2 Strategies to improve substrate quality

Agronomy, water and nutrient management practices have an impact on the quality and quantity of the substrate. For example agronomy, water and nutrient management practices are very important. Fig. 7 Shows ways to improve substrate production. By adding nitrogen and protein to the substrate we can reduce the need for extra nutrient supplements from chicken manure and horse manure.

Agronomy practices like intercropping, crop rotation, green manuring and conservation agriculture are ways to increase straw production and quality. Crop rotation and conservation agriculture make the soil and straw better.

Some researchers found that keeping crop residue increased wheat straw yield by 1.38 times compared to not keeping it. There are water management strategies, like pressured irrigation systems and ways to keep moisture in the soil that can improve crop quality.

Water harvesting systems help use rainfall efficiently which makes rain-fed agriculture more sustainable and reliable. Soil fertility management is also important for improving crop production and straw quality.

Soil management practices like straw incorporation, balanced fertilization and organic manure help improve soil health and nutrient cycling, which makes straw and grain quality better. The relationship between soil quality and substrate quality in mushroom production is complicated.

Substrate quality has an impact on soil quality. Some researchers showed that mushrooms can be contaminated with metals, which is a big health risk. This is why it is very important to use substrates.

Using high quality compost and casing layers is important. The casing layer is especially good for adding matter that makes the soil better. Some researchers found that waste mushroom substrate can improve soil characteristics and plant growth.

This suggests that using substrate can improve soil quality. Some scientists suggested using fungi and enzymes to make rice straw a better substrate. These fungi and enzymes break down lignin in rice straw which's hard to decompose.

By using these fungi and enzymes we can make more nutrients available for mushroom growth. Another researcher agreed that we need to improve the value of straw especially its carbohydrate content.

However some other researchers found that the size of straw particles and the amount of spawn inoculation can affect

mushroom production. Some other scientists think that incorporating straw into soil can make it better for mushroom growing. We can also use types of straw like wheat, barley or oat straw to make a compost that is rich in nutrients for mushrooms. Another approach is to check the nutrients in the substrate and add more if needed. For example some researchers found that agricultural residues with levels of potassium can increase mushroom production. Agronomy, water and nutrient management practices are very important for improving substrate quality.

Agronomy practices like crop rotation and conservation agriculture can make the soil and straw better. By using soil management practices we can improve soil health and nutrient cycling, which makes straw and grain quality better. The quality of the substrate is very important for mushroom production and agronomy, water and nutrient management practices play a role, in this.

6. Mushroom farming environmental, food and nutritional security

Mushroom farming has a potential to produce effective medicinal products and provide nutritionally enriched food. Mushroom farming is also good for the environment because it helps reduce pollution. Mushroom mycelia are used to extract and break down pollutants.

The impact of mushroom farming on the environment is shown in Figure 9. People are becoming more aware of the effects of mushroom farming. Some composting techniques are not good. Release harmful gases like methane and ammonia which are bad for the environment. These gases are released when nitrogen-containing molecules break down. Methanogens also create methane in environments without oxygen.

The carbon to nitrogen ratio is important for composting. Experts say that a ratio of 15 to 30 is good but 20 to 25 is even better.

Mushroom farming is not as bad for the environment as types of farming. For example producing one kilogram of shiitake mushrooms releases 1.87 kilograms of carbon dioxide, which's less than what is released by producing tomatoes, baby corn and potatoes. Mushroom farming also has a carbon footprint than beef, poultry, pork and egg farming.

Mushroom farming uses water than other types of farming. Compost and casing soil are the two things used to grow mushrooms. The mushroom is made up of 90 percent water. The compost and casing layer provide the mushroom with water.

Growing mushrooms requires water than growing many other food crops. 1.8 Gallons of water are needed to grow one pound of mushrooms. Most of the water used in mushroom farming is used for electricity generation. The water footprint of mushroom farming is lower than that of farming practices. Mushroom farming is considered carbon positive. Has lower greenhouse gas emissions, than other types of farming.

7. Future strategies for improving mushroom quality and environmental safety

We need to do something about climate change so we should make some rules about growing and using mushrooms. These rules are important for keeping the earth

healthy for a time, which is good for people now and people in the future. Growing mushrooms can make a difference for farmers and the earth and it can also help people have better lives. We need people from groups to work together to make people think growing mushrooms is a good thing. If we work together we can grow mushrooms and have more types of food to eat.

We need to learn more about how to grow and use mushrooms in a way that's good, for the earth. Here are some things we can do in the future.

8. Zero waste farming/eco-friendly waste management and circular economy

The European Union produces a lot of garbage every year from farming with over 700 million tons. The rest of the world produces more. The idea of an economy is becoming important because of increasing environmental problems caused by throwing away waste and running out of natural resources. The main goal of the economy is to make use of waste reduce it and recycle it.

Growing mushrooms is a way to make use of leftover farm and industrial waste

- A lot of waste from farms and industries is produced every year. It has a lot of value because it is rich in organic materials. These materials can be used to grow mushrooms.
- Burning crop waste in fields and using landfills has caused a lot of environmental damage including making global warming worse and harming animals and plants. It also affects peoples health.
- Using crop waste to grow mushrooms can make the biomass more nutritious and increase mushroom yields.
- Growing mushrooms on crop waste can be profitable for farmers. Is good, for the environment because it recycles waste. The potential of using crop waste to grow mushrooms has value.

8.1 Bioremediation of pollutants from water and soil:

- The world is facing a problem with pollution. This is because of chemicals in the soil, water and air. These chemicals are coming from factories and farms that use a lot of pesticides. Pollution can happen because of things like oil or heavy metals.
- Myco-remediation is a way to clean up pollution. It uses mushrooms to break down chemicals. This is a way to clean up the earth because it is gentle on the environment. Mushrooms are good at breaking down chemicals because they have special helpers called enzymes. These enzymes can deal with kinds of bad chemicals.
- Mushrooms are very good at cleaning up pollution. They can even clean up chemicals like polycyclic hydrocarbons. People are also using something called Spent Mushroom Substrate to clean up pollution. This is the stuff that is left over after mushrooms are grown. It can be used to clean up water and soil.
- Spent Mushroom Substrate is very good at absorbing chemicals. It can even help to clean up pesticides from soil. This means that soil can be healthier and safer for plants to grow. Spent Mushroom Substrate can also be used to clean up wastewater. It can remove things like

nitrogen from water.

- Some people have used Spent Mushroom Substrate to clean up wastewater from factories. They found that it was very good at removing chemicals. Spent Mushroom Substrate can also be used to reduce greenhouse gas emissions. This is important because greenhouse gases are bad for the earth.
- When Spent Mushroom Substrate is used to clean up manure it can reduce the amount of gases that are released. This is a way to keep the air clean. Some people have also found that using Spent Mushroom Substrate can make soil healthier. This is because it can help to break down chemicals in the soil.
- So mushrooms and Spent Mushroom Substrate are very good at cleaning up pollution. They can be used to clean up kinds of bad chemicals. This is important because pollution is a problem that we need to solve.
- Mushrooms and Spent Mushroom Substrate can help to keep the earth clean and healthy.

8.2 Reduction of greenhouse gas emission

- Spent Mushroom Substrate can also be used to reduce greenhouse gas emissions. This is done by using it as a helper when cleaning up manure. It can reduce the amount of gases that are released into the air. This is a way to keep the air clean.
- Using Spent Mushroom Substrate can reduce the amount of nitrogen that is lost. It can also reduce the amount of gases like ammonia and nitrogen oxide. This is important because these gases are bad, for the earth.
- Some people have found that using Spent Mushroom Substrate can make soil healthier. This is because it can help to break down chemicals in the soil. It can also help to reduce greenhouse gas emissions.
- So Spent Mushroom Substrate is an useful thing. It can be used to clean up pollution and reduce greenhouse gas emissions. This is important because we need to take care of the earth.

8.3 Breeding for mushroom improvement

- The cultivation of mushrooms is a new area of study when you compare it to breeding plants and animals. The button mushroom, also known as *A. Bisporus* has recently had big breeding operations set up similar to what they do with plants. For a time people did not know much about how mushrooms breed in the wild so it was hard to improve the genetics of the cultivated mushroom *A. Bisporus*.
- Now we know that mushrooms are a kind of species with a single multiallelic mating type component. This knowledge helps researchers look at how mushroomsre bred now and think of ways to make it better. The main goals of people who breed mushrooms and do research on them are to get mushrooms make them better quality and make them stronger against pests and diseases. They also want to reduce the cost of producing mushrooms and use compost in a way.
- To do this they use methods like selecting the mushrooms by chance using radiation and chemicals to create new traits cross breeding and using genes from other organisms. These methods have been working

well in the few decades.

- There are problems with growing, selling, storing and keeping mushrooms fresh that researchers are trying to solve. They also want to make mushrooms that can resist disease. Since the 1980s hybrid mushroom strains have become very popular. People have bred hybrids of mushrooms like *Lentinula*, *Pleurotus* and *Agaricus* by cross breeding them.
- These hybrid mushrooms are not only stronger against disease and pests. They can also handle environmental and cultural challenges better. New tools like DNA markers help breeders find the genes they want. They use techniques like polymerase chain reaction and random amplified polymorphic DNA to make markers.
- To make maps they need software to process the data. Now people can make transgenic mushrooms using DNA technology, which is a new and exciting possibility. They are using methods that work for fungi to transform mushrooms.
- To overcome the technical challenges people need to work together and invest in the research. The main goal is to breed mushrooms and that is what people are working towards by DOIing research, on mushroom breeding and cultivation of mushrooms.

Conclusion

Mushroom farming can really help with food and nutritional security. Keeping the environment safe by using waste. This is done by recycling waste materials. The quality and quantity of mushrooms grown are closely tied to the properties of the materials used. These raw materials directly affect the minerals in the mushrooms because the mushrooms mycelium is in contact with them and takes in nutrients like carbon, nitrogen, phosphorus, potassium and vitamins. However the materials used for mushroom farming are low in nitrogen and other nutrients. This makes it hard to grow high-quality mushrooms unless extra nutrients are added. To keep improving mushroom yield and quality we need a breeding program and advanced techniques. Some of these techniques include mutagenesis, mycelial matting and recombinant DNA technology.

Also understanding soil health is crucial for making nutrient- substrates for mushrooms. When we improve these substrates we can increase mushroom yield and nutritional quality. This review aims to connect soil health, substrate quality and mushroom production.

Earlier reviews did not address this connection. We found that there is limited information on this topic. Creating policies for mushroom production is important, with climate change and food security challenges. We need to ensure that our environment stays eco-friendly for now and future generations. Mushroom farming and soil health are closely linked to achieving this goal. By focusing on these areas we can make mushroom production more sustainable. Mushroom production can then support both food security and environmental safety.

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