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Review on Utilization Prospects of Wood-Based Substrate for Mushroom Cultivation

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Abstract: Mushroom cultivation uses a wide variety of lignocellulosic waste and is an efficient way to recycle agro-forest residues to produce food. The cultivation of edible mushrooms using a wood-based substrate represents the bioconversion of that waste into edible protein. This review provides an overview of different wood-based substrates utilised for the production of mushrooms in the world and Nepal. Many agro-forest wastes have been utilized as substrates for the cultivation of mushrooms and have shown good yield with biological efficiency. Four major types of mushroom namely Oyster mushroom (*Pleurotus ostreatus* (Jacq.) P. Kumm), Button mushroom (*Agaricus bisporus*), Shiitake mushroom (*Lentinula edodes* (Berk.) Singer) and Paddy straw mushroom (*Volvariella volvacea*) are cultivated commercially in Nepal. Paddy straw sawdust, maize cob and sugarcane bagasse were the most used substrates for Oyster mushrooms. Similarly, *Quercus* spp. and *Alnus* spp. wood logs were common for growing Shiitake mushrooms. Sawdust from different trees also offers a potential alternative substrate source for mushroom cultivation. Hardwood sawdust was an excellent mushroom substrate as they allow faster colonization providing better structure for the mycelium growth. A study showed the nutrient content, growth and yield of mushrooms vary depending on the substrate utilized. This showed more study is needed to acquire information on wood substrate ensuring the safety of consumers that is economically viable and readily available.

Keywords: Agro-Forest Residue, Lignocellulosic, Substrate, Wood Waste

1. Introduction

Mushrooms are saprophytic fungi that feed on dead and decaying organic matter. They are important sources of nutritious food, life-saving medicines and enzymes for biotechnology [1, 2]. Mushrooms are cosmopolitan, yet they are cultivated worldwide due to their nutritional and wide range of medicinal properties. Approximately, 14000 species described from millions of fungi in the world can be considered mushrooms, out of which 1-10% of mushrooms are predicted to be poisonous [3]. Among them, 350 species are considered food and 216 hallucinogenics. According to a study by Royse et al. [4] mushrooms represent a market of 63 billion US dollars in 2013 with a high demand for cultivated edible mushrooms (54%), medicinal mushrooms (38%) and wild (8%) respectively. Also, the consumption of cultivated edible mushrooms has increased from 1 to 4.7 kg per capita in the period 1997 to 2013. A recent study by Devkota and Aryal [5] showed 1291 species of mushrooms with 159 with food value, 74 with medicinal, 100 as toxic and 25 with other values. Mushrooms are utilized by the Nepalese community as food from time immemorial and are famous in Tamang (56 species) tribes followed by Magar, Gurung with the least utilization in Newar (22 species) communities [6].

Though mushrooms have economic, nutritive and medicinal values, their production is directly related to different factors i.e. temperature, humidity, substrate quality, and some light. The substrate used is important as it has effects on the chemical and functional characteristics of mushrooms [7]. Mushrooms grown on different substrates showed different characteristics of the fruiting body and chemical composition [8, 9]. All the available lignocellulosic substances, including various types of waste from agriculture, horticulture, forest, and the textile and wood industry can be used for growing mushrooms [9–11]. There are many species of mushrooms cultivated on sawdust obtained from different tree species with a variety of additive ingredients such as wheat bran, cornmeal, cereal grains and other organic materials. Studies showed the use of a substrate composed of a mixture of various materials is more beneficial for the production than the use of homogenous substrates due to an enriched nutritional environment [12, 13]. Paudel and Dhakal [14] used rice straw, maize husks, banana leaves, finger millet husk and a mixture of paddy straw and black gram pod shell (1:1) as a substrate for the cultivation of *P. ostreatus* and found finger millet substrate and paddy straw gave higher yields with higher biological efficiency. Shitake mushrooms (*L. edodes* (Berk.)) grown on sawdust of different woody species showed the highest yield and biological efficiency in the sawdust of Jackfruit (*Artocarpus heterophyllus* Lam) and the lowest in Champa (*Michelia champaca* L.) from the tropics [15]. Similarly, *Cordyceps militaris* (used in Chinese medicine) was grown on different substrates where cottonseed shells and corn cob particles were effective substrates for the production of fruit bodies and bioactive compounds [16]. Liang et al [17] used several grains such as brown rice, plumule rice, wheat and pearl barley supplemented with 1% peptone, yeast extract, ammonia sulfate, and monosodium glutamate as a nitrogen source to produce fruiting bodies and bioactive compounds of *C. militaris.* They found the highest yield and biological efficiency in pearl barley substrate (25.16 g/bottle and 87.36%) followed by brown rice and peptone substrate (21.84 g/bottle and 75.83%).

Mushroom quality and quantity depend on substrates as they uptake and accumulate various chemical elements from them [18, 19]. However, this process varied depending on the species and bioavailability of elements [20]. These days studies were conducted on the enrichment of essential minerals (Zinc (Zn), copper (Cu), lithium (Li), and selenium (Se)) in mushrooms to increase their nutritional and pharmaceutical values [21, 22]. Mushroom can also accumulate toxic metals which is hazardous to human health [23, 24]. This clearly shows the importance of substrates used for maintaining the growth, quality and chemical composition of mushrooms. Hence, we need to perform a multi-elemental investigation of cultivated mushrooms and specifically substrates used for mushroom cultivations.

This review identifies different wood-based substrates used for commercial mushroom cultivation and their prospects in terms of economy and health. Also, it provides the prospects of utilizing different local and exotic trees and wood substrates for effective cultivation and market value.

2. Wood-Based Substrate Utilized in Mushroom Production

A mushroom substrate is a substance that allows mushroom mycelium to develop and establish itself. The substrate offers the nutrition, moisture, and energy that mushrooms require to develop fruit [25]. Different types of wood are utilised for the production of different mushrooms commercially (Table 1).

Table 1. *Mushroom substrates utilized in Nepal.*

Mushroom	Substrates	Reference
Oyster Mushroom (*P. ostreatus*)	Paddy straw, Sugarcane bagasse, Sawdust, Maize cob, Finger millet husk, Rice straw + Black gram shells (1:1), Maize husk, Rice straw, Banana leaves	[14, 26]
Shiitake mushroom (*Lentinula edodes* (Berk.) Singer)	Tree logs (*Alnus nepalensis, Castanopsis indica, Betula alnoides, Juglans regia, Schima wallichii*)	[27]
Button mushroom (*Agaricus bisporus*)	Paddy straw, Saw dust, Wheat straw	[28, 29]
Paddy straw mushroom (*Volvariella volvacea*)	Rice straw	[30]

Grifola frondosa (Dicks.) Gray (maitake) is a medicinal mushroom that inhabits numerous hardwood species, particularly *Fagus crenata* (beech) and *Quercus spp*. (oak), in Asia, North America and Europe [31]. Harada et al. [32] cultivated *Grifola gargal* on *Fagus crenata* (beech) substrate showing a lower yield compared to other mushrooms. Oyster mushrooms (*P. ostreatus*) in particular, are valuable mushrooms with good marketability and are relatively easy to grow. Tisdale et al. [33] evaluated the suitability of *P. ostreatus* in five different wood substrates namely, *Falcataria moluccana* (Miquel) Barneby & Grimes, *Casuarina equisetifolia* L. ex J. R. & G. Forst, *Eucalyptus grandis* Hill ex Maid, *Psidium cattleianum* Sabine, and *Trema orientalis* (L.) and found these substrates did not impact on aroma but did influence its flavours. *Schizophyllum commune*, an edible mushroom grown on wood under natural conditions was cultivated on sawdust of different wood substrates. Dasanayaka and Wijeyaratne [34] found the maximum yield in the sawdust of jackfruit (*Artocarpus heterophyllus* Lam.) with the lowest yield on thungfaa (*Alstonia macrophylla* Wall.) sawdust. Indonesia utilizes a huge amount of Shorea wood (*Shorea leprosula* Miq.) which is mainly used for the generation of energy. Amrita et al. [35] used Shorea wood dust from the mill as a substrate for growing oyster mushrooms (*P. ostreatus*) and found the highest production in the first flush and gradually decreased to the fourth flush for long period. Further, they showed that the bio-treated sawdust with this mushroom was effective in enhancing biogas production by 2-3 times higher than cow dung. Likewise, lignocellulosic wood from Ghana (*Triplochiton scleraxylon, Ceiba pentandra and Terminalia superba*) was used for the cultivation of the oyster mushroom (*P. ostreatus*), showing that the yield and nutritional content of the oyster mushroom depend on the chemical constituents such as cellulose, hemicellulose, the lignin content of substrate used. *T. scleraxylon* wood with the highest content of cellulose, hemicellulose, carbohydrates and protein gave the highest mushroom yield compared to the other two species [36]. The investment assessment of growing oyster mushroom (*P. ostreatus*) on European aspen (*Populus tremula* L.) revealed high economic value with a profitability index of 1.93 and discounted payback period of 2 years and 8 months [37]. This could be an inspiration for the utilization of low-value wood and waste of soft deciduous trees. Oyster mushroom was grown on different wood logs (*Mangifera indica* L., *Dacryodes edulis* (G. Don) H. J. Lam and *Treculia Africana* Decne. ex. Trecul.) giving the highest yield (245.8100 g/kg) in *Mangifera indica* logs with the highest vitamin contents in *Dacryodes edulis* logs [38]. Sawdust from the mill was carbonized at 15, 25 and 35 minutes to test the phytochemical and productivity of *P. ostreatus*. The study showed the fruit body yield was highest in 15 minutes of carbonized sawdust followed by 35 minutes with a decrease of phytochemicals in the fruit's body with an increase in time of carbonization [39]. Although sawdust carbonized at 15 minutes increased the fruiting size, this should not be encouraged for commercial farming as it decreased protein content in the mushrooms.

Shiitake mushroom (*L. edodes*) grown in North America on different beech families (Fagaceae), White oak (*Quercus alba*, Linnaeus) and chestnut oak (*Quercus montana* Willd.) were preferred over the thinner barked species like red oak (*Quercus rubra*, Du Roi), scarlet oak (*Quercus coccinea* Muenchh.) and pin oak (*Quercus palustris* Muenchh.) [40]. In Taiwan, Shieh et al. [41] attempted to grow shiitake mushrooms on *Cunninghamia lanceolata* (Lamb.) Hook., (a widely grown species in Taiwan) shows its logs as unfeasible for commercial-scale production. In sawdust extracts from seven Brazilian eucalypt species (*Eucalyptus saligna* Sm., *Eucalyptus grandis* W. Hill., *Eucalyptus urophylla* S. T. Blake., *Eucalyptus pellita* F. Muell., *Eucalyptus paniculata* Sm., *Eucalyptus citriodora* Hook. and *Eucalyptus camaldulensis* Dehnh.), Andrade et al. [42] investigated the rate of mycelium expansion of Shiitake (*L. edodes*) and found *E. citriodora* Hook outperformed all other species examined by a substantial margin.

Ganoderma lucidum, a medicinal mushroom, was cultivated on different substrates (*Betula* spp., *Populus tremula* L., *Picea abies* (L.) H. Karst., *Pinus sylvestris* L. and *Larix* sp) with the highest yields in *Betula* spp and *P. tremula* sawdust [43]. β-glucan content was highest in the fruiting body of *G. lucidum* in *P. tremula* wood substrates indicating it is a source of bioactive compounds for the food and pharmaceutical industries. Another study by Kuhar et al [44] showed *G. lucidum* grown on *P. tremula* wood substrate contained a higher level of alkaline extract compared to *P. sylvestris* wood-based substrate. Roy et al. [45] cultivated *G. lucidum* in the sawdust of five kinds of wood (*Swietenia mahagoni* (L.) Jacq., *Dipterocarpus turbinatus* C. F. Gaertn., *Tectona grandis* L. f., *Gmelina arborea* Roxb. and *Michelia champaca* L.) supplemented with calcium carbonate and rice bran and observed the yield varied widely. Moreover, they found *S. mahagoni* sawdust with wheat bran had the highest biological efficiency with better yield among other treatments. *Sparassis latifolia*, an edible mushroom contains a high concentration of β-glucan with many biological and pharmacologic activities including antiangiogenic activity [46]. They showed larch and pine sawdust most suitable substrates for mycelial growth and fruit body formation.

3. Mushroom Production in Nepal and Substrate Utilization

Mushrooms are sources of nutritional and economic value for Nepalese. There are more than 1000 edible mushrooms in the world and more than 100 species of edible mushrooms are identified in Nepal with many bioactive compounds [47]. The major types of mushrooms cultivated in Nepal are oyster mushroom (*P. ostreatus*), button mushroom (*A. bisporus*), Shiitake mushroom (*L. edodes* (Berk.) Singer) and paddy straw mushroom (*V. volvacea*) (Figure 1). A study has shown that all these four varieties of mushrooms are suitable to grow in the Makanwanpur district due to rich climatic variability and different soil availability for cultivation [5]. Button mushroom and oyster mushrooms are popular among the people due to their market availability and low cost of production. Shiitake mushroom with antiviral compounds grows on dead woods of *Quercus* and *Castanopsis* trunk.

Sitaula et al. [26] grew oyster mushroom (*P. ostreatus*) on different substrates (paddy straw (100%), maize cob+ paddy straw (1:1), sugarcane bagasses+paddy straw (1:1) and sawdust+ paddy straw (1:1)) and found paddy straw was the best among all in growth and development of mushroom. Also, Dubey et al. [48] found paddy straw was a better substrate than wheat straw, banana leaves and sugarcane bagasse for oyster mushrooms with better growth and yield. Sawdust as substrate did not perform well compared to rice and wheat straw giving the poor yield and lower biological efficiency [49]. This study showed paddy straw to be a better substrate for oyster mushrooms. However, it is hard now to find paddy straw and there is a need to find other better and cheaper alternatives.

Shiitake mushroom was first introduced by the Division of Plant Pathology (NARC) in 1979 with the help of a Japanese volunteer named Naoaki Watanabe was successful in *Quercus* logs. Afterwards, shiitake was cultivated on the different substrates and recommended to farmers based on tree logs availability. Manandhar [27] choose different locally available fast-growing tree species logs to make them cost-effective for small farmers. Eighteen different tree species logs were chosen from Chhampy (1540 m) in Lalitpur, Devitar (1300 m) in Kavre and Lumle (1600 m) in Pokhara to study the growth of shiitake in the varied climatic zone. This study showed *Alnus nepalensis* D. Don., *Betula alnoides* Buch. Ham., and *Castanopsis indica* A. DC. tree logs which are common in many parts of the country were the best performers. However, further work is needed in improving the existing substrate, cultural practice and yield to ultimately reduce imports.

Figure 1. *Most popular mushroom grown in Nepal.*

4. Future Research Prospects

Nepal forest occupies 40.36% of the total area with 433 tree species belonging to 239 genera and 99 families [50]. This forest is capable of producing 0.15 million m^3 of industrial roundwood and 0.95 million m^3 of fuelwood [51]. During the processing of the industrial roundwood, a huge amount of waste (sawdust, bark, branches) is generated due to poor technology adopted by industry. Also, there is a continued net loss of 0.6 million m^3 of stem wood during harvesting [52]. This provides ample opportunity of utilizing this forest waste as a substrate for growing mushrooms. In Nepal, mostly Oyster mushrooms are grown in paddy straw, Shitake in *A. nepalensis* logs and *C. militaris* in brown rice. Choosing substrates is important as they are not only associated with yield but also with growth. This calls for more research on finding better substrates from local materials with the prospects.

There is a lot of research on the utilization of substrate for growing mushrooms based on the country's resource availability. However, more research should be carried out utilizing the locally available materials that are readily available to the farmers. According to the forest cover mapping of Nepal [50], 60% of the total forest cover area is composed of mixed types with hardwood covering 42.84%. Similarly, the report highlighted Uttis (*A. nepalensis*), Sallo (*Pinus* species), Chilaune (*Schima wallichii* (DC.) Korth.), Bakaino (*Melia azedarach* L.), Sisso (*Dalbergia sisso* Roxb. ex. DC.), Sal (*Shorea robusta* C. F. Gaertn.) and Katus (*C. indica*) are the most common species used by sawmill industries.

1) Research on wood logs from hardwood species having higher wood density is important as they provide nutrients to mycelium.
2) Research on the utilization of sawdust from sawmills as a substrate for growth and biological efficiency is needed for the Oyster mushroom, a popular most edible mushroom.
3) Research on growing Shiitake mushroom in fruit trees logs like (Mango, and Jackfruits) to see whether mushrooms grown on such substrate produce a fruit-like taste (Figure 2).

Figure 2. *Different wood-based substrates that will be utilized in the research.*

5. Conclusion

The review conducted on the utilization of different mushroom substrates showed paddy straw is most common for Oyster mushrooms and *Quercus* and *Alnus* logs for Shiitake (Table 1). In Nepal, with diverse physiography and enriched mycoflora, more research should be carried out on the mushroom. Though the country is rich in mycoflora, there are few published papers dealing with substrates utilization and bioactive compounds of mushrooms grown in Nepal. Government should provide adequate funds for its research and development of research institutions. Wild mushrooms can be grown in partnership with community forestry user groups so they can grow inside the forest in natural conditions. More research is needed on the utilization of raw materials with good opportunities for small scale farmers is needed.

Author Contributions

The author conceptualizes the idea and develop the methodology and wrote the manuscript.

Declarations

Declarations Ethics Approval and Consent to Participate

This manuscript is an original paper and has not been published in other journals. The author agreed to keep the copyright rule.

Competing Interests

The authors declare that they have no conflict of interest.

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