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REVIEW

Optimization of Biological efficiency and comparative analysis of nutraceutical properties in paddy straw and oyster mushrooms cultivation: A Review

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Mushrooms have always been considered to be a major healthy diet and natural medicine from the ancient times. The presence of various potential bioactive molecules is proved to cure many degenerative diseases which have widened the path of many more drug industries.Among all the mushrooms, paddy straw mushroom and oyster mushroom are two most demanding mushrooms in all over India due to its delicacy, flavour and nutrients. The varying climatic conditions, non-availability of quality spawn and substrate, contamination by molds and other micro-organisms are the key problem to get low yield. Many researchers have done several experiments to increase the biological efficiency which will help to meet the demand of millions of peoples as well as drug companies. Oyster mushroom contains medicinal properties due to the presence of low cholesterol, fat, sodium and potassium content. Likewise, the potential bioactive molecules and other nutrients present in these two mushrooms are described in this article.

Key words: Mushroom, Biological efficiency, nutrition, medicinal properties, pharmaceuticals

INTRODUCTION

Mushrooms attract human beings with their mesmerizing beauty and high nutritious value from ancient times. Mushrooms are macrofungi having fleshy fruiting body which arise from group of mycelia by using different substrates such as dead and decaying woods, organic matter and plant residues etc. Most of the mushrooms are under subdivision Basidiomycotina and Ascomycotina.The edible mushrooms are rich in high quality proteins, dietary fibers, minerals, vitamins and unsaturated fatty acids (Chang and Miles, 2004, Roy and Chakraborty, 2018). They are low in salts, carbohydrate and fat. Food and Agriculture organization has referred mushroom as a source of protein for the poor in developing countries. Moreover, the unique qualities of edible mushrooms such as flavour, texture, taste and colour which are attractive for consumption by the human society have been reviewed (Barman *et al*. 2018; Thakur and Singh, 2020) and presented in Fig. 1.

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In the current scenario, it is estimated that 2000 edible mushroom are identified out of 12000 species from which 35 species of edible mushroom are commercially grown and 200 wild species are used for medical and drug purposes (Beulah *et al*. 2013). Among all the edible mushrooms, the most popular four mushrooms are Button mushroom (*Agaricus bisporus*) (Chakraborty *et al*, 2017), Paddy straw mushroom (*Volvariella volvaceae*) (Thakur and Singh, 2021), Oyster mushroom, *Pleurotus ostreatus* (Roy *et al*., 2015a), *Pleurotus djamor* (Roy *et al.* 2015b) and milky mushroom (*Calocybe indica*) (Barman *et al*. 2015) which play an important role in Indian market. Button mushroom is grown in temperate climatic condition while milky, paddy straw and oyster mushroom are grown in tropical and subtropical climate. The popularity of paddy straw mushroom and oyster mushroom is extremely increasing for the easy cultivating technique with locally available materials, high yield and nutritional value (Banik and Nandi, 2004; Gregori, 2007).Paddy straw mushroom as well as oyster mushroom can be

grown by investing less amount comparing to other agriculture crops as they can be grown in open condition or low-cost thatched house.

Paddy straw mushroom, also known as Chinese mushroom or warm mushroom having the sixth rank worldwide, grows mainly from March to October and prefer the high temperature range of 25-35^0 C for mycelial growth while 34 to 37^0 C at the time of fruitification. The life cycle is completed within 28 days to 35 days (Biswas, 2014). More than 100 *species* of *Volvariella* have been identified through out the world, among which only 4 species are grown in Asiatic countries while three species *viz., V. esculenta, V. diplasia* and *V. volvacea* are reported to be grown in India. Nutritional value of these mushrooms depend on the type of agricultural waste used for its cultivation (Roy *et al*. 2014). Nucleic acid content changes during fruit body production in *V. volvacea* (Mukhopadhyay *et al*. 2006). Optimization of the conditions for fusion and regeneration of protoplast of *V. volvacea* have recently been reported by Chatterjee and Samajpati (2021a).

Oyster mushroom or Dhingiri mushroom has gained third rank globally as well as in India (Chatterjee and Samajpati, 2021b). *P. sajor-caju* and *P. florida* are very popular mushrooms among all 38 known *Pleurotus* spp. This mushroom is cultivated mainly in winter month i.e. from November to February and sometimes referred as winter mushroom. It requires the temperature ranges from 18 to 28^0 C which varies depending on the species (Table 1). It takes nearly 40 days' time to complete the whole life cycle.

Biological efficiency is a major parameter to measure the potentiality of various strains of mushrooms,grows on different substrates (Biswas and Layak, 2014). Biological efficiency (BE) is defined as the ratio of the weight of freshly harvested basidiocarp by dry weight of the substrate, expressed in percentage:

Biological Efficiency (%)= Fresh weight of mushroom/Weight of Air-dried substrate×100

Now-a-days the Biological efficiency, production and productivity of both of the mushrooms are decreasing and a lot of factors such as the methods of bed preparation, quality of spawn and substrate, several competitor molds and fungi, environmental factors etc. are responsible for this. A number of scientists are involved to find more potential and efficient way to increase the biological efficiency through various mushroom based researches.

From past decades, it was clear that the relationship between human and mushrooms are not only restricted to food as it is also used as a major pharmaceutical and nutraceutical resource component against several diseases and disorders. Both edible and wild mushrooms are characterized by several nutraceutical compounds like proteins, dietary fibers, polysaccharides, alcohols, terpenes, benzoic acid derivatives, steroids, unsaturated fatty acids, peptides, mineral elements, antioxidants etc (Rathore *et al*. 2017). Due to the wide nutraceutical compounds, mushrooms are traditionally used as the source of nutrients (Table 2) to improve the health and to prevent some diseases since the human civilization started (Pereira *et al*. 2012). Mushrooms can be used as antioxidant, antimicrobial, anticancer, antidiabetic, antiallergic, cardiovascular protector, hypo tensive, hepatoprotection, immun-omodulating, detoxification, anti-inflammatory and anti-tumor processes (Valverde *et al*. 2015; Chang and Wasser 2012; Yu *et al*. 2009; Zhang *et al*. 2011).The nutraceutical and therapeutic potential of mushroom is an amazing gift of nature. So, the big challenge for scientists is to explore the potential characters of mushroom and to preserve the possible propertiesof food mushroom as an alternative resource of medicine.

CULTIVATION METHODS

Paddy straw mushroom

Different cultivation methods are followed by different farmers to grow this mushroom like Heap method, bed method, spiral method and cage method etc. The materials used in all the above methods are same and the only difference is the procedure of preparation of beds. The bed preparation methods are as follows:

Cage Method : Well quality paddy straw bundles (25cm×10cm) should be taken and soaked in water for 6 to 8 hours. After draining the water properly (60-65%), ten bundles should be placed in six layers in the bottom of theframe or cage of size 100×60×25 cm. Spawn is spread inside the six layers at the rate of 1.5% on dry weight basis.

Finally, the cage is covered with plastic sheet or polythene after gentle pressing from the top. The cover is removed after the mycelium spread properly. Small pinheads will show within 10-15 days and harvesting is done at egg stage(Biswas and Layak, 2014).

Heap method : The paddy straw is kept in six layers in zig-zag manner and the height should be 2 feet. Spawn is applied in between the layers at the rate of 2% in dry weight basis. Then it covered with polythene sheet after compacting it and irrigating it if needed (Biswas and Layak, 2014).

Bed method : Well drained soaked paddy straw bundles are placed side by side and opposite direction such as 4 bundles in first layer and another 4 bundles in second layer but in opposite direction. Similarly, three more layers are prepared. Spawn (2% on dry weight basis) is applied in periphery of each layer by leaving 12 to 15cm from the edge.The bed is pressed gently and then covered with polythene sheet. The cover is removed when pinheads start appearing. From day 12th to 15th the harvesting will be started (Biswas and Layak, 2014).

Spiral method : Circular beds are prepared by using well drained soaked paddy straw and spawning is done at the rate of 1.5%. Then it is covered with sheets. Pinhead formation will start within 3-4 days. Harvesting is done in the egg stage (Thakur *et al*. 2003).

Indoor method **:** After composting the Paddy straw for 2 days, it is mixed with rice bran at the rate of 5% followed by filling for 2 days and pasteurization for 1 day. Spawning is done after this and harvesting starts in 9 to 10 days (Quimio, 1993).

Outdoor method : A raised platform is made with the help of bamboo, wood, soil or sand. Well drained soaked straw bundles of 40×10 cm sized has taken and 4 layered bed is prepared for summer and 7 layered bed for winter. Spawn is applied at the rate of 1.5 to 2% on dry weight basis followed by covering with polythene sheets. Covers are removed after 4 days and watering is done till the pin heads appear. Harvesting is done in button stage (Chang 1982; Hu, 1985).

Oyster mushroom

Paddy straw is chopped into 3 to 4cm length pieces and soaked in water for 6 to 8 h. Well drained chopped straw is taken and kept in a polythene bag of size 45×30cm. Multiple layers of chopped straw and spawn is prepared inside polythene bag. Four percent of spawn is used per polythene bag by wet weight basis. The polythene bag is tied in the top and small holes are done in polythene sheet. Then the beds are kept in dark room for 15 days or till the spawn run is complete. After complete spawn run, the polythene bags are cut open and hanged in racks. Harvesting is done in mature stage (Roy *et al*. 2015a).

Environmental factors affecting growth of paddy straw and oyster mushrooms

Paddy straw and oyster mushroom are majorly cultivated in the tropical and sub-tropical regions of India. Paddy straw mushroom is grown in summer and rainy season while oyster mushroom is grown in winter season. Various edaphic factors such as temperature, relative humidity, light and pH requirements varies among the two aforesaid mushroom cultivation. The suitable environmental factors and their range are given in Table 3.

The biological efficiency of paddy straw mushroom varies from 10-15 % where as that for Oyster mushroom is 100% under suitable environmental condition and proper care. It can be increased by modifying some techniques. The biological efficiency of both the mushroom can be increased by using high quality spawn replacing the low quality, changing the substrate material and supplements, alteration of optimum environmental condition, minimizing the contamination by other competitor micro-organisms etc. Some of the technical specifications or methods are described below which will greatly help in increasing the biological efficiency of both paddy straw as well as oyster mushroom.

TECHNICAL SPECIFICATION TO INCREASE BIOLOGICAL EFFICIENCY

Volvariella volvacea

According to Biswas and Layak (2014), cage method of cultivation is one of the best methods for increasing the biological efficiency which is up to 12.10%. They have also described that the substrate combination of banana pseudo stem and paddy straw in 1:1 ratio significantly increases the biological efficiency up to 14.90%. Hand threshed

indigenous paddy variety was known to enhance the BE up to 14.87% (Biswas and Layak, 2014). BE is significantly increasing to 16.45% and 15.30% when red gram powder and rice flour was applied as supplements respectively.

Pleurotus ostreatus

Combination of carbendazim and formalin can eliminate the mould fungi completely which increase the biological efficiency up to 106%. The competitor moulds can be inhibited by using the application of combination of thiram (100 ppm) and benomyl (50 ppm). The contamination of oyster mushroom bed can be decreased by treating the straw with phyto-extracts like neem (*Azadiracta indica*) and karanj (*Pongamia pinnata*) which also promote the biological efficiency up to 92.20% (Biswas 2015).

The amount of spawn applied in each bed plays a major role in promoting the biological efficiency. Highest biological efficiency of 87% is reported if spawn is applied at 5% rate. In wheat straw substrate, spawning at the rate of 5% helps in increasing the biological efficiency up to 101.25%. Increased biological efficiency is also reported when the combination of paddy straw and wheat straw is used as substrate in 1:1 and 4:1 ratio.i.e. 106.5% and 100.75% respectively.In addition to this, rice bran as a supplement at the rate of 5% increases the biological efficiency up to 125.75%.

Hot water treatment and chemical method (Bavistin 75ppm + Formalin 500ppm) of sterilization is reported to enhance the biological efficiency up to 115.75% and 122% respectively. It is reported that thorough spawning enhanced biological efficiency up to 122.25% while three-layer spawning enhanced up to 116.75%.

COMPARISON OF BIOACTIVE NUTRACEUTICAL PROPERTIES

Carbohydrates

The long chain carbohydrates, derived from mushroom are known to be the most effective compounds having immunomodulating, anticancer and antitumor characteristics.The presence of high level of non-fiber sugars make the mushroom enriched with carbohydrate.The sugars present in mushroom are xylose, arabinose, trehalose, glucose, rhamnose, fructose etc (Ferreira *et al*. 2009; Zaidman *et al*. 2005). The carbohydrate content in mushroom comprises of 50 to 65% on dry weight basis while *Pleurotus* mushroom comprises 40.6% to 53.3% carbohydrate in its fruiting body (Agrawal *et al*. 2018). The carbohydrate of *Pleurotus* spp mainly contains polysaccharides, α-glucans, hemicelluloses, chitin and pectic substances.The carbohydrate content in *Volvariella volvaceae* acounts to nearly 79.44% (Alexis *et al*. 2018) and in between 40 to 50% based on the dry weight. It was reported that the carbohydrate amount increases from button stage to egg stage followed by elongation stage.

Mushroom polysaccharides are common with a-linked glucose (galactose or mannose backbone in some mushrooms) but varying in branching pattern and structure among species. The major polysaccharide of mushroom, β-glucan have anticancer, immunomodulating, antioxidant and anticholesterolemic activity. These compounds don't have direct action on tumor cells, but they help in decreasing the stress in human body which directs the reduction of tumor size and increase the life period (Valverde *et al*. 2015). Polysaccharides .i.e. pleuran is isolated from *Pleurotus* species, agaritine from *Agaricus* species, ganoderan from *Ganoderma lucidum*, lentinan and erothionine from *Lentinus edodes* (Villares *et al*. 2012). Recent investigations have confirmed that one novel heteropolysaccharide having antitumor activity against HepG-2 cells, was isolated from *Pleurotus eryngii* (Ma *et al*. 2014).

Proteins

Mushrooms are one of the popular diets among vegetarians as they contain important amino acids and proteins which is also present in animal meat. Protein plays a role of major nutrient of dry matter of mushroom. The amount of protein varies according to the part of the mushroom, stage of mushroom, time of harvest and flush to flush. It was reported that digestibility of mushroom protein varies from 72 to 83%.*Volvariella volvaceae* is known to contain 14 to 27% crude protein on dry weight basis (Roy *et al.* 2014) while the digestibility protein of *Pleurotus* sp is nearly 90% (Barman *et al*. 2018).

Phenolic compounds

The secondary metabolites, phenolic compounds are characterized by several physiological activities

Table 1: Climatic requirement of paddy straw and oyster mushroom

	Paddy straw mushroom				Oyster mushroom	
	Mycelium formation		Fruiting		Mycelium formation	Fruiting
Parameter	Range	Optimum	Range	Optimum	Range	Range
Temperature	15^{0}C- 42^{0}C	35^{0}C ± 2^{0}C	25^{0}C -30^{0}C	28^{0}C ± 2^{0}C	15 ^{0}C -35 ^{0}C	20 ^{0}C- 30 ^{0}C
Relative Humidity	50 -70 (%)	60 ± 5 (%)	80 -100 (%)	90 ± 5 (%)	50-75 (%)	85-97 (%)
Light intensity	1000lux	1000lux	1000lux	1000lux	No light followed by natural diffused day light (154-220 lux)-	200-640lux
pH	6-7	6.5	6-7	6.5	4.0-7.0	3.5-5.0
Moisture	65%	65%	80%	80%	60-75 (%)	85-97 (%)

Table 2: Nutritive value of paddy straw and oyster mushroom

Content	Paddy straw mushroom (Per 100gm)	Oyster mushroom (Per 100gm)
Ascorbic acid	18.00 mg	-
Ash	1.10 g	8.6g
Calcium	5.60 mg	3 mg
Crude fiber	1.87 g	48.6 g
Fat	0.25 g	0.41g
Iron	1.70 g	1.33 mg
Moisture	90.40 g	89.8 g
Niacin	2.40 mg	4.96 mg
Phosphorus	0.10 g	120 mg
Potassium	0.32 g	420 mg
Protein	3.90 g	3.31g
Riboflavin	0.61 mg	0.35g

such as antimicrobial, antiatherogenic, antithrombotic, cardioprotective, anticarcinogenic, immune-modulatory, antioxidant etc (Valverde *et al*. 2015). In addition to this, these compounds protect against different disorders like brain and heart malfunction. These compounds possess one or more hydroxyl group and an aromatic ring. *Pleurotus ostreatus* has low level of phenolic compound while *Boletus edulis* and *Agaricus bisporus* have high level of phenolic compounds (Palacio *et al*. 2011).

Terpenes

Mushroom terpenes are playing a major role in controlling several diseases and having wide range of pharmaceutical properties like antimicrobial, anti-inflammatory, anticancer and anti-choline sterase activities. These terpenes are grouped as

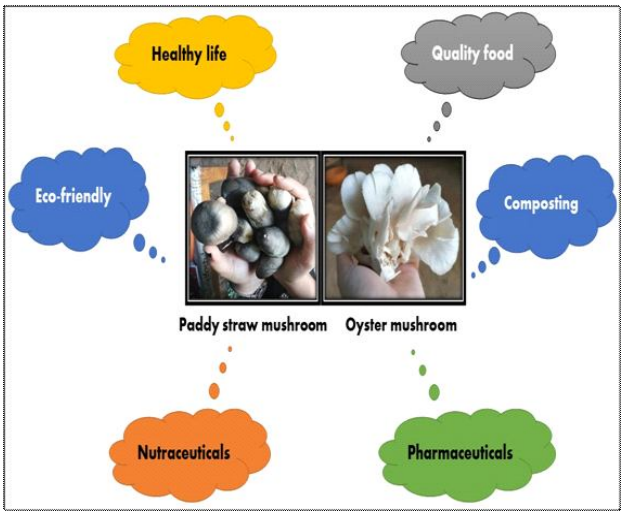

Fig. 1 : Benefits of paddy straw and oyster mushroom

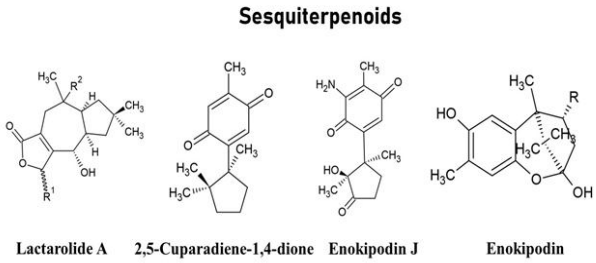

Fig. 2 : Chemical structure of Sesquiterpenoids

monoterpenoides, diterpenoides, triterpenoides and sesquiterpenoides (Fig 2). *Pleurotu scorni-copiae* possesses mono-terpenoides and sesquiterpenoides which have potential toxic effect against cancer cells.Lanostane, a triterpenoid has anticancer activity and is mostly derived from mushrooms (Dasgupta and Acharya, 2019).

Antioxidants

Antioxidants act as the protector of cell from several free radicals. The common antioxidants found in most of the food are ascorbic acid, phenolic acid, flavonoids, carotenoids and tocopherol (Barros *et*

Table 3: Effect of storage methods on nutrient components of oyster and paddy straw mushrooms

Species	Storage methods	Incubation period	Effect on nutrient components	Reference
	Freeze storing	1 year	Reduced amount of Amino acids	
	Processing through microwave	More than 3 years in proper storage condition	Iron, zinc, Calcium, Manganease, Calcium and Cupper amount decreases	
Pleurotus ostreatus	Frying	12 hour	Iron content increases	Rathore *et al* 2017
	Brining with 25% brine solution	1min	Protein, Carbohydrate and Fat content decreases	
	Oven dried at 60^0 C	Till the weight get constant	Protein decreases and carbohydrate increases	
	Blanching at 88^0 C	1min	Fat and Protein decreases, carbohydrate increases	
	Stored between 8-14^0 C	24 hour	Reduced amount of protein and moisture	
Volvariella volvaceae	Freezing	2days	Mineral level decreases	
	Frying	2 to 3 days	Iron and protein content decrease	
	Blanching at 95^0 C	15 min	Fat, Protein some other mineral decreases	Rathore *et al* 2017, Nur *et al* 2020, Khan *et al* 2021
	Oven drying	Till moisture content decrease to the lowest	Decrease in protein, fat and carbohydrate	

al. 2008). The presence of mushrooms in human diet will be very beneficial to act against the oxidative damage in human body as they are enriched with several antioxidants (Mau *et al*. 2004; Oyetayo, 2007). The antioxidant activity of mushroom differs based on the mycelia or fruiting body (Finimundy *et al*. 2013). Significant antioxidant activity (21.19%) in *V. volvaceae* has been recorded. *Pleurotus* sp is the excellent source of antioxidant which significantly increase the nutritive value by contributing towards the nutraceutical properties (Lakshmi *et al*. 2004).

Lipids

Lipids or polyunsaturated fatty acids are known to reduce serum cholesterol, having antioxidant activity such as protection against cancer and heart diseases. Ergosterol, the major sterol produced by edible mushrooms is known to possess antioxidant properties and helps in reducing the risk of cardiovascular diseases.Tocopherols can guard against cancer, heart diseases and degenerative disorders. Mushrooms are a good reservoir of linoleic acid and Oleic acid. One of

the major fatty acids, linoleic acid has high protection activity against arthritis, heart diseases and blood pressures (Valverde *et al*. 2015).A major aromatic compound, 1-octen-3-ol, derived from linoleic acid is responsible towards the mushroom flavor.

Other components

Mushrooms are abundant in several macro and micro nutrients such as calcium, potassium, phosphorus and magnesium. Presence of soluble and non-soluble fibers protect from cardio-vascular diseases by reducing the cholesterol level (Cheung and Lee 2000). Enriched with dietary fibers with non-dietary carbohydrates, mushrooms have widened the branch in providing several health benefits to human. The lower value of sodium in mushrooms proved to be a great diet for hypertensive persons.

Besides edible mushrooms also have several medicinal benefits such as anti-aging, digestion, immunity builder, protection from cancer, good for diabetic patients as well as healthy diet for heart patients.

Storage as an important factor affecting mushroom nutrients

Like all vegetables, mushroom contains high moisture which makes it as a perishable food. To store it for long period, it can be processed as pickle, canned, dried, baked etc. For long term storage, fresh mushrooms can be processed for drying, canning, freezing or immersing in sodium metabisulphate, L- ascorbic acid etc. Many studies have reported that several methods of storing are directly and indirectly affecting the nutrient composition, flavor, taste etc. Effect of storage methods on nutrient components of oyster and paddy straw mushrooms have been presented in Table 3.

FUTURE SCOPE AND CONCLUSION

The cultivation of paddy straw and oyster mushroom is spreading widely and taken up as a permanent business by a number of people. Paddy straw mushroom and oyster mushroom are the most preferred mushroom among the vegetarians as well as non-vegetarians. New techniques and methods have investigated by a several researchers to meet the demand of mushroom lovers and pharmaceutical industries by increasing the yield. These mushrooms are growing in all regions of India in several climatic conditions. The varied climatic conditions and sudden change of weather is one of the major problems faced by the mushroom growers. Another main problem is that the unskilled and untrained farmers are diverting their minds towards several unpromising methods which lead to contamination and yield loss. The unavailability of quality spawn and techniques is found to be a big challenge for rural farmers. Therefore, the government in co-operation with KVKs, NGOs and some other organizations should come forward to provide all the essentials to farmers. The extension workers must be active to deliver field trainings in several localities for disseminating the proper techniques among farmers. More researches like low concentration chemicals to reduce contamination, to increase spawn quality, use of low amount of substrate, to increase the flavor and essence etc. should be carried out by scientist to widen the platform of mushroom cultivation.

The nutraceutical and pharmaceutical properties of mushroom has expanded the network of drug industries to discover novel drugs, functional foods and nutrient supplements. The different formulations of mushroom products have already taken a major role in the lifestyle of healthy and sub healthy peoples. Being a suitable food for all age groups, mushroom is considered as a complete healthy diet by several scientists. The presence of several bioactive molecules along with the enormous nutritional supremacy has created its existence in pharmaceutical companies to develop potential functional foods. Proper care should be taken for maintaining and retaining the bioactive molecules from farm to the fork level so that the characters of these molecules will not lose during processing. A variety of wild mushrooms as well as local mushrooms contain some harmful anti-nutritional compounds which require to be analyzed by the scientists. To get rid of the challenges faced today, more future studies are required to know the mechanism of mushroom extracts and its role in production of phytochemicals, mushroom genomics and proteomics study, therapeutic action and biochemical pathway of secondary metabolites. The investigations which are still limited to lab conditions only, needs more focus on clinical trials and biotechnological studies to boost the

development of pharmaceuticals (Morris *et al*. 2016). The benefits of undiscovered wild mushrooms are yet to be analyzed. Another important point to be focused for future is to create awareness about the health benefits of mushroom among the consumers. Mushrooms, which were considered to be the perfect medicine in long past is neglected in recent days due to the improper maintenance of its purity, standards and lack of clinical trials (Rathore *et al*. 2017). Therefore, adoption of proper regulations, standards and collaborations with several private companies by the government bodies will not only lead to develop and discover many more novel drugs but also will add unique health benefits with a positive impact on human welfare in future (Thakur and Singh, 2020; Chaterjee and Samajpati, 2021b).

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