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A Review on Cultivation and Pharmacological Potential of White Button Mushroom (*Agaricus bisporus*)

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A B S T R A C T

Nature has been a source of medicinal agents for thousands of years and an impressive number of modern drugs have been isolated from natural sources, based on their use in traditional medicine. Since ancient time's plants as well as fungus sources of medicinal compounds have continued to play a dominant role in maintenance of human health. Over 50% of all modern clinical drugs are of natural product origin and play an important role in drug development programs in the pharmaceutical industry. Mushrooms are highly nutritious and environment friendly crops that carry numerous medicinal benefits. The cultivation of edible mushrooms carries great relevance in todays' world in the context of a growing population and extreme pressure on the environment. White button mushroom (*Agaricus bisporus*) is a very important nutritional and medicinal species which is used for recycling agro wastes including wheat straw, reed plant wastes, waste paper, oat straw, waste tea leaves, some water plants and others. The standardized cultivation techniques to be followed for cultivation laboratory scale button mushroom are as follows (i). compost to be prepared by short method of composting (ii). Cultivation trials of *A. bisporus* to be carried out in a closed room provided with air conditioner as source of cooling (iii). The relative humidity inside the cropping rooms to be maintained to 60-70% (iv). Spawn run will be completed in 15 days and required 12-15 days more for case run. These findings revealed that button mushroom can possibly be cultivated under laboratory condition. This can be a means of livelihood and a source of economic empowerment for women in both urban and rural areas and for small holder farmers, apart from being a source of food production. However, there is resurgence to propel efforts in terms of improvement of tools available to the breeder, decoding mushroom genome for new strain development in the future for the welfare of commercial pressure facing industry.

Introduction

The world population is increasing day by day. Currently, it is considered nearly 7 billion. Some theories suggest that by the year 2050, the global population will reach to 9 billion, and during 2100, it could be 20 billion (Bacci, 2012). Lack of food and deterioration in human health will be burning issue due to the population growth and urbanization with a concomitant reduction in arable land. To address global food demand (especially protein) can be converted into lingo-cellulosic agricultural and forest residues into protein-rich mushrooms is one of the most economically viable and sustainable biotechnology processes (Hawksworth, 1991).

Agriculture has remained the major force of Indian economy but a fight is still on to meet the ever increasing demand of nutritional security following secondary agricultural vocation. To meet such challenges, diversification in the agricultural activities which include mushroom production is important to address the problems of quality food, health and environmental sustainability (Singh *et al.,* 2017). In the present diet conscious era, mushrooms are increasingly considered as a future vegetable and their consumer demand has markedly expanded in the recent years owing to its medicinal and nutritional properties. Mushrooms are considered as a potential substitute of muscle protein on account of their high digestibility (Kalac, 2009). In addition to protein, mushroom is an excellent source of Vitamin-D, minerals such as potassium, iron, copper, zinc and manganese, low in calories, fat free, cholesterol free, gluten free and very low in sodium (Sharma *et al.,* 2017). From 2010-2017, the mushroom industry in India has registered an average growth rate of 4.3% per annum. Out of the total mushroom produced, white button mushroom share is 73% followed by oyster mushroom (16%), paddy straw mushroom (7%) and milky mushroom (3%) (Sharma *et al.,* 2017).

The white button mushroom (*Agaricus bisporus*) is very popular throughout the world and is the most important mushroom of commercial significance in India (Maheshwari, 2013). It belongs to phylum Basidiomycota, class Agaricomycetes, order Agaricales and family Agaricaceae. Initially, white button mushroom production was confined to temperate hilly regions of India. However, with the development of short method of composting and optimization of fruiting conditions using the chilling system, there has been a remarkable change in its production scenario and spread to all the corners of the country. *A. bisporus* Imbach is the wildest and cultivated edible mushroom and represents more than 40% of the world bearing of mushrooms(Callac *et al.,* 2000; Carlucci, 2003). It is cultivated in over 70 countries and on every ascetic, except Antarctica. The global production in the 1990s was more than $800 million/year and increased to $12,250 in 2002 (UN 2010) (Andersson and Gry, 2004). *A. bisporus* has a luscious taste with more nutritional value has very good aroma or flavoring taste is used as food and in food industries (Misharina *et al.,* 2010).

A.bisporus is considered to have high biological activity, low toxicity and has significance folklore and ethnopharmacological significance. Apart from food and food beverages it has a role in perfumery, cosmetic industries and pharmaceutical industries (Caglarirmak, 2009; Dastager, 2009). Wild *A. bisporus* were referred for customer due to their flavor and texture (Sadiq *et al.,* 2008)It has been reported lots of primary and secondary metabolites responsible for the therapeutic activity for the prevention and treatment of many diseases such as cancer, hyperlipidemia, microbial

diseases, cardiovascular problems, liver diseases, and immune problems. *A. bisporus* is a litter degrading basidiomycete commonly found in humic rich environments which are useful as a model organism and cultivated in large scale for the food industry. Due to its ecological niche, it produces a variety of enzymes for detoxification and degradation of humified plant litter (Gonaus *et al.,* 2016).

It was understood from the literature survey that medicinal agents for thousands of years and an impressive number of modern drugs have been isolated from natural sources, based on their use in traditional medicine. Since ancient time's plants as well as fungus sources of medicinal compounds have continued to play a dominant role in maintenance of human health. Over 50% of all modern clinical drugs are of natural product origin and play an important role in drug development programs in the pharmaceutical industry. Mushrooms are an important natural source of food and medicine. Traditional aboriginals knew the importance of edible and wild mushrooms and these are now being screened for their bioactivity in various ailments. However, there is scanty of information on cultivation techniques of button mushroom under laboratory conditions and recent updates on pharmacological potential button mushroom. Hence, in this narrative review of literature we aimed to describe the standardized laboratory cultivation techniques of button mushroom as climate in certain places across the globe does not permit for natural button mushroom production. Also recent perceptive on pharmacological potential of button mushroom was narrated based on recently published data and other available resources.

History and Ethnopharmacological Perspectives

A. bisporus is an edible basidiomycete mushroom native to grasslands in Europe and North America. Commonly known as white button mushroom, is widely cultivated in most countries and it constitutes the bulk of all mushrooms consumed in the United States and Australia. Historical evidence indicates that it was first cultivated in France and that cultivar strains originated in Western Europe (Atkins, 1974; Kerrigan, 1995; Jeong *et al.,* 2012). Ancient Egyptians believed mushrooms could grant immortality and thus, only the pharaohs were deemed worthy of eating or even touching them. In ancient Rome, mushrooms were often referred to as "food for the gods." In Russia, China, Mexico and other world cultures, folklore held that mushrooms conferred superhuman strength (Varo *et al.,* 1980). Conventionally, the fungus was used in the treatment of cancer, cerebral stroke and heart diseases. Furthermore, it has anti-aging property. They represent as one of the world's greatest untapped resources of nutrition and palatable food of the future. Mushrooms have been found to be more effective against cancer, cholesterol reduction, stress, insomnia, asthma, allergies and diabetes. They can be used to bridge the protein malnutrition gap because they have a high amount of protein. Mushrooms are useful to increase the immunity. Hence, it provides a nutrient supplement as a form of tablets. They are also useful for diabetic and patients with cardiovascular disorders (because they contain low starch and low cholesterol). One-third of the iron in the mushrooms is available in free form. Their polysaccharide content is used as an anticancer drug and combat HIV effectively (Prasad *et al.,* 2015; Bahl, 1983).

Biologically active compounds from the mushrooms possess antifungal, antibacterial, antioxidant, antiviral properties and have been used as insecticides and nematicides as well. There have been studies that demonstrate that women who eat these button mushrooms daily have reduced chances of getting breast cancer. The mushrooms can be thought to inhibit the

production of enzymes that affect the production of estrogen which is a hormone that causes cancer to develop. The special effects of this substance on other kinds of cancer are still being studied (King, 1993).

Various Composts for Cultivation of *A. bisporus*

Mushrooms are considered to be heterotrophic (saprophytic) organisms and thus possess no chlorophylls, but decompose organic materials to feed off (Miles *et al.,* 2004). *A. bisporus* can be cultivated on various lignocellulosic materials. Growing and cultivation of this species has succeeded on different composted organic such as chicken, horse or pigeon manures, straw residues from wheat, oat, Tifton (Andrade *et al.,* 2008)and reed crops (Alkaisi *et al.,* 2016; Rehman *et al.,* 2016),corn cob (Miles *et al.,* 2004), molasses, wheat bran (Peker *et al.,* 2007; Baysal *et al.,* 2007), sugarcane bagasse, tea leaves (Simsek *et al.,* 2008), brachiaria (*Brachiaria* sp.) (Andrade *et al.,* 2013), reed plant (*Phragmites australis*) straw (Muslat *et al.,* 2011), water hyacinth (*Eichhornia crassipes*) (Reddy *et al.,* 2013). Various compost materials used in different countries for the cultivation of button mushroom was enlisted in Table 1A, 1B and 1C.

Also, new techniques like the new Garbage Automatic Decompose-Extinguisher (GADE) were used to produce composts for cultivating and producing *A. bisporus* and *Pleurotus ostreatus* with the highest growth and rate of spinning (Horisawa *et al.,* 2006). *A. bisporus* has a significant role in producing lignin degradation enzymes (manganese peroxidase and laccase) (Bonnen *et al.,* 1994) and is a ready source of enzymes, including laccase which is important in polyphenol oxidation (Hou *et al.,* 2004). Recent work showed this enzyme was secreted by partnering *A. bisporus* and *Trichoderma sp.* to increase the production of this enzyme in agricultural composts (Flores *et al.,* 2009). Spent mushroom composts have been found to be useful in organic agriculture (Beyer, 2003). The temperature inside the pile rises to 60°C whereas the degrees from 40-50°C are suitable for decomposition (Owaid, 2009).

Standardised Lab Cultivation Techniques of *A. bisporus*

Spawn production

Wheat grains should be used as support media for spawn production. Wheat grains should be boiled in water for 30 min (wheat grains:water;1:2 w/v) so as to cook them soft enough to be pressed within the fingers. Extra water should be sieved out, grains should be allowed to cool and then mixed with calcium carbonate & calcium sulphate powder at 10g/kg of wheat grains respectively. Empty glucose bottles should be filled with these grains at 250 g per bottle, plugged with non-absorbent cotton, wrapped with paper and then autoclaved at 15 psi for 30 min. After cooling the autoclaved bottles overnight, these should be shaken to restore transparent visibility of the glass and then inoculated aseptically with mycelial bits from the slant cultures. The bits should be placed in such a manner that their mycelium touched the grains. These bottles should be incubated at 22±1°C for 15-20 days. The culture bottles thus produced should be the master/mother cultures. After 10 days, master/mother culture should be shaken so that grains were transferred into 10-15 freshly prepared bottles. These spawn bottles should be stored at 25°C to use for spawning the substrate (Figure 1) (Netam *et al.,* 2018).

Composting

Fresh, good quality wheat straw should be spread on pucca floor and wetted thoroughly for 48 hours while keeping it in the form of

loose heap (~0.5m high) to attain 70-75% moisture content. Considering stacking day as 0 day, first turning should be done 3 days after stacking, urea at 1.8 kg/qt. of straw should be mixed with wet straw, again stacked into heap and covered with polythene and kept overnight to facilitate solubilization of the chemical fertilizer and their adsorption on to the bran. Subsequent turning should be done at 3 days' interval with a total of seven turns required for complete decomposition of compost. Wheat bran (choker) at 2.5 kg per quintal of straw should be mixed during 3rdturning, while gypsum was mixed during 6thturning at 3.5 kg/qt. of straw. Light brown colored compost having no smell of ammonia should be allowed to cool down before spawning (Figure 2) (Netam *et al.*, 2018).

Filling and spawning

Good quality compost should be mixed with *A. bisporus* spawn at0.7-1.0% of wet compost weight and filled into polythene bags of size 18×20″. The spawned compost should be then compressed, levelled and mouth of polythene bags should be covered with a clean newspaper. Compost filled bags should be then shifted to the growing room until complete mycelia impregnation. Holes should be made throughout the bag to allow aeration.

The filled bags should be incubated at 21-23°C with sufficient light & humidity and water should be sprayed on top of the bags covered with newspaper twice a day throughout spawn running period (Figure 3) (Netam *et al.*, 2018).

Casing

Casing mixture should be prepared by mixing cocopeat, soil and sand (3:2:1 v/v). Coco-peat instead of farmyard manure should be used because of its unique water holding and structural properties, coco-peat has been regarded as the most suitable and more ideal for casing (Kaur and Rampal, 2017). All the ingredients should be separately sterilized for 30 minutes at 121°C at 15 psi before mixing. The sterilized casing mixture should be used to cover spawn impregnated compost bags at uniform thickness of 3-4 cm following removal of newspaper. Case run should be considered complete when mycelia covered the top of casing layer. Case run should be done at a temperature of 21-23°C. Spraying of water should be continued directly on cased bags till the end of cropping (Figure 4) (Netam *et al.*, 2018).

Crop Management and Harvesting

An air conditioner room of 10 x 12 sq. ft. should be used for cultivation. Very little or no ventilation should be provided until the appearance of first pin heads. Thereafter intermittent cross-ventilation should be given for period of total 3-4 hrs per day. A temperature of 21-23°C should be maintained during spawn run period and 15-20°C after pin head stage. Relative humidity of 70-80%should be maintained throughout the cultivation.

Mushrooms should be harvested by gentle twisting and the soil end parts of fruit bodies were cut off. The yield data should be recorded daily for number of fruit bodies and their weight was observed. Spray of water should also be continued on cased bags till end of crop. Yield data for total number and total weight of fruiting bodies per bag should be recorded up to a period of 4 weeks following appearance of pin head and biological efficiency could be calculated as follows (Netam *et al.*, 2018).

Biological efficiency = (Total weight of fresh mushroom/Total dry weight of compost) X 100

Mushroom Breeding Strategies

Mushrooms have gained the reputation of being difficult organisms to work with and it was widely acknowledged that the mushroom, particularly *A. bisporus* is not easy to manipulate through breeding. During early attempts at genetic improvement in the cultivated mushroom *A. bisporus*, there was not much understanding of the natural breeding system. The mushroom is now known to be a "secondarily homothallic" species with a single multiallelic mating type factor (Elliott and Langton, 1981). This understanding can evaluate the breeding methods previously used and to suggest alternatives. Strain selection based on single spores, multispores or tissue culture may give improvement in the short term but is not as effective as methods with controlled crossing. Mixing fertile strains may produce hybrids but they are sometimes difficult to identify. It is better to use non-fertile isolates because only the hybrids show fruiting. Early recognition of hybrids can be done using markers that can be expressed only in hybrid cultures and the incorporation of genetic resistant trait is especially useful for this.

Increasing the yield and quality of crops as well as resistance to diseases are the primary goals for mushroom breeders and mushroom research. Other goals include reducing production costs and the efficient use of compost for growth. Methods of mass selection based on natural chance mutation and programmed mutation by ionizing radiations such as γ-rays, X-rays and chemicals as well as cross breeding and transgenic breeding are some of the methods carried out for this purpose. However, cross and transgenic breeding are more effective and have shown greater promise and progress in the last few decades (Fan *et al.,* 2006). Areas of research for mushroom breeding relate directly to commercial benefits such as problems associated with cultivation, distribution and storage, senescence-induced browning and disease resistance.

Hybrid Breeding

The hybrid mushroom strains introduced in the 1980s were well received and popular and have limited the choice of production characteristics and range of tolerance to environmental and cultural stresses. Cross breeding has been carried out since1983 in mushrooms with the production of hybrids in Lentinula (Zhang and Molina, 1995), Pleurotus and Agaricus (Fristche, 1983). Hybrid strains have not only given mushrooms thatshow resistance to diseases and pests but also reduced the dependence and risks of environmental and cultural stresses. Hybrids obtained by pairing monosporic cultures are cultivated to evaluate the production characteristics accompanied by RAPD and RFLP analysis. Mushroom breeding requires a large investment of capital and patience from both the breeder and grower. A number of specific industry standards have been adopted to grow strains available to the public for the last 30years. For a new strain to be successful, some modifications in growing parameters are required for optimal growth. Traditionally growers had to adapt growing systems to accommodate cultural needs such as modifying flushing regimes, watering patterns and harvesting practices to optimize strain performance. Modifying cultural practices such as frequency and timing of irrigations are required for successful future strain development.

Transgenic Breeding

At present there are no transgenic mushroom strains available commercially but several research groups are working towards that direction with good progress. The use of recombinant DNA technique for creating

transgenic mushrooms has created numerous possibilities and opportunities. Importing genes from unrelated sources is now possible and it is not restricted to searching for desirable genes only within the species. Transformation techniques used with other filamentous fungiare being adapted for the mushroom (Van De Rhee *et al.,* 1996a). Various techniques such as polyethylene glycol, electroporation and particle bombardment have been used to incorporate DNA into protoplasts, mycelium orbasidiospores (Li *et al.,* 2006). An efficient homologous site-directed integration of the transformation plasmid was done by isolating the tyrosinasegenes responsible for mushroom browning from *Agaricus bisporus* and introducing it in antisense orientation (van de Rhee *et al.,* 1996b). However, the multinuclear nature of fertile Agaricus mycelia presented a problem for stable transgenic mushrooms. Another gene isolated and identified in mushrooms was the mannitol-dehydrogenase (MtDH) gene and its 3-dimensional structure has now become available Sassoon *et al.,* 2001). Isolation of this gene can allow the production of mushrooms with altered mannitol profiles and ultimately yield strains with higher dry matter content or better pathogen resistance (Stoop and Mooibroek, 1998). The use of direct gene delivery techniques such as particle bombardment has also been carried out as an alternative method for genetic transformation in mushrooms (Li and Horgen, 1993). This process involves the bombardment of intact tissues with tungsten or gold particles coated with donor DNA and penetrating the recipient tissue. It has the advantage of being less laborious and often the problematic production and regeneration of protoplasts can be avoided. In many laboratories, attempts have been under taken to introduce hygromycin-B resistance and other selectable markers by particle bombardment. However, this technique has not yet resulted in the selection of stable transformants or an applicable system.

Pharmacological Activities

Anticancer activity

A. bisporus is effective in case of breast cancer because it decreases aromatase enzyme activity and estrogen biosynthesis. The researcher evaluated the activity of mushroom extracts in the estrogen receptor positive/aromatase positive and found to have decreased testosterone induced cell proliferationin MCF‑7aro cells but had no effect on MCF‑10A, anontumorigenic cell line (Chen *et al.,* 2006).

Anticholesterolemic and antiglycemic

Jeong *et al.,* conducted a research investigation with the main objective to evaluate the hypothesis that intake of the fruiting bodies of *A. bisporus* regulates antiglycemic responses. For these studies the rats were fed hypercholesterolemic diet and type 2 diabetes induced by injection of streptozotocin for 3 weeks in rats. The result allowed reduced plasma glucose, TG concentrations, liver enzyme activities, alanine aminotransferase and aspartateamino transferase (Jeong *et al.,* 2010).In hypercholesterolemic rats, oral feeding of *A. bisporus* for 4 weeks resulted in a significant decreasein plasma TC, LDL, and concluded that *A.bisporus* had both hypoglycemic and hypolipidemic activity in rats (Jeong *et al.,* 2010).

Table.1A List of compost material used across globe

Component	Proportion of Dry Matter (Kg)
Manure Compost in USA (Miles *et al.*, 2004)	
Horse Manure	50.00
Chicken Manure	6.00
Beer Residues	2.50
Gypsum	1.25
Total weights	59.75
Modified Straw Compost in Taiwan (Miles *et al.*, 2004)	
Paddy Straw	85.00
Urea	1.00
Ammonium sulfate	2.00
Super phosphate calcium	3.00
Potassium sulfate	0.80
Calcium carbonate	2.50
Total weight	94.30
Tea Leaf Compost in Turkey (Simsek *et al.*, 2008)	
Tea leaves	400.00
Wheat bran	113.00
Ammonium nitrate	3.67
Urea	2.17
Molasses	16.00
Gypsum	24.00
Total weight	559.80

Table.1B List of compost material used in Iraq
(Owaid, 2009; Muslat *et al.*, 2014; Owaid and Ibrageem, 2017)

Component	Proportion of Dry Matter (Kg)	Proportion of Dry Matter (Kg)	Proportion of Dry Matter (Kg)
Wheat straw	400.00	400.00	400.00
Wheat bran	113.00	113.00	113.00
Ammonium nitrate	17.10	20.00	15.00
Urea	10.10	12.00	10.00
Molasses	16.00	16.00	16.00
Gypsum	24.00	24.00	24.00
Total weight	580.20	585.00	578.00

Table.1C List of compost material used in Turkey (Baysal *et al.*, 2007; Colak *et al.*, 2007)

Dry Matter Component (Kg)	Wheat Straw Compost	Reed Straw Compost	Mixture Compost (1:1)
Wheat straw	11.32	-	5.66
***Phragmites australis* Reed straw**	-	11.38	5.69
Chicken manure	9.33	9.33	9.33
Urea	0.56	0.56	0.56
Gypsum	1.44	1.44	1.44
Total weight	22.65	22.71	22.68
C:N ratio	9.50:1	21.70:1	20.30:1

Fig.1 Preparation of spawn

Fig.2 Wheat straw composting for button mushroom

Fig.3 Filling and spawning of button mushroom

Fig.4 Process of casing for button mushroom cultivation

Anti-inflammatory activity

The anti-inflammatory activity of methanolic extracts of *A. bisporus* was investigated on activated macrophages and found that some edible mushrooms species have a potential anti-inflammatory capacity *in-vitro* (Moro *et al.,* 2012).

Enhances maturation of bone marrow derived dendritic cells

In a study reported by Rene *et al.,* delineated that supplementation with *A. bisporus* on the maturation of bone marrow-derived dendritic cell (BMDC)of C57BL mice and found that dose-dependently increased expression of maturation markers CD40, CD80, CD86 and major histocompatibility complex-II (Ren *et al.,* 2008).

As a source of antibiotics and in cosmetics industry

A. bisporus contain a group of benzoquinone which belongs to antibiotics group and tyrosinase enzyme which was isolated from this species is completely resemble human tyrosinase which is very beneficial in field of cosmetics (Bozena *et al.,* 2017).

Intestinal fermentation

Kawakami *et al.,* reported the intestinal fermentation of *A. bisporus* in rats. It was proved by physical examination of animals by bacterial and HPLC analysis of cecal content and concluded that the mushroom powder of *A. bisporus*has a beneficial effect on the intestine (Kawakami *et al.,* 2016).

Skin disorders

This investigation was based on an effect of purified tyrosinase from *A. bisporus* on B16F10 melanocytes for the melanin production through blocking pigment cell machinery. Using B16F10 melanocytes showed that the stimulation of melanogenesis by purified tyrosinase is due to increased tyrosinase absorption. Cellular tyrosinase activity and melanin content in B16F10 melanocytes were increased by purified tyrosinase in a dose dependent manner. The results indicated that purified tyrosinase can be treated as a contestant for the treatment of vitiligous skin conditions (Zaidi *et al.,* 2016).

Antimicrobial activity

The study involved isolating *Erwinia spp.* and *Ralstonia solanacearum* from infected plants followed by subjecting the isolates and commercially acquired *Staphylococcus aureus*, *Enterococcus faecalis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Streptococcus pneumoniae*, *Proteus vulgaris*, *Candida albicans*, *Aspergillus niger*, *Fusarium oxysporum*, *Ustilago maydis*, *Microsporum gypseum* and *Malassezia furfur* were successfully antagonized by extracts of *A. bisporus* mushroom(Waithaka *et al.,* 2017).

A. bisporus as nanoparticles

Owaid *et al.,* developed the methanolic nanoparticles of *A. bisporus* have various advantages to treat cancer, viral, bacterial, fungal diseases, etc… This type of the nanoparticle synthesis by edible and medicinal mushrooms are economic and suitable to apply in nanomedicine due to the huge number of fruiting bodies which are produced in the world (Owaid and Ibraheem, 2017; Esskandari *et al.,* 2017; Majumder, 2017).The commercial mushroom production process is usually performed in buildings or tunnels under highly controlled environmental conditions. In nature, the basidiomycete *A. bisporus* has a significant impact on the carbon cycle interrestrial ecosystems as a saprotrophic decayer of leaf litter (Kabel *et al.,* 2017). *A. bisporus* mushroom is a useful bio-factor for agro-waste recycling and can be grown on various composts, such as composts of wheat straw, reed plants, waste paper, oat straw, waste tea leaves and some water plants. Our review study delineated that button mushroom can possibly be cultivated under laboratory condition. This can be a means of livelihood, a source of economic empowerment for women in both urban and rural areas for small holder farmers apart from being a source of food production. *A. bisporus* has diverse pharmacological activities. Mainly in the pharmaceutical field, it was used for synthesis of nanoparticles with antimicrobial and anticancer activities. The huge quantities of *A. bisporus* mushroom grown are suitable for the nanomedicine field to synthesize ecofriendly nano-drugs. Furthermore, *A. bisporus* are a valuable asset for the welfare of humans since they have tremendous medicinal food, drug and mineral values.

Future Perspectives

The use of genetic engineering in mushroom industry will be determined by economic factors related to necessity and resources. Due to funding constraints, mushrooms are very much lagging behind other crops in terms of advancement in molecular biotechnology. Public acceptance of genetically modified foods and greater consumption of mushrooms can increase research efforts. Traits controlled by single genes such as viral, insect resistance, resistance to fungal, bacterial pathogens and pesticides can be targeted first since they are simpler to tackle.

With mapping of the mushroom genome and understanding of the functional genomics in

mushrooms, complex traits such as yield, size, colour, shelf-life, and physical stress which are controlled by more than one gene can be undertaken in the future. Mushrooms can also be utilized as bioreactors in industry for the synthesis of proteins and pharmaceutical compounds. A higher biomass of mushrooms can be produced on low-cost waste materials in a secure containment facility with the option of automation and mechanical harvesting. The proteins manufactured in mushrooms will also have higher specific biological activities in humans than those produced from plants. The production of new mushroom cultivars with novel and improved traits will provide the industry with options for solving food problems and increase the production efficiency. Improvement of tools available to the breeder, decoding mushroom genome and commercial pressure facing the industry can propel efforts for new strain development in the future.

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