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REVIEW

Production of biofortified mushrooms : green corridor for nutrient enrichment and nutraceutical property development

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Mushrooms are worthwhile foodstuffs certainly in all nook and cranny of the earth in large part because of their nutritional value and medicinal use especially with increased interest in recent decades. There are various categories of mushrooms present all over the world .Among them some are poisonous ,medicinal and edible. The utilization of edible mushrooms upgrade the nutritional properties and culinary values.It is an exceptional source of secondary metabolites, unsaturated fatty acids, polysaccharides, minerals, and proteins. Numerous studies have shown the benefits of edible mushrooms in preventing a number of chronic conditions.The edible mushroom possesses several bioactive components, including polyphenols and antioxidant capacity,in addition to having medicinal potential. Recent socioeconomic trends suggest that substituting edible mushrooms for other important sources of functional components in food products may ultimately prove to be a stimulant for a range of disorders linked to lifestyle, both in prevention and therapy.It is the facts which one will be useful to improve the food products with fitness facilities,which could be valuable for the industry of medical nutrition, a business that resulted from the merger of the food and pharmaceutical industries. To enhance the nutrient quality and other metabolic function we can insert different nutrients (Ca, Fe, Se, Li, Zn) which can improve the quality of mushroom. Depends on the substrate mushroom's yield and nutrition value will improve.

Keywords: Edible, nutraceutical, therapeutic, mushroom, biofortification.

INTRODUCTION

Agriculture is the most sensitive working zone which one depends upon food security, economic status, climatic variation and sustainability.Cultivation of crop is a major factor to improve the growth of agriculture.

Due to the variation of climate farmers should alter the variety of the crops with better approved one (Porter *et .al*. 2014). In the ecosystem fungi takes part as a recycler. They help in degradation of substrate and discharge some vital supplements in to the environment (Campbell, 2022). Mycophagy describes the practice of consuming mushrooms.. The technique of intentionally increasing the amount of one or more micronutrients (such as vitamins and minerals) in food is known as biofortification (Hotz, 2013). In case of mushroom biofortification, there are two forms of new fortified mushrooms come: closed cup white, cheastnut which one will provide vitamin D and vitamin B12,will help the people to recover their insufficiency of vitamins (Pattanayak and Das, 2022). In addition to being a good source of dietary fibre, chitin, and ß-glucans, Mushrooms are also a rich source of minerals like P,Mg, Se, Cu, and K(Mallikarjuna *et al.* 2013). Not merely for their

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flavour and nutritional value, humans have been eating mushrooms for hundreds of years. Several investigation reflects that mushrooms are enriched with various biocatalytic compounds like flavonoids,anti-oxidant& phenolic molecules which have prevents to control cancer & inflammatory diseases with multiple health benefits (Fontana *et al.* 2013)

From different studies it is noted that mushrooms have some bioactive compounds, which one is beneficial for human's nutrition. Mushrooms are first ground into a powder to boost the nutritional value of foods like cakes, bread, burgers, spaghetti, and snacks (Lu *et al*, 2020). The introduction of processed food items containing mushrooms has raised consumer awareness of mushrooms. An average of 5 kg of mushrooms were consumed annually by consumers, and it is projected that this number would go up as more people learn about the advantages of including mushrooms in the balance diet (Royse *et al.*2017).

The production of truffles and mushroom increased globally over the past 9 years, from 2012 to 2020, from 31.78 to 42.79 million metric tones (Fig.1). According to a recent statistic record from the United States (FAO), the important 5 producers of mushrooms and truffles worldwide in 2017 were reported to be China (7.8 MMT, which granted to nearly 80% of the world's manufacturing), the US (0.42MMT), Netherlands (0.30 MMT), Poland (0.30 MMT), and Spain (0.16 MMT) The need for edible mushroom is growing day by day. An increasingly significant area of agriculture is the cultivation of edible mushrooms (FAOSTAT, 2019).

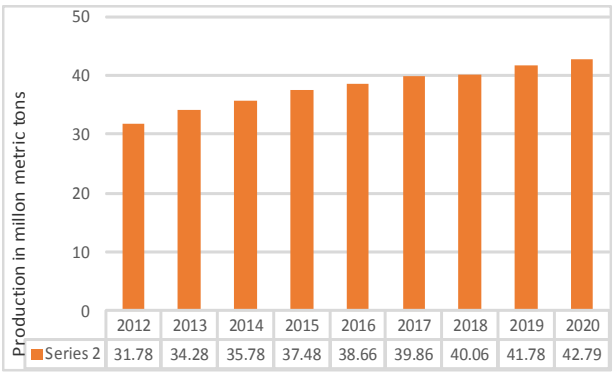

Fig.1: Increase in global output of mushrooms and truffles from 2012 to 2020

For the biofortification purpose scientists have used different species of mushroom with different nutrients (as substrate).In case of lithium biofortification there are three species *Ganoderma lucidum. Pleurotus eryngii and Pleurotus ostreatus. Pleurotus floridanus*is utilized for calcium based supplements. The accumulation of Se is observed in *Agaricus bisporus, Lentinula edodes, Pleurotus osteatus.* By using Fe salt , can enhance the nutrients in mushrooms like *Pleurotus eryngii, P. ostreatus, or Pholiota nameko*

Lithium-biofortified food production through mushroom cultivation

Now a days personality disorder, including manic depression constitute an critical level of psychiatric ailment. There are different types of phychopharmacological drugs have been made available. Among them lithium cation is an important and effective nutrient , helps to recover the bipolar affective disorder (Lioyd *et al.* 2011). It is used in the treatment of acute mania, unipolar depression ,reduction in suicidal, aggressiveness rates and also prevent the neurodegenerative disorders including Alzheimer's disease. Lithium leads role for mood stabilization and may reduce aggressiveness behavior in general people (Goldstein and Mascitelli, 2016 ; Yeh *et al.* 2008)

Mushrooms are enriched in different elements such as Se,Zn,Cu. But natural Li is scarce in mushroom. Mushrooms are probably wealthy target of any such biofortification strategy. Recently, food fortification with li has received attention as a major concern.For the dietary supplementation of this element act as an interesting role not only for the health beneficiary purpose but also accepted as alternative food supplement. (Goldstein and Mascitelli, 2016)

Preparation of substrate for *P. osteratus, P. eryngii* and *G. lucidum* have been mentioned in Tables 2 and 3. From different study, there are three mushroom species *G.lucidum,P. eryngii, P.ostreatus* are used with lithium in the form of carbonate / acetate for nutrient enhancement.

In the substrate Li is amplified in the form of Li_2CO_3 or CH3COOLi in the concentration of 0.25, 0.5,

Table 1: Preparation of substrate for *P. ostreatus*

Material required	Quantity
Mixture of beech and alder sawdust	1:1 (vol)
Wheat bran	20%
Wheat straw	10%
Corn flour	5%
Soyabean meal	3%
Chalk	1%
Gypsum	1%

Table 2: Preparation of substrate for *P.eryngii* and *G.lucidum*

Material required	Quantity
Mixture of beech and alder sawdust	1:1(vol)
Wheat bran	20%
Corn flour	5%
Soybean meal	3%
Sucrose	1%
Gypsum	1%
Water content	45%

0.75, 1.0 Mm. For the mushroom spawn preparation we need to go for incubation at 25° C for 9 days. Mycelium growth is showed different results for different species. Li_2CO_3 at higher concentrations considerably affected the growth of the mycelium colony (1.0mM and 0.75 mM for *G. lucidum* and *P. eryngii* and 0.5 mM for *P. ostreatus*). (Niedzielski *et al.* 2015)

Lithium accumulation effectiveness in various mushroom species

There are two form of Li is acted as substrate (LiCO3 and CH3COOLi). But most ofthe cases $LiCO_3$ is more useful than CH3COOLi. Although *P. eryngii* is not developed properly at higher concentration of Li2CO3. *G.lucidum* contains large amount of Li as $LiCO_3$. To produce functional foods from mushroom it needs to enhance the cultivation in biochemical way. Some mushroomsmay ameliorate Li from the substrate and can improve their fruiting bodies without changing their morphological character. Commercially application of Li increases nutraceutical property and biomass production. The acetate form of Li helps to produce a greater colony of mycelium as well as larger fruiting bodies. According to study,the addition of Li in *G.lucidum* has given some positive outcomes.

Biofortification of mushroom using calcium based supplements

Calcium is a micronutrient which is the most ample mineral in human body. Human body contains 99% of Ca which is stored in bones and teeth. Calcium plays a vital role in blood clotting. Due to the deficiency of Ca, has been arisen rickets,osteoporosis (Singh et al. 2016). *Pleurotus floridanus* is used for biofortification of Ca to increase the Ca level as well as yield.There are two Ca based supplement is used organom-icroliquid(OML),Organic Mycrowhitener(OMW).The calcium supplement act as nutrient sources as well as stimulating the metabolism of the growing mushroom and are based on patented calcium salts of carboxylic acids.

Preparation of substrate

There are two growth media sawdust supplemented with wheat bran (SD+WB) and saw dust only. Sawdust, wheat bran, calcium carbonate (CaCO3) and water were thoroughly mixed together in ratio 12:1:0.13:5 for substrate with wheat bran supplement.. The substrate with no wheat bran supplement had a ratio of 12:0.13:5 for mixture of sawdust, lime and water respectively.

Application of Calcium supplement

when the bags were fully intensified with the mycelia of the mushroom, the calcium supplements were applied prior to fruiting.

Selenium biofortification in Hericium erinaceus (Lion's Mane mushroom)

Se is a necessary trace element that is found in humans and other mammals. It increases a number of biological functions, such as the anticancer, antioxidant, and immune-regulating effects of mushrooms. Through the process of Se biofortification the metabolism and growth of mushroom will influnece.There are 3 substrate of Se is used but among them selenomethionine

(SeMet) is more effective. From the different types of mushroom *Hericiumerinaceus*is more operative source.As mushrooms can convert inorganic selenium into a variety of crucial organic selenium proteins, including selenium-polysaccharides, selenium-metabolites, and selenoamino acids, selenium enrichment culture is an efficient method for enhancing bioactivity. Se biofortified mushrooms can reduce the tumerigenesis of mammary gland and multiplication of cancer cells.It is also used as netraceutical and dietary suppliments.

Biofortification of mushroom with Fe salt

All human cells require the trace element iron (Fe), a transition metal, to survive in the body's numerous physiological functions. It is a crucial part of many proteins including myoglobins, enzymes,hemoglobins,which carry out crucial metabolic processes like DNA synthesis, transpotation of oxygen, production of oxidative energy (Moll *et al.* 2017). It plays a vital role in blood transportation. Fe deficiency causes different disorder such as anemia, dyspnea, chestpain, tinnitus, hearing loss (Comín-Colet *et al.* 2021). Biofortication of Fe is done in different food crop like cowpea,rice,wheat,soyabean to increase the Fe content in different food.The mushroom can be a viable alternative for enhancing food with minerals vital to human health as it is being grown commercially in increasing numbers and has strong bioremediation properties (Rzymski *et al.* 2016). There are three species of mushroom (*P.erygii, P.ostreatus, Pholiota nameko*) are chosen for the deposition of 3 types of Fe salts in various doses of Fe salt(FeSO4,FeCl3, FeHBED). The addition of Fe salts to some mushroom species changed the concentration of this and other chosen metals (Mg,Na,Ca,Mn,K)

Nutritional composition

Edible mushrooms offer a lot of nutritional value on their own, especially in terms of protein and carbs. Additionally, a rich source of minerals and nutrients has been included to the definition of edible mushrooms.(Kayode *et al.* 2015). *Pleurotus sajor-caju*, (PSC) is processed into a fine powder that has several desirable qualities. According to their results, the powder of PSC had an excessive amount of carbohydrates (60.5 g/100 g), which resulted in 452 cal/g (Han *et al.* 2016). Mushrooms offer both digestible and non-digestible carbohydrates, including chitin, mannans and beta-glucan. Digestible carbohydrates include mannitol, trehalose,glocose and glycogen. Later, these two carbs account for a greater proportion of all carbohydrates (Samsudin and Abdullah, 2019). According to the determined metabolisable energy values in Hebelomam-esophaeum (1513.5 kJ/100 g) and in *Ganoderma* spp. each variety of mushrooms is a concentrated source of energy, and they compare favourably to cereals in terms of their energy values (Aremu *et al.*2009).

There are different part of mushrooms – cap, stalk, gills. In case of oyster mushroom these parts are showed different configuration (Table 3). Their stalk contains high moisture as compare to other parts of the mushroom (Oluwafemi *et al.* 2016).

Different components of exotic oyster mushroom grown in PSC and Gmelina wood has been presented in Table 4. The oyster mushroom which one has developed on Gmelina wood is more favourable than the wild one (Kayode *et al.* 2015)

Fortification of the maize flour with mushroom flour from *Agaricus bisporus* and *Pleurotus ostreatus*, aimed to enhance the dietary values of the flour. To this, the compositional traits and their interactions have been investigated (Ishara *et al.*2018). The protein content of maize flour increased with mushroom flour content from 6.9 g/100g to 15.87 g/100 g (*Agaricus bisporus*) as much as 19.32 g/100 g (*Pleurotus ostreatus*), and a sizeable boom in fiber (0.53-5.89 g/100 g) turned into located . Generally, edible mushrooms contain an excessive quantity and precise best protein content material for approximately 20-40 g/100 g of dry weight basis.It is able to become the nutraceutical food for the next generation (Farzana and Mohajan ,2015).

Phenolic compounds which include myricetin, quercetin, caffeic acid, catechin, and pyrogallol are found in all edible mushrooms. Except, antioxidant components (i.e. Phenolics, carotenoids, ascorbic

Table 3: Different constituents of oyster mushroom

Parts	Protein (g/100g)	Globulin (%)	Albumin(%)	Crude fibre(g/100g)	Ash content (g/100g)	Fat content (g/100g)
Stalk	21	47.3	3.3	7.5	5.00	1.5
Cap	34.2	23.3	4.1	3.2	5.5	1.6
Cap with a stalk	30.5	44.7	4.5	8.1	8.2	1.52

Table 4: Growth of exotic oyster mushroom on PSC and Gmelina wood

Components(g/100g)	PSC*(Pleurotus sajor-caju)*	Gmelina wood
Moisture	7.20	7.00
Protein	25.2	19.30
Crude fat	7.2	6.6
Ash	8.25	7.1

acid, tocopherols, ergosterol, and polysaccharides) are mainly detected in each fruiting bodies, mycelium of mushroom.

Nutraceutical Value

In addition to their nutritional benefits, mushrooms have also been used for a longer period to treat various ailments. Due to its medicinal properties, it had been consumed during clinical treatments. It has been established scientifically that the numerous medicinal characteristics of mushrooms—many of which have been employed traditionally in folklore of various parts of countries. It has been found that these benefits are caused by a number of the mushrooms biologically active and fitness-enhancing compounds. (Samsudin *et al.*,2019). Due to the high levels of antioxidant substances found in mushrooms, they are utilised to prevent ailments including cancer, hypertension, and hypercholesterolemia.Because mushrooms contain some antioxidant molecules, they can protect cells from free radical damage, delay ageing, and even fend off numerous diseases.(Sánchez, 2017). In case of mushroom is provided more â-glucans, frequently referred to by their common names, such as grifolan (*Grifolafondosa*), ganoderan (*Ganoderma lucidum*), lentinan (*Lentinula edodes*), pleuran (*Pleurotus ostreatus*) and schizophyllan (*Schizophyllum commune*) (Zhu *et al.*2015). Mushroom's â-Glucans has not only immunomodulatory properties but also it has antibacterial activities.(Rasmy *et al.* 2010), Many edible mushrooms include B-glucans, a water-soluble nutritional component have been shown in numerous studies to have anticancer, antioxidant, anticholesterolaemic, neuro protective and immunomodulatory properties. They are also acknowledged in humans as strong immune stimulators. According to studies, B-glucans cause these biological reactions via binding to a membrane receptor (Ma *et al.* 2018). List of medicinal mushrooms is provided in Fig. 2.

A complex substance called lentinan is shielded from a variety of mushrooms,including *Lentinulaedodes*, and used in Japan as a homoeopathic treatment for cancer. Lentinan is typically used as an adjuvant in the treatment of tumours in clinical assays (i.e. chemotherapy and radio therapy) (Valverde *et al.* 2015). Additionally, selenium, an antioxidant that is thought to prevent cancer, is found in *lentinulaedodes*. Laccases, antimicrobial proteins,Lectins, ribonucleases, ribosome-inactivating proteins, fungal immunodulatory proteins are only a few examples of the bioactive proteins and peptides found in mushrooms that have great significance for pharmaceutical usage (Xu *et al.* 2011).

Important cell membrane components called hygrophoruseburneus serve as both antigens and their receptors. Cantharelluscibarius, a species of edible mushroom, is antibacterial and effective against actinomycetes, yeast, filamentous fungus, and both Gram-negative and Gram-positive bacteria (Aina *et al.* 2012).

The impact of fortification of edible mushrooms on food quality

The usage of food products containing edible mushrooms has expanded because of their medicinal qualities and nutritional advantages. According to several studies, adding powdered mushrooms to different food products caused an increase in protein, ash and crude fibre. The development of fortified powder mushrooms has improved the nutritional content and quality of various food products.When 10% powdered mushroom was added to the bread and muffin batter, it increased the protein content compared to the control. high protein content of mushroom powder will improve bread quality (Majeed *et al.*2017). Vital and nonvitalglutens are the two different forms of gluten. Nonvital gluten is only employed to enhance proteins, not for its viscoelastic qualities (Ortolan and Steel, 2017).

Along with bread, cake, muffins, and biscuits, bakery products like powdered mushrooms are overly high in protein. The width and thickness of the biscuits could increase with the addition of 10% powdered desert truffle (Gadallah *et al.* 2016).

Protection from constipation, cardiovascular disorders, and weight issues are all part of human fitness (Kendall, 2010). One of the main causes of the decreased exact volume in bread and cakes is also the high fibre content in both bakery goods. The necessity for water absorption normally increases as composite flour's fibre level rises (Gajula, 2017). Inversely, it provides a heavier loaf and reduces the bread's extent. Due to the lengthier dough development, the addition of flour with a high fibre content material has a detrimental effect on bread quality.reduction in fuel retention and a barrier to the dough's potential growth.

Shiitake, porcini, and powdered oyster mushrooms can be used to complete the protein enrichment of pasta and noodles (Wahyono *et al.* 2018). Noodles treated with 10% mushroom powder appear to have less enrichment than the control based on moisture content. The fibrein mushroom's powder competes with starch during the formation of the noodles, reducing starch swelling and water absorption.Except that the 10% more powdered mushroom added to the noodles' fibre content material demonstrates a substantial difference from the control's lower moisture content (Foschia *et al.* 2015).

Numerous food items, including noodles, paratha, rice porridge, cake, and cake, had higher ash contents than the control. A higher ash content indicates that there are more minerals in the food goods. Food products that incorporate with mushroom's powder have a different texture, appearance,flavour and stability depending on the mineral content (Sivam *et al.*2010). Because of its meaty flavour, powdered mushrooms are used to flavour rice porridge. Additionally, they are rich in minerals, fibre, and protein. Aishah and Wan Rosli looked at the sensory characteristics and close composition of rice porridge. Their findings revealed that the 6% oyster mushroom powder added to rice porridge increased consumer acceptability compared to the control.With the exception of fat level, parathabread follows a similar pattern. Additionally, the research noted that paratha bread enriched with 6% oyster mushroom had a significantly lower fat level (Aishah and WanRosli, 2013).

Pork patties are made using shiitake mushrooms. In pork patties, this powdered fungus serves as phosphate. Phosphate is used as a culinary

Fig. 2: List of medicinal mushrooms

additive that helps foods hold more water, cook more efficiently, and have better texture. Furthermore, it safeguards the scent and promotes the quick development of the cured meat's colour (Chun *et al,*2005). However, the panellists were less enamoured with the majority of the food items supplemented with powdered mushrooms in terms of texture, aroma, taste, and general acceptability when it came to sensory qualities. The darker colour of food items that have been enhanced with mushroom powder is a factor in how consumers feel about most products with mushrooms as an ingredient (Hourant, 2014).

CONCLUSION AND FUTURE SCOPE

Mushroom is a chief source of nutrition particularly protein and minerals for vegetarian people. It acts as an alternative crop. It can be cultivated like an indoor crop. Now a days the climate is changed due to scarcity of water,erosion, low productivity,overgrowth of population. To solve this problem, there will be need to adopt diversify agriculture and new sustainable technologies. Mushroom cultivation is an effective biological tool which one can solve the problem through recycling the waste material used as substrate (straw, sugarcane bagasse, ricebran, tree leaves,coconut husk) cheap source of high quality food protein, neutraceutical value of medicinal mushroom.It can absorb toxins from heavy metals. Cultivation of mushroom is a labour intensive and less investment. It can provide jobs in semi urban and rural areas. Especially woman group can do these cultivation through the Government policies.Mushroom cultivation is one of the most vital agribusiness in the world. It is very profitable as it can be stared with a low investment. Different minerals are used to enrich the nutrients in mushroom through biofortificationprocess. Sebiofortified mushrooms can protect from neurodegenerative and immunological disease. Sebiofortified mushroom can provide income generation for the youths. Through the biofortification of Ca can enhance the nutritional value as well as medicinal use. Acute mania and unipolar depression are both treated with Li biofortified mushrooms. Additionally, it is generally recognised that mushrooms contain bioactive substances with health benefits, including ergosterol, -glucans, lentinan, and peroxidase. This assertion is supported by numerous research that demonstrate the antiviral, anticancer, and antihypertensive properties of mushrooms. It has been investigated whether mushrooms could be used in food applications. The findings of these studies gave positive proof that using mushrooms in food products enhances the product's physical and nutritional properties. There are many opportunities linking the use of fungi in many different sectors. Mushroom cultivation is a skill can slowly be involved in many things. There are some growth of work on mycotextiles,mushroom supplements, mycoremediation,phycology. Reishi is one of the species which one is used for mycotextile because of the density of the mycelium. Mushroom suppliments are used as a value added products. Myco-remediation is a process of using mycelium to remediate toxins.

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