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Global Development of Mushroom Biotechnology

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Abstract
There are At least 12000 species of fungi that can be considered as mushrooms with at least 2000 species showing various degrees of edibility. To date, only about 35 mushrooms species have been cultivated commercially, and about 20 are currently on an industrial scale. The majority of these cultivated species are both edible and posses certain medicinal properties [6].
Mushrooms are in prime focus in the food industry for their multi-functional benefits. They are gaining popularity owing to their high nutritional values and are gradually approaching a "super food" status. Mushrooms are a rich source of proteins and have very low or zero fat and cholesterol, and hence are widely accepted in most of the regions of the world. Increase in the consumption of processed food across the world is one of the major driving factors of the mushroom market. Being a promising and profitable business, mushroom cultivation is widely adopted by growers. Factors such as R&D and innovations to enhance the acceptability and continuous improving technologies to increase mushroom shelf-life are also projected to drive the mushroom market in the next five years.
Technological developments in the mushroom industry in general have witnessed increasing production capacities, innovations in cultivation technologies, improvements to final mushroom goods, and utilization of mushrooms' natural qualities for environmental benefits, mainly due to contributions from developing countries such as China, India, and Vietnam. However, there is always the need to maintain current trends and to continue to seek out new opportunities. The challenge is to recognize opportunities such as increasing consumption capabilities with the increase in world population and to take advantage of this by promoting the consumption of mushrooms. Those countries, in which mushroom cultivation is not yet well established, will find difficulty to cope with the new competitive circumstances generated by globalisation. Some insights into biotechnological development of mushroom production in the world are reviewed in this paper.
Keywords: *Mushroom biotechnology, Global Scenario, world production, Medicinal Mushroom, Pleurotus, Agaricus, Lentinula.*

1. Introduction

The ultimate aim in the modern applied aspects of any scientific endeavour is to integrate, wherever possible, the various discipline of sciences, as well as the associated technological processes, in order that maximum benefits may accrue from such efforts. Combined production of mushrooms for human food, health care, animal feed and soil conditioner/fertilizer from rural to urban organic wastes should be one of the aims of such integrated schemes that can eventually be made into profitable operation.

The term mushroom is not a taxonomic division. Mushrooms are macrofungi with distinctive fruiting body, which can be hypogeous or epigeous, large enough to be seen with the naked eye and to be picked by hand [4]. Mushrooms have long been used as a valuable food source and as traditional medicines around the world, especially in Japan and China. Records of health promoting properties such as antioxidant, antimicrobial, anticancer, cholesterol lowering and immunostimulatory effects have been reported for some species of mushrooms [5].

Due in large part to a continually increasing world population, humankind, particularly in developing countries, is facing three basic problems that are daily growing more acute: a shortage of food, a reduction in the quality of health, and environmental deterioration. This overview considers the concepts of applied mushroom biology and the international mushroom movement, and their respective contributions to the development of the world mushroom industry and its links with global business. Applied mushroom biology represents a new discipline concerned with research, development, and initiatives (R, D, and I) related to the mushroom industry. The international mushroom movement is a framework that embraces the complementarities and interconnectedness of the four main international mushroom organizations.

2. Mushroom: Global scenario

Fleshy mushrooms (members of the class Basidiomycetes) have long been valued as highly tasty and nutritional foods by many societies throughout the world [5]. To the ancient Romans they were 'the foods of the Gods', to the early Egyptians they were 'a gift from the God Osiris' while, more appropriately, the Chinese considered them 'the elixir of life'. Several ancient societies dating back as far as the Palaeolithic period recognised the psychoactive, hallucinogenic properties of some mushrooms, especially *Amanita muscaria* and *Psilocybe spp*., and involved them in ancient religious beliefs and practices [1].

France was the leader in the formal cultivation of mushrooms. Some accounts say that Louis XIV was the first mushroom grower. Around this time mushrooms were grown in special caves near Paris set aside for this unique form of agriculture. From France, the gardeners of England found mushrooms a very easy crop to grow which required little labour, investment and space. Mushroom cultivation began gaining popularity in England with more experimentation with spawn and publicity in journals and magazines.

In the late 19th century, mushroom production made its way across the Atlantic to the United States where curious home gardeners in the East their luck at growing this new and unknown crop. However growers had to depend on spawn imported from England which, by the time it reached the U.S was of poor quality [28].

Mushroom farming has become popular all over the world with advancement and dissemination of information on its cultivation technology. Mushroom is an indoor crop and the production can be controlled suiting a particular market condition. Global mushroom industry has expanded horizontally and vertically, meaning that the expansion has been in production and addition of newer types of edible mushroom varieties for commercial cultivation. Today China is leading in global mushroom production. China produces approximately 70 per cent of world mushroom production (2008), and mushroom is their sixth economically important crop in terms of country's revenue generation. The second highest mushroom producing country is USA, followed by European

Union Countries. European Union production is confined to France, Germany, The Netherlands, Italy, Poland, Spain, Hungary and others. Lately there is increased contribution in mushroom production from Eastern European countries like Poland and Hungary where mushroom production has received a boost as evident from the production figures of these countries [8].

2.1.In Latin America

It has been shown that mushroom cultivation was introduced to Latin America till 1933 from Europe [18]. Such early efforts in central Mexico ended up in the establishment of the company Hongos de Mexico in 1949, nowadays the largest farm in Latin America producing around 55 tonnes of *Agaricus* mushrooms per day. This was followed by other Latin American countries, such as Argentina, Colombia, Brazil, Chile, Guatemala, Peru, Ecuador, Venezuela, Costa Rica, and more recently Bolivia [17].

Annual production has increased steadily in Latin America since 1945. During the period 1995-2001, estimated commercial mushroom production in this region increased 32%, from 49,975 to 65,951 tonnes/year (equivalent to ca. 2,627 tonnes of protein). Thus mushroom production increased at a rate of about 5% per year. Despite this remarkable development, Latin America only produces about 1.3% from the total world commercial production of cultivated mushrooms [6] [14] which has been estimated to be in excess of 4,909,300 tonnes per year (fresh weight). Most production is commercialized in the fresh market, and a small proportion is processed for further distribution. Many countries have high level of imports to satisfy the local demand of fresh and processed mushrooms. Leading countries are Mexico (58.6%), Chile (17.6%), and Brazil (10.6%) accounting for 86.8% of total mushroom production. Mushroom cultivation brings about social, economic, and ecological benefits to Latin America. It has been estimated that there is still a low mushroom consumption per capita of about 125 g per year. The total economic value reaches more than 167 million dollars per year, and about 34 thousand people work, directly or indirectly, for this activity. Around 656,796 tonnes of by-products from agriculture and forestry are recycled every year as substrates for mushroom cultivation. *Agaricus*, the common cultivated mushroom; and *Pleurotus*, the oyster mushroom, are the most important cultivated mushrooms in an estimated proportion of about 95% and 5%, respectively. *Lentinula*, the shiitake mushroom, is beginning to be commercially grown in Colombia, Brazil, Guatemala, Argentina, and Mexico [17]. Although facing serious problems of basic knowledge, working capital, technical assistance, strain or spawn availability, and marketing strategies, Latin American mushroom growers have succeeded in: 1) Adapting European, North American and/or Asian technologies to the local conditions of each country; 2) Promoting consumption and marketing of fresh and processed mushrooms; and 3) Training mushroom farm workers [17].

2.2.In United States

United States of America is the largest consumer of mushrooms in the world today. US trade flows for canned mushrooms dominated by imports, especially those from China, India, and Indonesia. The trade deficit trended irregularly downward for China, India, and Indonesia from 2003-06 following the continuation of high antidumping duties on imports of canned mushrooms from these countries. By 2007-08, however, imports from China, India, and Indonesia had raised to a five-year high, in spite of the antidumping duties on US imports. China, India, and Indonesia have principle suppliers of canned mushrooms to the US market since 2003-04, are global exporters of canned mushrooms and have been very successful in selling lower priced products into the US market. Imports of canned mushrooms into US amounted in 64867 tons in 2007-08, down by 2 per cent from 66212 tons in 2003-04. Imports were down by 23 per cent in volume from 2007-08 to 2008-09. Imports from China were down in 2005-06, not only for antidumping duties already mentioned, but also because of a drop in Chinese production. U.S. exports of fresh and canned mushrooms are small relative to imports, amounting

to 7212 tons and 709 tons in 2007-08, and 8119 tons and 1281 tons 2008-09, respectively. Canada is the principal market for US exports of fresh mushrooms, accounted for nearly 90 per cent of export volume annually since 2003-04. US mushroom exports to Japan and France, by comparison, are principally specialty mushrooms. There are no US non tariff measures applicable to imports of canned or fresh mushrooms, nor are mushrooms subjected to any domestic content laws, guaranteed minimum prices, or requirements that import be entered through certain ports. US imports of fresh and canned mushrooms must be packaged and labelled correctly and should have all the necessary customs entry paperwork, according to existing regulations of US. There are no sanitary / phytosanitary measures affecting the entry of any mushrooms in the US market [8].

2.3.In Sub Saharan Africa

For the full benefit of mushrooms to be realized in Africa, a thorough understanding of African mushroom resources, and strategies for the cultivation, marketing and development of endogenous species, will need to be aggressively pursued. Africa constitutes at least 25% of the total mushroom biodiversity worldwide but contributes barely 0.4% of total mushroom sales and new mushroom products on the global market. Yet mushrooms are well known in most indigenous African recipes [19] and, at the onset of the rainy seasons, it is customary to find rural people across many African countries (for example, Cameroon, Nigeria, Malawi, Ghana, Benin Republic, Togo, Uganda, Ethiopia, Kenya, Equatorial Guinea and Zimbabwe) going out to search mushrooms from decaying wood and palm trees [32]. The cultivation of mushrooms for food and medicine is increasingly popular across the world, including Africa. However, the pace of progress in Africa is slow. Never before in contemporary times has the potential of mushrooms been so widely known and advocated. Twenty years ago, Chang (1993) described mushrooms as the gourmet food of the 21st Century. Hitherto, their application has transcended food and medicine into bioremediation of oil spills. Commendable progress on mushroom cultivation techniques has been widely reported [7], but many prospective farmers in SSA who want to grow mushrooms do not have access to information. Some mushroom farmers are aware of cultivation techniques using a range of substrates but, generally, they face a lack of information on the commercial potential of indigenous mushrooms. Mushroom production capacity of SSA is, proportionally, minimal compared to that of Latin America, China and Europe [15]. Chioza and Ohga (2014) reported 240 kg per grower in Malawi, with a sale price of about two USD per kg. These values are not significantly different across SSA. The mushroom sector in Africa is characterized by a lack of infrastructure, inadequate technical support, a scarcity of mushroom scientists and poor knowledge of mushroom diversity [20]. About 95% of all articles published in Africa and elsewhere on the state of mushroom production in Africa point strongly to the under exploitation of mushrooms.

There is an endemic lack of basic epistemic knowledge about a “one magic bullet substrate” for raising mushrooms with minimal contamination. Additionally, the lack of operating capital, technical assistance, strain and/or spawn availability, and marketing strategies are grossly inadequate to rapidly improve the mushroom sector. So far, African mushroom growers have only succeeded in growing *Pleurotus species* (Oyster mushrooms) especially *Pleurotus ostreatus*, *Pleurotus sajo-caju* and *Pleurotus pulmonarius*, on corn cobs, rice husks, maize bran and sawdust. Cultivation of these exotic mushrooms is generally expensive for an average African farmer. In the coming decades, efforts in Africa would have to be concentrated on developing spawn from local mushroom species as well as utilizing local available tropical weeds and grasses usually left unused or burnt in situ on many farms. At the Phytobiotechnology Research Foundation Ecological Farm in Bamenda, Cameroon [32], spawn development and fruiting of P. ostreatus using local grasses such as elephant grass stems (*Pennisetum purpureum*) and spear grass (*Heteropogon contortus*) has achieved 70% biological efficiency

levels. Laboratory experiments suggest that initial crude fiber from these grasses were 80% utilized when the first flush of *P. ostreatus* fruit bodies were harvested.

Generally, mushroom growers across Africa use rice bran, rice husks, maize husks and bran (as well as sawdust) in various proprietary proportions, together with calcium oxide for pH stabilization. Although yields have been commendable, thorough scientific analyses of these substrates and biological efficiency studies are lacking. The Phytobiotechnology Research Foundation (PRF) runs a mushroom cultivation unit with intensive research on the domestication and commercial cultivation of local mushroom species [32]. PRF is a Non-Governmental Organization registered with the Cameroon Government CIG Reg. No: NW/GP/29/07/10856 and 0068/E.29/1111/Vol.8/APPB, with a Euroaid No: 958820266. The word Phytobiotechnology was first framed by Dr Kenneth Yongabi Anchang who is currently the director. The Foundation's work on mushrooms is not only focused on the cultivation of mushrooms for food but also for medicine. Innovative work has steadily progressed on the preparation of widely cultivated *P. ostreatus* spawn using a number of local substrates prepared from farm wastes in Cameroon, using novel energy saving substrate sterilization methods involving a plant-derived biocide.

2.4.In Nigeria

Mushroom resources have been exploited in most developed economies because of their huge agro-industrial, medicinal and commercial benefits. Nigerians utilized mushroom-forming fungi only for food and folk medicine for many decades. Oyster and shiitake mushroom were some of the common edible mushrooms that were successfully cultivated in Nigeria on small-scale basis. The mushroom resources in Nigeria are grossly under-studied and their attractive potentials under-exploited for addressing economic and industrial development. Resourceful biotechnological approach in the application of mushrooms in agriculture, medicine, industry and environment is inchoate and uncommon in the country [33].

Mushrooms are widespread in nature and they are the earliest form of fungi known to mankind. In Nigeria, many people in both urban and rural areas are familiar with mushroom-forming fungi growing around them some of which they exploit for food and medicine. This practice although reported all-over the country is more pronounce amongst the Yoruba speaking people.

Concomitant varieties of mushrooms that abound in Nigeria have continued to gain recognition and elicit different interests and questions as potentially resourceful tool in economic modulation pari passu prevailing reliance on leafy plants. It is saddening to see that people from all works of life associate mushrooms with negative events in Nigeria and most African countries. This image, in addition to the slow development of mushroom cultivation practices is changing due to reports elsewhere in the world that illuminate potentials of mushroom-forming fungi and mushroom products and their uses in different spheres of human welfare [32].

This is apart from their hitherto pivotal roles in sustaining eco-energy balance in nature. In Africa, mushroom resource exploration and exploitation is fraught with lack of infrastructure and technical supports from national and international agencies, scarcity of mushroom scientists, poor political and legislative support, poor knowledge of mushroom biodiversity due to dearth of mushroom taxonomists and bad press reports amongst others.

Reports on Nigerian mushrooms such as are old and currently an under-representation of Nigerian mushroom's diversity, composition and uses. African nations are seldom listed among the largest producers and exporters of edible mushrooms and mushroom products [33].

2.5.Production and exports from Asia:

China, India, and Indonesia are the three most important global mushroom exporting countries in Asia. All three countries became the major suppliers of canned mushrooms to the US market since 2003-04, together accounting for 86 per cent of total US canned-mushroom import volume in 2007-08. All three Countries have mushroom canning industries that are export oriented, with US market a primary

destination for their production, and all face barriers to their exports in certain third-country markets.

2.5.1. In China

China has become the leading global producer of mushrooms and exporter of canned mushrooms since 2004. China's dominance has occurred even though most Chinese growers are using growing methods considered rather primitive and low technology relative to those used in the United States and other major producing countries. China's common-mushroom industry consists of thousands of small-volume family-run growing operations nationwide, employing mainly family labour. Common and specialty mushrooms are grown in sheds made of bamboo, straw, and clay, or in caves, without any mechanical climate control which limits production to the cooler months of October–December and March– May. Since 2003-04, mushroom canning in China is being done in number of very modern facilities. The Bluefield Industrial Food Company started production in 2004 and is one of only a few canneries that export products which do not have to pay any antidumping duties. This cannery, with an estimated production capacity of 80,000 tons of canned foods including mushrooms, is reported to have received FDA registration for processing low-acid canned foods and Hazard Analysis and Critical Control Point (HAACP), Quality Control Certification. COFCO Industrial Food import & Export Co., a subsidiary of COFCO Corporation, also operates a modern cannery and is reported to account for 10 per cent of Chinese canned mushroom exports in recent years. Dujiangyan Xingda Foodstuff Co., another exporter of canned mushrooms to the United States, also operates 56 modern mushroom-growing houses [8].

Table 1: Mushroom Production- China & World

Year	*World, 000, ton*	*China, 000, ton*	*%*
1987	1,060	60	5.7
1983	1,453	175	12.0
1990	3,763	1,083	28.8
1994	4,904	2,640	53.8
1997	6,158	3,918	63.6
2002	12,250	8,650	70.6
2006	.?	14,400	?
2008	?	18,200	?
2010	?	21,500	?

Source: Indian Council f Agricultural Research (ICAR).

2.5.2. In India

India produces about 250 thousand tons of edible mushrooms annually (author's assessment on spawn consumption). The Indian mushroom industry is made up of a few very modern growing and processing facilities. Agro Dutch estimated production capacity of 50000-60000 metric tons of fresh mushrooms for canning annually. In 2003-04, has accounted for an estimated 25 per cent of all U.S. imports of canned mushrooms to Canada, Mexico, Israel, and Russia. A second Indian mushroom grower and processor, Himalaya International also has a state-of-the-art, ISO certified, and HAACP compliant mushroom production facility including canned mushroom processing operation with an anticipated production of 9,000 metric tons of canned mushrooms annually. There are scores of smaller units of 200-500 TPA capacity (about 35- 40 units) with climate controlled facility growing button mushrooms in almost all regions of the country in India, growing mainly button mushrooms for local market. These smaller units are located in Tamil Nadu, Haryana, Punjab, Uttar Pradesh, Maharashtra, Gujrat, Himachal Pradesh, West Bengal, Sikkim, Assam and other places in the country, besides the seasonal growing activity in western plains of India in winter months [8].

2.6.In European Union Countries:

The EU is a global producer of mushrooms and has been for a number of years. In EU countries, the largest canned production in 2007 were from The Netherlands, Spain, Poland, France, and Italy, with The Netherlands accounting for nearly one-fourth of total EU production in 2007. Most mushrooms produced in the EU are traded within member countries and the EU is not a global exporter to non-

EU countries. Countries shipping the greatest share of canned mushrooms within the EU in 2007 were the Netherlands, Spain, Poland, France, and Germany. Since its entry into the EU, Poland has become the EU's largest-volume producer of fresh mushrooms, growing more than 238000 tons of mushrooms annually. The mushroom industry in Poland is composed of more than 2000 mushroom farms, ranging in size from many small family-run farms to some large operations. The mushrooms produced are of high quality and the production facilities are technologically advanced. The costs of labour (mainly Romanian workers), energy, and supplies are less than those in the United States, and the capital investment by Polish growers, especially in their composting operations, is high. The combination of high-quality product and low production costs has enabled mushroom growers in Poland to ship fresh mushrooms even to some non-EU member countries [8].

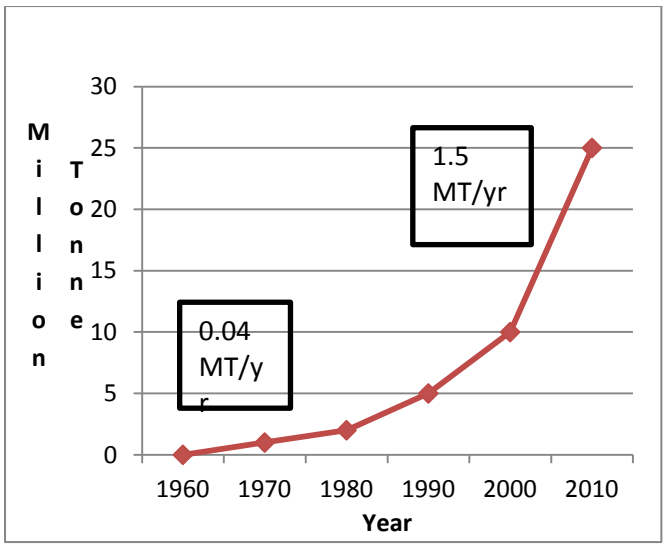

Figure 1: World Mushroom Production (Million Tonne)

Source: Indian Council of Agricultural Research (ICAR).

3. Resourceful Biotechnological Approach in the Application of Mushrooms

3.1. Medicinal Mushrooms: a Rapidly Developing Area of Biotechnology for Cancer Therapy and other Bioactivities

3.1.1 Medicinal Properties

Historically, most medicinal mushroom species were relatively scarce and were collected from the forests where they grew on dead or living trees and forest litter. They are predominantly lignocellulose degraders. For medicinal purposes, they were almost always prepared either as hot water extracts, concentrates or in powdered form. Nowadays almost all of the important medicinal mushrooms have been subjected to large-scale artificial cultivation by solid substrate or low moisture fermentation, thus removing the historical scarcity factor and allowing large commercial operations to develop. Mushroom cultivation is the only large-scale biotechnological process that creatively utilises lignocellulosics [29].

The practice of using medicinal mushrooms in Chinese traditional medicine dates back into antiquity and has been recorded in ancient Chinese manuscripts [2]. Increased scientific and medical research in recent years and published in peer reviewed journals, especially in Japan, Korea and China, and more recently in the US, is increasingly confirming the medicinal efficacy and identifying the bioactive molecules [31],[21], [11]. Recent advances in chemical technology have allowed the isolation and purification of some of the relevant compounds especially polysaccharides which possess strong immunomodulation and anti-cancer activities.

3.1.2 Anti-Cancer Properties

There have been extensive in vivo studies demonstrating the anti-cancer activity of the extracted, purified glucanpolysaccharides and polysaccharide peptides in animal models [31]. These studies strongly suggest an immunomodulating mode of action. However, in in vitro studies on various cancer cell lines, there is evidence for direct cytotoxic effects on the cancer cells for some, but not all, of the polysaccharides [3]. Many of the proprietary mushroom polysaccharides have proceeded through Phase I, II and III clinical trials mainly in Japan and China while some are now occurring in the US [13]. In almost all cases the polysaccharides are used as adjuvant treatments with conventional chemotherapy/radiotherapy with many

forms of cancer. Highly encouraging results have been forthcoming together with the observations that their incorporation into treatment regimes significantly reduced the side-effects so often encountered by patients. Several of the purified mushroom polysaccharides have been in clinical use in Japan, China and Korea for many years, with no reports of any significant short term or long-term adverse effects. These compounds are not miracle drugs but can increase the quality of life of cancer patients and may offer increased survival rates for some types of cancer [13]. There is also increasing experimental evidence that regular incorporation of certain powdered medicinal mushrooms in the diets of animals or topical application of extracts can have a cancer prevention effect and restriction of tumour metastasis [12],[26]. A survey conducted among mushroom workers in the Nagano Prefecture in Japan implied that regular eating of medicinal mushrooms (mainly Flammulina velutipes) was associated with a much lower death rate from cancer than for other people in the Prefecture [12].

3.2 Biotechnology of Agricultural Wastes Recycling through Controlled Cultivation Mushroom

The agricultural wastes recycling with applications in agro-food industry is one of the biological challenging and technically demanding research in the biotechnology domain known to humankind so far. Annually, the accumulation of huge amounts of vineyard and winery wastes causes serious environmental damages nearby winemaking factories. Many of these ligno-cellulose wastes cause serious environmental pollution effects, if they are allowed to accumulate in the vineyards or much worse to be burned on the soil. At the same time, the cereal by-products coming from the cereal processing and bakery industry are produced in significant quantities all over the world [18], [30].

To solve the environmental troubles raised by the accumulation of these organic wastes, the most efficient way is to recycle them through biological means [22]. As a result of other recent studies, the cultivation of edible and medicinal mushrooms was applied using both the solid state cultivation and controlled submerged fermentation of different natural by-products of agro-food industry that provided a fast growth as well as high biomass productivity of the investigated strains [22], [29].

These plant wastes can be used as the main ingredients to prepare the organic composts for edible and medicinal mushrooms growing in order to get organic food and biological active compounds from the nutritive fungal biomass resulted after solid state cultivation or submerged fermentation of such natural materials [24], [23].

Taking into consideration this biological advantage there were tested some variants of biotechnology for agricultural wastes recycling through the controlled cultivation of edible and medicinal mushrooms Ganoderma lucidum (Curt.:Fr.) P. Karst (folk name: Reishi or Lingzhi), Lentinus edodes (Berkeley) Pegler (folk name: Shiitake) and Pleurotus ostreatus (Jacquin ex Fries) Kummer (folk name: Oyster Mushroom) on organic composts made of cereal grain by-products as well as winery and vineyard wastes [22].

3.3 The Biotechnological Potential of Mushroom Tyrosinases

Over the last decade there has been a significant interest in developing biotechnological applications of tyrosinases. These applications include the production of L-DOPA (3,4-dihydroxyphenyl-L-alanine) from L-tyrosine, the production of cross-linked protein networks for use as novel food additives and the detection of phenolic compounds in wastewater or their removal from it. Much of the research into these applications has involved mushroom tyrosinases.

Tyrosinase (EC 1.14.18.1; tyrosine, L-DOPA: oxygen oxidoreductase; catecholase; diphenol oxidase; polyphenol oxidase – PPO) is a copper-containing enzyme that catalyzes sequential oxidation steps with various phenolic substrates. In the first reaction, often referred to as the »monooxygenase« or »cresolase« activity, a hydroxyl group is introduced into the ortho position of the aromatic ring while in the second reaction, often referred to as the »diphenolase« or

»catecholase« activity, the o-dihydroxy compound produced in the first reaction is oxidized to an o-quinone. Both reactions involve molecular oxygen [9]. These activities can be used as the basis for several biotechnological applications [10].

Although tyrosinases are widely distributed in microorganisms, plants and animals, much of the current interest in the development of biotechnological applications has focused on the use of mushroom tyrosinases. Several aspects of mushroom tyrosinases have been extensively reviewed, such as their biochemical characteristics, their roles in the metabolism of the producing organism and some of their potential biotechnological applications [25]. However, relatively little attention has been given to the production and purification of mushroom tyrosinases and a realistic appraisal of their biotechnological potential.

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