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Supplementation of Basal Substrate to Boost up Substrate Strength and Oyster Mushroom Yield: An overview of Substrates and Supplements

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A B S T R A C T

Oyster mushroom (*Pleurotus* spp.) is one of the very attractive crops successfully cultivated in most developing countries due to its easy cultivation technology. The most amazing point of mushroom cultivation technology is its landless agriculture on useless lignocellulosic agricultural wastes. The oyster mushrooms have potentials to utilize various kinds of waste materials as substrate than any other mushrooms and in consequence convert them into valuable vegetable food at par with non-vegetarian food in terms of nutritional attributes. Since these natural lignocelluloses contain limits of their nutrient constituents, require supplementations in the form of chemical and biological supplements. Addition of the supplements with basal substrate has been as common practice to enhance the yield, nutritional and medicinal values. The present manuscript comprised the detailed information in context of oyster mushroom cultivation, used multiple basal substrates and supplements (additives) as reported in past researches. Therefore, the technology of mushroom agriculture enables us to acquire substrate materials at very low cost or even for free to get biotechnological foods and further led to conserve our environment through efficient bioconversion of wastes with sustainable food security.

Introduction

Among the white-rot fungi, genus *Pleurotus* as the oyster mushrooms are famous for conversion of substrate into edible mushrooms (Mandeel *et al.*, 2005) and known as 'dhingri in India well known edible fungi. Cohen et al (2002) described the properties of *Pleurotus* spp. in relation to their biotechnological applications and its multitude potential. The cultivation of mushroom is recognized as worthwhile agribusiness and popular white vegetable having excellent flavour and taste (Naraian *et al.*, 2014). Moreover, they are easiest and least expensive commercial mushroom to grow (Banik and Nandi 2004; Pant *et al.*, 2006) artificially. The versatility and absolute ease of cultivation coupled with

oyster mushrooms that are edible, have led to a great demand in recent years. Consequently, now oyster mushrooms are the second largest produced mushrooms in the world (Kuforiji and Fasidi, 2009).

Bioconversion of lignocellulosic residues through cultivation of *Pleurotus* spp. offers the best prospect to utilize renewable resources in the production of protein rich food that will sustain food security for peoples (Tisdale *et al.,* 2006; Naraian *et al.*, 2009). The cultivation of *Pleurotus* spp. is an economically important food industry worldwide, which has vastly expanded in past few years and become the second most cultivated mushroom for food purposes. This is the most economic conversion system of lignocellulosic waste into food products (Wood, 1984). The majorities of mushroom cultivation systems initially began as empirical processes, but transformed and have been better understood as the interactions between substrate and microorganisms.

The genus *Pleurotus* comprise of edible lignocellulolyic mushrooms with medicinal properties and important biotechnological and environmental applications. Nutritionally it has unique flavour and aromatic properties, which is considered rich in protein, fibre, carbohydrates, vitamins and minerals. *Pleurotus* spp. is promising as medicinal mushrooms, exhibiting antibacterial, hypochlosterolemic and immunomodulation activities (Patel *et al.*, 2012). In addition, the most important aspects of *Pleurotus* spp includes use of their lignocellulolytic system for the variety of applications, such as bioconversions of agricultural wastes into valuable food product, animal feed and biodegradation of organopollutants and industrial contaminants.

Traditionally, oyster mushrooms are widely grown on paddy and wheat straw which has become costlier because of its several other uses like animal fodder. It has been well established that deficient supply of proper nutrients with natural lignocellulosic substrates dynamically affects of mushroom cultivation phases (Xing *et al.,* 2006; Naraian *et al.,* 2014). The deficiency of several nutrients is improved by the deliberative supplementation of external compounds (Naraian *et al.,* 2010). In addition, yield can be intermittently raised by optimization of cultural conditions viz., by adding supplements to shorten the crop period for *Pleurotus* spp. and also increases mushroom productivity (Curvetto *et al.,* 2002; Naraian *et al.,* 2009). In this regard, various additives are recommended as supplements to the basal substrates for enhancement of oyster mushrooms yield (Ralph and Kurtzman, 1994).

In the present review, we have compiled a detailed account and discussion, which has been presented on different kind of variable substrates and their co-supplements employed in mushroom cultivation studies.

Oyster Mushroom Family

Based on the characteristics of mating compatibility the genus of *Pleurotus* contains a broad family of approximately 40 known biological species (Jose and Janardhanan, 2000) and commonly referred as ‘oyster mushrooms’ due to its general morphological appearance like an oyster. These are: (1.) *P. ostreatus*, (2.) *P. florida*, (3.) *P. sajor-caju*, (4.) *P. eryngii*, (5.) *P. pulmonarius*, (6.) *P. colombinus*, (7.) *P. sapidus*, (8.) *P. populinus*, (9.) *P. tuber-regium* (10.) *P. ferulae* (11.) *P. fossulatus* (12.) *P. nebrodensis*, (13.) *P. abieticola*, (14.) *P. albidus*, (15.) *P. djamor-cornucopiae*, (16.) *P. cornucopiae*, (17.) *P. citrinopileatus* (18.) *P. euosmus*, (19.) *P. djamor*, (20.) *P. flabellatus*, (21.) *P.*

salmoneo-stramineus, (22.*) P. salmonicolor*, (23.) *P. opuntiae*, (24.) *P. calyptratus*, (25.) *P. cystidiosus*, (26.) *P. fuscosquamulosus* (27.) *P. abalonus*, (28.) *P. smithii*, (29.) *P. dryinus*, (30.) *P. levis*,(31.) *P. australis*, (32.) *P. purpureo-olivaceus*, (33.) *P. rattenburyi*, (34.) *P. gardneri*, (35.) *P. parsonsii*, (36.) *P. velatus*, (37.) *P. nidiformis*, (38.) *P.incarnatus*, (39.) *P. fuscus var. Ferulae* and (40.) *P. populinus.* These specific mushroom species are artificially cultivable however, naturally flourish under temperate and sub tropical environments.

Cultivation of Oyster Mushroom

Oyster mushrooms are cultivated worldwide because of its easy cultivation technology, availability of raw materials and number of species suitable for environment (Kacharoo *et al.,* 1997). Falck (1917) in Germany performed the first successful experimental cultivation of *P. ostreatus*. Falck (1917) inoculated tree stumps and wooden logs with mycelium of *P. ostreatus* (Agaricus ostrelis) and could harvest fresh oyster mushroom. Kaufert (1935) reported medium, sexual spores of *Pleurotus carticatus* Fr. Furthermore; Block et al (1959) cultivated *P. ostreatus* first time under laboratory conditions using sawdust as substrate. They used a mixture of oatmeal, sawdust for the cultivation, and found best results on eucalyptus sawdust followed by pine sawdust. They reported some growth abnormalities in fruitbodies due to insufficient light conditions and found optimal mushroom production within 10-32°C temperature range.

In India, Bano and Srivastava (1962) at CFTRI Mysore reported cultivation of *P. flabellatus* on paddy straw. In a different trial, corncobs as substrate were used under the sterile condition for growing *P. ostreatus* (Toth, 1970). A Hungarian method based on sterile production was patented in 1969 (HTTV patent) for growing oyster mushrooms. Moreover, Stanek and Rysava (1971) developed a method of application of thermophilic microorganisms in the fermentation of substrate used for the cultivation of *P.ostreatus*. Besides, Zadrazil (1974) reported a method for continuous preparation of substrates used in *Pleurotus* mushroom (*P.ostreatus* and *P.florida*) cultivation. In other hand, Jandaik and Kapoor (1976) grew, *P. sajor-caju* on various substrates including wheat and banana pseudostems. Chang *et al.,* (1981) too successfully developed a method for cultivation of *P. sajor-caju* using cotton waste from textile industry. Later Singh *et al.,* (1994) successfully developed a method of cultivation of *P. sajor-caju* on dried san stem sticks and observed very good yield.

Furthermore, the technique of oyster mushroom cultivation has prevalent and peoples used substrate vary from country to country and worldwide. The researches for the advancement of technology for better yields are simultaneously switched on. Workers have widely used the technology of substrate strengthening through supplementation and optimization of production. Major studies and developments regarding searches of new substrates and their strengthening through supplementation are discussed as below.

Ligno-cellulosic Wastes for Oyster Mushroom Cultivation

In India, the total quantity of agricultural by-products or wastes, those are cellulosic in nature account for more than 25 million tonnes per year (Ghose and Ghose, 1978). These materials assume the potential source of raw materials for mushroom cultivation. The important among these include different

cereals straws, sugarcane bagasse, cotton waste, jute, coir, coir pith (coir waste), coca pods, mango seed kernels, different oil cakes including rubber seed cake, sunflower straw, ground nut pod shell, tapioca starch waste, water hyacinth and certain other dry and wetland weeds, vegetable waste, banana and its market wastes.

A lot of work has been performed on the suitability of various substrates for *Pleurotus* cultivation. *P. sajor-caju* and *P. flabellatus* were found to grow on various substrates, namely rice straw, wheat straw, ragi straw, hulled corn cob, waste cotton, banana pseudo stem and waste paper (Jandaik 1974; Bano *et al.,* 1978; Shivaprakasham *et al.,* 1982). Thilagavathy *et al.,* (1991) observed maximum yield of *P. sajor-caju* from banana pseudo stem. Various researches suggested variety of substrates including jowar straw, ground nut pod (Khandar *et al.,* 1991), wheat straw (Gupta and Langar 1988), rubber wood waste, sawdust of rubber (Mathew *et al.,* 1991), oil palm mesocarm waste (Babu and Nair 1991), water hyacinth and fermented coffee pulp (Upadhyay and Sohi 1988) for the cultivation of *P. florida*. Kacharoo *et al.,* (1997) reported that wheat straw is the best substrate for *Pleurotus* cultivation.

Zervakis *et al.,* (2001) studied growth of *Pleurotus ostreatus, P. eryngii, P. pulmonarius* on different substrates: wheat straw, cotton gin-trash, peanut shells, poplar sawdust, oak sawdust and olive cake which were poor substrate for most species examined, while almost strains performed adequately on corn cobs. Rosado *et al.,* (2002) proposed that cotton residue might be used for the production of mushroom fruiting. Thus, many more number of lignocellulosic substrates has been further reported in various consecutive studies, which are compiled in the following (Table 1.)

Biological and Chemical Waste Supplements to Boost up Yield of Oyster Mushroom

Lignocellulosic materials as such having deficient supply of nutrients, primarily requires supplementation with various materials, which in general is recommended prior to spawning for the enhancement of yield of oyster mushrooms. From the very beginning of mushroom agriculture; integrated use of various nitrogen and carbon rich chemical and biological supplements was began to enhance yield. Various oil seed cake, powdered pulses, wheat and rice bran etc are surprisingly added as supplements (Bahukhandi 1990). Supplementation of chicken manure as supplement was suggested during the cultivation of *P. sajor-caju* and *P. flabellatus* (Vijay and Upadhyay, 1989). Jandaik and Kapoor (1974) reported addition of oat meal and arhar dal powder for better yield of *Pleurotus* spp. Moreover, it was observed that supplementation of mushroom beds with horse gram after the spawn run significantly increased the mushroom yield (Bano *et al.,* 1978). In addition, workers suggested many different lignocellulosic substrates which includes: wheat bran, cotton meal, brewer's grain, wood dust, chicken manure (Baysal *et al.,* 2003; Vijay and Upadhyay, 1989), rice bran (Jeznabadi *et al.,* 2016; Chae and Ahn, 2013; Peng *et al.,* 2000), cotton seed cake (Naraian *et al.,* 2009), wheat bran (Moonmoon *et al.,* 2011) and soybean flour (Jeznabadi *et al.,* 2016) for better yield.

The substrate for *Pleurotus* spp. cultivation supplemented with cotton linter (cotton seed cake) at the rate of 259g/3kg dry substrate (8%) had given the best results (Bano and Rajarathnam, 1979). Supplemented straw with cottonseed powder, yeast mud, ground nut cake and rice bran led best response concerning yield of *Pleurotus* spp.

Table.1 Summary of Different Lingo-cellulosic Basal Waste Substrates used for the Cultivation of Oyster Mushroom.

Substrate	Reference
Rice straw	Jandaik and Kapoor (1974); Bano *et al.*, (1978); Shivaprakasham *et al.*, (1982) Khandar *et al.*, (1991)
Wheat straw	Gupta and Langar (1988); Kacharoo *et al.*, (1997); Naraian *et al.*, (2014); Zervakis *et al.*, (2001); Jandaik and Kapoor (1974); Bano *et al.*, (1978); Shivaprakasham *et al.*, (1982); Delmas (1989); Heltay *et al.*, (1960)
Rubber wood waste, sawdust of rubber	Mathew *et al.*, (1991)
Oil palm mesocarm waste	Babu and Nair, (1991)
Water hyacinth	Fan *et al.*, (2015)
Cotton gin-trash and peanut shells,	Zervakis *et al.*, (2001);
Banana leaves	Chang- Ho (1979)
Banana pseudostems	Jandaik and Kapoor (1974); Bano *et al.*, (1978); Shivaprakasham *et al.*, (1982)
Barley straw	Martinez-Carrera (1989)
Bean pods	Poppe (1995)
Bean straw	Poppe (1995)
Brassica-haulms	Sohi and Upadhyay (1989); Zadrazil (1989); Singh *et al.*, (2011)
Coffee pulp	Martinez-Carrera (1989); Sanchez *et al.*, (2002); Upadhyay and Sohi (1988)
Coffee sawdust	Sanchez *et al.*, 2002
Corncobs	Heltay (1957); Heltay *et al.*, (1960); Naraian et al, (2009, 2014)
Corn stover	Bassous *et al.*, (1989)
Cottonseed hulls	Sun Pei-Ji and Jian-Jun Yu (1989)
Cotton straw silage	Danai *et al.*, (1989)
Groundnut shells	Tagwira *et al.*, (1999); Khandar *et al.*, (1991)
Lemon grass leaves	Martinez-Carrera. (1989)
Newspapers	Hashimoto (1976)
Paper waste	Poppe (1995); Jandaik and Kapoor (1974); Bano *et al.*, (1978); Shivaprakasham *et al.*, (1982)
Ragi straw	Bano *et al.*, (1979); Bano *et al.*, (1978); Jandaik and Kapoor (1974)
Sorghum stover	Tagwira *et al.*, (1999)
Soybean stems	Pani *et al.*, (1997); Bugarski *et al.*, (1997)
Sugarcane bagasse	Kneebone and Mason (1972); Martinez-Carrera. (1989)
Sunflower husks	Poppe (1995); Bugarski *et al.*, (1997
Tea leaves	Stamets (1993); Poppe and Höfte (1995)

Textile industry waste	Khan *et al.*, (1989)
Treebark, chopped	Imbernon *et al.*, (1976)
Water hyacinth	Gujral *et al.*,(1989)
Water spinach	Gujral *et al.*,(1989)
Wood logs	Olah *et al.*, (1979)
Wood shavings	Poppe (1995)
Spent substrate of *Pleurotus*	Poppe (1995)
Spent substrate of *Agaricus* and *Volvariella*	Oei (1991)

Table.2 Summary of Different Biological and Chemical Supplements used with Basal Substrate during the Cultivation of Oyster Mushroom and their Relative References.

Supplements	Reference
Oil seed cakes and meals, powdered pulses,	Bahukhandi (1990), Naraian et al. (2009)
Chicken manure	Vijay and Upadhyay (1989); Baysal *et al.*, (2003)
Oat meal and arhar dal powder	Jandaik and Kapoor (1974)
Wheat bran	Jeznabadi,*et al.*, (2016); Moonmoon *et al.*, (2011)
Rice bran	Jeznabadi (2016); Chae and Ahn (2013); Peng *et al.*, (2000); Vijay and Upadhyay (1989); Bahukhandi (1990)
Mustard seed cake	Naraian *et al.*, (2009)
Wheat bran and soybean flour	Jeznabadi *et al.*, 2016
Cotton linter (cotton seed cake)	Shashirekha *et al.*, (2005); Naraian *et al.*, (2009); Vijay and Upadhyay (1989).
Ground nut cake	Vijay and Upadhyay (1989); Naraian *et al.*,(2009)
Urea	Naraian *et al.*, (2009)
Ammonium sulphate	Naraian *et al.*, (2009)
Yeast mud,	Vijay and Upadhyay (1989)
Dairy spent wash	Naraian *et al.*, (2011)
Pea pod shell, Brassica straw, Cauliflower leaves and radish leaves	Singh and Singh (2012, 2014)
Molasses	Naraian *et al.*, (2009)
Oyster shell powder	Naraian *et al.*, (2014)
Starfish	Choi *et al.*, (2009)

According to Vijay and Upadhyay (1989) the results obtained with the supplementation of mustard cake, chicken manure, wheat bran and rice bran were also good for *Pleurotus* spp. production. The stimulating nature of the OSP at low levels was observed, which was due to the presence of surplus amounts of

micronutrients (Naraian *et al.,* 2009). Recently, Singh and Singh (2014) reported enhanced biological efficiency, protein and essential amino acids of oyster mushroom grown on paddy straw substrate supplemented with different vegetable waste including pea pod shell, cauliflower leaves, radish leaves and brassica straw.

To boost up the strength of the substrates, several chemical and biological supplements have been contemporarily attempted by the researches in past. The use of supplements considerably influenced both yields and quality of mushrooms. The important and major findings of the supplementation studies are summarized in the table as below.

Future Aspects

Since mushroom cultivation is a labour intensive and high profit venture; which provides employment to small farmers who have less land or no land. For increasing the mushroom yield; rather than search of better and cheap substrates and their supplements, the following fundamentals are suggested which must be practiced: (a) search and identification of potent and novel varieties for better yield (b) search of temperature resistant varieties and (c) development of high yield and resistant transgenic strains through the strategy of genetic manipulations. In addition, government and their organizations must turn their attention towards nourishing the institutions with the objectives of popularizing the technology of mushroom cultivation. They must too facilitate the programmes of technology transfers from laboratory to fields as a campaign was run before for other crops.

In conclusion, based on the critical review of the literature it can be concluded that commercial production of oyster mushroom is considered to be dependent on the availability and utilization of cheap as well as waste substrate as well as supplements. The utilization of agro wastes for the production of beneficial oyster mushrooms is a well established economical and ecological practice. Since availability and popularity of substrates/supplements are regional and geographical, so that substrate optimization needs to be popularized by creating technical awareness to the farmers. The promotion of oyster mushroom cultivation would facilitate employment and be helpful to meet nutritional and medicinal needs to reduce malnutrition and livelihood of landless poors and economically weak sections.

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