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Nutritional and antioxidant significance of selenium-enriched mushrooms

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Abstract

Background: The element selenium (Se) acts as a double-edged sword for humans and animals by being a nutrient at trace level and a toxin at elevated concentrations. It is needed for the biosynthesis of selenoenzymes and selenoproteins which mediate an array of activities such as antioxidant defense, detoxification, immunomodulation, carcinogenesis prevention, thyroid functioning, and sperm motility and maturation. Because of their culinary, nutritional, and health benefits, the demand for mushroom cultivation is increasing in India. The mushrooms are enriched with proteins, phenolics, antioxidants, vitamins, and microelements. Most of the edible and cultivated mushrooms show an array of biological properties. However, they are Se deficient, and it mandates the cultivation of Se-fortified edible mushrooms.

Aim of work: This review focuses on Se forms, distribution, dietary importance, mushroom cultivation, need of Se-enriched mushrooms, enrichment methods, nutritional and antioxidant significance, and anticancer activity of Se-biofortified mushrooms.

Methodology and results: Se-enriched mushrooms are produced by cultivation on substrates enriched with either inorganic or organic forms of Se and Se-hyperaccumulated agricultural residues. Edible mushrooms accumulate Se from substrate into selenoproteins and selenoenzymes as selenomethionine and selenocysteine, the organic and most bioavailable forms of Se. Without affecting the biological efficiency, the enrichment process enhances the total protein and total phenolic content and bioaccessibility of trace elements. The antioxidant action was higher for Se-fortified mushrooms in terms of total phenolics, total antioxidant, 1, 1-diphenyl-dipicrylhydrazyl (DPPH) scavenging, metal chelating, and lipid peroxidation inhibition activities in comparison with unfortified mushrooms. Also, Se-enriched mushrooms are known to retard chemically induced mammary tumors and proliferation of lung cancer cell lines.

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Conclusions: Se-biofortified mushrooms act as potential functional food, nutraceutical, and diet supplements. Dietary intake of Se-fortified mushrooms aids in treatment and prevention of various conditions such as HIV infection, cancer, aging, cardiovascular, neurodegenerative and immunological diseases. The cultivation of Se-enriched mushrooms leads to sustainable empowerment of marginal, landless farmers; rural women; unemployed youth; and self-help groups. However, the technology development for Se enrichment is needed for commercial scale production. Other studies on volatile Se compound release during cultivation, safe disposal of spent compost, and Se leaching into ground water are warranted. The impact of cooking and traditional preservation methods on Se availability from mushroom meal to humans has to be evaluated.

Keywords: Anticancer, Antioxidant, Functional food, Hyperaccumulated, Nutraceutical, Selenium-enriched mushrooms, Selenoproteins

Introduction

The element Selenium (Se) is an essential nutrient at trace levels for human health, as it is needed for the biosynthesis of selenoenzymes and selenoproteins such as glutathione peroxidase, thioredoxin reductase, iodothyronine deiodinase, and selenoprotein W and P, respectively. They mediate an array of activities such as antioxidant defense, detoxification, anti-inflammation, immunomodulation, carcinogenesis prevention, thyroid functioning, and sperm motility and maturation. Thus, these virtues make Se as one of the dietary supplements for humans (Kora and Rastogi 2016; Kora and Rastogi 2017). However, the Se metalloid acts as a double-edged sword for humans and animals by being a nutrient at trace levels and a toxin at elevated concentrations (Kora 2018a). The minimum and maximum dietary allowance of Se for healthy adults is 70 and 400 μg/person/day (Council NR 1989). The Se content in vegetables varies from 0.017 to 0.12 μg/g, and in fruits it ranges from 0.0062 to 0.089 μg/g. In fishes and seafood, the Se content varies from 0.56 to 2 μg/g (Falandysz 2008).

The important oxidation states of Se are selenate (Se^{6+}), selenite (Se^{4+}), elemental selenium (Se^0), and selenide (Se^{2-}). The inorganic forms of Se include sodium selenite (Na_2SeO_3), sodium hydrogen selenite ($NaHSeO_3$), sodium selenate (Na_2SeO_4), selenium dioxide (SeO_2), and elemental selenium (Se^0) (Kora 2018a). Usually, the organic Se is mainly present as selenoamino acids such as selenomethionine in plant-based foods and selenocysteine in animal-originated foods. The main selenium sources for plants, fungi, and bacteria are soil, sediment, and water, and it is passed naturally to animals and humans via food chain. The Se abundance in plant- and animal-based food sources depends upon various factors such as Se content in soil and water, bioavailability, biotransformation, food web transfer, and accumulation capability of Se ions and organo Se compounds (Falandysz 2008). Generally, the selenium concentration in the soil surface is below 0.5 mg/kg, and the seleniferous soils contain > 0.5 mg/kg. In the seleniferous soils of Indian state of Punjab, the Se levels in surface soils ranges from 2.7 to 6.5 mg/kg. While in crop products such as wheat grain and husk, and rice and mustard, it ranges from 13 to 670 mg/kg. While, in the rice leaves, the concentration ranged from 1.5 to 1.9 mg/kg (Dhillon and Dhillon 1991; Sharma et al. 2009; Sharma et al. 2014). Thus, all these studies indicate significantly high levels of Se in various crop products grown in seleniferous soils. It is attributed to the deposition of seleniferous materials from Shiwalik hills via seasonal rivulets and use of underground water for irrigation (Dhillon and Dhillon 1991).

This mini review is a concise summary of published data on Se forms and distribution, Se importance in human diet, mushroom cultivation in India, need of Se-enriched mushrooms, methods of Se enrichment in mushrooms, nutritional and antioxidant significance, and anticancer activity of Se-biofortified mushrooms. In addition, the application of Se-enriched mushrooms as functional food, nutraceutical, and diet supplements is briefly discussed.

Mushroom cultivation in India

The most important edible and cultivated mushroom species grown in different states of India are *Agaricus bisporus* (button mushroom) (Fig. 1), *Pleurotus sajor-kaju*, *Pleurotus ostreatus*, *Pleurotus djamor* (oyster mushroom) (Fig. 2), *Calocybe indica* (milky mushroom) (Fig. 3), *Volvariella volvacea* (paddy straw mushroom), *Lentinula edodes* (shiitake mushroom), and *Hypsizygne ulmarius* (elm oyster mushroom) (Fig. 4). In India, an All India Coordinated Research Project on Mushroom (AICRPM) was initiated at Indian Council of Agricultural Research-National Research Centre for Mushroom (ICAR-NRCM). The ICAR-NRCM was instrumental in the development of technology for superior strains, casing materials, supplements, safer chemicals, standardization of various cultivation techniques, utilization of diverse substrates, disease and pest management, shelf life improvement, post-harvest processing, etc in a span of 35–36 years. Due to their culinary, nutritional, and health benefits, the demand for mushroom cultivation is increasing in India (Ahlawat et al. 2008). Mushrooms are

Fig. 1 The *Agaricus bisporus* (button mushroom) a at cropping stage and b packed in polythene bags

enriched with proteins, phenolics, antioxidants, vitamins (B, C, D, riboflavin, thiamine, nicotinic acid, folic acid, niacin), microelements (K, Fe, Zn, Cu, P), etc. They are low in sugars, sodium, cholesterol, fat, and calorific value. As they are low in Na and high in K, they are considered as a suitable food for persons suffering with hypertension, obesity, and diabetes. Even after cooking and processing, the vitamins are retained in the mushrooms. Most of edible and cultivated mushroom show an array of biological properties such as hypolipidemic, antibacterial, antiviral, antitumor, chemopreventive, and immunomodulatory activities (Olga and Alla 2017; Rodriguez Estrada et al. 2009; Savic et al. 2009).

The need for selenium-enriched mushrooms

Most of the cultivated, edible mushrooms are selenium deficient, as the selenium content is very low (< 1–8.5 μg Se/g dry weight). In some of the wild grown, edible fungi and mushrooms, the Se content ranges from 12-200 μg/g (Costa-Silva et al. 2011; Falandysz 2008). However, most of the wild grown, edible mushrooms are not amenable for large scale cultivation and have negligible culinary value. This mandates the cultivation of selenium fortified edible mushrooms on various substrates enriched with either inorganic or organic forms of Se. As the edible mushrooms are known to accumulate Se from substrate and rich in proteins; their growth on selenium rich/amended substrates results in Se incorporation into selenoproteins and selenoenzymes. The various organo selenium compounds identified in the mushrooms are selenomethionine, selenocysteine, selenomethylselenocysteine, etc. (da Silva et al. 2010; Falandysz 2008; Savic et al. 2009). It is known that the chemical form and dose determines the biological activity of Se (Kora 2018b). The organic, most bioavailable forms of Se such as selenomethionine and selenocysteine show antioxidant, antimutagenic, and anticancer activities (Savic et al. 2009).

Methods of selenium enrichment in mushrooms

Generally, the methods used to enrich fruiting bodies of edible mushrooms with Se are through the addition of either inorganic (SeO_2, Na_2SeO_3, Na_2SeO_4) or organic selenium (selenized yeast, selol) to the organic substrate and irrigation water during cultivation and cultivation on selenium hyperaccumulated agricultural residues such as paddy and wheat straw grown on seleniferous soils (Bhatia et al. 2014; Cremades et al. 2012; Oliveira and Naozuka 2019; van Elteren et al. 1998). A successful enrichment strategy depends on the addition of Se source during substrate production and irrigation; concentration and dose of Se source; species, biological efficiency, and physiology of mushrooms; bioaccessible and bioavailable organic Se levels; protein distribution and selenoprotein content; native antioxidant (ergothioneine) content; bioaccessibility of other essential elements; morphological and chemical characteristics, yield of biomass; and organoleptic properties of the produce (Cremades et al. 2012; Oliveira and Naozuka 2019). A

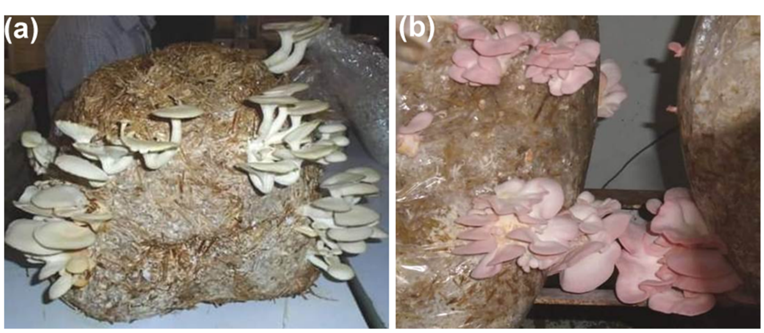

Fig. 2 The oyster mushrooms at cropping stage a *Pleurotus sajor-kaju* (white oyster) and b *Pleurotus djamor* (pink oyster)

Fig. 3 The various stages of milky mushroom (*Calocybe indica*) cultivation at a spawn running stage, b pin head emerging stage, and c cropping stage

comparative account of selenization methods reported for various species of edible mushrooms, in terms of amended Se form, Se load in substrate, and bioaccumulated Se concentration in fruiting bodies, is given in Table 1.

A study was carried out on *Pleurotus ostreatus* growth on substrate supplemented with inorganic Se (Na_2SeO_3 and Na_2SeO_4) at a dose of 100 μg/g. The fruiting bodies accumulated 205–213 and 154.7–169.3 μg/g, with Na_2SeO_3 and Na_2SeO_4 amended substrates, respectively. It was found that the enrichment depends upon chemical form of Se, and the Na_2SeO_3 is a better enrichment source than Na_2SeO_4 (Savic et al. 2009). Another study based on button mushrooms (*A. bisporus*) growth on compost irrigated with Na_2SeO_3 at a concentration of 100 μg/mL accumulated 3.1 μg/g of biomass (Cremades et al. 2012). In different studies carried out with *A. bisporus*, the fungus accumulated 0.3–2.8 (Prange et al. 2019) and 110.2 μg/g (Stefánka et al. 2001), when the substrate was amended with Na_2SeO_3 at 10 μg/g. In a similar report on oyster mushroom enrichment with Na_2SeO_3, the *P. djamor* and *P. ostreatus* species accumulated 76 and 19 μg/g of biomass at an initial substrate Se loading of 25.6 and 6.4 μg/g, respectively (Oliveira and Naozuka 2019). In another report on Na_2SeO_3 loaded *P. eryngii* species, 4.6–9.3 μg/g was accumulated at initial substrate loading of 5–10 μg/g (Rodriguez Estrada et al. 2009). The milky mushroom *C. indica* grown Na_2SeO_3 (5 μg/g) supplemented substrate showed 3.2 μg/g in fruiting bodies (Rathore et al. 2018). In the case of *Ganoderma lucidum*, an enrichment of 72 μg/g was recorded, when cultivated on Na_2SeO_3 amended substrate at 100–250 μg/g loading (Zhao et al. 2004). The *P. pulmonarius* and *P. ostreatus* species bioaccumulated 23.1 and 261 μg/g, when the substrate was supplemented with 56.2 (Milovanovic et al. 2019) and 25.4 μg/g (da Silva et al. 2010) of Na_2SeO_3, respectively. The *A. bisporus* strains bioaccumulated 160 and 192.7 μg/g, when the substrate was supplemented with 10 (Dernovics et al. 2002) and 35 μg/g (Savic et al. 2011) of selenized yeast, respectively. When *P. ostreatus* and *P. cornucopiae* species were enriched with selenized yeast

Fig. 4 The a harvested paddy straw mushroom (*Volvariella volvacea*), b shiitake mushroom (*Lentinula edodes*), and **c** elm oyster mushroom (*Hypsizygne ulmarius*) at cropping stage

Table 1 A comparative account of selenization methods reported for various species of edible mushrooms, in terms of amended Se form, Se load in substrate and bioaccumulated Se concentration in fruiting bodies

Mushroom species	Amended Se form	Substrate Se load (μg/g)	Fruiting body Se concentration (μg/g)	Reference
Agaricus bisporus	Na_2SeO_3	4.6	30	Piepponen et al. (1984)
A. bisporus	Na_2SeO_3	10	110.2	Stefánka et al. (2001)
A. bisporus	Na_2SeO_3	10	0.3-2.8	Prange et al. (2019)
A. bisporus	Na_2SeO_3	100	3.1	Cremades et al. (2012)
A. bisporus	Na_2SeO_3	30-300	1300	Werner and Beelman (2002)
A. bisporus	Selenized yeast	10	160	Dernovics et al. (2002)
A. bisporus	Selenized yeast	10	770.7	Gergely et al. (2006)
A. bisporus	Selenized yeast	35	192.7	Savic et al. (2011)
A. bisporus	Se-hyperaccumulated wheat straw compost	27	122	Bhatia et al. (2014)
Pleurotus ostreatus	Na_2SeO_3	3.2	57.6	da Silva et al. (2012)
P. ostreatus	Na_2SeO_3	6.4	19	Oliveira and Naozuka (2019)
P. ostreatus	Na_2SeO_3	25.4	261	da Silva et al. (2010)
P. ostreatus	Na_2SeO_3	100	205–213	Savic et al. (2009)
P. ostreatus	Na_2SeO_4	100	154.7–169.3	Savic et al. (2009)
P. ostreatus	Selenized yeast	25	42.4–50.2	Savic et al. (2012)
P. ostreatus	Se-hyperaccumulated wheat straw	24	44.3	Bhatia et al. (2013b)
P. sajor-kaju	Se-hyperaccumulated wheat straw	24	43.5	Bhatia et al. (2013b)
P. sajor-kaju	Se-hyperaccumulated wheat straw	27	43.5	Bhatia et al. (2014)
P. florida	Se-hyperaccumulated wheat straw	27.9	141	Bhatia et al. (2013a)
P. florida	Se-hyperaccumulated wheat straw	24	110	Bhatia et al. (2014)
P. djamor	Na_2SeO_3	25.6	76	Oliveira and Naozuka (2019)
P. djamor	Se-hyperaccumulated wheat straw	24	145.4	Bhatia et al. (2013b)
P. eryngii	Na_2SeO_3	5-10	4.6–9.3	Rodriguez Estrada et al. (2009)
P. pulmonarius	Na_2SeO_3	56.2	23. 1	Milovanovic et al. (2019)
P. cornucopiae	Selenized yeast	25	42.8	Savic et al. (2012)
P. fossulatus	Se-hyperaccumulated wheat straw	24	37.2	Bhatia et al. (2013b)
P. citrinopielatus	Se-hyperaccumulated wheat straw	24	26.1	Bhatia et al. (2013b)
Volvariella volvacea	Se-hyperaccumulated paddy straw	29.7	35	Bhatia et al. (2014)
Calocybe indica	Na_2SeO_3	5	3.2	Rathore et al. (2018)
Lentinula edodes	Na_2SeO_3	10	46	Gergely et al. (2006)
L. edodes	Na_2SeO_3	50	170	Nunes et al. (2012)
Ganoderma lucidum	Na_2SeO_3	100–250	72	Zhao et al. (2004)

at 25 μg/g, the fruiting bodies were fortified with 42.4–50.2 and 42.8 μg/g, respectively (Savic et al. 2012).

In Indian states of Punjab and Haryana, most of the post-harvest agricultural residues such as wheat and paddy straw are burnt in the fields which lead to the decline in soil fertility and release of large quantity of gases and particulate matter into the air. A study was carried out on Se uptake by *P. sajor-kaju* and *V. volvacea* which were cultivated on Se-hyperaccumulated wheat (24 μg/g) and paddy (29.7 μg/g) straw grown in seleniferous soils of Punjab. The Se concentration in Se-enriched *P. sajor-kaju* (43.5 μg/g) and *V volvacea* (35 μg/g) was much higher than the control. It is attributed to Se bioaccumulation in mushrooms, and the study showcases the utilization of Se-hyperaccumulated agricultural residues as a substrate for production of Se-biofortified mushrooms (Bhatia et al. 2014). In a related study employing Se-hyperaccumulated wheat straw (24 μg/g), the *P. citrinopielatus*, *P. fossulatus*, *P. sajor-kaju*, *P. ostreatus*, *P. florida*, and *P. djamor* species were enriched with 26.1, 37.2, 43.5, 44.3, 110, and 145.4 μg/g, respectively (Bhatia 2014; Bhatia et al. 2013b). Also, the species *P. florida* was fortified with 141 μg/g, when cultivated on Se-hyperaccumulated wheat straw (27.9 μg/g) (Bhatia et al. 2013a). In the case of *A. bisporus* grown on Se-hyperaccumulated wheat straw compost (27 μg/g), the biomagnification value was found to be 122 μg/g (Bhatia 2014).

Nutritional and antioxidant significance of se-biofortified mushrooms

The mushrooms are a rich source of antioxidants such as phenolics, ergothioneine, etc., and the antioxidant molecules in living systems reduce the oxidative stress which inturn results in the development of various diseases. The antioxidants mediate the reversal, prevention, or delay of cellular damage caused by free radicals generated during various metabolic processes which occur in the body (Rodriguez Estrada et al. 2009). The cultivated, edible mushrooms are considered as poorer source of Se and they only make a marginal contribution towards Se intake through diet (Costa-Silva et al. 2011). In a study on Se enrichment of *P. ostreatus* with Na_2SeO_3 amended coffee husks, it was noted that the fungi not only absorbs but also biomagnifies Se (da Silva et al. 2012). The Se-enrichment process does not affect the fungal capability towards biodegradation of organic substrate, i.e., biological efficiency. Notably, the enrichment process enhanced the bioaccessibility of other elements such as Fe, Mg, P, S, and Zn. Additionally, the Se bioaccumulation process favors the formation of more bioaccessible selenoproteins (Oliveira and Naozuka 2019). The in vivo bioavailability of Se in male Wistar rats fed with enriched *P. ostreatus* mushrooms and Na_2SeO_3 diets was studied. It was found that the total Se concentration in the plasma was higher in rats fed with enriched mushrooms than fed with Na_2SeO_3 diet. The results confirmed that the Se-enriched mushrooms are an alternative Se food source for humans than the inorganic forms, as it is present in more bioavailable organic form such as selenoproteins (da Silva et al. 2010). It was found that the selenomethionine is the dominant organic form in fruiting bodies, and Se-biofortification process enhanced the total protein and total phenolic content in comparison with unfortified mushrooms (Bhatia 2014). The organic Se is known to exhibit fungistatic activity against *Cladobotryum dendroides*, *Trichoderma harzianum*, and *Mycogone perniciosa*, and the IC50 values ranged from 31.7–67.6 μg/g (Savic et al. 2012).

Various studies carried out on button, oyster, and paddy straw mushroom species grown on Se-hyperaccumulated wheat and paddy straw, the antioxidant action was enhanced in terms of total phenolics, total antioxidant, 1, 1-diphenyl-dipicrylhydrazyl (DPPH) radical scavenging, metal chelating, and lipid peroxidation inhibition activities, in comparison with unfortified mushrooms (Bhatia 2014; Bhatia et al. 2014). The Se enrichment study carried out with organic form of selenium (selol) in edible and medicinal mushroom; *Hericium erinaceum*, the selenium containing exopolysaccharides (Se-EPS), were biosynthesized with a Se content of 4.8 mg/g. The produced Se-EPS in white rot fungus were evaluated for their in vitro antioxidant activities in terms of reducing power, lipid peroxidation inhibition, and DPPH radical scavenging assays. The Se-EPS exhibited potent antioxidant action in multiple tests and implicated its utility as dietary supplement and nutraceutical (Malinowska et al. 2009). The Se-enriched *G. lucidum* polysaccharide extracts (Se-GLP) demonstrated Se dose-dependent radical scavenging action, which is superior than the polysaccharide extracts obtained from non-enriched fungus (Zhao et al. 2008). In another Se biotransformation study carried out with *G. lucidum*, the inorganic Se was transformed to water soluble Se-containing protein with an elevated level of Se concentration (4.8 mg/g protein). The selenoprotein showed 3 times higher superoxide and hydroxyl radical scavenging activities and correlated its antioxidant action quantitatively with Se content (Du et al. 2007). In the case of *C. indica* cultivated on wheat straw supplemented with Na_2SeO_3 (5 μg/g), the fruiting bodies biotransformed the inorganic Se and accumulated the organic Se as selenoproteins (56–68%), polysaccharides (22–29%), and nucleic acids (1.4–2.7%). Also, the fortification process enhanced the total protein content in addition to threonine and cysteine levels. In turn, it also elevated the total phenolics, DPPH scavenging activity, and ferric reducing antioxidant power (FRAP), and a strong correlation was noted among polyphenols and antioxidant activities (Rathore et al. 2018).

Anticancer activity

Numerous earlier reports indicated that Se supplementation in diet is known to modify the different stages of carcinogenesis such as initiation, promotion, and progression. In this scenario, a study was carried out with female Sprague Dawley rats, in which the Se-fortified *A. bisporus* mushroom diet was fed, and 7, 12-dimethylbenz (a) anthracene (DMBA) was chosen as an experimental mammary carcinogen. It was found that the dietary addition of Se enriched white button mushrooms considerably enhanced the activity of both liver and mammary glutathione S-transferase and drastically suppressed the occurrence of DMBA-induced mammary epithelial cell DNA adducts. This study confirmed that the dietary supplementation of selenized mushrooms is an efficient means to retard chemically induced tumors (Spolar et al. 1999). In another cytotoxicity study against lung cancer cell line A549 employing hexane fractions of Se-fortified button, oyster, and paddy straw mushroom species, a higher proliferation inhibition was noted in comparison with unfortified control mushrooms (Bhatia 2014).

Importance of selenized mushrooms as functional food, nutraceutical, and diet supplement

The Se-biofortified mushrooms act as potential functional food, nutraceuticals, and diet supplements. The selenized mushrooms serve as functional foods, as they are fortified with Se and exhibit additional functions such as antioxidant and anticancer activities. The dietary intake of Se-fortified mushrooms as a functional food aids in the treatment and prevention of various conditions such as HIV infection, cancer, aging, cardiovascular, neurodegenerative, and immunological diseases (Cremades et al. 2012). Basically, the nutraceuticals are food-derived products which offer physiological and health benefits towards the prevention and treatment of various chronic diseases. The mushrooms cultivated on Se amended/hyperaccumulated substrate convert the Se into more bioavailable and less toxic form. It is important to note that more than 86% of the Se-containing compounds in Se-enriched mushrooms are organic in nature. Nearly 73% of the bioaccessible form is selenomethionine, and it is more bioavailable for an extended time than selenite (Bhatia 2014; Olga and Alla 2017; Witkowska 2014). In addition to their inherent culinary and nutrition values for human consumption, the recommended daily dose of 70 μg of Se can be achieved either through Se-enriched mushroom diet (Bhatia 2014; Rodriguez Estrada et al. 2009) or diet supplement derived from aqueous enzymatic extract of selenized mushrooms (Cremades et al. 2012).

Conclusions

As the edible and cultivated mushrooms are deficient in Se, their biofortification through substrate amendment is the need of the hour for a country like India. In India, agricultural residues are locally available and abundant, and a varied agro climate provides an opportunity for cultivation of wide variety of edible mushrooms. In comparison with non-fortified mushrooms, the cultivation of Se-enriched mushrooms generates more revenue for small and medium scale growers especially marginal, landless farmers; rural women; unemployed youth; and self-help groups leading to their sustainable empowerment.

In addition to their inherent culinary and nutrition values, the selenized mushrooms serve as multifaceted value added products such as functional food, nutraceutical, and diet supplements for human consumption. For commercial production in medium and large scale, technology development in terms of selection of Se form, optimization of dose and method of substrate amendment, amenability of mushroom species for fortification, biomass yield, morphological and chemical characteristics, cost effectiveness, organoleptic evaluation, etc. is warranted. Other aspects such as volatile selenium compound release during cultivation, safe disposal of spent compost, and Se leaching into ground water should be evaluated. Also, studies are needed on impact of cooking and traditional preservation methods on Se availability from mushroom meal to humans. Further studies are needed on toxicity, therapeutic dose for each disease, accumulated Se content in tissue and in circulation, and pharmacokinetic and pharmacodynamics of Se, after dietary supplementation of Se-enriched mushrooms. Besides, food labeling of Se-fortified mushrooms meeting the guidelines of regulatory agencies such as Food and Drug Administration (FDA) is required.

Abbreviations

AICRPM: All India Coordinated Research Project on Mushroom; DMBA: 7, 12-dimethylbenz (a) anthracene; DPPH: 1, 1-diphenyl-dipicrylhydrazyl; FDA: Food and Drug Administration; FRAP: Ferric reducing antioxidant power; ICAR-NRCM: Indian Council of Agricultural Research-National Research Centre for Mushroom; Na_2SeO_3: Sodium selenite; Na_2SeO_4: Sodium selenate; $NaHSeO_3$: Sodium hydrogen selenite; Se: Selenium; Se^0: Elemental selenium; Se-EPS: Selenium containing exopolysaccharides; Se-GLP: Se-enriched *Ganoderma lucidum* polysaccharide extracts; SeO_2: Selenium dioxide

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Authors' contributions

The author alone was involved in the data collection, compilation, writing, and interpretation during the manuscript preparation. The author read and approved the final manuscript.

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