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A Useful Way to Dispose of Phenolic-rich Agro-industrial Wastes: Mushroom Cultivation

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Abstract

The by-products resulting from the agricultural productions are arised in extrem quantities every year. Some agricultural by-pruducts such as olive press waste, green wallnut husks, tea wastes, coffee pulp etc. have been recognized as phenolic-rich wastes. The high polyphenol content in these wastes could have negative impact on soil and flora, if they are not disposed properly. Moreover, some studies have investigated the toxicity of phenolic compounds on aquatic organisms. Burning of these wastes may cause to increase amount of carbondioxide in atmosphere. Conversion of phenolic-rich wastes by different processes is therefore a desired aim. Mushroom has been used either as a therapeutic and protein-rich foods for many centuries. Mushrooom cultivation on agricultural wastes could be a promising method to reduce the the environmental pollution problems as well as production of tasty and healty foods. This paper reviews the potential uses of phenolic-rich materials as substrate in cultivation of edible and medical mushrooms.

Key words

coffee husk, grape pomace, green walnut husk, mushroom cultivation, olive press wastes, tea wastes

1. INTRODUCTION

Phenol is aromatic hydrocarbon and produced through both natural and anthropogenic processes [1]. US Environmental Protection Agency classified phenols as Priority Pollutants. They exhibit several toxic effects including chromosomal aberrations [2], endocrine disrupting effect [3,4], serious kidney and liver damage [5], mutagenicity and carcinogenicity [6].

Phenolic-rich agro-industrial wastes have no value as commercially. If inattentively disposed of in the surrounding environment by burying, burning, or dumping at unplanned and uncontrolled landfills, these wastes lead to climate change and environmental pollution. For that reason, there is a tendency to find a way to converte into valuable resources through proper management, with their utilization leading to reduced environmental pollution and further economic growth. Phenolic-rich agro-industrial wastes have potential to biochemically dissolved to produce several products like production of biogas, bio-ethanol etc. These wastes could also represent a possible source for mushroom cultivation as growing substrate.

Mushrooms are distinct both from plants and animals and belong to a separate group in the Fungi Kingdom. They are classified as a group of macrofungus. Chang and Miles [7] have defined mushroom as a macrofungus with a fruitbody, large enough to be seen by the naked eye and to be taken by hand. They have not got leaves, buds or flowers, yet, they form fruit and produce spores. Mushrooms, can synthesize and excrete different enzymes to degrade lignocellulosic materials such as and forestry residues, which can then be absorbed by the mushrooms for their nutrients [8]. Recent estimates of the number of fungi on the world changed between 2.2 and 3.4 million species [9].

Wild mushrooms are consumed by humans since ancient times. But commercial mushroom cultivation was started in France in 1650's by Agaricus bisporus cultivation. Mushroom production has increased steadily after World War II, and the production of edible and medical mushrooms such as Pleurotus spp., Lentinula edodes, Flammulina velutipes, Ganoderma lucidum have also shown great increase in the past few decades [10]. The total production of mushrooms in the world was only 1 million ton in 1978 [11] whereas the world production of cultivated edible mushrooms reached 34 million tones in 2013 [12]. During those 35 years, production increased by 3300%.

Technologies and innovations for human development are expanding every day. The world population have reached 7.6 billion inhabitants as of May 2018 [13]. It is estimated to reach 11.2 billion in 2100. However, humankind, particularly in some less developed countries, face three basic problems such as inadequate nutrition, increasing health problems, and increasing environmental pollution [14]. It is expected that the importance of these problems is set to rise as the world's population continues to increase.

Mushroom cultivation techniques is gaining importance in recent years to reuse or disposal of the solid organic wastes. Mushrooms can convert lignocellulosic materials into high quality food rich in protein, vitamins, dietary fibres, mineral salts and low in fat [15,16]. Taste of mushrooms frequently is descirebed as umami. Mushroom cultivation is not only a source for tasty and protein-rich food, it can also contribute to the production of effective medicinal products [14,17,18]. Many species of mushrooms have been used in traditional medicine for thousands of years. Mushrooms contain several biologically active substances including high-molecular-weight polysaccharides, glucans, chitinous substances, lectins, and secondary metabolites such as terpenoids, phenols, alkaloids, antibiotics.

Many of phenolic-rich agricultural wastes, such as tea waste, viticulture waste, tea waste, coffee pulp etc. can be provided at abundant and inexpensive cost in the different part of the world. Use of phenolic rich wastes as a raw material in cultivation of mushroom could be also useful ecological and environmental as well as economical. Kües [19] reported that Basidiomycota mushrooms are useful tools for the degradation of uncontrollable pollutants such as phenols, polyaromatic hydrocarbons, bisphenols, phenolic or non-phenolic textile dyes, halogenated aromatics, , naphthols etc. White-rot fungi can secrete some ligninolytic enzymes such as peroxidases and polyphenol oxidases destroying phenolic compounds [20,21].

As you can see, mushroom cultivation could be may contribute to the solution of these three key underlying problems that mentioned before. Finally, the aim of the presented review is to discuss the disposal of phenolic content rich agricultural wastes by mushroom cultivation. Moreover, the ability of mushrooms to remove phenolic compounds has also been investigated.

2. USES OF SOME PHENOLIC-RICH AGRO-INDUSTRIAL WASTES ON MUSHROOM CULTIVATION

A huge amount of phenolic-rich agro-industrial wastes and effluents are produced every year through the oil, juice, beverage, wine industries. These wastes are lignocellulosic, rich in source of nutrients, abundantly available and cheap. They contain high concentration of oil, phenol, lignin, cellulose, hemicellulose, ash, nitrogen and dissolved solids as shown in Table 1. In the following section, some of studies about the possibility of using of these phenolic rich agro-industrial wastes as growing media in the mushrooms production were presented.

Table 1. The composition of some of phenolic-rich agro-industrial wastes

	Ash (%)	Lipits (%)	Protein (%)	Hemicellulose (%)	Lignin (%)	Cellulose (%)	Sources
Olive press cake	1.4-2.4	3.9-8.7	2.9-4.8	7.9-11.0	8.5-14.2	14.5-24.1	[22]
Grape pomace	5.5	-	12.2	-	2.2-2.3	-	[23,24]
Tea waste	5.2	-	12.3	18.9	37.8	28.8	[25,26]
Coffee husk	5.4	0.5-3.0	8.0-11.0	7.0	9.0	43.0	[27]
Green walnut husk	1.86	-	8.3	3.5	13.5	17.7	Atila, F. (unpublished)

2.1. Olive Mill Wastes

Olive mill wastes are major environmental problem in Mediterranean Basin, due to its high phenol concentrations, that have a toxic impact for water, air, plants and soil microorganisms [28,29]. The two-phase extraction system generated about 0.8 ton of solid waste for per ton of processed olives [30]. According to the data, annual production of olive mill wastes reaches to million of tons in the world. So, large amounts of generated olive mills wastes should be disposed by appropriate methods to prevent environmental damage.

Kalmış and Sargın [31] suggested that 25–50% concentrations of olive mill wastewater (OMWW) can be used at for the moistening of the wheat straw substrate for Pleurotus sajor-caju and Pleurotus cornucopiae var. citrinopileatus cultivation. This can be a promising alternative method for the mushroom cultivation and disposal of OMWW. However, 75% OMWW or 100% OMWW was not adaptable with cultivation of these mushroom species. Zervakis et al. [32] also reported that the 75% OMWW has toxic effects on mycelial growth and yield of Pleurotus eryngii and Pleurotus pulmonarius. It was determined that when 75% OMWW was used in wetting of substrates, colonisation period was prolonged and BEs of Pleurotus eryngii and Pleurotus pulmonarius decreased 50%.

Kalmış et al. [33] investigate the feasibility of using OMWW as an alternative moisturing agent for Pleurotus ostreatus cultivation. Moreover they determined that effect of OMWW on some food quality characteristics of mushrooms. the use of 25%OMWW was suitable for P. ostreatus cultivation. Although food qualty was not effected by increasing concentration of OMWW in the moisturing mixture, fruitbody shape was deformed in high concentrations of OMWW. The use of OMWW up to 25% as moisturizer could be suggested for Pleurotus ostreatus cultivation. In adition, it could be an an environmentally friendly and pratical solution for disposal of OMWW

Ruiz-Rodriguez et al. [34] used wheat straw supplemented with 0 up to 90% olive mill waste for cultivation seven Pleurotus ostreatus strains. They reported that all P. ostreatus strains could grow but high OMW concentrations resulted in a prolonged cultivation period, losses of yield, biological efficiency and fruiting bodies quality. OMW concentrations did not affected total phenolic content and antioxidant activity of fruitbodies and phenolic compounds from OMW were not detected in the fruiting bodies.

Atila [35] reported that sawdust substrate could be supplemented with 25-75% portions of OMW to prepare the growing media for Pleurotus djamor, Pleurotus eryngii and Pleurotus citrinopileatus cultivation and using OMW as a substrate in mushroom cultivation provides an eco-friendly method for disposing of OMW.

Altieri et al [36] and Parati et al. [37] suggested composted olive mill solid waste for cultivation of Agaricus bisporus.

Koutrotsios et al [38] reported that Hericium erinaceus exhibited high yield in OMWW and olive pruning residues-based media. Moreover it was observed that phenolics and toxisity were decrease on OMWW. Uses of olive press cake was also suggested for Hericium erinaceus [39] and Hericium americanum production [40] in other previous studies.

According to results from several studies, using by-products from the olive oil industry in mushroom cultivation could help to reduce the environmental impact and production costs.

2.2. Grape Pomace

Grape (Vitis spp.) is produced 70 million tons every year in the world [41]. Grape pomace, consisting of the seed, skin, and stem, is the main solid organic waste from winery industries. Grape pomace represent, in general, 20–30% of the original grape weight [42]. This waste has highly lignified fibre, so its use as animal feed is limited. Morever, these residues also have highpolyphenol content. Makris et al. [43] reported that that extracts of grape seeds (either white or red) contain 10.3–11.1% of total polyphenols. Christ and Burrit [44] reported that the wine industry might have a negative impact on local water resources.

A relatively few studies have focused on the use of grape pomace as a substrate for mushrooms production. Koutrotsios et al [45] cultivated Pleurotus ostreatus, Pleurotus eryngii, and Pleurotus nebrodensis on growing media containing grape marc substrate. Grape marc substrates led to large increase of fruit-bodies content in total phenolics, antioxidant activity, β-glucans as well as mushroom yield.

Sanchez et al [46] evaluated the bioconversion of vineyard pruning and grape pomace by cultivation of Pleurotus spp. Biological efficiency and bioconversion of vineyard pruning and grape pomace ranged from 37.2 to 78.7% and from 16.7 to 38.8%, respectively. They suggested that uses of viticulture residues on Pleurotus spp. cultivation has great potential.

Pardo et al. [47] composted by- products from grape cultivation and wine industry such as vine shoots, grape stalks and grape pomace under controlled conditions for cultivation of two varieties of Agaricus bisporus. It was reported that composted vine shoots, grape stalks and grape pomace did not exhibit higher biologically efficient than traditional compost, but these substrates could be economically viable and environmentally advantageous.

2.3. Coffee Husk

Coffee is the second largest traded product in the world after petroleum Grape (Vitis spp.) is produced 70 million tons every year in the world [48], The coffee industry creates The coffee industry generates over ten million tonnes of residues in the world every year [49]. Generally, most coffee husk is burned to remove this toxic waste.

These by-products are rich in nutrients, caffeine, tannins and polyphenols [50]. Phenolic content of coffee husk limits the uses of it [51]. Maziero [52] studied the production of Pleurotus with coffee husk for, but it was no obtained success. Beaux and Soccol [53] used the coffee husk for Lentinus edodes production. They reported poor mycelial growth in comparison to other substrates in this substrate. Tan and Chang [54] studied the effect of tannic acid and caffeine on the growth of L. edodes. The results showed that tannic acid and caffeine have a toxic effect on the growth of L. edodes. Fan et al., [55] reported that the toxic content was higher in the coffee husk than that in the coffee pulp. Previous studies shown that immersion in water [56] or boiling [57] the coffee husk can be and effective method to remove toxic compounds from the substrate and to increase mushroom yield. Martinez et al. [58] confirmed that the toxic materials can be minimised by hot water treatment, but it also was noted that the other residue (waste water) would lead to environmental pollution [59].

On the other hand some previous studies showed that Pleurotus ostreatus has ability in producing fruiting body in coffee husk and coffe pulp. Leifa et al. [60] investigated the possibility of using coffee husk and coffee spent-ground as substrates for the cultivation of Flammulina velutipes. They reported that using as substrate coffee husk and coffee spent-ground is appropriate for cultivation of F. velutipes. evaluated the feasibility of using coffee husks as substrate for P. ostreatus and and P. sajor-caju cultivation. They reported about 97% of BE P. ostreatus. The results of Fan et al. [55] showed that it is possible to use coffee husk for Pleurotus spp. cultivation.

2.4. Tea Wastes

Tea is one of the most popular beverages in the world. A large amount of tea waste is left after extracting water-soluble components from tea leaves. Therefore, accumulated tea waste is a significant problem for many tea processing industries.

Yang et al. [61] suggested that the substrates containin 40–60% tea waste could be used as growing substrate for Pleurotus ostreatus cultivation substrate with high yield, biological efficiency and relatively shorter cropping time. It was investigated that the possibility of using tea production waste as a new casing material in Agaricus bisporus cultivation by Gülser and Pekşen [62]. They did not suggest using tea production waste alone as a casing material in Agaricus bisporus cultivation, but also they reported a mixture of tea production waste with peat in 1:1 (v:v) ratio increased the mushroom yield. Chukowry et al [63] obtained satisfactory results from substrate mixture containing 75 % sugarcane bagasse and 25 % tea wastes on cultivation of Pleurotus ostreatus. They reported using tea wastes as supplement material to prepare mushroom growing medium could reduced cost of fruiting bag preparation. Baktemur et al. [64] suggested that tea waste can be used successfully as substrate material in Pleurotus cultivation. Tea waste was also used in Ganoderma lucidum production by Peksen and Yakupoglu [26] and the successful results were obtained.

2.5. Green Walnut Husks

The consumption of walnuts is increased by the highly nutritional properties of the seed as well. The main by-product of walnut processing is the green husk. Generated amounts of green walnut husk are quite high. Yılmaz et al [65] reported that the ratio of fresh green walnut husk biomass to total fresh green walnut biomass varied between 65.37%-43.22%. There is a low utilization ratio of green husk because of its taxic content, called juglone. Juglone is an organic compound and occurs naturally in leaves, roots, husks, and bark of plants in Juglandaceae fam¬ily [66]. Also, Stampar et al. [67] has shown that within walnut green husk, juglone is the major phenolic compound. Burying or spreading of green walnut hulls to the soil can cause phytotoxicity. Several studies showed that juglone has inhibito¬ry effects [68,69] and allelopathic activity on several plants [70].

To the best of our knowledge, no study has been conducted to date on the use of green walnut husks in the preparation of mushroom growing media. The high quantities of these waste materials indicate the need for their assessment as an economical substrate for mushroom cultivation. Using green walnut husk on mushroom cultivation could provide extra income to walnut producers and help disposal of green husk.

3. DEGRADATION OF PHENOLIC COMPOUNDS FROM AGRO-INDUSTRIAL WASTES BY MUSHROOMS

It is also possible to enhance nutrition quality of agricultural wastes through mushroom cultivation. It has been emphasized in many studies that protein and mineral content of the agricultural wastes may be increased by mushroom cultivation [393,40,60]. In addition to improving the nutrient content of the agricultural wastes, several studies are focused on the elemination of phenolic compounds. Ntugias et al [71] evaluated utilization of olive mill wastewater for cultivation of 49 diverse white-rot strains. They found that using of olive mill wastewater for cultivation of white-rot fungi resulted to the increments of total phenolics (>60%) and reduction of color in mushroom fruit bodies. Morever, culture extracts from some strains reduced olive mill wastewater phenolics within a nine days period.

Tsioulpas et al. [62] investigated the ability of several Pleurotus spp. strains to eleminate phenolic compounds from OMW. In addition, they also studied the toxicity of the treated substrates, in order to select strains able to detoxify OMW. They concluded that Pleurotus spp. strains can be grown in OMW and the strains have ability to remove a significant portion of phenolic compounds from OMW.

Zerva et al. [73] reported the use of OMWW for mushroom cultivation can lead to valorization of this toxic waste but also they highlighted the ability of Pleurotus citrinopileatus LGAM 28684 and Irpex lacteus LGAM 238 species in terms of complete degradation of the phenolics content in OMWW. Saavedra et al. [74] suggested Pleurotus ostreatus was effective in elemimation of phenolic compounds, the initial concentration in the wet olive cake being reduced by around 90% in the wet olive cake treated with P. ostreatus. They reported the spent substrate could be used as soil amendments. Sanchez et al. [46] also reported some antinutritional factors of grape pomace such as phenolic components can be diminished by Pleurotus spp. using a solid state fermentation. Echeverria and Nuti [49] reported that caffeine (60%) and tannins (70%) content decrease in coffee husk after mushroom cultivation.

Wong and Wang [75] demonstrated that Pleurotus sajor-caju has ability to elemination of tannin in coffee spent ground. Brand et al. [76] reported the content of caffeine and phenolic compounds in coffee pulp as 0.75% caffeine and 3.7% phenolic compounds, while in coffee husks it was 1.2% caffeine and 9.3% phenolic compounds. It is noted that the toxic compounds (caffeine and phenolic compounds) in Brazilian coffee husk are much higher than in coffee pulp, so it is more difficult to treat coffee husk than pulp.

Fan et al. [55] evaluated use of coffee husk for Pleurotus ostreatus and Pleurotus sajor-caju cultivation. It was determined tanin content (79.2%) and caffeine content (60.7%) was decreased in substrate after cultivation. Although tannic concentration decreased in the medium, it was not determined tannic acid in the mycelia. This result concluded that Pleurotus spp. had the capacity of degrading tannic acid.

Sampedro et al [77] reported that olive mill waste is a promising substrate for mushroom cultivation. However, mushroom need long colonization times to reach stabilization of the organic matter and for removal of toxic content from the waste.

Leifa et al. [60] reported that caffeine (10.2%) and tannins (20.4%) contents decrease in coffee husk after Flammulina velutipes cultivation. The decrease of tannin content was 28% in coffee spent ground. They [60] suggested that caffeine or tannins were not adsorbed by F. velutipes fruitbody. They attributed the decrease in caffeine or tannin content of spent mushroom substrates to degradation of these contents by the mycelium. However Echeverria and Nuti [49] reported that caffeine was found in the fruiting body in some cases and this is a evidence that caffeine was not completely degraded.

Concluding Remarks

Accumulation of phenol-rich agro-industrial wastes in large quantities in places or disposal of them by burning causes environmental problems. The enzymes of Basidiomycota are efficient tools for the destruction of phenols from agro and industrial wastes. The use of phenolic-rich agricultural wastes for production of mushroom is a promising method of elemination these toxic contents. Phenol-rich agro-industrial wastes are rich in nutrient composition as well as bioactive compounds. The use of these wastes as mushroom growing substrates not only help to solve environmental problems, but also can prevent loss of valuable materials and reduce the mushroom production cost. Furthermore, phenolic-rich agro-industrial wastes can improve health preventive compounds in fruitbody such as antioxidants. Thus, mushroom production and distribution can serve as agents for promoting healthy society.

In conclusion, mushroom cultivation can lead to a agricultural revolution in the world, especially in less-developed countries. It has a great potential for generating great environmental and socio-economic impacts in human life. Moreover, spent mushroom substrates could be used to feed ruminants because toxic content decrease while protein increase.

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