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Phytoremediation potential of bamboo plant in China

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ABSTRACT

Phytoremediation is the use of plants as an organic factor in order to eliminate pollutants from soil, air, or wastewater in a cost-effective way. It can remove contaminations with five mechanisms including: Rhizosphere Bioremediation, Phytostabilization, Phytotransformation, Phytoextraction, and Rhizofiltration. One of the important aspects of phytoremediation systems is using native plants with high biomass and high ability in stress tolerance. Bamboo species cover a major part of China's forests, with over 500 species at 48 genera in tropical and sub-tropical regions with some special characteristics, including fast growing and high biomass Productions, which can be an appropriate option to use as a phytoremediation system. Different parts of a bamboo, including roots, shoots, rhizomes, leaves, and fibers can aid in environmental cleanup by removing contaminations from wastewater, air, and soil. This can cause the accumulation of pollutants in different bamboo organs, reducing anthropogenic CO2 emission with carbon sequester, and storing carbon in plant parts. The aim of this review work is to first investigate the phytoremediation system mechanisms in plants and then introduce bamboos as a successful plant for phytoremediation by assessing the role of roots, shoots, and fibers of bamboo plants in phytoremediation .

Key word : *Phytoremediation, Bamboo, Forest, Contaminations*

Introduction

In the present century, heavy metals arising from anthropogenic activities are some of the fundamental problems with agricultural soils (Xu *et al.*, 2016; Mahmoud and Ghoneim 2016), which have covered approximately 2.0×10^7 ha of China farmlands (19.4% of total farmland) (Shen *et al.*, 2016; Yao *et al.*, 2012; Yan *et al.*, 2015). It is reported that Cd, Cu, Pb, and Zn have the largest distribution of contamination in China soil by 7%, 2.1%, 1.5%, and 0.9%, respectively(Chen *et al.*, 2016). The main sources of anthropogenic activities in soil contamination in China farmlands are: industrial activities, sewage irrigation, sludge application, waste disposal, mining, and agricultural fertilization(Sun et al. 2016,Li et al. 2014). Basically, metals and metalloids,which are called heavy metals (because their high densities are more than 6gcm^{-3}) couldbedivided into essential (Cu, Zn, Mn, and Co) and non-essential metals (Pb, Hg, Cr, and Cd)(Khan et al. 2015,Park et al. 2011). Nonessential metals are significant threats to human and animal health because of the accumulation character in edible parts of vegetable and crops (Yan et al. 2015).Additionally, too much consumption of them can accumulate non-essential metals in the body's organs, causing deleterious effects on human health, especially in children (Qing et al. 2015,Li et al. 2015). Using plants for decontamination is one of the cheapest methods tophytoremediation. it works

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well in conjunction with the environment for removing heavy metals and pollution from soil, wastewater, and air. More precisely, phytoremediation is using plants as a sink of pollution proceeded to absorb contaminations especially heavy metals (Wang *et al.* 2011; Chen *et al.* 2016; Li *et al.* 2015; Chen *et al.* 2015; Ali *et al.*, 2013). Biomass obtained from phytoremediation in phytoextraction cycle can thenbe used as an energy source (Witters *et al.*, 2012). Phytoremediation in plant cells with accumulation process, especially in apoplast or symplast, plays an important role in the sequestration and degradation of heavy metals from soil (Nagendran *et al.*, 2006). On the other hand, the use of indigenous and native plants with the ability of high bioaccumulation in polluted regions can have a significant impact on reducing operating costs (Chehregani *et al.*, 2009). Meanwhile, bamboo has a significant importance as itis a fast-growing plant with the ability to keep pollution in roots, shoots, and fibers; therefore,itisknown as ''green clean'' in public places and energy productionzones among plants (Ali *et al.*, 2013). Bamboo is known as one of the most non-timber forest products with several utilizations which make it very suitable for some economic and ecological conditions (Huda *et al.*, 2012; Bai *et al.*, 2016). Bamboos are considered to be a new industry because of: 1-high growth rate(over 1 m in 24 h) (Ahvenainen *et al.*, 2017), 2-high power of spread in a short time (because of one unique system of root rhizome) (Wang *et al.*, 2016a; Wang *et al.*, 2016b; Changand Shiu, 2015) 3- large woody body (more than 30 cm in diameter and 12 m in height) (Huang *et al.*, 2016b; Huang *et al.*, 2016a), 4-havingsome characteristics such as strength, light colour, and high quality of wood, and most importantly, 5- beingwidely distributed and abundance inChinasothatitisknown as the second forest resources (Liu 2012). In addition, bamboo plants play a significant role in bioenergy programs and environmental management in comparison with other typesof trees because of its highcapacity to store carbon and its high oxygen emission rates (Bhandawat *et al.*, 2017). Different species of bamboo can absorb more than 62 tons of CO_2 in hectare every year (Krausea *et al.*, 2016) and can stock more than 10% of carbon forest ecosystems in China (Tang *et al.*, 2015). Bamboo species cover more than 5.38 million ha of China forest, where more than 70% of them are moso bamboo. This issue, together with high ability of biomass production and fast growing rate, caused moso bamboo to be of great importance in the bamboo family in China (Guan *et al.*, 2015). Numerous studies have been done on different bamboo utilizations, however there is not sufficient information about phytoremediation in bamboo, which can play an important role in wastewater treatment, soil contamination removal, and improvement of local climate in industrial areas and urban territories. This review was carried out to introduce the important role of bamboo in phytoremediation system in south of China, where bamboo is the dominant plant in the forests, and to investigate the phytoremediation mechanisms in plant and bamboo species.

Bamboo distribution in China

Bamboo plants belong to Gramineae (Poaceae family) and could be classified as a subfamily of Bambusoideae, which is a perennial woody and evergreen plant with cost-effective agricultural and forestry products (Chehregani *et al.*, 2009; Huang *et al.* 2016a; Jin *et al.*, 2016). Bamboo plants have made a large contribution in China forests (Yan *et al.*, 2015, Huang *et al.*, 2016a**)**. There are more than 1250 species at 75 genera of bamboo on the earth (Yang *et al.* 2008), which is over 30 million hectares (Dixon *et al.* 2016); among them, over 500 species at 48 genera grow in China, which cover tropical, sub-tropical, and temperate regions (Yang *et al.*, 2008; Huang *et al.*, 2015) with temperature ranging between 16°C and 38°C, rainfall between 1200 mm to 4000 mm, and altitudes between 770 m and 1080 (Yang *et al.*, 2008), especially in the south of Yangtze river (Wu *et al.* 2016).

This Chinese local plant has played a significant role in bioresources and phytoremediation programs because of the high growth potential and short maturation period (3-8 years) (Bhandawat *et al.* 2017).

Phytoremediation

Phytoremediation is one of the most organic, low-cost, and novelty methods to remove contamination, especially heavy metals, from the environment. It can be conducted in five ways.

(1) Rhizosphere Bioremediation: this process uses the activation of root exudates and enzymes in Rhizosphere, accumulates the organic carbon in soil, transfers the contamination from soil and water to areal organs, and volatilizes the pollutants by Phytovolatilization.
(2) Phytostabilization: this process cannot reduce

pollution from the waste site, but it can stabilize the waste site with erosion control and decrease the mobility and phytoavailibility of contaminants for plants.

(3) Phytotransformation: this process is one of the plant defense mechanisms for using plant capacity to tolerate toxicity.

(4) Phytoextraction: this process uptakes and absorbs contamination by plant biomass, transfers contamination from soil and water to plant biomass, and stores them to show the plant resistance.

(5) Rhizofiltration: this process mostly uses the filtration of wastewater and pollution by absorbing them into roots (Zhang *et al.,* 2010; Rahman and Hasegawa, 2011).

These five mechanisms occur in most plants along with phytoremediation. Additionally, plants as organic 'pumps' are able to pull in large amount of contaminated water from soil and wastewater and do the transpiration process. This shows the considerable and important role of plants in preventing the contamination of groundwater (Susarla *et al.,* 2002). Also, Phytoremediation can reduce soil contamination with some mechanisms, including abiotic losses (such as volatilization, photodegradation, leachate, and irreversible sorption), alternation in roots exudate and root tissues with enhancing biodegradation and dissipation, and microbial degradation (Wang *et al.,* 2011). Microbial in roots and rhizosphere can directly increase the phytoremediation by improving the metal translocation in phytoextraction process, reducing metal mobility in rhizosphere area through the phytostabilation process, and indirectly by enhancing the plant metal Torrance and improving the producing of high biomass (Rahkumar *et al.,* 2012).

Phytoremediation potential of bamboo species

Having high biomass production and a fast growing rate are the dominant characteristics of some types of plants, such as bamboos, that facilitate phytoremediation (Rahkumar *et al.,* 2012). Moreover, other characteristics, such as a wide root system, quick harvest, and plant tolerance to abiotic stresses, which are remarkable in choosing phytoremediation plants(Yang *et al.,* 2005), make bamboos an appropriate option for phytoremediation. Furthermore, considerable contribution of China forests, high pores in micro sizes, and the ability to absorb carbon on a large scale have introduced bamboo as a phytoremediation plant and caused it to be a considerable topic for researchers in the field of pollution control (Zhu *et al.,* 2010). In one study in 2007, the data obtained by the research indicated that damage of bamboo forest caused by winter storms increased the soil organic carbon (SOC); this issue revealed the important role of bamboo plants in the accumulation and fixation of carbon in environment (Liu *et al.,* 2016). Bamboo as a woody plant with a large body, high biomass production, and fast maturation period can play an important role in carbon storage in global carbon cycles (Yen, 2015). Bamboo plants can be considered as cheap tools to remove pollution in air, soil, and water in comparison to other available methods. Bamboo charcoal has the high capacity to absorb and remove heavy metals, nitrate –nitrogen, gases, and foams from the environment (Ma *et al.,* 2010). Bamboo leaves have also been identified as an effective tool to remove dye pollution in wastewaters (Zhu *et al.,* 2016).

The role of bamboo roots, shoots and fibers in phytoremediation

Plants with high production of root biomass, such as bamboo, can be an appropriate option for phytoremediation(Gerhardt *et al.,* 2009). The rhizofiltration process in bamboo leads to the widespread growth of plant roots in wastewater and contaminated area. Then, the roots absorb the contamination existing in wastewater, take up the pollutions, transfer them to plants organs, and accumulate and remove them by mechanisms such as Phytosorption, Phytovolatilization, and Hydraulic pumping systems in plants(Nagendran *et al.* 2006; Pulford and Watson, 2003). Roots, in plants such as bamboo species, play an important role in removing heavy metals by releasing protein in hypo accumulation. Then, by acidification of soil, they create good conditions for the mobilized metal ions in soil and the enhancement of metal bioavailability(Wu *et al.* 2010). In root cells, most of heavy metals bind to peptide and anionic groups and are stored in the vacuole. This mechanism can prevent heavy metal transfer to areal organs and protect plant photosynthesis and metabolism. This matter indicates the vital role of plants roots in heavy metal accumulation (Rascio and Navari-lzzo 2011). However, a small amount of contamination is mineralized to carbon dioxide and water (Alkorta and Garbisu, 2001). The result has shown that there is a large amount of Carbon in the underground root system of a bamboo plant (Wang *et al.,* 2016) that expresses the significant role of roots in carbon fixation in the environment. Phytoremediation in shoots occurs by phytoextraction of heavy metals from contaminated soil and accumulating them in areal organs, especially in shoot plants; this process works well in plants with high biomass product such as bamboo (Nagendran *et al.,* 2006). In bamboo plants, the harvest of root biomass is not virtually conceivable (Ali *et al.,* 2013). Bamboo shoots can also have an important usage in biochar to remove contaminations like heavy metals from soil and reduce global concerns by sequestering C in the atmosphere into soil (Lu *et al.,* 2017). Numerous studies have shown the role of bamboo shoot biochar in the elimination of perrhenate from aqueous solution (Hu *et al.,* 2016) and the reduction of bioavailability heavy metals in soil (Lu *et al.,* 2014). Therefore, bamboo shoots can also play a major role in phytoremediation. Fiber structure of bamboo is known as one of the largest sinks of C among different types of plants. Bamboo species can absorb CO_2 in atmosphere, sink C in root and shoot fiber structure, convert it to O, and finally return it to the environment. This is the benefit point for bamboo utilization after harvest and use in industry (Sijimol *et al.,* 2016) that can help us to reduce harmful greenhouse gases (Arfi *et al.,* 2009).

Phytoremediation potential of bamboo charcoal

Charcoals, according to carbon activities, is able to remove contamination, especially heavy metals from water and air. Thermal decomposition of charcoal is basically conducted according to this formula (Lalhruaitluanga *et al.,* 2010):

$$C_6H_{12}O_6 \xrightarrow[500\text{–}700\ \%C]{} 6C + 6H_2O$$

Bamboo charcoal, obtained from burning old bamboo in ovens at high temperature, can be used in water purification, protection against detrimental rays and waves, and insulation for humidity and odor control (Zhu *et al.,* 2012; Wang *et al.,* 2010). Bamboo charcoal is important because of the extent of the pores area compared with charcoals obtained from other plants. The pores can aid greatly in the water purification process by absorbing heavy metals in water (Lalhruaitluanga *et al.,* 2010). A comparison between bamboo charcoal and woods charcoals indicated one Significant increase in Number of holes, Mineral constituent, Absorption efficiency and Inner surface in bamboo charcoal (Lou *et al.* 2007). Efficiency of bamboo charcoal in the absorption and removal of pollution has been revealed in several studies, including the absorbance of nitrate –nitrogen by bamboo charcoal (Mizuta *et al.,* 2004), studies regarding heavy metals, and the absorbance of microbes by providing rich nutriment because of large space surface of bamboo charcoal (Lou *et al.* 2007).

Phytoremediation potential of Moso bamboo

Moso bamboo (phyllostachys pubescens, phyllostachys edulis), as one of the highest hypera accumulator species, has accounted for more than 70% of the bamboo family in China forests (Li *et al.* 2015; Guan *et al.* 2017; Tang *et al.,* 2016; Zhou *et al.* 2016b), and 80% of bamboo forest regions over the world (Song *et al.,* 2017; Song *et al.,* 2016). It is more than three million hectares of China forest (Zhou *et al.* 2016a; Huang *et al.* 2016; Wang *et al.* 2016a; Yuan *et al.* 2015) in subtropical regions (Li *et al.,* 2016; Song *et al.* 2016). Moso bamboo can grow in an altitude between 10 to 1700 meters above the sea level; however, in China, they are usually found in the elevations less than 800 m in mountain and hills (Zhang *et al.,* 2015). Moso bamboo is known as fastest growing plant in the world. It can grow up to 100 cm daily and 15-24m high in period of 40 to 60 days (Bai *et al.,* 2016; Li *et al.,* 2016; Sun *et al.* 2016). Moso bamboos are distributed in bamboo forest areas along 12-13 provinces in southern China including Jiangsu-Shanghai-Hubei-Chongqing-Sichuan-Yunnan-Guangxi-Hainan-Guizhou (between $1^4 \times 10^4$ ha) 2-Anhui- Guangdong (between $10^4 \times 30^4$ ha) 3-Hunan (between $30^4 \times 50^4$ ha) and 4- Zhejiang-Fujian-Jiangxi (more than 50^4)(Bai *et al.,* 2016; Fu *et al.,* 2014). Because of high biomass in shoot and timber, they are known as an important eco-friendly species (Zhou *et al.,* 2016a; Wu *et al.,* 2015). Underground biomass concentration in moso bamboo is about 85.5 to 94.0 ton ha^{-1}, which shows their high biomass product compared with other forest plants, and the share of carbon in below-ground biomasses is about 34% of gross product (Fang *et al.,* 2016). The average of biomass accumulation in moso bamboo is about 96 g $\leq^1$, which is a considerable amount compared to other hyperaccumulator species (Li *et al.,* 2015). Moso bamboo is known to be one of the main resource sinks of carbon with the ability of carbon sequestration in environment (Mao *et al.,* 2015; Xiaolu *et al.,* 2016). It has been shown that the carbon sequestration capacity of moso bamboo is higher than other common plants in southern China, such as the Chinese Fir (Cunninghamia Lanceolata (Lamb.) Hook), loblolly pine (*Pinus Taeda* L.), and oak (Quercus variabilis Bl.) (Zhang *et al.* 2014). Climate factors play an important role in carbon storage by moso bamboo. A study on the effects of drought on carbon storage in moso bamboo forest indicated that carbon storage and net co_2 sequestration were 14.35% and 125.07% lower than the control plots, respectively, which revealed the role of climate change in the carbon cycle in moso bamboo (Li *et al.* 2003). Moso bamboo with fast growing character has the highest demand for carbon compared with other plants, especially in its "explosive growth" period (35 to 40 days after shoot emergence) (Song *et al.,* 2016). Another study showed thatthis kind of bamboo species has kept and stored about 611.15±142.31 Tg of C in moso bamboo forests in China, of which 75% of Carbon was accumulated in plant soil and 25% was accumulated in plant organs (Li *et al.,* 2015). The amount of carbon storage is different depending on the moso bamboo coverage area. For example, in one study it was shown that the amount in Jian-ou city in China is about 145.3 Mg ha^{-1}(Zhuang *et al.*, 2015). Features such as a fast growing rate, high biomass production (82 t hm^{-2} of dry weight), ability to deal with different environmental conditions (tropical and subtropical zones), and also adaptation to survive in some polluted areas such as mines made the moso bamboo to be a considerable species among others bamboo species in phytoremediation (Chen *et al.*, 2015; Chen *et al.*, 2015). The high accumulation rate in moso bamboo roots is more than shoots, stems, and leaves (Liu *et al.*, 2015). This means that an increase in heavy metals leads to a change in the roots and increases the capacity of accumulation. In leaves, however, heavy metal accumulation conducted with the reduction of stomatal opening (Liu *et al.,* 2015). Additionally, moso bamboo root with 19.2% of plant biomass and 19.8% of carbon storage in the plant has an important role in carbon fixation and redistribution into the soil (Song *et al.,* 2017). However, Dan Liu *et al.* indicated that moso bamboo shoots also have high ability in Zn accumulation. Therefore, this high capacity of heavy metal accumulation in shoot and roots compared with other plants makes moso bamboo a suitable plant for phytoremediation (Liu *et al.* 2014). In cellular studies, it was specified that moso bamboo is also able to accumulate heavy metals in cytoplasm and vacuoles. It was shown that cytoplasm is the main zone of Cd accumulation in moso bamboo (Li *et al.*, 2016), while Chen *et al.*, concluded that vacuoles are the main zone of Cu accumulation in moso bamboo (Chen *et al.*, 2015). Bin Zhong *et al*. in one experiment indicated that most of lead (Pb) accumulation was found in the cytoplasm and the rest was found in the cell wall and vacuole; this issue reveals the ability of Moso bamboo to accumulate the heavy metals in plant cells (Bin Zhong *et al.* 2016). Thus, it can be concluded that Moso bamboo is an effective species in detoxification and phytoremediation because of its high metal tolerance, high accumulation of heavy metals, and great amount of biomass (Liu *et al.* 2015).

"BAMBOU-ASSAINISSEMENT" technology

This could be an innovative technology to use bamboo species from two main types: monopodial and sympodial for the phytoremediation of polluted areas and wastewaters. This categorization is according to the native environment: sympodial is adapted to tropical climates, and monopodial is adapted to temperate climates (Arfi *et al.*, 2009; Collin *et al* 2014). An extensive system of rhizomes, roots, and new calms have an important role in the purification of wastewater with absorbing properties of contamination and reduction of air pollution with sink carbon. Additionally, high product of bamboo biomass has added value to this system, because of the fast growing nature of bamboo species (Arfi *et al.*, 2009). The result obtained from an experiment showed that sympodial bamboo is one of the most important species in the reduction and adjustment of contamination from the environment, which has most carbon storage and carbon sequestration rates covering 80×104 ha of lands in China (Teng *et al.,* 2016).

Conclusion

Undoubtedly, technological progress accelerates the emergence of environmental phenomena including contamination of soil, air, and water, especially in industrialized countries such as China. Several methods have been introduced to reduce environmental pollution. However, the essential point is using economical methods with minimal damage to the environment. Phytoremediation is one of the most cost-effective ways to remove pollutants and contamination from the environment. Phytoremediation with five actions, including Rhizosphere Bioremediation, Phytostabilization, Phytotransformation, Phytoextraction, and Rhizofiltration, can remove pollutions from the environment using some processes such as absorption, transfer, accumulation, and evaporation in plants. One of the main successful characteristics of phytoremediation is using native plants with the highest biomass products. Bamboo plants can be considered as a suitable option for phytoremediation systems because they are the fastest-growing plants over the world and have high versatility in China's climatic conditions. Bamboo species have a high ability to accumulate pollution in roots, shoots, rhizomes, and leaves, and also have high carbon sequestration that could be stored in fibers, rhizomes, and leaves. They can play an important role in reducing environmental pollution, filtration wastewater, soil improvement, conserving natural ecosystems, and improving local climate; that is why it is called ''green clean'' in public places. Moso bamboo, as one of the greatest and most important species of bamboo in China, can play a significant role in the contribution of bamboo species in phytoremediation system. The purpose of writing this article was to show the importance of bamboo as an environmentally friendly plant with high adaptability, which demonstrates the high capacity of phytoremediation with this plant. We hope that by considering the phytoremediation role of bamboo a better view of the other aspects of this useful plant is revealed, which may help us to understand why the propagation and planting of bamboo in urban environments is needed.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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