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Bioremediation potential of natural polyphenol rich green wastes: A review of current research and recommendations for future directions

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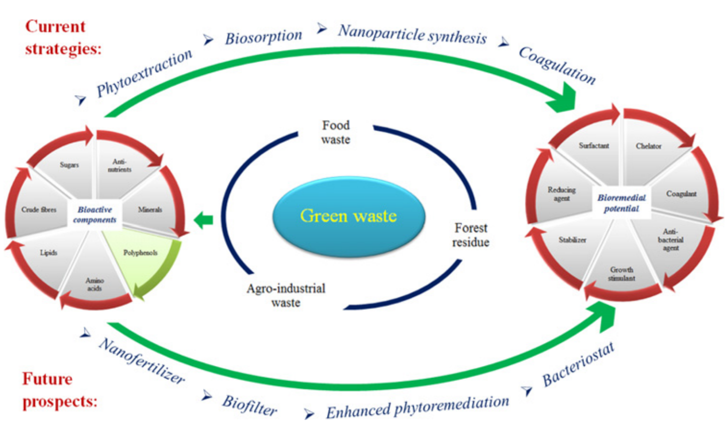
HIGHLIGHTS

- Food, agro-industrial and forest residues are the renewable sources of polyphenols.
- Total polyphenolic content of green waste range from 0.01 to 925 mg g^{-1} dry extract.
- Green waste offers eco-friendly and economical route to synthesize nanoparticles.
- Bioremedial traits of green wastes are biosorption, phytoextraction and coagulation.
- Natural polyphenol based nanoamendments or filters could be developed in the future.

GRAPHICAL ABSTRACT



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ABSTRACT

'Green waste' (food, agro-industrial and forest residues) is a renowned valuable resource of polyphenols. Natural polyphenols are relatively efficient in the clean-up of environmental pollutants based on their unique traits of chelation, adsorption, reduction, complexation, nutrient cycling, antibacterial effects and plant growth promotion. These significant traits have found emerging applications in the removal of heavy metals, pathogenic bacteria and dyes from contaminated soil and water through existing bioremedial techniques such as biosorption, phytoextraction and coagulation. Increasingly, polyphenol-rich natural extracts harnessed for green nanoparticle synthesis (production of particles between 1 and 100 nm in size using biological entities such as microorganisms or plant biomass) have found promising use as a remedial agent in the detoxification of toxic pollutants. However, current bioremediation approaches do not sufficiently exploit natural polyphenols, which are abundantly available and are non-toxic. This review examines the extent of natural polyphenol availability in green waste, and provides a critical view on the existing remedial options, knowledge gaps and hence scope for future research. It highlights the use of natural polyphenol-rich green wastes as nanofertilizers, bioamendments, biofilters and bacteriostats. Field application strategies such as microbe-assisted phytoremediation, bioaugmention and biostimulation are also emphasized, showing the multifunctional biotechnological potentials offered by natural polyphenols.

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1. Introduction

Intensive urbanization and industrialization, in addition to population pressure on limited natural resources, and to some extent the natural activities, have all posed immense stress to the global environment by generating toxic contaminants. The focal tool of the USEPA is to set out a suitable remediation strategy against environmental pollution that involves establishing a list of toxic chemicals presenting a significant risk to or via the environment. These so-called priority pollutants are 126 hazardous substances that include pesticides, hydrocarbons, heavy metals, explosives, chlorinated aliphatics, other chlorinated compounds, phenolics, benzene, toluene, ethylbenzene and xylenes (BTEX). Yet priority pollutants are not the only contributing part of the large chemical pollution puzzle. There is also a diverse group of new, unregulated contaminants that have found their way, and largely spread, into the environment on a worldwide basis and are considered to be 'emergent'. These include illicit drugs, pharmaceutical and personal care products (PPCPs), flame retardants, antibiotics, antiseptics, industrial additives, disinfection by-products and insect repellents (Thomaidis et al., 2012). What is of great concern is the escalating levels of these pollutants and their derivatives which most frequently pollute the environment and threaten the self-regulating capacity of the biosphere so ultimately imposing serious health risks to humans. It is therefore important to restrain or tone down these ever-increasing priority and emerging pollutants by developing newer and more appropriate cost-effective remediation technologies that are realistic, quick and deployable in an extensive array of physical settings.

At present, biological removal of unwanted organic chemicals from soil and water ('bioremediation or green remediation') is considered as an economic, sustainable and eco-friendly remediation technology (Fig. 1). Bio-/phytoremediation employs microorganisms, green plants or their enzymes to treat contaminated substrates for regaining their original natural condition, without transferring any harmful after-effects to the future (Megharaj et al., 2011). In this context, more recently natural polyphenols (secondary metabolites that constitute a large family of ubiquitous and varied aromatic substances, from simple to complex structures) that are present in all green plants and their residues are employed as a suitable bioremedial option to treat contaminated substrates. Among their bioremedial properties, adsorption, metal chelation and more recently, coagulation are probably the three most fully documented ones (Jeon et al., 2009; Smuleac et al., 2011; Stingu et al., 2012). The most significant features of natural polyphenols are that they are non-toxic, easily biodegradable and are present in almost all plant-derived industrial and household wastes that are considered as garbage. Since the remedial utilization of biopolyphenols is emerging, and to date, studies on the use of natural wastes that are rich in polyphenols are very few, there is much scope for future research on this aspect. This review provides a brief overview of (a) abundance and types of natural wastes, (b) polyphenols and their compounds, (c) sources, distribution and the variation in concentration of phenolic compounds in natural wastes, (d) existing remedial applications of natural polyphenols and (e) strategies for the economic utilization of biowaste-derived polyphenols in the clean-up of contaminated environments. The principal focus of this current review is to assist environmentalists in understanding the value of natural polyphenols as a viable resource with scope for exploitation in remedial work.

2. 'Green waste'—values and scope

Green waste comprises food, forestry, garden, agricultural and biological industrial wastes. It is estimated that 140 billion metric tonnes of biomass are generated globally every year from agriculture (Centore et al., 2014). Almost 60% of the total (6273 million tonnes per annum) food production is lost or wasted (Gustavsson et al., 2011). Fallen branches, leaves and flowers of trees, grass clippings, tree and shrub prunings and weeds from forest management and landscaping are left as trash. Husks, pomace, nut or seed shells, straw and residual stocks are generated steadily by agro-industrial activities. One of the burgeoning global problems is the management and minimization of the rapid increase in volume and type of green waste biomass produced. This is because of improper management and accumulation of waste biomass is contributing towards soil, water and air pollution. It is exacerbated by climate change resulting in negative effects on life in our biome. As the accumulation of these wastes is detrimental, concerns are rising and there is a need to develop eco-friendly technologies for the minimization of green wastes. Recently efforts have been made to transform green wastes into products of commercial utility as they are rich in bioactive compounds (vitamins, minerals, amino acids and polyphenols, see Fig. 2) with potentially productive uses (Balasundram et al., 2006). Although there is an emerging trend in the utilization of green wastes, they are still largely under-utilized