The EuroBiotech Journal

REVIEW
Environmental Biotechnology

Ricinus communis L. (Castor bean), a potential multi-purpose environmental crop for improved and integrated phytoremediation

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Abstract

Phytoremediation is a plant based environmental cleanup technology to contain (rendering less toxic), sequester and degrade contaminated susbtrates. As can be seen from data metrics, it is gaining cosiderable importance globally. Phytoremediation approach is being applied for cleanup of inorganic (potentially toxic metals), organic (persistent, emergent, poly-acromatic hydrocarbons and crude oil etc.) and co-contaminated (mixture of inorganic and organic) and/or polluted sites globally. Recently new approaches of utilizing abundantly available natural organic amendments have yielded significant results. *Ricinus communis* L. (Castor bean) is an important multipurpose crop viz., Agricultural, Energy, Environmental and Industrial crop. The current status of knowledge is abundant but scattered which need to be exploited for sustainable development. This review collates and evaluates all the scattered information and provides a critical view on the possible options for exploiting its potential as follows: 1. Origin and distribution, 2. Lead toxicity bioassays, 3. Progress in arbuscular mycorrhizal fungi-assisted phytoremediation, 4. Promising bioenergy crop that can be linked to pytoremediation, 5. A renewable source for many bioproducts with rich chemical diversity, 6. It is a good biomonitor and bioindicator of atmospheric pollution in urban areas, 7. Enhanced chelate aided remediation, 8. Its rhizospheric processes accelerate natural attenuation, 9. It is suitable for remediation of crude oil contaminated soil, 10. It is an ideal candidate for aided phytostabilization, 11. Castor bean is a wizard for phytoremediation and 12. Its use in combined phytoextraction and ecocatalysis. Further, the knowledge gaps and scope for future research on sustainable co-generation of value chain and value addition biobased products for sustainable circular economy and environmental security are described in this paper.

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Published online: 9 May 2017
doi:10.24190/ISSN2564-615X/2017/02.01

Introduction

Globally the value of land has increased exhorbitantly. Contaminated and polluted land will have adverse effects on quality of living and economy. Contaminated lands are not fit for food production due to possible bioavailability and accumulation of toxic substances in the food chain. Decontamination of such land and utilization for non-food crops would be beneficial environmentally, socially and economically. Phytoremediation gained enormous momentum for environmental decontamination and particularly the cases dealing with *Ricinus communis* (**Fig. 1**). For a successful rehabilitation of contaminated and polluted sites, selection of appropriate candidate species is necessary. Obviously the criteria for selection for such a species would be a) the plant must be tolerant to the stress imposed by the contaminants and pollutants and b) it must produce high biomass under several limitations. (**Fig. 2a, b**).

Origin and distribution

Castor bean (*R. communis* L.) has a long history from ancient times in literature of different parts of the world. It is native to Ethiopia, tropical Africa (1). In 1753, Linnaeus has identified the genus *Ricinus*. L. and J. Mueller Argavoskii described and placed in Euphorbiaceae (Surge family) and recognized only one species *R. communis* L. (2). It is a

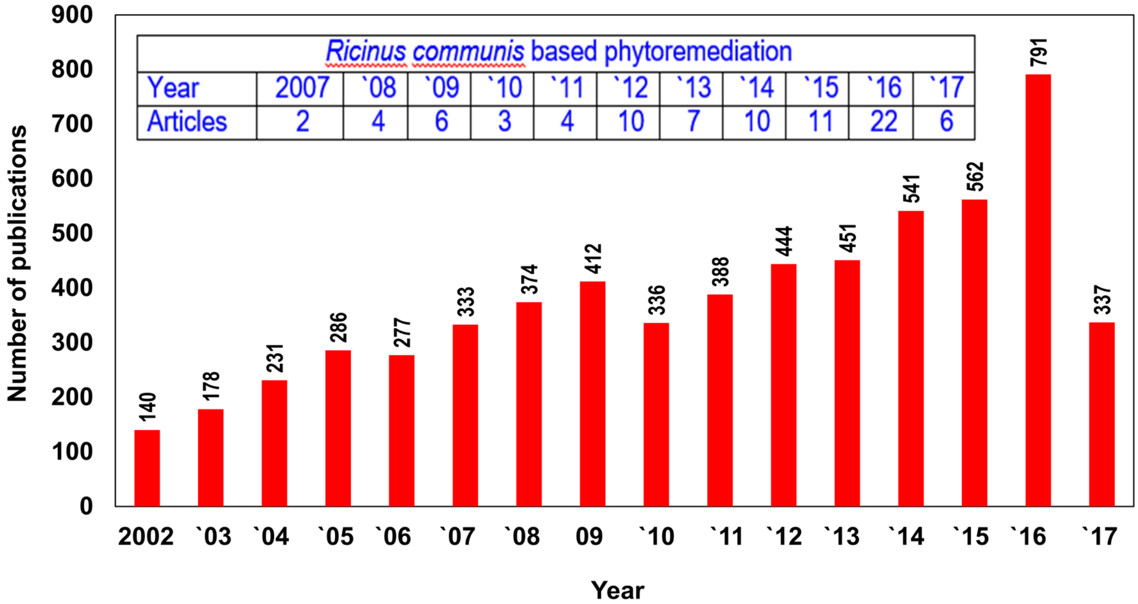

Figure 1. Number of papers published on phytoremediation. Keyword used = Phytoremediation and *Ricinus communis.* The inset shows exclusive papers on *R. communis*. Data source: www.sciencedirect.com

Figure 2. a) *R. communis* (castor bean) growing on contaminated soil – a dry land agricultural, energy, environmental and industrial crop, **b)** Its leaves are very large, lamina is more than 1 foot diameter, ideal for biomonitoring the quality of air in polluted urban ecosystems.

perennial crop cultivated in many dry regions of India and often grows in waste, degraded and contaminated soils as a wild. It is popularly known as 'Castor bean' or 'Castor oil plant' or 'Wonder tree'. (**Fig. 2 a,b**).

According to FAO, castor is cultivated in about 20 nations, India being the top producer of castor seed and oil followed by China and Brazil (**Fig. 3 a,b**). Castor is a multipurpose crop of international interest because of its commercial importance and unique biochemistry and valuable biomaterials such as, castor oil, ricinoleic acid, ricinoleyl-sulfate, lithium grease (lithium hydroxystearate), 10-undecylenic acid, 11-amino-undecanoic acid (3).

It has also been demonstrated that it can be grown in saline soils and soils contaminated with toxic metals like nickel, chromium, copper, manganese (4) and arsenate (5). Castor can also be used for phytoremediation of Cs^{137} (Cesium).

Castor has been considered for remediation and to improve green cover as it stabilizes the nutrient cycling (7). It is a fast

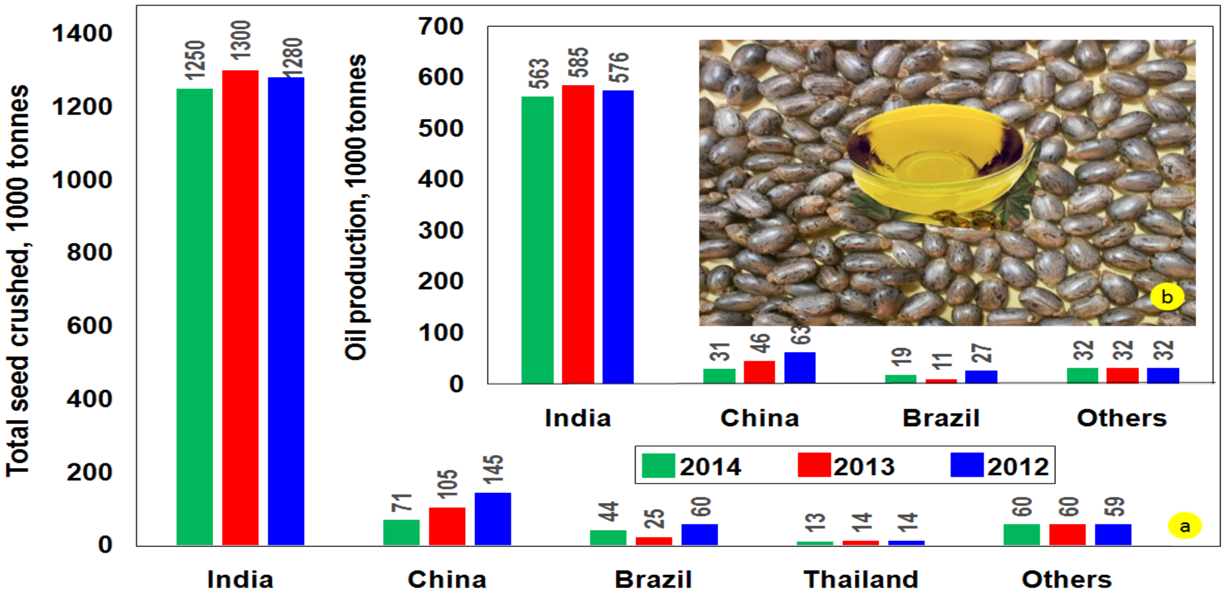

Figure 3. a) Annual crushing of castor seeds, **b)** Castor oil production (3).

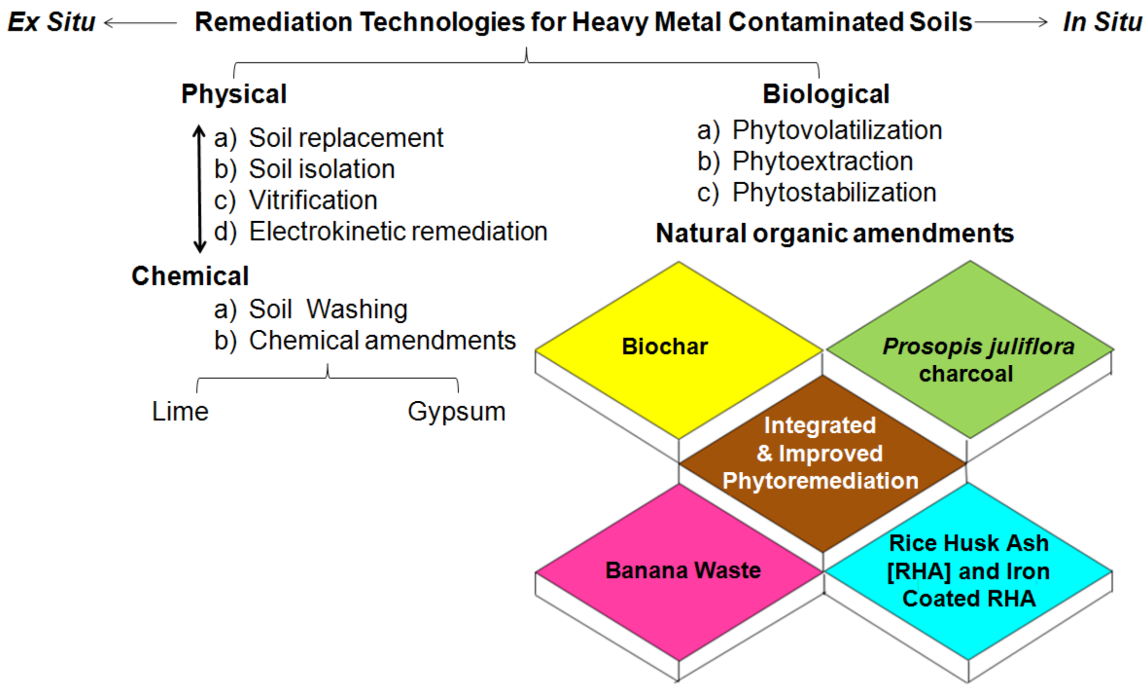

Figure 4. Approaches for large scale field applications of phytoremediation using low cost natural organic amendments (6).

growing perennial crop in semi-arid subtropical agro-climatic conditions yielding oil crop with potential for phytoremediation (8, 9). Recently, it gained considerable importance to remediate metalliferous substrates having high concentrations of Cu, Zn, Mn, Pb and Cd (**Table 1**). It is reported to remediate toxic metals and hazardous materials in the ecosystem (10). It is useful for phytoextraction of Boron and tolerant to Cu, Fe, Mn and Zn (11). Castor bean is an ideal plant suitable for remediation of Cd and Pb in contaminated soils (12). *R. communis* can remove the Cd high quantity from contaminated soils better than mustard (*Brassica juncea*) due to its large amount of above ground and underground biomass (13, 14).

The emerging strategies for improved and integrated phytoremediation on field scale are a) identification of contaminant tolerant and high biomass producing plant b) application of abundantly available low cost natural organic amendments (**Fig. 4 and 5**).

With this background we have conducted dosimetric studies for Lead (not essential) toxicity bioassays using *R. communis.* Pot experiments with various natural organic amendments are being conducted and additional investigations are in progress. (Data are huge and not shown as this being investigated a part of Ph.D. thesis).

Table 1. *R. communis* L. (Castor bean) an important dry land agricultural, energy, environmental and industrial crop for bioeconomy and environmental sustainability – an annotated synopsis of liteature

Year	Author(s)	Contribution to the theme of this paper	Ref.
2017	Saadaoui et al.	Castor bean diversity, seed oil and uses.	188
2016	Riberio et al.	Chemical constituents and their pharmacological activities	36
2016	Zhang et al.	Comparison of chelates for enhancing phytoremediation of Cd and Pb contaminated soil	54
2016	Chhajro et al.	Chelators applied to soil promote accumulation of Cd	55
2016	Wu et al.	Screening of high Cd accumulation varieties for remediation	65
2016	Pandey et al.	Energy crops in sustainable phytoremediation	99
2016	Huang et al.	Biochemistry of root exudates and Cu-accumulation	69
2016	Wang et al.	Growth in single element /co-contaminated soils:pot experiments	90
2016	Amouri et al.	Life cycle analysis approach for production of biodiesel	100
2016	Bauddh et al.	Bioeconomy and remediation of Cd contaminated substrates	101
2016	Hadi et al.	Ecophysiological changes in phytoremediation of Cd by castor	102
2016	Rani et al.	Phytostabilization of tannery sludge amended soil	103
2016	Silintonga et al.	Synthesis and optimization of feedstock for biodiesel production	105
2016	Srinivasarao et al.	Ecophysiological investigations in rainfed K deficient alfisols	106
2016	Wei et al.	Fractionation of stable Cd isotopes in the cadmium tolerant plant	107
2016	Yashim et al.	Phytoremediation potential in Northern Nigeria	109
2016	Yi et al.	Photosynthesis and antioxidant enzymes of castor growing in lead/ zinc tailings	110
2015	Hadi et al	Phytoremediation of Cd in hydrophonic condition	108
2015	Alexopoulou et al.	Performance of castor hybrids	111
2015	Armendariz et al.	Evaluation of castor genotypes or the production of biodiesel	112
2015	Aziera et al.	Uptake and translocation of zinc and cadmium in sewage sludge contaminated soil	113
2015	Saadawi et al.	Phytoremediation effect of Ricinus communis on crude oil contaminated soil	114
2015	Baishya et al.	Phytoremediation of crude oil contaminated soil in India	77
2015	Bauddh et al.	Bio-accumulation and partitioning of Cd in castor applied with organic and inorganic amendments	116
2015	Campbell et al.	Use of the sap flow method specific crop coefficient	119
2015	Capuani et al.	Acidic amendments and sewage sludge with phosphorus on castor bean applied for remediation	120
2015	Grichar et al.	Castor tolerance and weed control with pre-emergence herbicides	121
2015	Hadi et al.	Phytoremediation of cadmium by castor in hydrophonic condition	122
2015	Kang et al.	Copper phytotoxicity in hydroponic culture as a function of chemical forms in the root cells	123
2015	Liu et al.	Bio-aviation fuel production from hydroprocessing of castor oil	124
2015	Medeiros et al.	Bio-nanocomposite nanoparticles derived from castor oil	125
2015	Moncada et al.	Design and analysis of a second and third generation biorefinery	127
2015	Ribeiro et al.	Biomass allocation in seedlings of two contrasting genotypes subjected to temperature stress	128
2015	Rissato et al.	Phytoremediation of organochlorine pesticides polluted soils	129
2015	Rissato et al.	Phytoremediation of polluted soil with organochlorine pesticides	169
2015	Sanchez	Castor oil methanolysis to obtain biodiesel	130
2015	Severino et al.	Endosperm composition of castor seed	131
2015	Shi et al.	Drought stress altered root morphology decreases Cd acumulation	132
2015	Srivastava and Kumar	Response of castor to sulphur under irrigation, India.	134
2015	Zhang et al.	Castor cultivar leaves exhibit differences in Cd accumulation	136
2015	Zhang et al.	Citric acid assisted phytoextraction of heavy metals	135
2015	Mendes et al.	Castor bean as a potential environmental bioindicator	47

Table 1. (cont.) *R. communis* L. (Castor bean) an important dry land agricultural, energy, environmental and industrial crop for bioeconomy and environmental sustainability – an annotated synopsis of liteature			
Year	**Author(s)**	**Contribution to the theme of this paper**	**Ref.**
2015	Ma et al.	Serpentine bacteria promote metal translocation and bioconcentration in multi-metal polluted soils	76
2015	González-Chávez	Crude oil and bioproducts of castor bean grown on mine tailings	34
2014	Bonanno	Efficient biomonitor of atmospheric pollution in urban areas	48
2014	Silva et al.	Mucilage protects aluminum toxicity during germination and root elongation	133
2014	Atiku	Fuel properties of wild castor seed oil	137
2014	Bauddh et al.	A multipurpose crop for the sustainable environment	138
2014	Bauddh et al.	Vermicompost, chemical fertilizers, biofertilizers and customized fertilizers affect Cd partitioning	139
2014	Chen et al.	Cadmium tolerance, accumulation and relationship with Cd subcellular distribution	141
2014	Goyal et al.	Adaptive modulation of traits to urban environments facilitate phytostabilization	142
2014	Neto et al.	A comparative study of salt-tolerant castor bean with salt-sensitive *Jatropha curcas*	143
2014	Magriotis et al.	Castor bean presscake as an efficient low cost adsorbent for removal of textile dyes	144
2014	Rodrigues et al.	Ecophysiological investigation	145
2014	Zhang et al.	Cadmium accumulation/tolerance vs. antioxidant systems	148
2013	Andreazza et al.	Phytoremediator for copper-contaminated soils	70
2013	Bosiacki et al.	Phytoextraction of cadmium and lead from contaminated substrates	18
2013	Makeswari and Santhi	Adsorption of Cr(VI) from aqueous solutions	150
2013	Martins et al.	Removal of heavy metals leaf powder as a green adsorbent	94
2013	Olivares et al.	Mine tailings stabilization	10
2013	Pal et al.	Responses to lead stress	151
2013	Pandey	Suitability for phytoremediation of fly ash disposal sites	71
2011	Kathi and Khan	Phytoremediation approaches to PAH contaminated soil.	152
2013	Perdomo	Physicochemical characterization of seven Mexican varieties oil contents	153
2013	Sun et al.	Growth and ecophysiology irrigated with saline solution	51
2013	Severino and Auld	Growth and development of castor plant	154
2013	Tyagi et al.	Phyto-chemical constituents under the influence of industrial effluent.	156
2013	Wang et al.	Rhizoremediation of PAHs in co-contaminated soil by co-plantation	157
2013	Bale et al.	Castor oil fatty acid methyl ester (COFAME) yield	174
2013	Yasur and Rani	Ecophysiological effects of nanosilver	158
2012	Bauddh et al.	Ecophysiological investigation in salinity and drought affected cadmium contaminated soil	13
2012	Bauddh et al.	Comparative study of phytoremediation by two oil yielding plants on metal contaminated soil.	14
2012	De Souza Costa et al.	Cd and Pb phytoremediation	17
2012	de Abreu et al.	Organic matter and barium absorption	30
2012	Wu et al.	Ameliorative effect of castor on saline soil	53
2012	Adhikari and Kumar	Nickel phytoremediation	160
2012	Ananthi et al.	Natural and induced phytoextraction	159
2012	Bauddh and Singh	Saline, drought and Cd contaminated soil	161
2012	Dos Santos et al.	Pb-phytoextractor	163
2012	Lavanya et al.	Prospects for biodiesel production in India	164
2012	Melo et al.	Arsenic accumulation grown on contaminated soils.	165
2012	Prasad et al.	Electrochemical applications of carbon nanoparticles derived from castor oil soot	166
2012	Severino et al.	Challenges for increased production of castor	167
2012	Varun et al.	Glass industry contaminated substrates	168
2012	Singh et al.	Biosynthesis of silver nanoparticles using leaf extract and its antibacterial activity	179

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Year	Author(s)	Contribution to the theme of this paper	Ref.
2011	Huang et al.	Phytoremediation DDT and Cd co-contaminated soil	83
2011	Li et al.	Ecophysiological parameters influencing yield prediction on coastal saline land	84
2011	Kang and Zheng	Copper hyperaccumulator.	155
2011	Perea-Flores et al.	Microscopic image analysis for evaluation of and physico-chemical properties and morphological features for seeds	170
2011	Goytia-Jime´nez	Environmental variations on plant and oil content	171
2010	Reddy & Matcha	Role of nitrogen on development, growth and productivity	31
2010	Babita et al.	Drought tolerance and yield	173
2010	Santhi et al.	Activated from the epicarp adsorbs malachite green	175
2010	Shi and Cai	Oil crops for phytoremediation of zinc	176
2010	Singh et al.	Restoration of fly ash dump sites	177
2010	Ye et al.	Speciation of arsenic in conducting tissues	178
2009	Carreno et al.	Nickel-carbon nanocomposites prepared using castor oil	162
2009	Melo et al.	Arsenic accumulation in hydroponics	5
2009	Shi and Cai	Cd tolerance and accumulation	9
2009	Niu et al.	Phytoextraction of Cd and Pb – influence on root and aerial biomass	82
2009	Coscione and Berton	Phytoextractor of Barium	91
2009	Zhi-Xin et al.	Phytoextraction of Cd and Pb	180
2008	Al Rmalli et al.	Powdered leaf powder of castor bean as biosorbent of mercury from aqueous solutions of	181
2008	Figueroa et al.	Phytochelatin production on silver mine waste	182
2008	Oladoja et al.	Removal of basic dye using castor seed shell as a sorbent	183
2008	Sas-Nowosielska et al.	Soil remediation	184
2005	Lu et al.	Tolerance uptake and accumulation of cadmium	185
2000	Kammerbauer and Dick	Monitoring of urban traffic emissions *R. communis*	147
1994	Rigby et al.	Phloem translocation of a reduced oligogalacturonide	146
1994	Stephan et al.	Translocation of Fe, Cu, Mn, and Zn in phloem	186
1982	Scarpa and Guerci	Economic uses of the castor	187

Lead toxicity bioassays

Lead (Pb) availability to plants in the environment are from technogenic (various industrial effluents) and geogenic (mining) sources (15). Hydroponics are considered to be appropriate to evaluate the phytoremediation potential of species to tolerate high metal concentrations. Castor bean (*R. communis,* Euphorbiaceae) is a fast-growing, perennial shrub, with a well-developed root system, tolerance to poor soil fertility, high economic and biomass value. These traits make castor bean a candidate species for phytoremediation (16-19).

The seedlings of castor bean were transplanted to modified Hoagland's solution, and after one month of acclimatization, seedlings of uniform size were selected and treated for ten days with $Pb(NO_3)$ at different Pb concentration (0, 200 μM and 400 μM). To determine the plant tolerance level, metal accumulation, chlorophyll (20), proline (21), protein (22) and lipid peroxidation (23) were analysed. Sophisticated and reliable instrumentation such as Fourier Transform Infrared Spectrometer (FTIR) and Scanning Electron Microscopy and Energy –Dispersive X-ray Spectroscopy (SEM-EDS) were applied to characterize the functional groups, structural analysis and elemental composition of root cell wall.

Lead treatment at different concentration caused different levels of phytotoxicity, which includes chlorosis, visible damage of leaf and reduction in growth. Accumulation of Pb in the tissue of plants was calculated on a dry weight basis and was increased significantly as compared to control. Roots were the main accumulation site as they absorbed much higher quantities (16.67-19.53 mg g^{-1} dw) than stems (0.07-0.38 mg g^{-1} dw) while in leaves, Pb accumulation was (0.03-0.05 mg g^{-1} dw). Contents of Chl a, b and total chlorophyll were reduced about 50% in 200 μM and 30% in 400 μM when compared to the control. MDA (Malondialdehyde) estimation, an indicator of lipid peroxidation, showed that the MDA concentration in roots of castor plants was elevated and the magnitude of elevation ranged from 50 folds at 200 and 400 μM of Pb more than control respectively. Proline content increased at 200 μM Pb, but slightly greater at 400 μM when compared to control (**Fig. 6a-d**). Protein levels significantly decreased about 80% in both

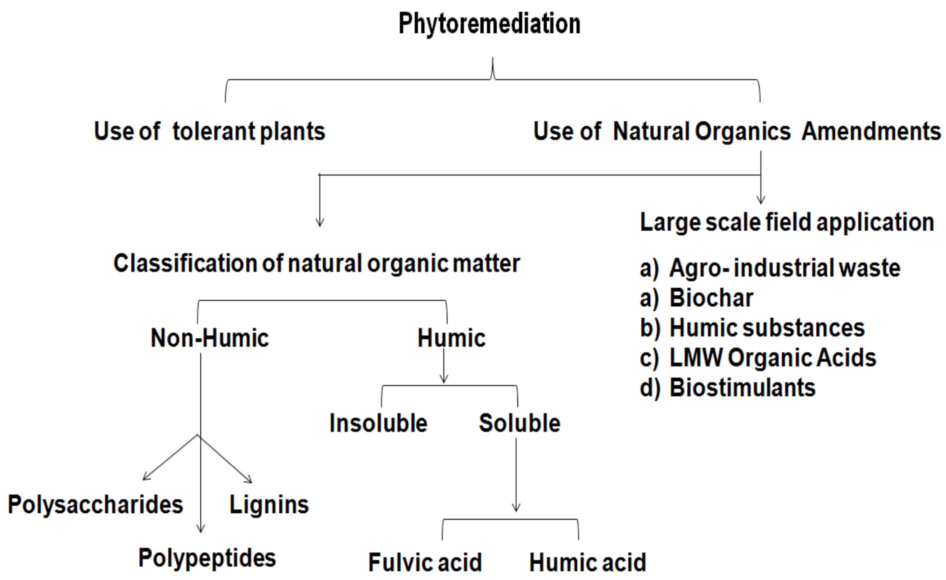

Figure 5. Strategies for improved and integrated phytoremediation (6, 189).

200 and 400 µM Pb treatment when compared to control. Lead treated roots exhibited increase in protein content in a dose-dependent manner. This was attributed to Pb induced protein synthesis inhibition or oxidation of proteins. SEM-EDX analysis revealed that disruption of plant root cell wall and changes in membrane permeability observed and metal adhered to the plant cell wall and vacuoles. Comparison of control and Pb treated [FTIR 4000~500 cm^{-1}] revealed Pb was bound to the carboxyl (-COOH) and hydroxyl (-OH) groups mainly hemicelluloses, cellulose, polysaccharides and other acidic polar compounds in the cell wall (**Fig. 7**).

Castor bean (*R. communis)* showed tolerance and accumulation of Pb in its tissues. Chlorophyll content and total protein decreased while proline and lipid peroxidation (MDA) content increased significantly at 200 µM and 400 µM when compared to the control. FTIR and SEM-EDX showed metal accumulation and disruption of root cell wall. These traits along with published literature qualifies castor bean as a suitable candidate for application in phytoremediation.

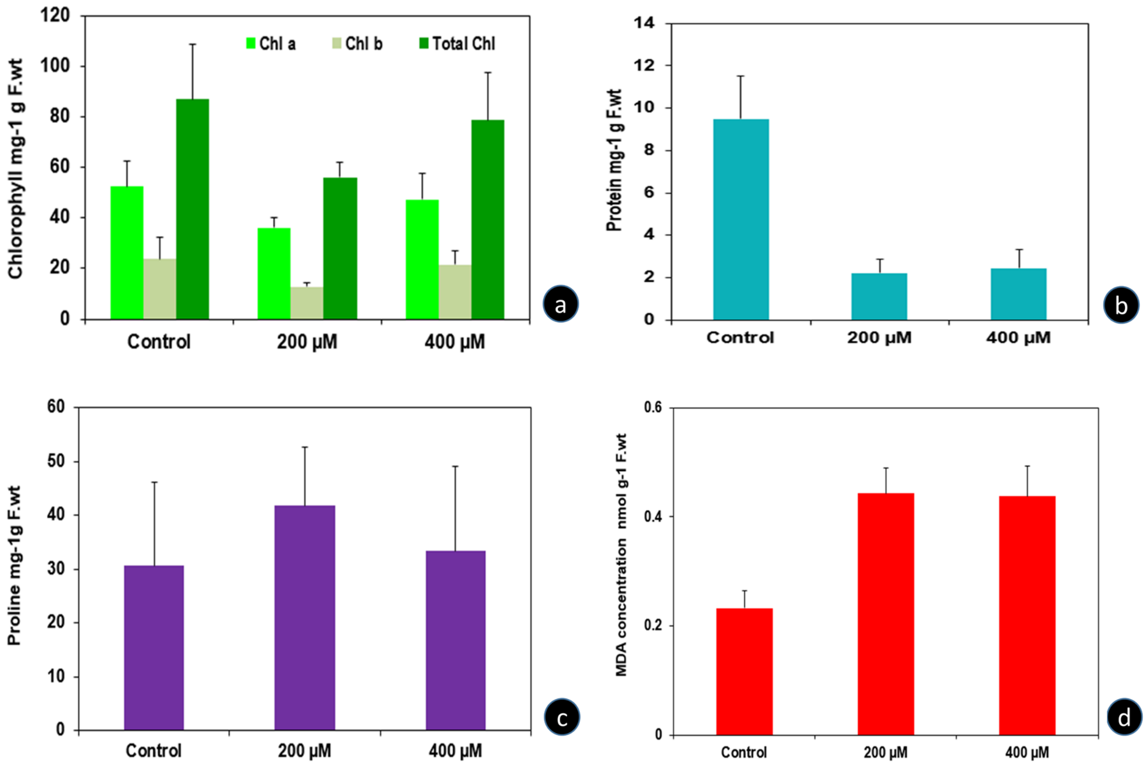

Figure 6. a) Chlorophyll measurement, **b)** Protein, **c)** Lipid peroxidation (MDA) and **d)** Proline in roots of castor seedlings after ten days of Pb treatment.

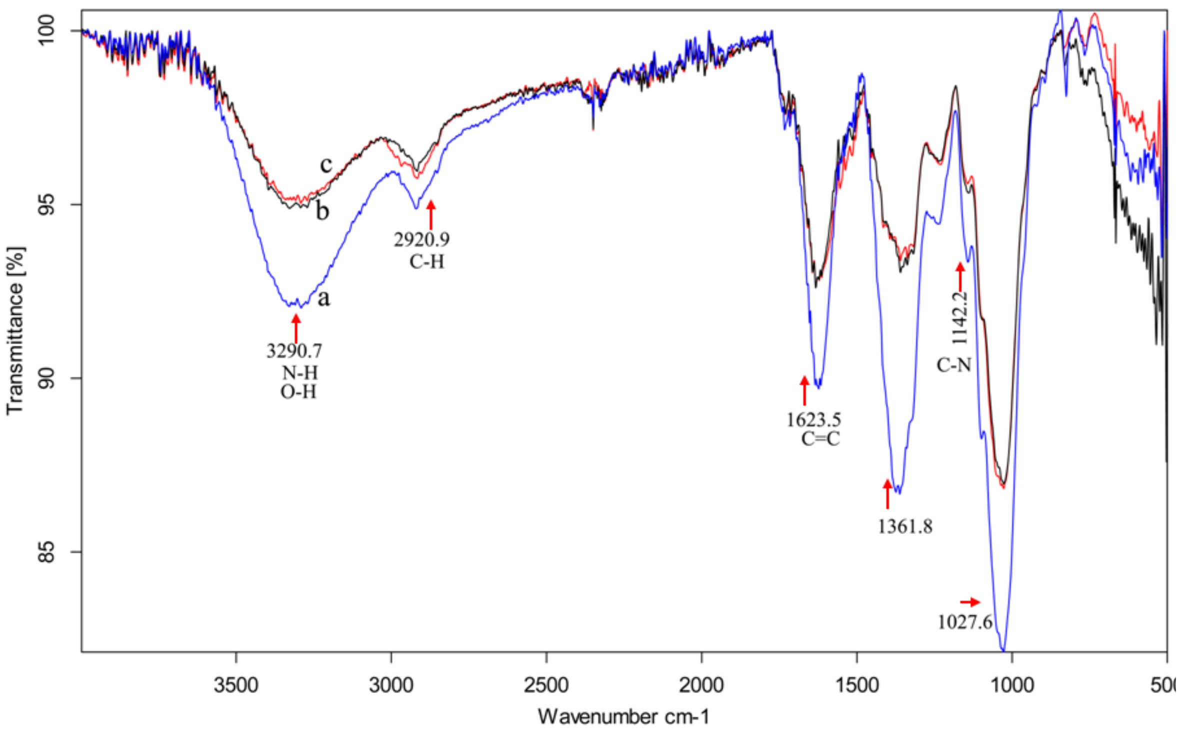

Figure 7. FTIR spectra of root cell wall of *R. communis* **a)** Control, **b)** 200 µM and **c)** 400 µM Pb (NO_3) solution after 10 days of treatment.

Castor promotes arbuscular mycorrhizal fungi-assisted phytoremediation

Arbuscular mycorrhizal fungi (AMF) are cosmopolitan and abundant, which form symbiotic association with plants (24). They assist the candidate species involved in phytoremediation processes of contaminated soils (25). They improve the water and nutrient intake by plants (26, 27).

Castor as a promising bioenergy crop coupling with phytoremediation

R. communis is a good candidate for biodiesel production and also an industrial crop (28) and the cultivation has encouraged for biodiesel and bioethanol production in Brazil (29, 30). Castor bean leaf area development and stem elongation and developmental aspects are proportional to leaf nitrogen levels (31). Castor oil and its derivatives, besides being used in medicine, are used in a wide range of sectors including agriculture, good quality lubricants, industrially useful fatty acids, pharmaceuticals, plastics engineering, and rubber, paper and textile industries (32).

Castor is a source of bioproducts with rich chemical diversity

Castor bean produces many of bioproducts such as seed oil, cake and seed coat for which will be useful for different purposes. India produces about 90% of the castor oil in the world (33). *R. communis* bioproducts like seed cake and seed coats are used as fertilizer to improve soil quality (34). The detoxified or refined seed protein would be used as fish feed, farm animals, poultry, pig rearing and seed cake is used as good fertilizer (35). Castor has an array of chemical diversity of which reflects in the pharmaceutical activity and it is a good alternative source of bioactive compounds aims to develop plant-based new drug discovery (36). Eighty three compounds from the seeds, leaves, roots and stems of Castor which include some alkaloids, terpenoids, flavonoids, benzoic acid derivatives, coumarins, tocopherols, terpenoids and fatty acids (36). In Brazil, castor oil is in great demand by the pharmaceutical and chemical industries. Castor products have tremendous social and ecological implications (33). Castor products are applied in gasohol (liquid biofuel) by conversion to transesterification (37). Castor seeds contain high levels of toxic compounds like ricin and ricinine (32, 38).

Castor seed oil is pale straw colored, viscous liquid. Crude oil has distinct odour, non-drying, it can deodorize in refining (39, 40). Castor bean oil is the only commercially available natural hydroxylated fatty acids (41) and has huge industrial applications for lubricants, grease, polymers, cosmetics, paints, soaps, linoleum, coatings, polyurethane, printing inks and plastics (42-45). About 1.3 Mt of castor oil seeds are produced in a year which yield 550 Kt of oil and India largely dominates the international market and exports 80% of oil alone (46).

Castor as good biomonitor and bioindicator of pollution in urban areas

The attention of air quality biomonitoring in the urban areas has been increased using different plant species as indicators to

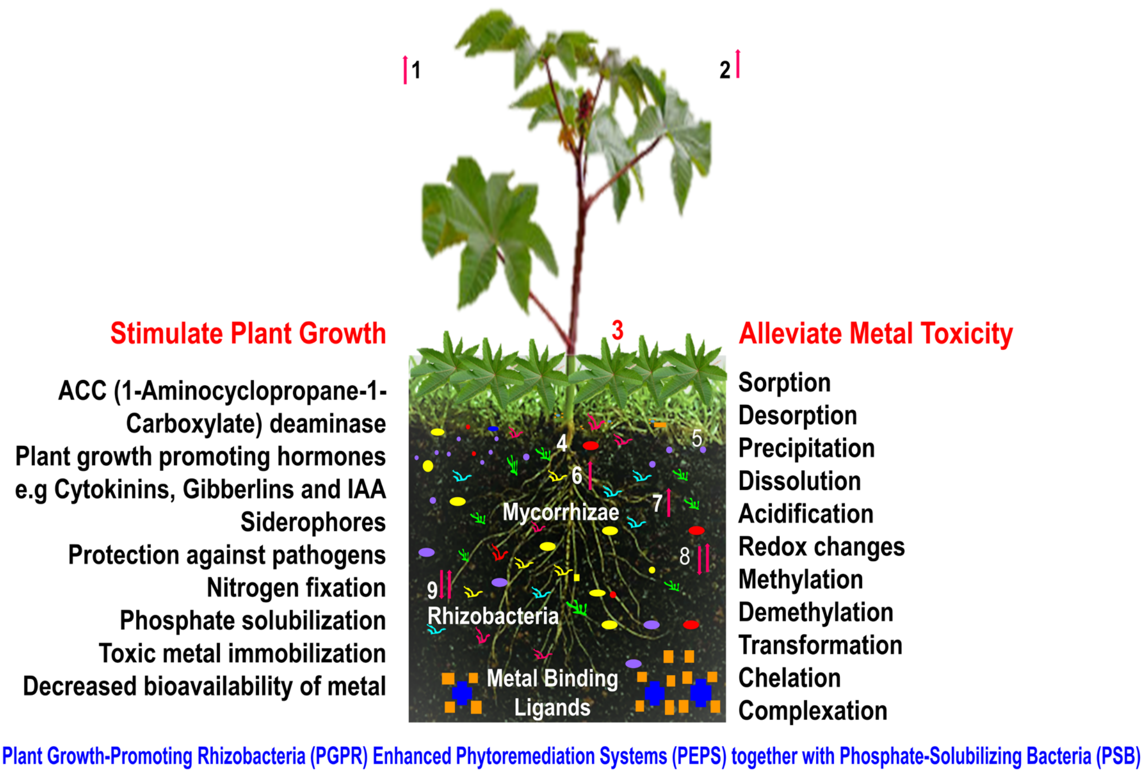

Figure 8. *Ricinus communis* interactions with rhizospheric bacteria, fungi. Key processes important for phytostabilization are 1 and 2 Phytovolatilization of organic contaminants including biomonitoring of atmospheric pollutants, 3. Leaf detritus increases organic matter in soil, 4. Robust root system contribute to phytostabilization, 5. Dissolved organic carbon can increase leaching, 6. Roots act as a sink for organic and inorganic contaminants, 7. Root exudates influence metal mobility and microbial activity, 8 and 9. Rhizosphere bacteria and mycorrhiza influence metal mobility and availability (35, 75, 76, and 78).

monitor the effects of pollution. Castor is a reliable bioindicator of air quality owing its large leaf surface area and rapid growth (47). Fruits of castor bean are more sensitive to Pb accumulation compared to leaves and fruits and leaves are used as good biomonitor of atmospheric pollution in urban areas (48)(**Fig. 2b**).

Pigments can also play a vital role as indicators for assessing the environmental quality and pollution. Chlorophyll and carotenoids (chloroplasts) show sensitive indicators to the heavy metal toxicity, especially to the levels of Pb in the soil (49). *R. communis* is a salt tolerant plant (50, 51) however, at seedling stage sensitive to salt stress (52). It could be useful to remediate seashore saline soils (53).

Castor enhance chelate aided remediation

Chelator is one type of bonding ion, which involves in the formation of two or more separate coordinate bonds. Citric acid (CA), ethylenediamine disuccinic acid (EDDS) chelates effect the growth, heavy metal accumulation, metal bioavailability in the rhizhosphere and the non-rhizosphere on metal accumulation and enhance the phytoremediation efficacy in castor bean of Cd and Pb contaminated soils (54). Ethylene diamine tetra acetic acid (EDTA), nitriloacetic acid (NTA), ammonium citrate have accelerated Cd uptake in *R. communis* in Cd contaminated soils (55).

Castor rhizospheric processes accelerate phytoremediation

Manipulation of rhizospheric processes of plants growing on metal-contaminated or co-contaminated soils accelerate the phytoremediation (56). Soil microorganisms, including the microbial consortia as well as the tissue-colonized symbiotic bacteria, are an integral part of the rhizosphere biota. They play vital role in the biogeochemical cycle, through various mechanisms involving recycling of plant minerals and nutrients in the environment (57). Further studies confirmed that microbial consortia could affect the mobility and bioavailability of the trace metal in the soil (**Fig. 8**). Pairing both of efficient plant growth promoting rhizobacteria with accumulator may be the best way for the restoration of vegetation on metal-contaminated land (58, 59).

R. communis interacts with rhizosphere microbial community and plays an important role in making soil nutrient bioavailability (35, 57, 58) *R.communis* derives benefit from the rhizospheric microbial populations through the recycling and solubilization of mineral nutrients, as well as the increased supply of metabolites including growth promoting phytohormones that stimulate growth (60). Thus alterations in the microbial consortia of rhizosphere soils greatly alter various processes in metal-polluted soils. These include recycling of nutrients, maintenance of soil structure, detoxification of pollutants, and control of plant pests and promoting plant growth and plant health (60-62). Castor bean is reported as a suitable candidate for phytostabilization of co-contaminated sites (organics and inorganics) (10, 63-65), heavy metals (11, 66-69) and polycyclic aromatic hydrocarbons (PAHs).

This process of phytostabilization is accomplished through phytoexclusion (use of plants with low metal uptake) (70) aided phytostabilization (11, 13), hydraulic control (inhibition of pollutant leaching), and phytorestoration (phytostabilization with the help of native plants) (71). Acceleration of the beneficial interaction between plants and rhizosphere microorganisms is a promising strategy to achieve anticipated results in the field of remediation of heavy metals (72). For a successful restoration of municipal waste dumpsites with metalliferous waste, it is necessary to exploit promising metal-tolerant plant-microbe partnerships. Disposal of hazardous waste was considered as the major industrial problem.

R. communis grows abundantly on the industrial waste-contaminated sites, along the road sides, rail tracks, open lands and other disturbed areas with high tolerance for growth under harsh environmental conditions. Several other studies have also shown that *R. communis* grows spontaneously in metal-contaminated sites and has been proposed as a good candidate for restoration of contaminants (18, 19, 73, and 74). It has been reported that *R. communis* is tolerant to different stresses like salinity, drought, frost and has proved to be the preferred phytoremediator when compared to *Brassica juncea*. Moreover, it grows fast and has been recommended for plantation on wasteland as it requires minimal inputs with little maintenance for its establishment (44, 58, 59, 75, and 76).

Besides the use of its biomass as biofuel and biofertilizer, it can make contaminated soils productive. Some investigations have been made with regard to ecophysiological response of *R. communis* under heavy metal stress and the role of plant growth-promoting bacteria on plant productivity and phytoremediation in artificially metal-spiked soils (pot culture and greenhouse experiments).

Plant roots discharge a wide range of carbon containing compounds into the rhizosphere of which play vital role in nutrient mobilization known as rhizodeposits. The root exudates such as organic acids and amino acids influence the tolerant capacity of castor in contaminated areas. Experiments were conducted to determine the efficacy of exudates from roots of castor in the Cu accumulation. The results indicated that the root exudates tartaric, citric and oxalic acids tolerate the high Cu concentrations in Cu mining area. This activity could be beneficial for the selection of castor as high Cu accumulator (69,77).

Castor is suitable for remediation of crude oil contaminated soil

Soil contamination with spent oils should limit some diffusion processes which reduce the availability of soil nutrients to plants (77,79) and causes harmful effects such as necrosis, growth stunting, leaf necrosis and low biomass production. Plant-based technology is eco-friendly and cost effective method to remediate the accidental spillage of crude oil on soils. *R. communis* can improve revegetation of cleaned-up oil polluted soils and grow in spent lubricating oil contaminated soils and can accumulate Mn, Ni, Pb and V (80, 81).

Castor is ideal for revegetation of fly ash dump sites

The plant has ability to grow in metalloid, organic pollutant, salinity, drought and sea shore soil areas due to its massive, deep root system to absorb more pollutants from contaminated soils and reduce soil erosion caused by water (13, 14, 44, 67, 82, 83-85). *R. communis* is a potential candidate for phytoremediation of fly ash disposal sites in tropical and sub-tropical regions and recommended for large cultivation on coal-based thermal power plants generated fly ash disposal lands. *R. communis* canopy is also implicated in effective carbon sequestration and enhance esthetically the landscape, co-generation of value chain and value based products (71).

Castor is an ideal candidate for aided phytostabilization

Humic substances are the natural organic matter formed by decaying of plant debris and strengthen the soil potential. These can change the soil bio-geochemical properties and contribute soil improvement. Some field experiments have proven that the castor residue or meal used as natural manure which enhance the soil fertility. It adds elements such as N, P, K, Zn, Mn and Cu to the soil.

Composting is a traditional practice in which the organic material is transformed into compost by microorganisms. The application of compost in contaminated soils can be reduce the concentration of toxic metals, change physico-chemical soil properties and enhance the fertility status due to presence of nitrogen, phosphorous, potassium and other elements. Mature compost is a material in which biological activity has slowed, dark in colour and a rich earthy smell. Compost can act as bioremediation tool and enhances the heavy metal immobilization and bioavailability of Cd and Pb (86). Composting process limits the solubility and bioavailability of toxic metal complexes and enhances the binding properties of the organic waste residuals to the organic compost matrix and matter. Pb being the most strongly bound element and Ni the weakest, with Zn, Cu and Cd showing intermediate sorption characteristics in municipal solid waste or sewage sludge (87).

Castor is a wizard of phytoremediation

Castor bean has the potential to tolerate and accumulate heavy metals like Cd (13, 14), As (67, 88), Ni (68, 89, 99), Zn (100), and Cu (70, 77) and high tolerance to Cd, Cu and Zn (90). *R. communis* is a good candidate for the removal of DDTs (dichloro diphenyl trichloroethane) and Cd from contaminated soils (78). It is a good potential phytoaccumulator for Ba (11, 91), Cd and Pb (91, 93). Castor leaf powder acts as a green adsorbent for the removal of heavy metals from aqueous solutions (94).

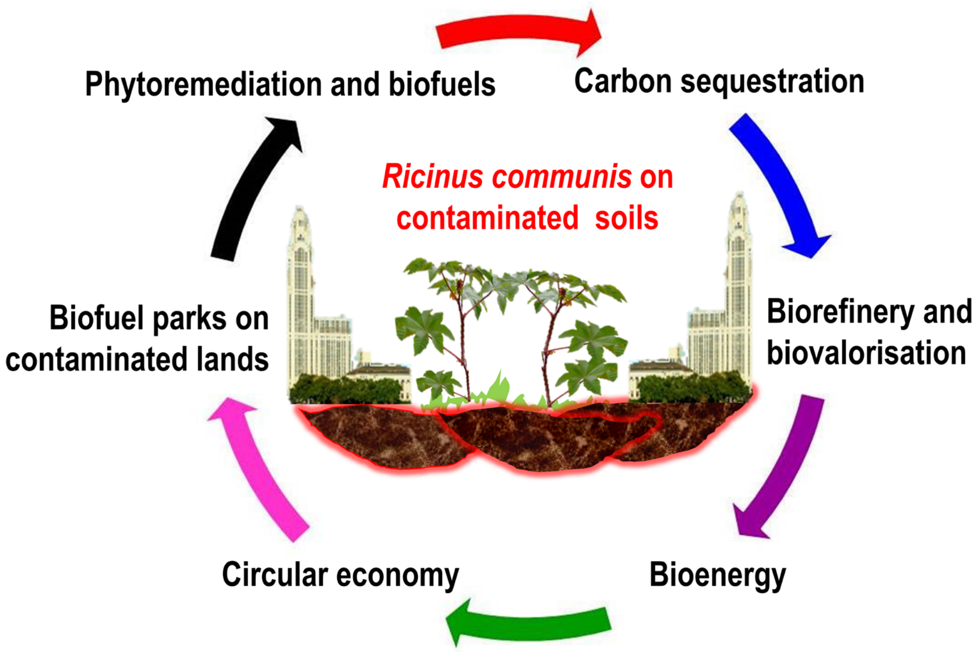

Figure 9. Coupling *Ricinus communis* with phytoremediation, biofuels and biorpoducts strengths sustainable circular economy (96-99).

Applications of combined phytoextraction and ecocatalysis

Phytoextraction process is the translocation of heavy metals from soil to aerial parts of the plant. The field of "phytomining" and "agromining" are emergenging areas (191). By comparing translocation and bioconcentration factors, one should be able to judge the efficient plants for field application. Castor possesses a unique root system with rich microbial diversity in rhizosphere that is an essential attribute for extraction of toxic contaminants (189). Ability of different plant taxa reacting to different concentration of metals can be a) produce high biomass with low concentration of metals in their tissues b) hyperaccumulate metals in large quantity in their tissues with low biomass, both the situation can be exploited for economic and environmental benefit (95). Plants capable of concentrating metals in their tissues serves as ecocatalysts (1) for green-fine chemistry (catalyst production from metal accumulating biomass) and (2) for biorefinery (prehydrolysis and organosolv pre-treatment of metal accumulated lignocellulosic biomass) 4,18, 56, 62, 68, 82, 88, 91, 135, 136, 157, 159,160, 163, 180, 189 and 190).

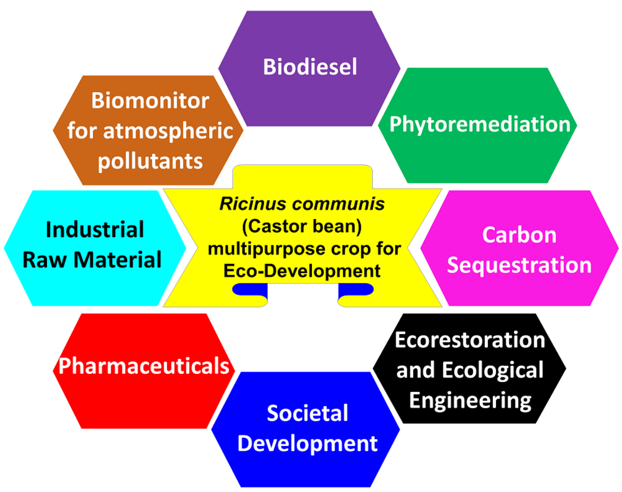

Figure 10. *Ricinus communis*, an important multipurpose crop viz., agricultural, energy, environmental and Industrial crop for eco-development (96-99).

Conclusions

Demand for bioproducts and energy based on phytoremediation supports sustainable circular economy. Land is under pressure for food and biofuels production. The challenge in this field is quick results and boosting economy. In such a scenario, optimization of productivity of plants used in phytoremediation of contaminated sites and co-generation of bioproducts would attract global attention for implementation with the involvement of all the stake holders (**Fig. 9 and 10**). The general belief is that phytoremediation is low cost but takes long time. In this back drop, multipurpose high biomass producing plants like *R. communis* with proven record as shown in table 1 have great scope for boosting bioeconomy linking biofuels, value chain and value additions. Phytoproducts and bioenergy via innovative and efficient technologies are already a reality offering great opportunities and solutions to major societal, environmental and economic challenges, including environmental security (96, 97, 192).

Acknowledgments

BRK is grateful to Rajiv Gandhi National Fellowship (RGNF-UGC) for Disabilities [ID No. 201314-RGNF-2013-14D-OBC-AND-56604]. The authors are thankful to the University of Hyderabad for basic infrastructural facilities; and to Dr Sateesh Suthari for some technical help.

Conflict of interest statement

The authors declare that there is no conflict of interest.

References

1. Weiss EA. Castor, Sesame, and Safflower, Leonard Hill, London, 1971.
2. Moshkin VA. History and Origin of Castor, pp. 6-10. In: Moshkin VA. (ed) Castor. Oxonian Press Pvt. Ltd., New Delhi, 1986.
3. McKeon TA, Hayes DG, Hildebrand DF, Randall J, Weselake RJ (Eds). Industrial Crops. 2016 - Academic Press. 474 pages.
4. Gupta AK, Sinha S. Phytoextraction capacity of the plants growing on tannery sludge dumping sites. Bioresour. Technol. 2007, 98, 1788–1794.
5. Melo EEC, Costa ETS, Guilherme LRG, Faquin V, Nascimento CWO. Accumulation of arsenic and nutrients by castor bean plants grown on an As-enriched nutrient solution, J. Hazard. Mater., 2009, 168: 479–483.
6. Wiszniewska A, Hanus-Fajerska E, Muszynska E, Ciarkowska K. Natural organic amendments for improved phytoremediation of polluted Soils: A Review of Recent Progress. Pedosphere, 2016, 26(1), 1–12.
7. Singh AS, Kumari S, Modi AR, Gajera BB, Narayanan S, Kumar N. Role of conventional and biotechnological approaches in genetic improvement of castor (*Ricinus communis* L.), Ind. Crops Prod., 2015, 74: 55–62.
8. Cecchi CGS, Zanchi C. Phytoremediation of soil polluted by nickel using agricultural crops, Environ. Manag., 2005, 36: 675–681.
9. Shi G, Cai Q. Cadmium tolerance and accumulation in eight potential energy crops, Biotechnol. Adv. 2009, 27(5): 555–561.
10. Olivares AR, Carrillo-González R, González-Chávez MDCA, Hernández, RMS. Potential of castor bean (*Ricinus communis* L.) for phytoremediation of mine tailings and oil production, J. Environ. Manage., 2013, 114: 316–323.
11. de Abreu CA, Coscione AR, Pires AM, Paz-Ferreiro J. Phytoremediation of a soil contaminated by heavy metals and boron using castor oil plants and organic matter amendments, J. Geochem. Explor., 2012, 123: 3–7.
12. Costa ET de S, Guilherme LRG, de Melo EEC, Ribeiro BT, Inacio ESB, Severiano EC, Faquin V, Hale BA. Assessing the tolerance of castor bean to Cd and Pb for phytoremediation purposes, Biol. Trace Elem. Res., 2012, 145: 93–100.
13. Bauddh K, Singh R.P. Growth, tolerance efficiency and phytoremediation potential of *Ricinus communis* L. and *Brassica juncea* L. in salinity and drought affected cadmium contaminated soil, Ecotox. Environ. Safe., 2012a, 85: 13–22.
14. Bauddh K, Singh RP. Cadmium tolerance and its phytoremediation by two oil yielding plants *Ricinus communis* L. and *Brassica juncea* L. from the contaminated soil. Int. J. Phytoremed., 2012b, 14(8): 772–785.
15. Kumar A and Gottesfeld P. Lead content in household paints in India. Science of The Total Environment, 2008, 407(1): 333-7
16. Zhuang X, Chen J, Shim H, Bai Z. New advances in plant growth promoting rhizobacteria for bioremediation, Environ. Int. 2007, 33: 406–413.
17. de Souza Costa ET, Guilherme LRG, de Melo ÉEC, Ribeiro BT, dos Santos B, Inácio E, da Costa Severiano E, Faquin V, Hale BA. Assessing the tolerance of castor bean to Cd and Pb for phytoremediation purposes, Biol. Trace Elem. Res., 2012, 145 (1): 93–100.
18. Bosiacki M, Kleiber T, Kaczmarek J. Evaluation of suitability of *Amaranthus caudatus* L. and *Ricinus communis* L. in phytoextraction of cadmium and lead from contaminated substrates, Arch. Environ. Prot., 2013, 39 (3): 47–59.
19. Yi X, Jiang L, Liu Q, Luo M, Chen Y. Seedling emergence and growth of *Ricinus communis* L. grown in soil contaminated by lead/zinc tailing, In: Proc. 2014 Ann. Cong. Advanced Eng. Tech., CAET, 2014, pp. 445–452.
20. Arnon DI. 1949. Copper enzymes in isolated chloroplasts, polyphenoxidase in *Beta vulgaris*. plant physiology 24: 1-15.
21. Bates, L. S., Waldren, R. P., & Teare, I. D. Rapid determination of free proline for water stress studies. Plant and Soil, 1973, 39, 205–207.
22. Lowry, O. H., Rosebrough, N. J., Farr, A. L., and Randall, R. J. Protein Measurement with the Folin Phenol Reagent J. Biol. Chem. 1951, 193, 265–275.
23. Heath RL, Packer L.. Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. *Archives in Biochemistry and Biophysics* 1968,125,189–198.
24. Miransari M. Hyperaccumulators, arbuscular mycorrhizal fungi and stress of heavy metals, Biotech. Adv., 2011, 29: 645–653.
25. Leung HM, Yea ZH, Wang MH. Interaction of mycorrhizal fungi with *Pteris vittata* (As hyperaccumulator) in As-contaminated soils, Environ. Pollut., 2006, 139: 1–8.
26. Bhalerao SA. Arbuscular mycorrhizal fungi: a potential biotechnological tool for phytoremediation of heavy metal contaminated soils, Int. J. Sci. Nat., 2013, 4(1): 1–15.
27. Cabral L, Soares CRFS, Giachini AJ, Siqueira JO. Arbuscular mycorrhizal fungi in phytoremediation of contaminated areas by trace elements: mechanisms and major benefits of their applications, World J. Microbiol. Biotechnol., 2015, 31(11): 1655–1664.
28. Baldwin BS, Cossar RD. Castor yield in response to planting date at four locations in the south-central United States, Ind. Crops Prod., 2009, 29: 443–448.
29. Oliveira LB, Araujo MSM, Rosa LP, Barata M, Rovere ELL. Analysis of the sustainability of using wastes in the Brazilian power industry, Renew. Sustain. Energy Rev., 2008, 12: 883–890.
30. de Abreu CA, Cantoni M., Coscione AR, Paz-Ferreiro J. Organic matter and barium absorption by plant species grown in an area polluted with scrap metal residue, Applied Environ. Soil Science, 2012, Article ID 476821, 7 pages http://dx.doi.org/10.1155/2012/476821.
31. Reddy KR, Matcha SK. Quantifying nitrogen effects of castor bean (*Ricinus communis* L.) development, growth, and photosynthesis, Ind. Crops Prod., 2010, 31: 185–191.
32. Ogunniyi DS. Castor oil: a vital industrial raw material. Bioresour. Techn., 2006, 97: 1086–1091.
33. Scholz V, da Silva JN. Prospects and risks of the use of castor oil as a fuel, Biomass Bioenergy . 2008, 32: 95–100.
34. González-Chávez MCA, Olivares AR, Carrillo-González R, Leal ER. Crude oil and bioproducts of castor bean (*Ricinus communis* L.) plants established naturally on metal mine tailings, Int. J. Environ. Sci. Tech., 2015, 12: 2263–2272.
35. Annapurna D, Rajkumar M, Prasad MNV. Potential of Castor bean (*Ricinus communis* L.) for phytoremediation of metalliferous waste assisted by plant growth-promoting bacteria: possible cogeneration of economic products. In: Prasad MNV (ed), *Bioremediation and Bioeconomy*, Amsterdam: Elsevier, 2016, pp. 149–178.
36. Ribeiro, P.R., de Castro, R.D. and Fernandez, L.G.. Chemical constituents of the oilseed crop *Ricinus communis* and their pharmacological activities: a review. *Industrial Crops and Products* 2016, 91, 358-376.
37. Visser EM, Filho DO, Martins MA, Steward BL. Bioethanol production potential from Brazillian biodiesel co-products, Biomass Bioenergy, 2011, 35: 489–494.
38. Severino LS, Auld DL. A framework for the study of the growth and development of castor plant, Ind. Crops Prod., 2013, 46: 25–38.

39. Marter AD. *Castor:* Markets, Utilization and Prospect, Tropical Product Institute, G152, 1981, p. 55–78.
40. Wiese EA. Oil seed crops, Trop. Agri. Ser., Longman, 1983, pp. 31–53.
41. Glaser LK, Roetheli JC, Thompson AE, Brigham RD, Carlson KD. Castor and *Lesquerella*: sources of hydroxyl fatty acids. In: *1992 Year book of Agriculture*, USDA Office, Publishing Visual Communication, Washnigton, 1993, pp. 111–117.
42. Dole KK, Keskar VR. Dehydration of castor oil, Curr. Sci., 1950, 19(8): 242–243.
43. Osava M. Energy in a castor bean. 2003. http://www.tierramerica.net/english/2003/0526/ ianalisis.shtml.
44. Rajkumar M, Freitas H, Influence of metal resistant plant growth-promoting bacteria on the growth of *Ricinus communis* in soil contaminated with heavy metals, Chemosphere, 2008, 71: 834–842.
45. Barnes D, Baldwin BS, Braasch DA. Degradation of ricin in castor seed meal by temperature and chemical treatment, Ind. Crop Prod., 2009, 29: 509–515.
46. FAO (Food and Agriculture Organization). http://faostat.fao.org, 2005, (online) accessed on November 18, 2016.
47. Mendes MG, Santos CDJr, Dias ACC, Bonetti AM. Castor bean (*Ricinus communis* L.) as a potential environmental bioindicator, Genetics Mol. Res., 2009, 14(4): 12880–12887.
48. Bonanno G. *Ricinus communis* as an element biomonitor of atmospheric pollution in urban areas, Water Air Soil Poll., 2014, 225(2): 1852.
49. Gomes SM de S, de Lima VLA, de Souza AP, do Nascimento JJVR, do Nascimento ES. Cloroplast pigments as indicators of lead stress, Eng. Agri. Jaboticabol., 2014, 34(5): 877–884.
50. Li G, Wan SW, Zhou J, Yang ZY, Qin P. Leaf chlorophyll fluorescence, hyperspectral reflectance, pigments content, malondialdehyde and proline accumulation responses of castor bean (*Ricinus communis* L.) seedlings to salt stress levels, Ind. Crop Prod., 2010, 31(1): 13–19.
51. Sun Y, Niu G, Osuna P, Ganjegunte G, Auld D, Zhao L, Peralta-Videa JR, Gardea-Torresdey JL. Seedling emergence, growth, and leaf mineral nutrition of *Ricinus communis* L. cultivars irrigated with saline solution, Ind. Crops Prod., 2013, 49: 75–80.
52. Pinheiro HA, Silva JV , Endres L, Ferreira VM, Camara CA, Cabral FF, Oliveira JF, de Carvalho LWT, dos Santos JK and Filho BGS. Leaf gas exchange, chloroplastic pigments and dry matter accumulation in castor bean (*Ricinus communis* L.) seedlings subjected to salt stress conditions, Ind. Crops Prod., 2008, 27: 385–392.
53. Wu XH, Zhang HS, Gang L, Liu XC, Qin P. Ameliorative effect of castor bean (*Ricinus communis* L.) planting on physic-chemical and biological properties of seashore saline soil, Ecol. Eng., 2012, 38: 97–100.
54. Zhang H, Guo Q, Yang J, Ma J, Chen G, Chen T, Zhu G, Wang J, Zhang G, Wang X, Shao C. Comparison of chelates for enhancing *Ricinus communis* L. phytoremediation of Cd and Pb contaminated soil, Ecotoxicol. Environ.Saf., 2016, 133: 57–62.
55. Chhajro MA, Rizwan MS, Guoyong H, Jun Z, Kubar KA, Hongqing H. Enhanced accumulation of Cd in castor (*Ricinus communis* L.) by soil-applied chelators, Int. J. Phytoremed., 2015, 18: 664–670.
56. Ananthi TAS, Manikandan PNA. Potential of rhizobacteria for improving lead phytoextraction in *Ricinus communis.* Remediation, 2013, 24(1): 99–106
57. Rajkumar M, Sandhya S, Prasad MNV, Freitas H. Perspectives of plant-associated microbes in heavy metal phytoremediation, Biotechnol., 2012, Adv. 30: 1562–1574.
58. Ma Y, Prasad MNV, Rajkumar M, Freitas H. Plant growth promoting rhizobacteria and endophytes accelerate phytoremediation of metalliferous soils, Biotechnol. Adv., 2011a, 29: 248–258.
59. Ma Y, Rajkumar M, Luo Y, Freitas H. Inoculation of endophytic bacteria on host and non-host plants–effects on plant growth and Ni uptake, J. Hazard. Mater., 2011b, 196: 230–237.
60. Dakora FD, Phillips DA. Root exudates as mediators of mineral acquisition in low-nutrient environments, Plant Soil, 2002, 245: 35–47.
61. Jones DL, Dennis PG, Owen AG, van Hees PAW, Organic acid behavior in soils—misconceptions and knowledge gaps, Plant Soil, 2003, 248: 31–41.
62. Rajkumar M, Ae N, Prasad MNV, Freitas H. Potential of siderophore producing bacteria for improving heavy-metal phytoextraction, Trends Biotechnol., 2010, 28 (3): 142–149.
63. Romeiro S, Lagôa AMMA, Furlani PR, de Abreu CA, de Abreu MF, Erismann NM. Lead uptake and tolerance of *Ricinus communis* L., Braz. J. Plant Physiol., 2006,18 (4): 483–489.
64. Wang C, Li G, Zhang Z, Peng M., Shang Y, Luo R, Chen Y. Genetic diversity of castor bean (*Ricinus communis* L.) in Northeast China revealed by ISSR markers, Biochem. Syst. Ecol., 2013, 51: 301–307.
65. Wu S, Shen C, Yang Z, Lin B, Yuan J. Tolerance of *Ricinus communis* L. to Cd and screening of high Cd accumulation varieties for remediation of Cd contaminated soils, Int. J. Phytoremed., 2016, 18(11): 1148–1154. doi:10.1080/15226514. 2016.1186595.
66. Lu XY, He CQ. Tolerance, uptake and accumulation of cadmium by *Ricinus communis* L., J. Agro-Environ. Sci., 2005, 24: 674–677.
67. Mahmud R, Inoue N, Kasjima S, Shahenn R. Assessment of potential indigenous plant species for the phytoremediation of arsenic-contaminated areas of Bangladesh, Int. J. Phytoremed., 2008, 10: 119–132.
68. Malarkodi M, Krishnaswamy R, Chitdeswari T. Phytoextraction of nickel contaminated soil using castor phytoextractor, J. Plant Nutrition, 2008, 31(2): 219–229
69. Huang G, Guo G, Yao S, Zhang N, Hu H. Organic acids, amino acids compositions in the root exudates and Cu-accumulation in castor (*Ricinus communis* L.) under Cu stress, Int. J. Phytoremed., 2016, 18(1): 33–40.
70. Andreazza R, Bortolon L, Pieniz S, Camargo FAO. Use of high-yielding bioenergy plant castor bean (*Ricinus communis* L.) as a potential phytoremediator for copper-contaminated soils, Pedosphere, 2013, 23(5): 651–661.
71. Pandey VC. Suitability of *Ricinus communis* L. cultivation for phytoremediation of fly ash disposal sites, Ecol. Eng., 2013, 57: 336–341.
72. Glick BR. Using soil bacteria to facilitate phytoremediation, Biotechnol. Adv., 2010, 28: 367–374.
73. Makeswari M, Santhi T. Tannin gel derived from Leaves of *Ricinus communis* as an adsorbentfor the Removal of Cu (II) and Ni (II) ions from aqueous solution. International Journal of Modern Engineering Research 3 (5), 3255-3266.
74. Anastasi U, Sortino O, Cosentino SL, Patanè C Seed yield and oil quality of perennial castor bean in a Mediterranean environment. International Journal of Plant Production, 2015, 9(1): 99–116.
75. Ma Y, Rajkumar M, Zhang C, Freitas H. Beneficial role of bacterial endophytes in heavy metal phytoremediation. J Environmental Management, 2016, 174,14-25.
76. Ma, Y., Rajkumar, M., Rocha, I., Oliveira, R.S., Freitas, H. Serpentine bacteria influence metal translocation and bioconcentration of *Brassica juncea* and *Ricinus communis* grown in multi— metal polluted soils. Front. Plant Sci. 2015, 5, 757.
77. Baishya M, Kalita MC. Phytoremediation of crude oil contaminated soil using two local varieties of castor oil plant (*Ricinus communis*) of Assam, Int. J. Pharma Bio. Sci., 2015, 6(4): 1173–1182.
78. Schneider J, Bundschuh J, do Nascimento CW. Arbuscular mycorrhizal fungi-assisted phytoremediation of a lead-contaminated site, Sci. Total Environ. 2016, 572: 86–97.
79. Agbogidi, O.M. and Egbuchua, C.O. Heavy metal concentrations of soil contaminated with spent engine oil in Asaba, Delta State. Acta Agronomica Nigeriana 2010, 10 (1): 65-69.
80. Vwioko DE, Anoliefo GO, Fashemi SD. Metal concentration in plant tissues of *Ricinus communis* L. (Castor oil) grown in soil contaminated with spent lubricating oil, J. Appl. Sci. Environ. Manage., 2006, 10(3): 127–134.
81. Vwioko DE, Fashemi DS. Growth response of *Ricinus communis* L.

(castor oil) in spent lubricating oil polluted soil, J.Applied Sci. Environ. Manage., 2005, 9(2): 73–79.
82 Niu Z, Sun L, Sun, T. Response of root and aerial biomass to phytoextraction of Cd and Pb by sunflower, castor bean, alfalfa and mustard, Adv. Environ. Biol., 2009, 3: 255–262.
83 Huang H, Yu N, Wang L, Gupta DK, He Z, Wang K, Zhu Z, Yan X, Li T, Yang X-E. The phytoremediation potential of bioenergy crop *Ricinus communis* for DDTs and cadmium co-contaminated soil, Bioresour. Technol., 2011, 102(23): 11034–11038.
84 Li G, Zhang H, Wu X, Shi C, Huang X, Pei-Qin P. Canopy reflectance in two castor bean varieties (*Ricinus communis* L.) for growth assessment and yield prediction on coastal saline land of Yancheng District, China, Ind. Crops Prod., 2011, 33: 395–402.
85. Haung H, Yu N, Wang L, Gupta DK, He Z, Wang K, Zhu Z, Yan X, Li T, Yang X-E. The phytoremediation potential of Bioenergy crop *Ricinus communis* for DDTs and cadmium co-contaminated soil, Bioresour. Technol., 2011, 102: 11034–11038.
86. Daniela K, Jakub E, Lukas P. Effect of compost amendment on heavy metals transport to plant, MendelNet, 2015, pp. 249–254.
87. Smith SR. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge, Environ. Int., 2009, 35: 142–156.
88. Bosiacki M, Kleiber T, Kaczmarek J. Evaluation of suitability of *Amaranthus caudatus* L. and *Ricinus communis* L. in phytoextraction of cadmium and lead from contaminated substrates, Arch. Environ. Prot., 2013, 39 (3): 47–59.
89. Giordani C, Cecchi S, Zanchi C. Phytoremediation of soil polluted by nickel using agricultural crops, Environ. Manage., 2005,. 36(5): 675–681.
90. Wang S, Zhao Y, Guo J, Zhou L. Effects of Cd, Cu and Zn on *Ricinus communis* L. growth in single element or co-contaminated soils: Pot experiments, Ecol. Eng., 2016, 90: 347–351.
91. Coscione AR, Berton RS. Barium extraction potential by mustard, sunflower and castor bean, Scientia Agricola 66, 2009, pp. 59-63.
92. Bonanno G. *Ricinus communis* as an element Biomonitor of atmospheric pollution in urban areas, Water Air Soil Poll., 2014, 225(2): 1852.
93. Costa ET de S, Guilherme LRG, de Melo EEC, Ribeiro BT, Inacio ESB, Severiano EC, Faquin V, Hale BA. Assessing the tolerance of castor bean to Cd and Pb for phytoremediation purposes, Biol. Trace Elem. Res., 2012, 145: 93–100.
94 Martins AE, Pereira MS, Jorgetto AO, Ma UM, Silva RIV, Saeki MJ, Castor GR. The reactive surface of Castor leaf [*Ricinus communis* L.] powder as a green adsorbent for the removal of heavy metals from natural river water, Applied Surface Sci., 2013, 276: 24–30.
95. Fitz WJ, Wenzel WW. Arsenic transformation in the soil–rhizosphere–plant system, fundamentals and potential application of phytoremediation, J. Biotechnol., 2002, 99: 259–278.
96. Prasad M.N.V. Phytoremediation and biofuels In, E. Lichtfouse (ed.), Sustainable Agriculture Reviews 17, 2015 © Springer International Publishing Switzerland. Page 159-261.
97. Prasad, M.N.V. (Ed) Bioremediation and Bioeconomy. 2016 Elsevier, USA. Pages 698.
98. Tripathi V, Edrisi SA, Abhilash PC. Towards the coupling of phytoremediation with bioenergy production Renewable and Sustainable Energy Reviews 2016, 57 1386–1389.
99 Pandey VC, Bajpai O, Singh N. Energy crops in sustainable phytoremediation, Renew. Sust. Energy Rev., 2016, 54: 58–73.
100 Amouri M, Mohellebi F, Zaid TA, Aziza M. Sustainability assessment of *Ricinus communis* biodiesel using LCA approach, Clean Techn. Environ. Policy, 2016, DOI 10.1007/s10098-016-1262-4.
101 Bauddh K, Singh K, Singh RP. *Ricinus communis* L. a value added crop for remediation of cadmium contaminated soil, Bull. Environ. Contam. Toxicol., 2016, 96(2): 265–269.
102 Hadi F, Ali N, Fuller MP. Molybdenum (Mo) increases endogenous phenolics, proline and photosynthetic pigments and the phytoremediation potential of the industrially important plant *Ricinus communis* L. for removal of cadmium from contaminated soil. Environ. Sci. Pollut. Res. Int., 2016, 23(20): 20408–20430.
103 Rani P, Kumar A, Arya RC. Phytostabilization of tannery sludge amended soil using *Ricinus communis*, *Brassica juncea* and *Nerium oleander,* J. Soils Sedim., 2016, DOI 10.1007/s11368-016-1466-6.
104 Chhajro MA, Rizwan MS, Guoyong H, Jun Z, Kubar KA, Hongqing H. Enhanced accumulation of Cd in castor (*Ricinus communis* L.) by soil-applied chelators, Int. J. Phytoremed., 2015, 18: 664–670.
105 Silitonga AS, Masjuki HH, Ong HC, Yusaf T, Kusumo F, Mahlia TM. Synthesis and optimization of *Hevea brasiliensis* and *Ricinus communis* as feedstock for biodiesel production: A comparative study, Ind. Crops Prod., 2016, 85: 274–286.
106 Srinivasarao Ch, Shanker AK, Kundu S, Reddy S. Chlorophyll fluorescence induction kinetics and yield responses in rainfed crops with variable potassium nutrition in K deficient semi-arid alfisols, J. Photochem. Photobiol. B: Biol., 2016, 160: 86–95.
107 Wei R, Guo Q, Wen H, Liu C, Yang J, Peters M, Hu J, Zhu G, Zhang H, Tian L, Han X, Ma J, Zhu C, Wan Y. Fractionation of stable cadmium isotopes in the cadmium tolerant *Ricinus communis* and hyperaccumulator *Solanum nigrum*, Scientific Reports 6: Art. No. 24309. 2016, doi:10.1038/srep24309.
108 Hadi F, Ul-Arifeen MZ, Aziz T, Nawab S, Nabi G. Phytoremediation of cadmium by *Ricinus communis* L. in hydrophonic condition, American-Eurasian J. Agric. & Environ. Sci., 2015, 15(6): 1155–1162.
109 Yashim ZI, Agbaji EB, Gimba CE, Idris SO. Phytoremediation potential of *Ricinus communis* L. (Castor oil plant) in Northern Nigeria, Int. J. Plant Soil Sci., 2016, 10(5): 1–8.
110 Yi X, Jiang L, Chen J, Liu Q, Yi S. Effects of lead/zinc tailings on photosynthetic characteristics and antioxidant enzyme system of *Ricinus communis* L, Chinese J. Ecol.,2016 35(4): 880–887.
111 Alexopoulou E, Papatheohari Y, Zanetti F, Tsiotas K, Papamichael I, Christou M, Namatov I, Monti A. Comparative studies on several castor (*Ricinus communis* L.) hybrids: growth, yields, seed oil and biomass characterization, Ind. Crops Prod., 2015, 75B: 8–13.
112 Armendáriz J, Lapuerta M, Zavala F, Garcia-Zambrano E, del Carmen Ojeda M. Evaluation of eleven genotypes of castor oil plant (*Ricinus communis* L.) for the production of biodiesel, Ind. Crops Prod., 2015, 77: 484–490.
113 Aziera ZN, Majid NM. Uptake and translocation of zinc and cadmium by *Ricinus communis* planted in sewage sludge contaminated soil, UKM J, Publisher Penerbit Univeriti Kebangsaan, Malyasia, 2015.
114 Saadawi S, Algadi M, Ammar A, Mohamed S, Alennabi. Phytoremediation effect of Ricinus communis, Malva parviflora and Triticum repens on crude oil contaminated soil. J. Chemical and Pharmaceutical Research, 2015, 7: 782-786.
115. Bauddh K, Singh K, Singh B, Singh RP. *Ricinus communis*: a robust plant for bio-energy and phytoremediation of toxic metals from contaminated soil, Ecol. Eng. 2015, 84: 640–652.
116. Bauddh K, Singh RP. Effects of organic and inorganic amendments on bio-accumulation and partitioning of Cd in *Brassica juncea* and *Ricinus communis*, Ecol. Eng., 2015, 74: 93–100.
117 Al-Rmalli WS, Dhamani AA, Abuein MM, Gleza AA. Biosorption of mercury from aqueous solutions by powdered leaves of castor tree (*Ricinus communis* L.), J. Hazard. Mat., 2008, 152: 955–959.
118 Al-Harbawy AW, Al-Mallah MK Production and characterization of biodiesel from seed oil of castor (*Ricinus communis* L.) plants. International Journal of Science and Technology 2014, 3(9): 508–513.
119 Campbell DN, Na C-I, Rowland DL, Schnell RW, Ferrell JA, Wilkie A. Development of a regional specific crop coefficient (Kc) for castor (*Ricinus communis* L.) in Florida, USA by using the sap flow method, Ind. Crops Prod., 2015, 74: 465–471.
120. Capuani S, Fernandes DM, Rigon JPG, Ribeiro LC. Combination between acidity amendments and sewage sludge with phosphorus on soil chemical characteristics and on development of Castor bean, Communications in Soil Sci. Plant Analysis, 2015, 46(22): 2901–2912.
121 Grichar WJ, Dotray PA, Trostle CL. Castor (*Ricinus communis* L.) tol-

erance to postemergence herbicides and weed control efficacy, Int. J. Agronomy, 2012, Article ID 832749, pp. 5.
122. Hadi F, Ul-Arifeen MZ, Aziz T, Nawab S, Nabi G. Phytoremediation of cadmium by *Ricinus communis* L. in hydrophonic condition, American-Eurasian J. Agric. & Environ. Sci., 2015, 15(6): 1155–1162. DOI: 10.5829/idosi.aejaes.2015.15.6.94212.
123. Kang W, Bao J, Zheng J, Hu H, Du J. Distribution and chemical forms of copper in the root cells of castor seedlings and their tolerance to copper phytotoxicity in hydroponic culture, Environ. Sci. Pollut., 2015, R22(10): 7726–7734.
124. Liu S, Zhu Q, Guan Q, He L, Li W. Bio-aviation fuel production from hydroprocessing castor oil promoted by the nickel-based bifunctional catalysts. Bioresour. Technol., 2015, 183: 93–100.
125. Medeiros, A.M.M.S., Machado, F. and Rubim, J.C. 2015. Synthesis and characterization of a magnetic bio-nanocomposite based on magnetic nanoparticles modified by acrylated fatty acids derived from castor oil. European Polymer Journal 71: 152-163.
126. Chatzakis MK, Tzanakakis VA, Mara DD, Angelakis AN. Irrigation of castor bean (*Ricinus communis* L.) and sunflower (*Helianthus annus* L.) plant species with municipal wastewater effluent: impacts on soil properties and seed yield. Water 2011, 3: 1112–1127.
127. Moncada J, Cardona CA, Rincon LE. Design and analysis of a second and third generation biorefinery: The case of castor bean and microalgae, Bioresour. Technol., 2015, 198: 836–843.
128. Ribeiro PR, Zanotti RF, Deflers C, Fernandez LG, Castro R, Ligterink W, Hilhorst HWM. Effect of temperature on biomass allocation in seedlings of two contrasting genotypes of the oilseed crop *Ricinus communis*, J. Plant Physiol., 2015, 185: 31–39.
129. Rissato SR, Galhiane MS, Fernandes JR, Gerenutti M, Gomes HM, Ribeiro R, de Almeida MV. Evaluation of *Ricinus communis* L. for the phytoremediation of polluted soil with organochlorine pesticides, BioMed Res. Int., Article ID 549863. 2015, 8.
130. Sánchez N, Sánchez R, Encinar JM , González JF, Martinez G. Complete analysis of castor oil methanolysis to obtain biodiesel, Fuel, 2015, 147: 95–99.
131. Severino LS, Mendes BSS, Lima GS. Seed coat specific weight and endosperm composition define the oil content of castor seed, Ind. Crops Prod., 2015, 75B: 14–19.
132. Shi G, Xia S, Ye J, Huang Y, Liu C, Zhang Z. PEG-simulated drought stress decreases cadmium accumulation in castor bean by altering root morphology, Environ. Experim. Bot., 2015, 111: 127–134.
133 Silva GE , Ramos FT, de Fajra AP, Franca MG. Seeds' physicochemical traits and mucilage protection against aluminum effect during germination and root elongation as important factors in a biofuel seed crop (*Ricinus communis*), Environ. Sci. Pollut. Res. Int., 2014, 21(19): 11572–11579.
134 Srivastava SK, Kumar J. Response of castor (*Ricinus communis* L.) to sulphur under irrigated conditions of Uttar Pradesh, India, Plant Archives, 2015, 15(2): 879–881.
135. Zhang H, Chen X, He C, Liang X, Oh K, Liu X, Lei Y. Use of energy crop (*Ricinus communis* L.) for phytoextraction of heavy metals assisted with citric acid, I. J. Phytoremed. 2015, 17(7): 632–639.
136. Zhang H, Guo Q, Yang J, Shen J, Chen T, Zhu G, Chen H, Shao C. Subcellular cadmium distribution and antioxidant enzymatic activities in the leaves of two castor (*Ricinus communis* L.) cultivars exhibit differences in Cd accumulation, Ecotoxicol. Environ. Saf. 2015, 120: 184–192.
137. Atiku FA, Warra AA, Enimola MR. FTIR spectroscopic analysis and fuel properties of wild castor (*Ricinus communis* L.) seed oil, Open Sci. J. Analyt. Chem., 2014, 1(1): 6–9.
138 Bauddh K. *Ricinus communis* (castor bean): a multipurpose crop for the sustainable environment, Dream-2047, 2014, 16(11): 31–32.
139 Bauddh K, Singh RP. Studies on bio-accumulation and partitioning of Cd in *Brassica juncea* and *Ricinus communis* in presence of vermicompost, chemical fertilizers, biofertilizers and customized fertilizers, Ecol. Eng., 2014, 74: 93–100.
140. Andreazza R, Bortolon L, Pieniz S, Camargo FAO. Use of high-yielding Bioenergy plant castor bean (*Ricinus communis* L.) as a potential phytoremediator for copper-contaminated soils, Pedosphere, 2013, 23(5): 651–661.
141. Chen Y, Liu X, Wang M, Yan X. Cadmium tolerance, accumulation and relationship with Cd subcellular distribution in *Ricinus communis* L., Acta Scientiae Circumstantiae, 2014, 34(9): 2440–2446.
142, Goyal N, Pardha-Saradhi P, Sharma GP. Can adaptive modulation of traits to urban environments facilitate *Ricinus communis* L. invasiveness? Environ. Monit. Assess., 186: 7491.
143. Neto MCL, Lobo AKM, Martins MO, Fontenele AV, Silveira JAG. Dissipation of excess photosynthetic energy contributes to salinity tolerance: A comparative study of salt-tolerant *Ricinus communis* and salt-sensitive *Jatropha curcas,* J. Plant Physiol., 2014, 171(1): 23–30.
144. Magriotis ZM, Carvalho MZ, de Sales PF, Alves FC, Resende RF, Saczk AA. Castor bean (*Ricinus communis* L.) presscake from biodiesel production: an efficient low cost adsorbent for removal of textile dyes, J. Environ. Chem.Eng., 2014, 2(3): 1731–1740.
145. Rodrigues CRF, Silva EN, Moura R, Viegas RA. Physiological adjustment to salt stress in *R. communis* seedlings is associated with a probable mechanism of osmotic adjustment and reduction in water lost by transpiration, Ind. Crops Prod., 2014, 54: 233–239.
146. 146. Rigby NM, McDougall AJ, Needs PW, Selvendran RR (1994) Phloem translocation of a reduced oligogalacturonide in *Ricinus communis* L. Planta 193:536–541.
147. Kammerbauer J, Dick T (2000) Monitoring of urban traffic emissions using some physiological indicators in *Ricinus communis* L. plants. Arch Environ Contam Toxicol 39:161–166.
148. Zhang H, Guo Q, Yang J, Chen T, Zhu G, Peters M, Wei R, Tian L, Wang C, Tan D, Ma J, Wang G, Wan Y. Cadmium accumulation and tolerance of two castor cultivars in relation to antioxidant systems, J. Environ. Sci., 2014, 26(10): 2048–2055.
149. Akande TO, Odunsi AA, Olabode OS, Ojediran TK. Physical and nutrient characterization of raw and processed castor (*Ricinus communis* L.) seeds in Nigeria. World Journal of Agricultural Sciences, 2012, 8(1): 89–95.
150. Makeswari M, Santhi T Removal of malachite green dye from aqueous solutions onto microwave assisted zinc chloride chemical activated epicarp of *Ricinus communis.* Journal of Water Resource and Protection Vol.5 No.2 (2013), Article ID: 28297,17.
151. Pal R, Banerjee A, Kundu R. Responses of castor bean (*Ricinus communis* L.) to lead stress, Proc. Nat. Acad. Sci. India Section B: Biol. Sci., 2013, 83(4): 643–650.
152. Kathi S, Khan AB. Phytoremediation approaches to PAH contaminated soil. Indian Journal of Science and Technology 2011, 4: 56-63.
153. Perdomo FA, Acosto-Osorio AA, Herrera G, Vasco-Leal JF, Mosquera-Artamonov JD, Millan-Malo B, Rodriguez-Garcia ME. Physicochemical characterization of seven Mexican *Ricinus communis* L. seeds & oil contents, Biomass Bioenergy, 2013, 48: 17–24.
154. Severino LS, Auld DL. A framework for the study of the growth and development of castor plant, Ind. Crops Prod., 2013, 46: 25–38.
155. Kang W, Zheng J. Ricinus communis, a new copper hyperaccumulator. J. Anhui. Agric Sci. 2011, 39: 1449–1451.
156. Tyagi K, Sharma S, Rashmi R, Kumar S. Study of phyto-chemical constituents of *Ricinus communis* Linn. under the influence of industrial effluent, J. Pharmacy Res., 2013, 6: 870–873.
157. Wang K, Huang H, Zhu Z, Li T, He Z, Yang X, Alva A. Phytoextraction of metals and rhizoremediation of PAHs in co-contaminated soil by co-planting of *Sedum alfredii* with ryegrass (*Lolium perenne*) or Castor (*Ricinus communis*), Int. J. Phytoremed., 2013, 15 (3): 283–298.
158. Yasur J, Rani PU. Environmental effects of nanosilver: impact on castor seed germination, seedling growth, and plant physiology, Environ. Sci. Pollut. Res. Int. 2013, 20(12): 8636–8648.
159 Ananthi TAS, Meerabai RS, Krishnasamy R. Potential of *Ricinus communis* L. and *Brassica juncea* (L.) Czern. under natural and in-

duced Pb phytoextraction, Universal J. Environ. Res. Tech., 2012, 2(5): 429–438.
160. Adhikari T and Kumar A. Phytoaccumulation and Tolerance of Riccinus Communis L. to Nickel. International Journal of Phytoremediation. 2012, 14, 481-492.
161 Bauddh K, Singh RP Growth, Tolerance efficiency and phytoremediation potential of *Ricinus communis* (L.) and *Brassica juncea* (L.) in salinity and drought affected cadmium contaminated soil. Ecotoxicology and Environmental safety, 2012, 85, 13-22.
162 Carreno LVN, Garcia ITS, Raubach WC, Krolow M, Santos CCG, Probst LFD, Fajardo HV. Nickel-carbon nanocomposites prepared using castor oil as precursor: A novel catalyst for ethanol steam reforming, J. Power Sources, 2009, 188: 527–531.
163 dos Santos CH, de Oliveira Garcia AL, Calonego JC, Spósito THN, Rigolin IM. Pb-phytoextraction potential by castor beans in soil contaminated (Potencial de fitoextração de Pb por mamoneiras em solo contaminado,. Semina Cienc. Agrar., 2012, 33(4): 1427–1433.
164. Lavanya C, Murthy IYLN, Nagaraj G, Mukta N. Prospects of castor (*Ricinus communis* L.) genotypes for biodiesel production in India, Biomass Bioenergy, 2012, 39,204-209.
165. Melo EEC, Guilherme LRG, Nascimento CWA, Penha HGV. Availability and accumulation of Arsenic in oilseeds grown in contaminated soils, Water, Air, & Soil Pollut., 2012, 223(1): 233–240.
166. Prasad KS, Chuang MC, Ho JAA. Synthesis, characterization, and electrochemical applications of carbon nanoparticles derived from castor oil soot, Talanta, 2012, 88: 445–449.
167. Severino LS, Auld DL, Baldanzi M, Candido MJD, Chen G, Crosby W, Tan D, He X, Lakshmamma P, Lavany C, Machado OLT, Mielke T, Milani M, Miller TD, Morris JB, Morse SA, Navas AA , Soares DJ, Sofiatti V, Wang ML, Zanotto MD, Zieler H. A review on the challenges for increased production of Castor, Agronomy Journal. 104(4): 853–880.
168. Varun M, D'Souza R, Pratas J, Paul MS. Metal contamination of soils and plants associated with the glass industry in North-central India: prospects of phytoremediation, Environ. Sci. Pollut. Res., 2012, 19: 269–281.
169. Rissato SR, Galhiane MS, Fernandes JR, Gerenutti M, Gomes HM, Ribeiro R, de Almeida MV. Evaluation of *Ricinus communis* L. for the phytoremediation of polluted soil with organochlorine pesticides, BioMed Res. Int., Article ID 549863. 2015, 8.
170. Perea-Flores MJ, Chanona-Perez JJ, Garibay-Febles V, Calderon-Dominguez G, Terres-Rojas E, Mendoza-Perez JA, Bucio-Herrera R. Microscopy techniques and image analysis for evaluation of some chemical and physical properties and morphological features for seeds of the castor oil plant (*Ricinus communis*), Ind. Crops Prod., 2011, 34(1): 1057–1065.
171. Goytia-Jimenez MA, Gallegos-Goytia CH, Nunez-Colin CA. Relationship among climatic variables with the morphology and oil content of castor oil plant (*Ricinus communis* L.) seeds from Chiapas, Revista Chapingo. Serie Ciencias Forestales y del Ambiente, 2011, 18: 42–48.
172. Nazir A, Malik RN, Ajib M, Khan N, Siddiqui MF. Hyperaccumulators of heavy metals of industrial areas of Islamabad and Rawalpindi. Pak. J. Bot., 2011, 43(4): 1925–1933
173. Babita M, Maheswari M, Rao LM, Shanker AK, Rao DG. Osmotic adjustment, drought tolerance and yield in castor (*Ricinus communis* L.) hybrid, Environ. Experim. Bot., 2010, 69(3): 243–249.
174. Bale AT, Adebayo RT, Ogundele DT, Bodunde VT (2013) Fatty acid composition and physicochemical properties of castor (*Ricinus communis* L.) seed obtained from Malete, Moro local government area, Kwara State. Nigeria. Chemistry and Materials Research 3(12): 11–13.
175. Santhi T, Manonmani S, and Smitha T. Removal of malachite green from aqueous solution by activated carbon prepared from the epicarp of *Ricinus communis* by adsorption. *Journal of hazardous materials,*2010, 179: 178-186.
176. Shi G and Cai Q Zinc tolerance and accumulation in eight oil crops Journal of Plant Nutrition 2010, 33(7):982-997.
177. Singh DP, Kumar N, Bhargava SK, Barman SC. Accumulation and translocation of heavy metals in soil and plants from fly ash contaminated area, J. Environ. Biol., 2010, 31: 421–430.
178. Ye LW, Wood BA, Stroud LJ , Andralojc JP, Raab A, McGrath AS, Feldmann J, Zhao FJ. Arsenic speciation in phloem and xylem exudates of castor bean, Plant Physiol., 2010, 154: 1505–1513.
179**.** Singh A, Mittal S, Shrivastav a R , Dass S , Srivastava J.N. Biosynthesis of silver nanoparticles using Ricinus communis L. Leaf extract and its antibacterial activity. J. of Nanomaterials and Biostructures 2012, 7:1157 - 1163.
180. Zhi-xin N, Sun LN, Sun TH, Li YS, Wang H. Evaluation of phytoextracting cadmium and lead by sunflower, *Ricinus*, alfalfa and mustard in hydroponic culture, J. Environ. Sci. (China). 2007, 19: 961–967.
181. Al-Rmalli WS, Dhamani AA, Abuein MM, Gleza AA. Biosorption of mercury from aqueous solutions by powdered leaves of castor tree (*Ricinus communis* L.), J. Hazard. Mat., 2008, 152: 955–959.
182. Figueroa JAL, Wrobel K, Afton S, Caruso JA, Corona JFG, Wrobel K. Effect of some heavy metals and soil humic substances on the phytochelatin production in wild plants from silver mine areas of Guanajuato, Mexico, Chemosphere, 2008, 70: 2084–2091.
183. Oladoja NA, Aboluwoye OC, Oladimeji YB, Ashogbon AO, Otemuyiwa IO. Studies on castor seed shell as a sorbent in basic dye contaminated wastewater remediation, Desalination, 2008, 227: 190–203.
184. Sas-Nowosielska A, Galimska-Stypa R, Kucharski R, Zielonka U, Malkowski E, Gray L. Remediation aspect of microbial changes of plant rhizosphere in mercury contaminated soil, Env. Monit. Assess., 2008, 137(1-3): 101–109.
185. Lu XY, He CQ. Tolerance, uptake and accumulation of cadmium by *Ricinus communis* L., J. Agro-Environ. Sci., 2005, 24: 674–677.
186. Stephan WU, Schmidke L, Pich A. Phloem translocation of Fe, Cu, Mn, and Zn in *Ricinus* seedlings in relation to the concentrations of nicotianamine, an endogenous chelator of divalent metal ions, in different seedling parts, Plant and Soil, 1994, 165:181–188.
187. Scarpa A, Guerci A. Various uses of the castor oil plant (*Ricinus communis* L.). A review, J. Ethnopharmacol., 1982, 5: 117–137.
188. Saadaoui E, Martín JJ, Tlili N, and Cervantes E. Castor bean (*Ricinus communis* L.): Diversity, seed oil and uses. pages 19-33. In, Ahmad P Ed. Oil Seed Crops: Yield and Adaptations under Environmental Stress, 2017. John Wiley & Sons, Ltd USA.
189. Chandra R, Kumar V. Phytoextraction of heavy metals by potential native plants and their microscopic observation of root growing on stabilized distillery sludge as a prospective tool for in situ phytoremediation of industrial waste. Environ Sci Pollut Res, 2017, 24: 2605 – 2619.
190. Grison C. Combining phytoextraction and ecocatalysis: a novel concept for greener chemistry, an opportunity for remediation. Environ Sci Pollut Res 2015, 22: 5589 – 5591.
191. van der Ent A, Baker AJM, Reeves RD, Chaney RL, Anderson CW, Meech JA, Erskine PD, Simonnot M-O, Vaughan J, Morel JL, Echevarria G, Fogliani B, Rongliang Q, Mulligan DR. Agromining: Farming for Metals in the Future? Environ Sci Technol. 2015, 49, 4773–4780.
192. Gerhardt KE, Gerwing PD, Greenberg BM. Opinion: Taking phytoremediation from proven technology to accepted practice. Plant Science, 2017, 256: 170-185.