Journal of Materials and Environmental Sciences
ISSN : 2028-2508

JMES, 2017 Volume 8, Issue 5, Page 1770-1782

http://www.jmaterenvironsci.com/

Cactus an eco-friendly material for wastewater treatment: A review

F. Ben Rebah[1,2*], S.M. Siddeeg[3,4]

[1]*Community College at Khamis Mushait, King Khalid University, Saudi Arabia.*
[2]*Higher Institute of Biotechnology of Sfax (ISBS), Tunisia*
[3]*Department of Chemistry, College of Science, King Khalid University, P. O. Box 9004, Abha, Saudi Arabia.*
[4]*Chemistry and Nuclear Physics Institute, Atomic Energy Commission, P. O. Box 3001, Khartoum, Sudan.*

Received 17 Jun 2016,
Revised 11 Jan 2017,
Accepted 18 Jan 2017

Keywords
- ✓ *Cactus,*
- ✓ *wastewater treatment,*
- ✓ *coagulant,*
- ✓ *flocculant,*
- ✓ *biosorbent,*
- ✓ *biofilter media*

benrebahf@yahoo.fr
Tel: +966 545 325 969

Abstract

Renewable approaches involving the use of natural materials for pollutant removal from wastewaters can offer a favorable solution fitting well with the definition of sustainability. Materials from biological origin (Bean, Moringa, Maize, etc.) have been investigated for their potential use for wastewater treatment. Interestingly, cactus, an abundant plant, offers various options for the treatment of wastewater. The present paper reviews wastewater treatment technologies that may involve cactus. This biomaterial can be involved as coagulant/flocculant, as biosorbent and as packed material for biofilter. Also, cactus may offer enzymatic system useful for the transformation of toxic textile dyes. The results obtained in the depollution of wastewaters using various cactus preparations showed very high and promising pollutant removal efficiency. Generally, cactus reduced significantly many wastewater parameters (turbidity, COD, heavy metal, conductivity, salinity, etc.). Consequently, for many accessibility criteria (composition, properties, abundant, non-toxic, etc.) cactus may be useful material for wastewater treatment making it appropriate for regions of the world, where cactus is available.

1. Introduction

Different methods are used to treat wastewaters from various origins. Each method is selected depending on the characteristics of the wastewater and the treatment objectives. Depending on its origin, wastewater contains a complex mixture of organic and inorganic pollutants. Discharged in the environment without treatment, wastewater leads to the breakdown of the ecosystem and creating potential health risks. A complete sequence of wastewater treatment may consist of the combination of a number of physical (membrane technologies, adsorption, ion exchange, etc.), chemical (coagulation, chemical oxidation, electrochemical treatments, etc.) and biological (biofilter, sequential batch reactor, etc.) processes. In spite of their availability to remove various pollutants from wastewaters, these methods represent some disadvantages. For example, although the advantages offered by the coagulation-flocculation process (lower sensitivity to toxic loadings and to higher amounts of organics, the easy operation, the energy saving, etc.), the used chemicals (such as aluminum salts, acrylamides, etc.) remain in treated water and may induce health problems (neurotoxicity and carcinogenic properties, genotoxicy, etc.), which were reported on various organisms [1, 2]. In addition, chemicals added for wastewater treatment may react together and generate new products with unknown health effects [3]. On the other hand, the adsorption process, which is based on the use of the activated carbon also offers various advantages (eco-friendly, high efficiency, simplicity of design, ease of operation and insensitivity to toxic substances). However, its use is limited due to its higher cost, the need for carbon regeneration after exhausting, and the loss of adsorption efficiency after regeneration [4].
Generally, depending on the used process and on the wastewater subject to treatment, the technology may be costly economically infeasible and also not eco-friendly, due to the negative impact of its secondary effluent into the environment. Consequently, developing a cost-effective wastewater treatment process remains with extreme importance. In this context, a renewable approach involving application of biomaterials in the removal of pollutants from wastewaters can offer a promising solution. Various natural materials of biological origin (bean, moringa, maize, etc.) have been investigated for their potential use for wastewater treatment [5-14]. Interestingly, cactus is an abundant natural product, cost effective, safe for human health and biodegradable,

offering various options (coagulant/floculant, biosorbent, etc.) for the treatment of wastewater. This meets the development of environmental and economical goals of many regions of the world tending not only to improve wastewater treatment process but also to minimise the negative impacts of treated wastewater disposal on human health.All the utilities of cactus in wastewater treatment will be discussed in the present paper.

2. Cactus as coagulant/flocculant for wastewater treatment

The coagulation/flocculation process offers various advantages for the treatment of both industrial and municipal wastewaters including the lower sensitivity to toxic loadings and to higher amounts of organics, the easy operation, the energy saving, etc. However, it was demonstrated in numerous studies that chemicals (such as aluminium salts, acrylamides, etc.) used in the coagulation-flocculation process remain in treated water and may induce health problems. As indicated above, various health effects such as neurotoxic, carcinogenic, genotoxic and cancerogenic properties, were reported [1].Moreover, synthetic polymers and undesirable substances associated with them may react with others added materials during the treatment and create by-products with unknown health effects [3]. For example, alum, the most widely used coagulant, was reported to be related with Alzheimer's disease [15, 16].

Within the use of synthetic wastewater flocculants/coagulants, human health risks exist [17] limiting the use of treated water in agriculture practice. Consequently, it is recommended to ponder the toxic properties of any synthetic polymer considered for adding to water [18]. Hence, there is a need to consider alternate flocculants/coagulants such as natural materials. These natural materials should be available, cost effective, safe for human health and biodegradable. They are derived from seeds leaves, pieces of bark or sap, roots and fruits of various plants, such as bean, cactus, moringaandmaize [5-7, 19, 20]. For example, many researchersreported the possibility of using moringa as a potential coagulant especially for very high turbid water [8, 9]. Additionally, it was reported that *Aloe vera* has water purification properties [10-13]. Recently, many research activities have demonstrated the possibility of the use of cactus as a promising natural flocculant/coagulant to substitute synthetic polymers, for wastewater treatment [14].

Various studies pointed out the importance of using cactus as flocculant, coagulant or coagulant/flocculant aid for the removal of turbidity, COD and heavy metal (Table 1 and 2).Generally, all the studies were concentrated on the preparation and the optimization of the added cactus based biopolymer (Table 1), which may considerably affect the efficiency and the cost of the process. The biopolymer dosage is one of the most important parameters to be optimized and insufficient dosage or overdosing would result in poor treatment performance.

In one of the early research conducted on cactus, cladodes of *Cactus latifaria* were tested as a coagulant for turbid synthetic water (suspension of kaolin), and the obtained results showed higher level of turbidity removal [20]. Similar study was performed using the inner pads of cactus Opuntia, where cactus pads were sliced, dried (8 h at 80˚C), ground into a fine powder and then sieved to size 53 – 106 µm [21]. The obtained powder tested as coagulant showed similar results to that obtained by the preliminary evaluation [20]. Interestingly, results were comparable to those achieved when using *Moringaoleifera* extracts. Moreover, the optimum cactus coagulant dose was found to be lower than that of aluminium sulphate [20, 22].

As listed in Table 1, different preparations methods of cactus were tested for wastewater from various origins. The mucilage, obtained by boiling *O. indica* cactus cladodes offered a good potential in reducing the conductivity, turbidity, COD, sludge load, oil and greases while applied as coagulant for cosmetic industry wastewater treatment [23]. As a result of this work, the highest turbidity, conductivity and COD removals reached 67.8 %, 20.1 % and 38.6 %, respectively. Generally, the removal efficiency was highly controlled by the polymer dose. Taking into consideration the COD removal, the maximum efficiency was found for mucilage, with 21.1 mg COD/mg mucilage. Interestingly, this process offers the production of more biodegradable sludge. However, the produced sludge quantities varied depending on the wastewater organic load. The maximum sludge production reached 450 ml/L at high-load (13300 mg COD/L) [23].

Likewise, the poultry slaughterhouse wastewater was treated using coagulant extracted from cactus *O.ficusindica* [30]. In this case, viscous polyelectrolytes (soluble sugars) were extracted by maceration of 132 g of cactus pieces in 750 ml of tap water (stirred for 30 minutes). Interestingly, the use of these natural polyelectrolytes increases the aggregation and settling properties of colloids and complex organics such as oil, grease, fats, proteins and suspended solids. Mixing aluminum salt (at concentrations 300 - 600 mg/L) and natural polyelectrolytes (at concentrations 0.6 – 0.8 mg/L) allowed the removal of 86 % of COD, 93 % of oil and grease, 89 % of turbidity and 93 % of suspended solids [30]. However, it is very important to point out that the required residence time and concentrations of cactus polyelectrolytes and chemicals (aluminum or iron salts), depend on the nature and concentrations of recalcitrant organic and inorganic compounds of the effluents. Similar work was conducted with coffee berry effluents having COD of 2000 mg/L remained after biological treatment allowing 87 – 88 % COD removal [34]. The coagulation-flocculation treatment of this effluent required only 50 mg/L of aluminum sulfate and 2.5 mg/L of cactus polyelectrolytes to remove 97% of the total organics and the total coliforms [34]. In contrast, the same process was used as preliminary treatment for cassava meal industrial wastewater (containing 14000 mg/L of COD). Doses of 50 mg/L and 2.5 mg/L for aluminum sulfate and cactus polyelectrolytes, respectively allowed COD reduction to 2000 mg/L, which may permit the biological activated sludge process to perform efficiently [35].

Table 1: Effluent treatment by coagulation-flocculation using cactus for organic pollutant removal

Effluents	Cactus preparation	Optimal conditions	Removal efficiencies (%)	Reference
Jeans laundry effluent : - COD =1094.20 mg/L -Turbidity = 104 FTU	Coagulant : extraction from *O. ficusindica* (using NaCl)	Cactus extract at 2.60 mg/L and pH 5 used with floculant ($FeCl_3$) at 160 mg/ L and pH 5	COD : 64.8 Turbidity: 1.25	[24]
Fabric dyeing mesh effluent : - COD = 1264 mg/ L -Turbidity = 31.5 FTU	Coagulant extraction from *O. ficusindica* (using NaCl)	Cactus extract at 160 mg/L and pH 6 used with floculant ($FeCl_3$) at 640 mg/ L and pH 6	COD : 87.19 Turbidity: 3.61	[24]
Dye industry effluent: - Turbidity : 2250 ppm - pH 9.23	Coagulant : catcus (Opuntia) powder, dried under sunlight and then at 800ºC for 6 hours.	2 g/L at pH 8	Turbidity : 80-85	[25]
Tannery wastewater - BOD : 933.33 mg/L - COD : 1400 mg/L - Sulfate : 135.19 mg/L	Cactus dried and grinded	6 mg/L at pH 7.9	COD :70 BOD: 70 Sulphate 90	[26]
Simulated industrial paint effluent : - pH: 7.6 - Colour : 0.4583 - COD : 7693 mg/L - Turbity : 7760 NTU	Cactus(*O. ficusindica*) dried at 100°C for 2 h, powdered and sieved through a 0.2-mm sieve. The coagulant was extracted using 3N NaCl	3 g/L at pH 7.2–7.8	Colour : 88.37 COD: 78.20 Turbidity: 82.60	[27]
Tannery effluent: - COD :8000-180000 mg/L - pH 5.5	Dry Opuntia (60 °C for 24 h) powder grinded and sieved to get particles size of 600 µm	0.2 mg cactus/500 mL and pH 5.5.	Turbidity: 8.54 COD : 80.65	[28]
Textile effluent : - COD : 2350 mg/L - Turbidity : 38 NTU - Abs at 630 nm : 10.67	Mucilage of *O. ficusindica* : washed with distilled water and sun dried for 3h, cutted into small pieces, then powdered and dried at 60°C for	Mucilage as flocculent at 40 mg/L combined with coagulant ($Al_2(SO_4)_3$)	Colour: 99.84 COD : 88.76 Turbidity : 91.66	[29]

	24h.			
Polutry slaughterhouse effluent: -pH: 6.6 – 7.4; - Suspended solid (SS): 623- 2027 mg/L -COD: 992-3350 mg/L - Oil and grease : 210-1746 mg/L	Extraction of viscous natural polyelectrolytes from *O. ficusindica* by maceration in water (32 g of cactus in 750 ml H_2O_2)	Aluminium salt (300-600 mg/L) combined with cactus ployelectrolyte (0.6 – 0.8 mg/L at pH : 6- 7)	COD : 86 SS: 93 Oil and grease : 93	[30]
Municipal effluent : -Turbidity : 453 NTU -COD : 827 mg/L	Mucilage of cactus cladodes separated using a rough sieve.	50 mg/L at pH 10	COD : 65	[31]
Food industry effluent : -pH: 4.94; -SS: 230mg/L -COD 2376 mg/L	Crude cactus juice ground with a grinder and filtered	Cactus as floculant at dose of 0.056 g/L, pH 3.92; used with alum at 4 g/L	SS: 88.7 COD : 69.1	[14]
Glue industry effluent : - pH: 6.7; - SS: 270 mg/L - COD 99200 mg/L	Flocculant: crude cactus juice ground with a grinder and filtered	Cactus as floculant at dose of 0.616 g/L, pH 4.21; used with alum at 5 g/L	SS: 83.3 COD : 59.1	[14]
Leachate from controlled discharge: -COD :92 g/L, -SS :0.37 g/L -pH : 9.97	Flocculant: crude cactus juice ground with a grinder and filtered	0.081 g/L	COD : 88 SS : 91	[32]
Leachate from controlled discharge : -COD :92 g/L, - SS :0.37 g/L -pH : 9.97	Flocculant : dried cactus juice at 60ºC	0.180g/L	COD : 82 SS : 85	[32]
Petrochemical effluent - COD : 45 g/L, - SS: 0.29 g/L - pH : 9.23	Flocculant: crude cactus juice round with a grinder and filtered	0.081 g/L	COD : 72 SS : 85	[32]
Petro-chemical effluent: -COD : 45 g/L, -SS: 0.29 g/L -pH : 9.23	Flocculant: dried cactus juice at 60ºC	0.180g/L	COD : 69 SS : 75	[32]
Municipal effluent: -COD: 725-1325 mg/L.	Opuntia mucilage		COD : 44.2-44.4	[33]
Cosmetic industrial effluent: -COD: 16700 mg/L -Turbidity 3390 NTU - pH : 5.6.	Mucilage obtained by boiling small pieces of cladodes.	21.1 mg COD/mg polymer pH 5.6.	Turbidity : 67.8 COD : 38.6	[23]

The effluent from tanning industry, characterized by high BOD, COD, suspended solids, settleable solids, sulphide, chloride and chromium, was also subject to coagulation/flocculation treatment by cactus powder preparation (Optima pieces dried at 60°C, grinded and sieved to obtain 600 µm particles). For wastewater with COD ranging from 8000 to 180000 mg/L, an optimum dose (0.4 g/L) of cactus powder, at pH 5.5, allowed 78.54 % and 75 % of turbidity and COD removals, respectively. These values were lower than these obtained while using the powder from *Cicer arietinum* and *Moringaoleifera* at the same concentration, with maximum turbidity and COD reduction of 82.02 % and 90 %, respectively [27]. *Ficusindica* mucilage was also tested for textile wastewater collected from Tunisian industry. In this case, the observed optimum conditions (pH 7, mucilage dose = 40 mg/L and mixing speed up to 50 rpm for 10 min) allowed 99.84 % of decolourization showing a good performance while compared to commercial polyacrylamide [30].

Another extraction method, based on the use of salt solution (NaCl, KCl and $NaNO_3$), was applied to prepare coagulant from *O. ficusindica* for the removal of turbidity and COD from two types of textile wastewater, namely jeans washing laundry effluent and fabric dyeing effluent [24]. Interestingly, the NaCl extracted natural polymer exhibited significant coagulant activity and produced less sludge while compared with $FeCl_3$. The optimization assays showed the variability of optimum conditions depending on the effluent. The conditions for jeans washing laundry effluent were: 160 mg/L of $FeCl_3$, 2.6 mg/ L of natural coagulant and pH 5, while for fabric dyeing effluent they found to be 640 mg/L of $FeCl_3$, 160 mg/L of natural coagulant and pH 6. In the same work, it was demonstrated that coagulation efficiency of cactus *O. ficusindica* polymer was not affected by the storage condition at room temperature for up to 4 days [24]. A similar extraction process using salts (NaCl and $BaCl_2$) was also conducted by Vishali and Karthikeyan (2015) [27] and the obtained cactus based-coagulant was tested for the treatment of a simulated paint effluent. The 3 N NaCl extracted cactus polymer allowed removal efficiencies comparable to $FeCl_3$, with values of 82.11 %, 79.05 %, 78.43 % for colour, COD and turbidity, respectively [27]. Based on previously results [24, 27], the eluent type and concentration used for the natural coagulant preparation considerably affect the extraction rate of cactus active components responsible for the coagulation. Both research activities suggested that NaCl acts as a better eluent allowing the extraction of the maximum amount of active coagulant components. Similar studies were performed using natural coagulants, extracted from chestnut and acorn by salt solution, for the removal of water turbidity [36] and congo red dye [37].

An interesting opportunity based on the addition cactus juice during the electrocoagulation–electroflotation treatment process was performed by other authors [38]. In this work, cactus pieces were grounded, mixed with 100 mL distilled water (10 % dilution) and homogenized. Then, the obtained aqueous viscous extract was filtered to remove large particles. Adding 300 mg/L of cactus juice under optimal operating conditions of electrocoagulation-electroflotation process (cactus juice at 0.016 mL/L, initial pH 8.2, conductivity of 3.04 mS/cm), enhanced the turbidity removal by 15.1 % for a simulated highly turbid industrial wastewater (300 mg/L of silica gel) [38].

In the same perspective, the use of cactus mucilage was optimized and compared to other biopolymers (guar and mesquite seed gum) using response surface methodology (a Box-Behnken design). In this work, the effects of biopolymer doses (25, 50 and 75 mg/L) was tested on wastewaters at various organic loads (725; 1425 and 1325 mg COD/L). Generally, variable results were obtained depending on the used biopolymer. Opuntiamucilage removed only 44.2 - 44.4% of COD and 71.08 % of the metals, which are lower than that obtained for the other biopolymers. However, as a results of the coagulation-flocculation process, the sludge produced quantity is controlled by the type of biopolymer and the initial organic load [33]. These results were in agreement with that reported previously [31] where Opuntiamucilage, at a dose of 50 mg/L used for the treatment of 827 mg COD/L municipal wastewaters, allowed 65 % of COD removal at pH 10. However, for the same wastewater, using *Prosopis galactomannan*, the results showed higher COD removal compared with cactus (up to 90% at pH 10 and for a dose of 75 mg/L).

It was demonstrated that cactus juice may be considered as a promising natural flocculant as a substitute for polyacrylamide, during the treatment of industrial wastewater (wastewater from food and glue industries) by coagulation–flocculation process using alum as coagulant. Depending on the wastewater's origin, the bioflocculant showed removal efficiencies ranged from 83.3 to 88.7 % for suspended solids and from 59.1 to 69.1 % for COD [14]. In the work of Khadhraoui et al. (2015), using the same prepared material of cactus, both crude and dried cactus juice removed COD in petrochemical and leachate wastewaters at efficiencies of 72 - 88% (with crude cactus juice) and 69 - 82% (with dried cactus juice), respectively. For petrochemical and leachate wastewaters, flocculation also reduced the suspended solids by 85 – 91% (with crude cactus juice) and by 75 - 85% (with dried cactus juice), respectively [30].

Simultaneously to the removal of organic pollutants by the coagulation/flocculation process with cactus, the removal of heavy metal was evaluated (Table 2). However, the majority of experiments was conducted using aqueous solution containing heavy metals. Among the works using real wastewater, the removal of chromium from paint manufacturing industry wastewater was conducted using *O. ficusindica* fruits as coagulant. A coagulant optimum dose of 1.5 g/L and pH 7 allowed removal percentages in the range 85 – 92 % of Cr (VI), at initial concentration ranging from 20 to 60 mg/L. At the same time, *O. ficusindica* fruits significantly reduced conductivity, the salinity, the turbidity, the acidity, the total alkalinity, the total hardness and the total dissolved solids from this wastewater [39]. More recently, it was demonstrated that *O. ficusindica* powder was effective in the coagulation/flocculation of Pb (II) ions from both synthetic and real contaminated water. Interestingly, cactus powder can effectively remove Pb (II) ions, even in the presence of other ions [40].

Table 2: Effluent treatment by coagulation-flocculation using cactus for heavy metal removal

Effluents	Cactus preparation / optimal dose	Removal efficiency (%)	References
Polluted river water	*O. ficusindica*cuted, sun-dried (4 weeks), oven-drying at 60 ºC (24 h) and then ground to a fine powder. The powder used at 8 mg/L and pH 5	Pb:100 Zn : 85.74 Cd: 84.16 Cu : 93.02	[40]
Tannery effluent (Fe :72.92 mg/L)	Cactus dried and grinded (6 mg/L at pH 7.9)	Fe : 98	[26]
Drinking water contaminated with As	Cactus mucilage: - 3 ppm gelling extract, pH 8, 30 minutes -3 ppm gelling extract, pH 8, 36 hours	As : 15 - 50	[41]
Municipal effluent	Opuntia mucilage	Metals : 71.08	[33]
Aqueous solution (Cu (II), Cd (II) and Fe (III))	Electrolytes extracted by mixing *O. ficusindica* pieces with water and stirring for 30 min	Cu (II) : 38.50 Cd (II) : 19.43 Fe (III) : 30.12	[44]
Aqueous solution (Cr and Ni at 10 mg/L)	Cactus polyelectrolyte extracted using tap water (132 g of cactus pieces in 750 ml water, stirred for 30 min)	Cr : 68 Ni :88.4	[45]

Based on the presented results related to the use of cactus in the coagulation/flocculation process for wastewater treatment, the variability of the biomaterial efficiencies could be related mainly to two factors. The first is the cactus polymer preparation and the second is the original characteristics of the wastewaters. The wastewater characteristics considerably controlled the process efficiency, as reported for the synthetic polyelectrolytes [44, 45]. The pollutant removal variability was also observed for other biofloculants[46], while using dried and grinded isabgol for the treatment of leachate.

3. Cactus as biosorbent

The adsorption process is a very important separation method based on the use of a suitable absorbent characterized by porous structure allowing high surface area and showing fast adsorption kinetics [47]. This method is noted to be competitive to other techniques applied for water treatment. This is due to various factors such as the cost efficiency, eco-friendly and insensitivity of the used materiel to toxic substances, high efficiency level, design simplicity, easy operation, etc. [48]. Activated carbon is widely used as an adsorbent for the removal of pollutants from wastewaters. However, due to some limitations related to the activated carbon cost, the additional costs for regeneration after exhausting, and the loss of adsorption efficiency after regeneration, many research activities have been conducted in order to explore alternative cheaper adsorbents. Therefore, various materials, including natural materials, wastes and byproducts generated by industries were investigated [49].

The use of the adsorption for heavy metal removal (Cd, Cr, Cu, Pb, Zn, etc.) from wastewater has been extensively studied using various biomaterials (algae, bacteria, fungi, yeasts, peanut shells, soybean hulls and corncobs, etc.) [50-54]. These natural materials are limited in their use due to their lower abundance and high cost. Interestingly, cactus was tested as an adsorbent and large number of experiment was conducted in order to remove metals from grown water [55, 56]. Table 3, summarized some of the carried out experiments using biosorbent derived from cactus. As reported in Table 3, the removal of Cr (VI) from industrial wastewater by cactus leaves was studied using different adsorbent / metal ion ratios, under various parameters (pH, contact time and metal concentration). The adsorption process was found to follow a first-order rate mechanism with rate constant (evaluated at 30ºC) around 6.8×10^{-3} min^{-1} [57]. The obtained removal efficiency of cactus was lower (20 % at pH 2) compared with that observed for other low-cost abundant adsorbents, such as natural wool (removal rate 70% of Cr (VI) at 30ºC). This can be explained by the wool largest capacity and affinity for metal selective removal [57].

Table 3: Cactus as biosprbent for effluent treatment

Effluents	Cactus preparation	Removal efficiency (%) / biosorption capacity (mg/g) / used conditions	References
Aqueous solution (Cu, Cd and Fe)	Cactus polyelectrolyte extracted using tap water (132 g of cactus pieces in 750 ml water, stirred for 30 min). The mucilage was used at 10 % (v/v), 150 rpm at 30 ° C	Cu (II): 38.50 % Cd (II) : 16.12 % Fe (III) :30.12 %	[44]
Aqueous solution (As (V): 60−80 µg/L)	Gelling extract and non-gelling extract of *O. ficusindica*	As (V) : 2.8 - 0.14 mg/g	[58]
Aqueous solution (Cd II, Pb(II) at 30 to 300 mg/L)	Dried *O. ficusindica* cladodes	- Cd (II) : 30.42 mg/g (dosage 2 g/L at pH 5.8 and 25ºC) - Pb(II): 98.62 mg/g (dosage of 2 g/L at pH 3.5 and 25ºC)	[59]
Dyes : -Methylene Blue (Basic blue 9) -Eriochrome Black T (Mordant black 11) Alizarin S (Mordant red 3)	The prickly pear cactus cladodes sun dried (3 weeks), cutted, dried at 60ºC (24 h) and powdered	- Methylene Blue : 189.83 mg/g - Eriochrome Black T : 200.22 mg/g - Alizarin S.: 118.35 mg/g	[59]
Dye: (Brilliant green)	*O. ficusindica* fruit peel oxidized with H_2SO_4 (1M) followed by $NaClO_4$ (1M)		[60]

In another study, removal of arsenic from drinking water was assessed using cactus mucilage at various contact time with gelling extract [39]. The results indicated that as much as the contact time increased, the amount of the As increased. Biosorption of heavy metals (Fe, Cd and Cu) by *O. ficusindica* and factors affecting the process, such as concentration and agitation speed, have been studied [44]. The study showed the optimum conditions to immobilize the examined metals. The obtained results are in agreement with the conclusion of Nozaki, et al. (1993) concerning the use natural polyelectrolyte as auxiliary of flocculation and coagulation in wastewater treatment [61].

The removal of Cu (II) from aqueous solutions was conducted using activated biochar prepared from *O.ficusindica* cactus fibres (cactus fibers heated at 200 ºC for 30 min, then carbonized at 600 ºC for 1 h and activated with nitric acid) [62]. The obtained material showed high adsorption capacity for Cu (II) ions at low pH (pH = 3). Similarly, the efficiency of biochar in removing U (VI) was showed, even in acidic solutions. With this preparation, adsorption process is related to the presence of carboxylic moieties as predominant binding

sites[63]. Consequently, the biochar material constitutes a good candidate for the heavy metal removal from contaminated wastewater [62, 63]. In the same context, ectodermis of Opuntia treated with 1 M H_2SO_4 (24 hours) or with various temperatures (60 ºC, 100 ºC for 24 hours) were tested for removing Cr (VI), Cr (III), Fe, Zn, Cd, Cu, Ni and Pb from mine drainage samples [64]. Interestingly, in aqueous solution removal values of 77 % of Cr (VI) and 99 % of Cr (III) were observed at pH 4, using 0.1 g of sorbent /L. Under optimal conditions for chromium removal, mine drainage samples were effectively treated showing high metal removal, where Cd, Cr, Cu, Ni, Pb were reduced to their non-detectable levels rates, Fe and Zn showed 89 % and 75 % removal rates, respectively [64].
The use of cladodes of *O. streptacantha*as biosorbent for Pb^{2+} removal from contaminated water was investigated[65]. In this case, cactus was dried at 60 ºC (for 24 h), crushed, milled and sieved through a 0.5 mm sieve. The obtained biomass was treated with 0.01 MHCl overnight then washed with ultrapure water and dried again at 60 ºC. Interestingly, an adsorption efficiency of Pb^{2+} removal higher than 94 % was obtained at pH 5 and 2.5 g/L of cactus biomass. This biomass offers sorption capacity of 28.9 mg/g at pH 5 similar to that obtained for sphagnum moss peat (30.7 mg/g), groundnut husks (39.3 mg/g), sago waste (46.6 mg/g) and coconut shell (26.51 mg/g) [66, 67]. However, these values seem to be less efficient than those observed for zeolite (175 mg/g), waste slurry (1030 mg/g), lignin (1865 mg/g), chitosan (796 mg/g) and seaweed (344 mg/g) [67, 68].
Adsorbent derived from cactus species are also tested for the removal of various dye types. For example, the dried prickly pear cactus cladodes (dried material: three weeks on the sun and 24 h at 60 ºC) was investigated as biosorbentfor the removal of Methylene Blue (MB), Eriochrome Black T (EBT) and Alizarin S (AS) from aqueous solutions [59]. The biosorption found to be rapid and the speed increased by decreasing the biosorbent particle size. However, the biosorption rate depends on the pH and on the dye types with a high biosorption of cationic dye. In this context, Methylene Blue showed a biosorption capacity of 190 mg/g at basic pH, however, the highest biosorption capacity of Alizarin S (200 mg/g) and Eriochrome Black T (118 mg/g) was obtained in acidic pH [59].
Moreover, cactus fruit peel was oxidized with H_2SO_4 (1 M) followed by $NaClO_4$ (1M) and used to remove Brilliant Green [60]. This chemical treatment allowed the conversion of various cactus functional groups, such as alcoholic and aldehyde to carboxylic acids, which may be involved in the dye sorption. Similarly to the results obtained by Barka et al. (2013) [59], the biosorption process is controlled by both pH and temperature. For instance, at pH around 3, the adsorption capacity was found to be around 167, 143 and 125 mg/g at 20, 30 and 40ºC, respectively [60].
For the same purpose, *O. ficusindica* fruit waste was used for the removal of basic (Basic Blue 9 and Basic Violet 3) and direct (Direct Green 1 and Direct Orange 26) dyes [69]. The waste collected after the consumption of the fresh fruit was subject to various preparations (non-treated dried material, dried material activated with NaClO and dried material activated with NaOH). All the preparations were heated at 323 K, then cooled at room temperature and washed with distilled water until the pH of the water was neutral. The final adsorbent materials were ground and then sieved to obtain 0.84 to 2 mmsize particles. As a result, the activation process increased the adsorption capabilities and specific surface area of prepared adsorbents by more than 50 %. Moreover, the activation reagent used affects considerably the behavior of the adsorbent. Hence, NaClO allowed better removal rate for basic dye, while NaOH treatment showed greater removal rate in the presence of direct anionic dyes, with removal percentages up to 96 % [69].
The effectiveness of cactus as adsorbent for the treatment of tannery wastewater was also demonstrated [26]. A cactus powder, generated by grinding sun dried cladodes was performed with removal values up to 70 %, 90 %, 70 % and 98 % for COD, sulphate, BOD and iron, respectively. Nitrogen pollution can be also reduced using cactus fibers dried at 40 ºC for 48 h [70]. This fiber material showed significant retention capacity for a wide pH range (6 – 10) and an enhancement of the biosorption potential with the temperature. Generally, the high temperature increases the size pores allowing the fiber swelling and, consequently, more diffusion of ammonium ions in the internal structure of the cactus fibers [70]. Interestingly, after the adsorption process, the cactus fibers laden with nutrient (specifically ammonium ions) could be used as an organic fertilizer and may present an interesting alternative to chemical fertilizers, unless no harmful compounds such as heavy metals are present in the wastewater subject of treatment.
Moreover, the removal of organochlorine pesticides (aldrin, dieldrin, and dichlorodiphenyltrichloroethane DDT) from wastewater was performed using fresh and dried (at 80 ºC for 24 h) *O. ficusindica* materials [71]. Remarkably, the use of fresh cactus leaves in a filtration column process was reported as an effective method for small scale water treatment system.

4. Cactus as support for biofilter

Biofilter is one of the most important biological processes employed to remove organic pollutants from air, water, and wastewater. The biofilterused to treat wastewater from various origins (municipal and industrial wastewaters such as food processing, aquaculture, etc.) is packed with fixed media offering a surface area for microbial growth [72, 73]. The microorganisms grow on this media and form a biofilm allowing high pollutant removal efficiency [74, 75]. Generally, the biofilter performance is controlled by the support characteristics, such as surface area, void volume, bulk density, water holding capacity, buffer capacity, sorption capacity and chemical composition [72, 76]. Various materials have been used as a packing media (compost, peat, plastic, clay, etc.). Interestingly, dried pieces of *O. imbricata* were tested as packing medium to treat municipal wastewater [77]. The results obtained for the packed reactor with cactus based support showed an effective removal rate of COD from municipal wastewater. The recator achieved a COD removal efficency more than 95 % after 20 h of hydrolic retention time (HRT) and an air flow rate of 1 lpm. Cactus support offered higher surface area allowing a high dissolved oxygen (DO) concentration and a continous and stable performance of the reactor for a longer period. Moreover, cactus carrier contains organic compounds and minerals [41] which may stimulate bacterial growth and enhance biomass accumulation in the biofilter. Biofilter packed with cactus could be an alternative for municipal wastewater treatment at low cost [77].

5. Cactus biopolymer for sludge conditioning

Sludge conditioning is a process employed to prepare sludge for dewatering processes using mineral salts and synthetic polymers [78, 79]. This chemical process present some disadvantages to the environment as described for the coagulation/flocculation using chemical reagents [80, 81]. The use of biological materials as conditioner in sewage sludge treatment represents a processing technology in line with the sustainable development goals. On the best of our knowledge, the only work describing the possibility of using cactus juicefor conditioning wastewater sludge was conducted by Betatache et al., (2014)[82]. In this case, the juice was prepared using cladodes of *O. ficusIndica*; washed, catted into small pieces, blended and then sieved to obtain the juice. Dried juice (60ºC for 3 days) was used as natural coagulant. Interestingly, the application of this natural materials for wastewater sludge conditioning showed acceptable results compared with those obtained with polyelectrolytes, such as the cationic polymer (Chimfloc C4346), the non-ionic polymer (Sedipur NF 102), the anionic polymer (Sedipu AF 400) and the inorganic conditioners, $FeCl_3$ and $Al_2(SO_4)_3$ (Table 4). The use of cactus juice as sludge conditioner allowed good filtration process free of large flocs. In addition, the values of dryness, residual turbidity and resistance of filtration were similar to those obtained using Chimfloc C4346 and better than those obtained with Sedipur NF400, Sedipur AF102 and inorganic chemicals ($FeCl_3$ and $Al_2(SO_4)_3$). Moreover, cactus juice offered the lowest optimum dosage of 0.4 g/Kg [82].

Table 4: Efficiency of cactus juice as coagulant for municipal wastewater sludge compared to chemical reagent; values obtained at optimum doses [82]

	Optimum dosage (g/Kg)	Resistance of filtration (m/Kg)	Dryness of filtration cake (%)	Turbidity of the filtrate (NTU)
Dried cactus juice	0.4	0.13×10^{12}	20.5	2.5
Chimfloc C4346	8	0.3×10^{12}	20.5	1.5
Sedipur NF 102	25	9×10^{12}	18.50	13.5
Sedipur NF 400	16	23×10^{12}	10.00	5
$FeCl_3$	80	1×10^{12}	22	2.4
$Al_2(SO_4)_3$	70	1×10^{12}	21.50	2.2

6. Cactus for textile dyestransformation

Recently, cladode and callus of cactus, *Nopaleacochenillifera,* demonstrated the ability in the decolorization of various textile dyes (Table 5) [83]. According to table 5, the decolration rate depends on the used materials and on the dye subject to treatment. This rate varied from 43 % (for Green HE4BD) to 99 % (for Malachite Green) and from 33 % (for Golden Yellow HER) to 91 % (for Malachite Green), respectively while using cladode and callus of cactus.

Table 5 : Decolration rate of textile dyes while using cladode and callus of cactus,*Nopaleacochenillifera*[83]

Textile dyes (concentration 40mg/L)	Decolorization rate (%) obtained with cladode	Decolorization rate (%) obtained callus
Malachite Green	99	91
Green HE4BD	43	76
Red HE7B	51	65
Orange M2R	72	60
Navy Blue HE2R	91	55
Methyl Orange	65	37
Golden Yellow HER	85	33

Interestingly, it was demonstrated that cactus cell cultures and intact plants (cladodes) may transform toxic textile dyes into less phytotoxic metabolites. For example, Red HE7B was transformed into 3-amino-5-imino-5,8-dihydronaphthalen-2-ol, 2-amino-6-(carboxycarbonyl)-3,4-dihydroxybenzoic acid, 4-aminophenol, and phenol. The analysis of enzymes involved in dye biotransformation show the presence of various enzymes in cactus, such as laccase, tyrosinase, azoreductase and 2,6-dichlorophenolindophenol reductase [83]. These results are in line with what was reported [84] concerning the phytoremediation potential and the involved biochemical mechanisms in various plant species. Generally, the reported enzymes are well investigated in various plant and microorganisms and are responsible of the transformation of xenobiotic aromatics [85-99]. By this way, cactus can be added as a new potential candidate to treat textile dye wastewater using its enzymatic system. However, more investigations are needed to explore this potential for real dyed wastewaters.

7. Factors making cactus as an eco-friendly material for wastewater treatment

The main factor behind the possibility of using cactus as material for waste water treatment is its biochemical composition without any toxic effects [90]. It was reported by many studies that cactus is composed of low protein and lipid contents, and polysaccharide is considered as the main ingredient [14]. Interestingly, cactus species are known by the polysaccharic mucilage production. The presence of minerals, such as Ca^{2+} and K^{+}, is necessary for the gelatinous properties of mucilage [91]. It was reported that calcium ion exists in the cactus mucilage as calcium-oxalate and this has strong effect in molecular conformation of the mucilage increasing its water holding capacity [93]. Moreover, the rate of mucilage viscosity was observed to be enough to show industrially desired consistency to liquid formulations, especially in suspension preparations, suggesting the possible use of this product as natural thickeners [90, 94]. The high flocculation/coagulation capacity of cactus may related to its polysaccharide structure that composed of various carbohydrates, such as l-arainose, d-galactose, l-rhamnose, d-xylose and galacturonic acid [26, 95]. In this context, it was reported that galacturonic acid is significantly implicated as the main active coagulant agent, based on its polymeric structure. This polymeric structure provides a bridge for particles to adsorb. Moreover, the functional groups of cactus polysacharides included carboxyl (-COOH), hydroxyl (–OH) and amino or amine (–NH_2) groups, as well as hydrogen bonds. These functional groups considered as preferred groups for the flocculation process [14]. The presence of polysaccharide as cactus main compound, may play an important role in the thermal stability of the cactus based biofloculant [32]. It is also very important to point out the presence of two factors making cactus an attractive candidate for the treatment of wastewaters from various origins. The first is the flocculation stability of cactus based flocculant at wide range of pH (3 - 12) and the second is the enhancement of the flocculation activity in the presence of divalent and trivalent cations [32]. These proprieties (moisture, pH, the sugar composition, etc.) make the mucilage as a suitable media for microbial growth [96]. This fact is in favour with the use of cactus as packed material for biofilter. Moreover, this composition make cactuses as a natural biosorbent material that well fit with the definition of sustainability, making them appropriate for regions of the world, where cactus is available.

Conclusion

For many accessibility criteria, cactus based materials are very attractive for wastewater treatment. Cactus plants are renewable, abundant, environmentally friendly, adaptable and biodegradable. The capability of various cactus preparations for pollutant removal was also observed. The cactus can be used as coagulant/flocculant, as biosorbent and as packed material for biofilter. Interestingly, the presence of cactus enzymatic system useful for the transformation of toxic textile dyes makes it as potential material for textile wastewater treatment. However, according, to this review, the limit of using cactus in wastewater treatment is related to the variability of efficiencies of cactus preparations, which depends on wastewater characteristics. Therefore, efforts should be made to optimize the procedures for each wastewater independently. For future study, it is recommended that more experiment should be done with respect to certain modifications in various treatment procedures. The resulting implementable technology should be introduced for regions of the world, where cactus is available and an environmental impact should be performed to determine the applicability of the technology. Also, the technology performance should be evaluated at large scale in real conditions for various wastewater systems.

References

1. Mallevialle J., Bruchet A., Fiessinger F., *J. Am. Water Works Assoc.* 76 (1984) 87-93.
2. Dearfield K.L., Abernathy C.O., Ottley M.S., Brantner J.H., Hayes P.F., Mutation Research/Reviews in Genet. Toxicol. 195 (1988) 45-77.
3. Özacar M., Şengil İ.A., *Colloids Surf. A: Physicochemi. Eng.* Asp. 229 (2003) 85-96.
4. Ginos A., Manios T., Mantzavinos D., *J. of Hazard. Mate.* 133 (2006) 135-142.
5. Zhang J., Zhang F., Luo Y., Yang H., *Process Biochem.* 41 (2006) 730-733.
6. Pritchard M., Mkandawire T., Edmondson A., O'Neill J.G., Kululanga G., *Phys. Chem. of the Earth, Parts A/B/C*, 34 (2009) 799-805.
7. Antov M.G., Šćiban M.B., Petrović N.J., *Bioresour. Technol.* 101 (2010) 2167-2172.
8. Katayon S., Noor M.J.M.M., Asma M., Ghani L.A.A., Thamer A.M., Azni I., Ahmad J., Khor B.C., Suleyman A.M., *Bioresour. Technol.* 97 (2006) 1455-1460.
9. Pritchard M., Craven T., Mkandawire T., Edmondson A.S., O'Neill J.G., *Physics and Chemistry of the Earth, Parts A/B/C*, 35 (2010) 791-797.
10. Arjunan N., Murugan K., Madhiyazhagan P., Kovendan K., Prasannakumar K., Thangamani S., Barnard D.R., *Parasitol. Res.* 110 (2012) 1435-1443.
11. Shyam R., Kalwania G., *Chem. Sci. Trans.* 3 (2014) 29-36.
12. Abirami P., Devi N.A., Sharmila S., *Asian Journal of Environmental Science*, 5 (2010) 5-7.
13. Mangale S.M., Chonde S.G., Raut P., *Res. J. Recent Sci.* ISSN, 2277 (2012) 2502.
14. Sellami M., Zarai Z., Khadhraoui M., Jdidi N., Leduc R., Rebah F.B., *Water Sci. Technol.* 70 (2014) 1175-1181.
15. Martyn C.N., Osmond C., Edwardson J.A., Barker D.J.P., Harris E.C., Lacey R.F., *The Lancet*, 333 (1989) 61-62.
16. Letterman R.D., Pero R.W., *J. Am. Water Works Assoc.* 82 (1990) 87-97.
17. Aizawa T., Magara Y., Musashi M., *Aqua*, 39 (1990) 334-340.
18. Aguilar M.I., Sáez J., Lloréns M., Soler A., Ortuño J.F., Meseguer V., Fuentes A., *Chemosphere*, 58 (2005) 47-56.
19. Ndabigengesere A., Narasiah K.S., Talbot B.G., *Water Res.* 29 (1995) 703-710.
20. Diaz A., Rincon N., Escorihuela A., Fernandez N., Chacin E., Forster C.F., *Proc. Biochem.* 35 (1999) 391-395.
21. Jadhav M.V., Mahajan Y.S., *Desalin. Water Treat.* 52 (2014) 5812-5821.
22. Bhole A.G., *Aqua London*, 44 (1995) 284-290.

23. Carpinteyro-Urban S., Vaca M., Torres L.G., *Water Air Soil Poll.* 223 (2012) 4925-4936.
24. Souza M.T.F., Ambrosio E., Almeida C.A., Souza Freitas T.K.F., Santos L.B., Cinque Almeida V., Garcia J.C., *Environ. Monit. Assess.*186 (2014) 5261-5271.
25. Kannadasan D.R.T., Thirumarimurugan M., Sowmya K.S., *IOSR J. Environ. Sci. Toxicol.Food Technol.*3 (2013) 41-43.
26. Swathi M., Singh A.S., Aravind S., Sudhakar P., Gobinath R., Devi D.S., *Int. J. App. Sci. Eng. Res.* 3 (2014) 436-446.
27. Vishali S., Karthikeyan R., *Desalin. Water Treat.*56 (2015) 1489-1497.
28. Kazi T., Virupakshi A.,*Int. J. Innov. Res. Sci. Eng. Technol.*2 (2013) 4061-4068.
29. Bouatay F., Mhenni F., *Int. J. Environ. Res.* 8 (2014) 1295-1308.
30. Ikeda E., Rodrigues D.G., Nozaki J., *Environ. Technol.* 23 (2002) 949-954.
31. Torres L.G., Carpinteyro-Urban S.L., Vaca M., *Nat. Resour.* 3 (2012) 35.
32. Khadhraoui M., Sellami M., Zarai Z., Rebah F.B., Leduc R., *Envion. Eng. Manag.* In press (2015).
33. Carpinteyro-Urban S., Torres L.G., *Int. J. Environ. Res.* 7 (2013) 717-726.
34. Oliveira G., Nogami E., Nozaki J., *Bull. Environ. Contam. Toxicol.* 64 (2000) 771-779.
35. Oliveira M.A., Reis E.M., Nozaki J., *Environ. Res.* 85 (2001) 177-183.
36. Sciban M., Antov M., Klasnja M., *Acta Period. Technol.* (Serbia), (2006).
37. Patel H., Vashi R.T., *J. Sau. Chem. Soc.* 16 (2012) 131-136.
38. Adjeroud N., Dahmoune F., Merzouk B., Leclerc J. P., Madani K., *Sep. Purif. Technol.* 144 (2015) 168-176.
39. Gandhi N., *Res. World* 4 (2013) 110.
40. Nharingo T., Zivurawa M., Guyo U., *Int. J. Environ. Sci. Technol.*12 (2015) 3791-3802.
41. Young K., Anzalone A., Alcantar N., In: Abstracts of papers of the american Chemical Society, Am. Chem. Soc. 1155 16TH ST, NW, Washington, DC 20036 USA, 2005, pp. U3767-U3767.
42. Zhu G., Zheng H., Zhang Z., Tshukudu T., Zhang P., Xiang X., *Chem. Eng.*178 (2011) 50-59.
43. Golob V., Vinder A., Simonič M., *Dyes Pig.* 67 (2005) 93-97.
44. GadA., Attia M., Ahmed H., *J. Am. Sci.* 6 (2010), 79-87
45. Mane P.C., Bhosle A.B., Jangam C.M., Mukate S.V., *J. Nat. Prod. Pla. Resou.* 1 (2011) 75-80
46. Al-Hamadani Y.A.J., Yusoff M.S., Umar M., Bashir M.J.K., Adlan M.N., *J. Hazard. Mater.* 190 (2011) 582-587.
47. Masschelein, W.J. (1992). Unit processes in drinking water treatment. New York: Marcel Dekker, p. 322.
48. Salleh M.A.M., Mahmoud D.K., Karim W.A.W.A., Idris A., *Desalin.* 280 (2011) 1-13.
49. Ali I., Gupta V.K., *Nat. Proto.* 1 (2007) 2661-2667.
50. Marshall W.E., Wartelle L.H., Boler D.E., Johns M.M., Toles C.A., *Bioresou. Technol.* 69 (1999) 263-268.
51. Vaughan T., Seo C.W., Marshall W.E., *Bioresou. Technol.*78 (2001) 133-139.
52. WafwoyoW., Seo C.W., Marshall W.E.,*J. Chem. Technol. Biotech.* 74 (1999) 1117-1121.
53. Madrid Y., Barrio-Cordoba M. E., Camara C., *Anal.* 123 (1998) 1593-1598.
54. Santos M. C. D., Lenzi E., *Environ. Technol.* 21 (2000) 615-622.
55. Belayneh A., Batu W., *J. Water Resou. Ocean Sci.* 4 (2015) 18-23.
56. Derbe T., Dargo H., Batu W., *Chem. Mater. Res.* 7 (2015), 84-92.
57. Dakiky M., Khamis M., Manassra A., Mereb M., *Advan. Environ. Res.* 6 (2002) 533-540.
58. Fox D.I., Pichler T., Yeh D.H., Alcantar N.A., *Environ. Sci. Technol.*46 (2012) 4553-4559.
59. Barka N., Ouzaouit K., Abdennouri M., Makhfouk M.E., *J.e Taiwan Instit. Chem. Eng.* 44 (2013) 52-60.
60. Kumar R., Barakat M.A., *Chem. Eng.* 226 (2013) 377-383.
61. Nozaki J., Messerschimidt I., Rodrigues D.G., *Arquivos de biologia e tecnologia*. 36 (1993), 761
62. Hadjittofi L., Prodromou M., Pashalidis I., *Bioresou. Technol.* 159 (2014) 460-464.
63. Hadjittofi L., Pashalidis I., *J. Radional. Nuc. Chem.* 304 (2015) 897-904.
64. Barrera H., Ureña-Núñez F., Bilyeu B., Barrera-Díaz C., *J. Hazard. Mater.* 136 (2006) 846-853.
65. Miretzky P., Muñoz C., Carrillo-Chávez A., *Bioresou. Technol.* 99 (2008) 1211-1217.
66. Quek S., Wase D., Forster C.F., *Water Res.* 24 (1998) 251-256.
67. Bailey S.E., Olin T.J., Bricka R.M., Adrian D.D., *Water Res.* 33 (1999) 2469-2479.
68. Babel S., Kurniawan T.A., *J. Hazard. Mater.* 97 (2003) 219-243.
69. Peláez-Cid A.A., Velázquez-Ugalde I., Herrera-González A.M., García-Serrano J., *J. Environ. Manag.* 130 (2013) 90-97.
70. Wahab M.A., Boubakri H., Jellali S., Jedidi N., *J. Hazard. Mater.* 241–242 (2012) 101-109.
71. Gebrekidan A., Nicolai H., Vincken L., Teferi M., Asmelash T., Dejenie T., Zerabruk S., Gebrehiwet K., Bauer H., Deckers J., *Clean Soil, Air, Water*, 41 (2013) 235-243.

72. Ben Rebah F., Kantardjieff A., Yezza A., Jones J.P., *Desalin.* 253 (2010) 141-146.
73. Gutierrez-Wing M.T., Malone R.F., *Aquacultu. Eng.* 34 (2006) 163-171.
74. He S. B., Xue G., Kong H. N., *J.Hazard. Mater.* 143 (2007) 291-295.
75. Watten B.J., Sibrell P.L., *Aquacultu. Eng.* 34 (2006) 198-213.
76. Savage A.J., Tyrrel S.F., *Bioresou. Technol.* 96 (2005) 557-564.
77. May-Esquivel F., Ríos-González L., Garza-García Y., Rodríguez-Martínez J., *Environ. Res.* 2 (2008) 238-245.
78. Akhtar N., Iqbal J., Iqbal M., *J. Hazard. Mater.* 108 (2004) 85-94.
79. Qi L., Cheng R., Wang H. C., Zheng X., Zhang G. M., Li G. B., *Desalin.Water Treat.* 25 (2011) 170-175.
80. Bolto B., Gregory J., *Water Res.* 41 (2007) 2301-2324.
81. Lu Z., Medicament of Water Treatment, Publishing Company of Chemical Industry, Beijing, (2002).
82. Betatache H., Aouabed A., Drouiche N., Lounici H., *Ecolog. Eng.* 70 (2014) 465-469.
83. Adki V.S., Jadhav J.P., Bapat V.A., *Int. J. Phytoremed.* 14 (2012) 554-569.
84. Golan-Goldhirsh A., Barazani O., Nepovim A., Soudek P., Smrcek S., Dufkova L., Krenkova S., Yrjala K., Schröder P., Vanek T., *J. Soils Sedi.* 4 (2004) 133-140.
85. Jadhav J., Govindwar S., *Yeast*, 23 (2006) 315-323.
86. Ghodake G.S., Talke A.A., Jadhav J.P., Govindwar S.P., *Int. Journal of Phytoremed.* 11 (2009) 297-312.
87. Kagalkar A.N., Jagtap U.B., Jadhav J.P., Bapat V.A., Govindwar S.P., *Bioresou. Technol.* 100 (2009) 4104-4110.
88. Oturkar C.C., Nemade H.N., Mulik P.M., Patole M.S., Hawaldar R.R., Gawai K.R., *Bioresou. Technol.* 102 (2011) 758-764.
89. Strack D., Vogt T., Schliemann W., *Phytochem.* 62 (2003) 247-269.
90. Gebresamuel N., Gebre-Mariam T., *J. Biomater. Nanobiotechnol.* 3 (2012) 8.
91. Sepúlveda E., Sáenz C., Aliaga E., Aceituno C., *J. Arid Environ.* 68 (2007) 534-545.
92. Garvie L.A.J., *Naturwissenschaften*, 93 (2006) 114-118.
93. Trachtenberg S., Mayer A.M., *Protoplasma*, 109 271-283.
94. Saenz C., In: International Society for Horticultural Science (ISHS), Leuven, Belgium, 2006, pp. 231-24.
95. Vijayaraghavan G., Sivakumar T., A. V. Kumar, *Int. J.Advan. Engi. Res. Stud.* 1 (2011) 88-92.
96. Saenz C., *J. Arid Environ.* 46 (2000) 209-225.