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Application of Locally Sourced Plants as Natural Coagulants For Dye Removal from Wastewater: A Review

M. Mathuram[1], R. Meera[1], G. Vijayaraghavan[2*]

[1] *Department of Biotechnology, Rajalakshmi Engineering College, Chennai, India.*
[2*] *Department of Chemical Engineering, Rajalakshmi Engineering College, Chennai, India.*
**vijayaraghavan.g@rajalakshmi.edu.in*

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*Corresponding author
G.Vijayaraghavan.
vijayaraghavan.g@rajalakshmi.edu.in
Phone no +91-9865220987

Abstract

Locally sourced plants are indigenous plants with optimum health condition, better environmental tolerance and these plants are cost effective. A total of 8 plants and the effects of specific plant part in the removal of dye from effluent are compiled in this review. Removal of dye is an important in step in the treatment of effluent prior to discharge in order to maintain a safe environment. Coagulation using commercial coagulants is the most widely applied technique in the treatment. However, conventional coagulants are pH sensitive and they generate higher sludge volume. Natural coagulants are more effective in treating effluent as they do not alter the pH and produce low sludge volume that can be used as eco-products. Thus natural coagulants are economical and eco-friendly. The present review provides a new insight into the potential of locally sourced plants as alternatives to chemical coagulants in effluent treatment processes.

1. Introduction

Life on earth was established and has been sustained due to one very essential resource, water. Water plays a considerable role in every aspect of our lives- from being the integral part of our bodies to having colossal importance in many industrial operations such as diluting, fabricating, cooling, and smelting and so on. Being a resource of such significance, it is expected that water would be conserved and revered for its existence; but regrettably it is also the most polluted resource [1]. The magnitude and appalling consequence of water pollution has not been completely understood or appreciated until recent years. With the rise of mankind and our thirst to reach the pinnacle of existence, natural resources have been used imprudently and without caution. Technology, automation and machinery have seen an advancement that has never before been dreamt of; but our environment, natural resources, and the smaller species in it have suffered for these errors. It is now known that such large scale pollution of water is caused by the mixing of municipal and industrial waste water with freshwater [2]. Treatment can be done on water containing certain chemical wastes with relative ease and can be reused for purposes other than drinking. But one of the chemicals that pose a major complication in treatment are dyes; especially dyes that are synthetic and have a complex structure, since they are highly stable and are not readily biodegradable [3]. In addition, 22% of the total effluents generated by industries come from the textile industry [4].

Dyes are composed of two components- the chromophore and the auxochrome. The chromophoric group provides colour, while the auxochrome, which is attached to the chromophore facilitates absorption of light. Dyes are classified based on a variety of parameters including source (natural or synthetic), chemical structure, application to fiber type [5], [6].

Synthetic dyes find wide use in industrial applications and are mainly derived from coal tar and petroleum based intermediaries. Over a 1, 00,000 dyes for commercial purpose are used in the textile industry, with production of about 7×10^5 to 1×10^6 tons annually. Of this an estimated amount of around 10-15 % is released into the environment as waste [7].

This discharge causes various ill effects to the environment and people, either directly or indirectly [8]. They have the capacity to decrease light penetration in water bodies and hence upset the aquatic ecosystem [9]. They also have the ability to sequester with metals and may cause micro toxicity to organisms that thrive in water. When they come into contact with humans, they can also cause skin and eye irritation [10], skin sensitization, due to oral ingestion or inhalation [11]. These compounds are also known to penetrate into the ground water and render it unusable due to its toxicity.

Up to 80% of water in India re- enters the ecosystem as waste water, but the Central Pollution Control Board (CPCB) has the ability to process only 30% of it [12], and so there is an urgent need to treat waste water effectively. One of the important steps in effluent treatment is the dye removal process. Currently methods such as adsorption, solvent extraction, microfiltration membrane separation, hydrophobic precipitation, coagulation etc...[13]. Among these methods, coagulation is gaining importance. Conventionally, coagulation is done by using inorganic coagulants such as aluminium or iron based compounds. These help neutralise surface charges of suspended particles, which leads to aggregation of particles and their subsequent settling due to gravity. However, sludge obtained after this process may still contain toxic substances and their disposal becomes problematic [14]. Thus, inorganic coagulants are being replaced by natural materials.

Natural coagulants produce 20-30% less voluminous sludge than those produced by alum compounds and are also presumed non-toxic for human health [15]. This review article looks at eight natural materials that are locally sourced and perennially available to act as coagulants in the dye removal process.

2. Coagulation

Coagulation is an important industrial process that enable solid liquid separation in wastewater treatment and in sludge de watering for various industries including textile, mineral processing, metal working, food, cosmetic and so on [16].

Coagulation as a process is not new to the world; in fact, it has been used many centuries before by Egyptians, who smeared almonds around vessels to clarify river water as early as 2000 BC. Alum was later introduced by the Romans and its use was recorded in 77 AD. By 1757 alum was used for municipal waste water treatment in England. Since then, the search for coagulants has been a never ending process, since acceptable standards for water have reduced especially in case of turbidity from 1.0 to 0.3 [17].

Coagulation can be understood better by the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory. Derjaguin, Landau, Vervey, and Overbeek (DLVO) developed a theory of colloidal stability, which explains the amassing of aqueous dispersions quantitatively and talks about the force existing because of interaction of charged surfaces through a liquid medium. [18]. In simple words, coagulation is the process that destabilises colloidal suspensions upon addition of a coagulant. The destabilisation of turbidity and colour-causing compounds can be brought about by three different mechanisms of coagulation,

- Electrostatic coagulation (or) Electrocoagulation
- Adsorptive coagulation
- Precipitation coagulation (or) Sweep coagulation

2.1. Electrostatic coagulation

This process introduces highly charged polymeric metal hydroxide species to neutralise electrostatic charge on suspended solids and oil droplets to enable aggregation.The mechanism is shown in Figure 1. This process uses a cationic species for neutralisation of surface charges, and also, the coagulated floc contains less bound water and is more easily filterable.

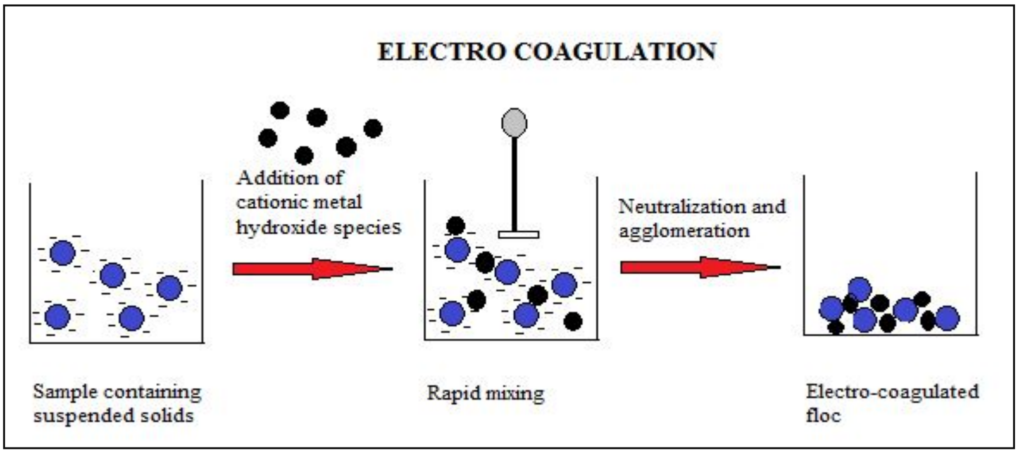

Figure 1: Mechanism of Electrostatic Coagulation.

2.2. Adsorptive coagulation

In this mechanism of coagulation, particles are adsorbed onto the cationic hydrolyses products $FeOH_2^+$ and $FeOH_2^+$.The products are formed at low pH, with the optimal range being 6-8. The mechanism is shown in

Figure 2. A characteristic feature of this method is that dosing is comparative to the removal of organic matter, and that this is a rapid process.

2.3. Precipitation coagulation

In precipitation coagulation or sweep coagulation, colloids are integrated into neutral iron hydroxide flocs. This occurs predominantly in waters with decreased suspended solids content (10 mg/L). The mechanism is shown in Figure 3. To facilitate formation of hydroxide flocs, more coagulant must be dosed than is used in adsorptive coagulation.

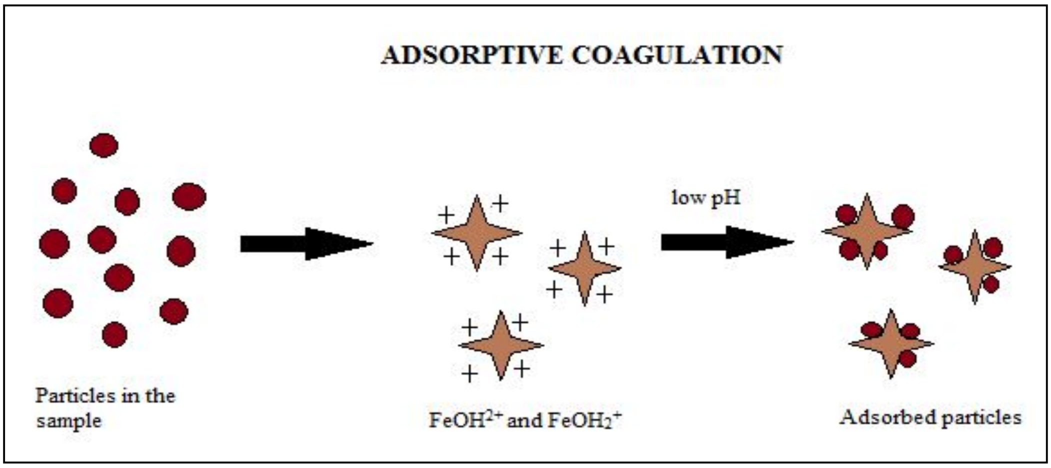

Figure 2: Mechanism of Adsorptive Coagulation.

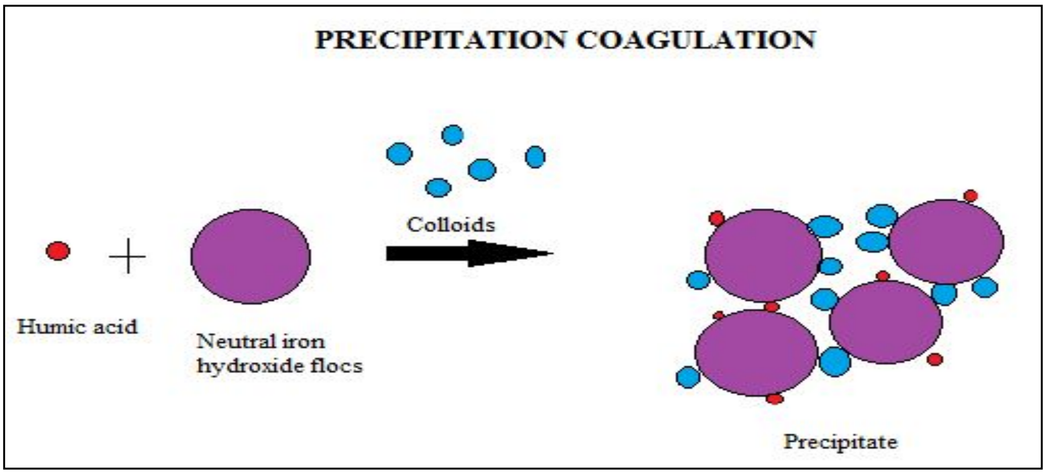

Figure 3: Mechanism of Precipitation Coagulation.

The coagulation process is gaining importance nowadays because it is both cost efficient and has an easy approach. Chemical coagulants may be hydrolysing metallic salts (for example Ferric chloride and Ferric sulphate), pre-hydrolysing metallic salts (for example Polyaluminium chloride (PACl) and Polyferric chloride (PFCl)) or synthetic cationic polymers (for example Aminomethyl polyacrylamide and polyalkylene) [19]. Most commonly used among these are inorganic salts such as $Al\ (SO_4)_3$ and $FeCl_3$, or synthetic organic polymers [20]. However, the main disadvantage of this process is the use of large number of chemicals which are hazardous to the environment. Their impact on human health is also significant; especially the effects of inorganic salts on diseases like Alzheimer's and the neurotoxic and carcinogenic effects of acrylic amide or poly acryl amides. In addition, usage of $FeCl_3$ also produces a high concentration of chlorides and is hence not desirable for most effluent treatments, including treatment of concrete wastewater [21]. When aluminium compounds are used, their high positive charge causes them to bind with negatively charged particles to bring about coagulation. Even though the most of the added Al is removed by filtration or sedimentation, there is an increased concentration of it in the water [22]. Presence of aluminium in drinking water can also be directly linked to diseases like dialysis encephalopathy and Alzheimer's [23]. The detailed comparison on Chemical coagulants and natural coagulants are listed in Table 1. Therefore, natural coagulants, which are derived from plants or even crustaceans, are being introduced to counter the harmful effects of chemical coagulants, while also being efficient and economically viable [24].

Table 1: Comparison between Chemical and Natural coagulants

Parameters	Chemical coagulant	Natural coagulant	References
Economy	Higher cost involved in procuring chemicals and during treatment processes	Cost effective, since they are abundantly available	[85] [88]
Dosage	Larger dosage required to bring about coagulation.	Lesser dosage required	[86]
Effectiveness	Extended usage leads to lesser effectiveness and leads to addition of dissolved solids (salts) to the water.	They are more stable and do not lead to formation of dissolved solids.	[89] [90]
Toxicity	Highly toxic and has irritant characteristics	Lesser toxicological risk (generally non-toxic)	[82] [87]
Sludge	Large amounts of sludge which contains hazardous chemicals.	Lesser amounts of sludge which are mostly biodegradable.	[81] [83]
Removal of heavy metals	Heavy metals like Zn, Cd, As cannot be settled easily.	Settling of heavy metals occurs along with coagulation process.	[90]
pH	There will be a significant change in pH due to formation of metallic salts	Do not alter pH of water being treated	[80] [84]

3. Bio coagulants

Records show that in India, bio coagulants like Nirmali seeds *(Strychnos potatorum)* have been used for water clarification between the 14th and 15th centuries [25]. Use of bio coagulants has gained importance once again, one of the main reasons being that they are abundantly available, easy to procure and do not alter pH and biodegradability in water. Additionally, if the natural materials are locally sourced, transportation costs are also cut down significantly. Natural coagulants are predominantly either polysaccharides or proteins. Sometimes, even though polymers are labelled non-ionic, there is not necessarily an absence of charged interactions. The presence and nature of clay particles and background electrolytes also facilitates coagulation by polymeric materials [26].

Many such natural materials have been reported to have high efficiency specifically in dye removal from effluents; this review looks only at eight potential plant based coagulants, which are locally sourced (from Chennai, Tamilnadu). These materials, due to their inherent properties as discussed below, can be expected to function as highly efficient coagulants.

3.1. Canna Indica

Canna Indica, belonging to the family Cannaceae[27], is locally known as 'Kal Vazhai' and is an easily cultivable perennial plant, which is naturalised in most parts of Southeast Asia. The scientific classification of *Canna Indica* is given in Table 2. It has been cultivated as a minor food crop since 16th century, and is one of the four most consumed root crops in the tropics.

Table 2: Scientific classification of *Canna Indica*

KINGDOM	Plantae
ORDER	*Zingiberales*
FAMILY	*Cannaceae*
GENUS	*Canna*
SPECIES	*Indica*
BIOLOGICALNAME	*Canna Indica*

This plant has been used ethno medically to treat malaria, diarrhoea, dysentery and also in treatment of fever bruises and so on [28]. It is believed that these properties are due to various bioactive compounds present in it. Presently, its use beyond the medical field has been established; that is, its use in industrial treatment of water has been identified. Industrial effluent is made to pass through *C. Indica* wetlands, which proves to be efficient in removal of increased organic load, colour and nitrogen compounds from the waste water [29]. The rhizobium of the plant is believed to be responsible for removal of pollutants. The essential oil of the rhizome has been isolated by hydro distillation and upon analysis by GC and GC/MS, it is found to contain 43 compounds representing 95.32% of the oil [30]. These compounds include an exhaustive list of various aldehydes, alcohols, alkenes, carboxylic acids [31], which contain the –COOH and free –OH surface groups that boost the coagulation capability of the extract. Although studies on root of C. Indica are more predominant, biochemical studies on the aerial parts and seed of the plant show that they also have the potential to be used as bio coagulants. Acetone seed extracts show the presence of alkyl resorcinol's and phospholipids [32], while methanolic seed extracts show a high polyphenolic concentration [33]. When the whole plant was subjected to chloroform, methanol and extraction, three compounds, namely betulinic acid, oleonilic acid, traraxer-14-en-3-one were identified [34]. Though there are no particular studies depicting the use of C. Indica as bio coagulants, it is evident from its use in wetlands to treat effluents and from the composition of various plant parts that the high content of alcohol and acidic groups can bring about coagulation process.

3.2. Tamarind seed husk

Tamarindus Indica or the Tamarind tree is a leguminous tree of the Fabaceae family [35]. Though it is indigenous to tropical Africa, it has been cultivated in India for so long that it is disputed to have originated here. The scientific classification of *Tamarindus Indica* is given in Table 3.

Table 3: Scientific classification of *Tamarindus Indica*

KINGDOM	Plantae
ORDER	*Fabales*
FAMILY	*Fabaceae*
GENUS	*Tamarindus*
SPECIES	*Indica*
BIOLOGICALNAME	*Tamarindus Indica*

A study done on reduction of turbidity of lake water using tamarind seed powder shows a percentage reduction of turbidity as 65.82% [36]. Other studies have shown that in treatment of effluents using tamarind powder, turbidity and COD removal of 97.78% and 43.50%have been achieved (at optimum mixing time) [37] and colour removal of 100% has been achieved [38]. It has also been stated that tamarind seeds have the capability to reduce fluoride content. These properties may be attributed to the high polyphenolic content, especially tannins. Tannins have been proven to be a better alternative to chemical coagulants, and their effectiveness is attributed to their structure as well as the degree of tannin modification. It is known that phenolic groups can readily deprotonate to produce phenoxide which is stabilised via resonance. This is said to enhance the effect of coagulation, and since tannins consist of a large number of phenolic group, they naturally have better coagulation capacity. Though the tamarind seed has been extensively studied, the husk is always discarded. But it is now known that the husk too contains similar constituents as the seed and can itself be used as a natural coagulant. From a study on the constituents on tamarind seed husk, 39% composition was elucidated to be polymeric tannins and such tannins also made up 77% of total polyphenolic compounds [39]. Additionally, tamarind seed husks are also known to contain polysaccharides such as xyloglucans, simple phenols such as epicatechin and 3,4-dihydroxyphenyl acetate and also other polyphenols like procyanidin B2 [40]. Since all the above mentioned compounds have high number of –OH groups, and because the husk has radical scavenging activity, it can contribute to high coagulation capabilities. Further studies on the application of the husk to treat effluents by coagulation are required. This process will also be highly cost efficient, as Tamarindus Indica is widely distributed throughout India (India is the world leading producer with production of 300,000 tonnes annually), especially in South India [41].

3.3. Typhaceae

The *Typhaceae*s are a family of angiosperms, and its members can often be recognised as large marsh herbs with two ranked leaves and brownish spike of flowers. They also grow abundantly in eutrophicated water bodies [42].They are classified as semi-aquatic or more appropriately, emergent weeds, along with other plants such as Phragmites communis, Ipomoea cornea [43]. Locally in India *T. angustofolia*, also called Sambu, is more dominant and is seen widely spread on marsh lands. The scientific classification of *Typhaceae* is given in Table 4. Plants on marshlands are most widely known for their ability to filter toxins and heavy metals from the water. The members of this family have long been used in traditional medicine due to their significant wound healing property [44]. But now, their efficiency in treating effluents is being discovered by construction of wetlands [45]. Typhaceae is one of the few families in which all the members have high content of tannins in them, which could contribute to high coagulation capacity.

Table 4: Scientific classification of *Typhaceae*

KINGDOM	Plantae
ORDER	*Poales*
FAMILY	*Typhaeceae*
GENUS	*Typha*
SPECIES	*angustifolia*
BIOLOGICALNAME	*Typha angustifolia*

Certain members of the family such as *T. latifolia* have already been studied as potential effluent treatment plants. Through the construction of wetlands, they have reported percentage reduction in total suspended solids, biological oxygen demand, chemical oxygen demand as 72%, 74%, 55% respectively [46]. A study on the chemical composition on another member T. domingesis reveals that it contains polyphenols, coumarins, proanthocyanidins, hydroxycinnamic acids in its fruit and linolenic acid, linoleic acid in its flowers [47]. Since all these compounds contain a high number of –OH, =O and –COOH groups, it is highly probable that these plants could be used as coagulants but as such this property has not been elucidated.

3.4. Adenanthara pavonina

A.pavonina, belonging to the family Fabaceae [48] is a perennial, non-climbing, leguminous tree, found in most parts of India. It is native to India and China and is known locally as Aanai kuntrimani or Manjadi, seeds of this tree have long been used to treat inflammation in traditional medicine, a use which is now supported by results of various studies. The scientific classification of *Adenanthara Pavonina* is given in Table 5.Its bark is now found to have various properties, including anthelmintic, analgesic and antibacterial properties [49]. The leaves of A. pavonina are said to have hypoglycaemic, anti-hyperglycaemic, anti -cancer and invitro alpha amylase inhibitory activity [50],[51],[52]. This tree is often quoted to be an underutilised tropical legume, since it has potential uses far beyond the field of medicine, which have not yet been discovered. The seed is believed to contain appreciable amounts of proteins, crude fat and minerals. Further studies on this account show that in fact the seeds contain various amino acids including arginine, cysteine and histidine, fatty acids such as palmitic, stearic, arachidonic, lignoceric, and stigmasterol and its glycoside, dulcitol [53]. Since a number of the above mentioned compounds are amphiphiles, they can easily neutralise surface charges on particles, leading to their aggregation and subsequent coagulation. Also, *A.pavonina* is a perennial tree, which indicates that utilising its seeds to treat effluents will be an economical and easy process. This is a novel application of *A. pavonina* seeds, which have previously been used only in medicine and as an oil source.

3.5. Azadirachta indica

This tree in the mahogany family *Meliaceae* is commonly known as Neem or Indian lilac (Azadirachta indica). Neem trees are found abundantly in tropical and sub-tropical regions [54] and they are indigenous to India, Nepal, Pakistan, Bangladesh and Sri Lanka. The scientific classification of *Azadirachta indica* is given in Table 6.

able 5: Scientific classification of *Adenanthara Pavonina*

KINGDOM	Plantae
ORDER	*Fabales*
FAMILY	*Fabaceae*
GENUS	*Adenanthera*
SPECIES	*pavonina*
BIOLOGICALNAME	*Adenanthera pavonina*

Table 6: Scientific classification of *Azadirachta indica*

KINGDOM	Plantae
ORDER	*Sapindales*
FAMILY	*Meliaceae*
GENUS	*Azadirachta*
SPECIES	*indica*
BIOLOGICALNAME	*Azadirachta indica*

The Neem tree is widely noted known for its drought resistance and its fruits and seeds are the source of Neem oil. Neem products are believed by Siddha and Ayurveda practitioners to be anthelmintic, antifungal, antidiabetic, antibacterial, antiviral, contraceptive and sedative [55]. Neem seed is very important both because of its high lipid content as well as the presence of a large number of bitter principles such as azadirachtin, nimbin, nimbidin, salanin and nimbolin B in considerable quantities [56]. Azadirachtin, a tetranortritrepenoid [57] belonging to the limonoid group has proven effectiveness as a pesticide and is reported as non-toxic to humans [58]. A study on the effectiveness of herbs in community water treatment [59] showed that Neem reduced 94% of fluoride with an optimum dosage of 2 gm/L. This study indicates that removal of fluoride from raw water is very high as compared with other works carried out. With this we can draw to a conclusion that

Neem has some potential elements to reduce the toxic effects of excess fluoride. An experimental study [60] reported that Neem seeds exhibited the highest removal efficiency in the range of 98 to 99%. At different dosages, the turbidity of the raw pond water sample reduced from 64 NTU to 1 NTU. However increase in the dosage did not increase the removal efficiency. Ranking based on removal efficiency, settling rate, clarity, availability and cost of the materials indicates that Neem seed acts as a better coagulant. With further studies, Neem seeds could be employed as natural coagulants for surface water treatment.

3.6. Banana stem

Banana is an edible fruit produced by herbaceous plants in the genus *Musa* [61].According to a policy note produced by the Tamil Nadu Agricultural University for the year 2015-2016, Tamil Nadu ranks first in the production of banana (56.50 lakh MT) and second in the area of cultivation (1.18 lakh ha)[62]. The scientific classification of *Musa* is given in Table 7.

Table 7: Scientific classification of *Musa*

KINGDOM	**Plantae**
ORDER	*Zingiberales*
FAMILY	*Musaceae*
GENUS	*Musa L.*
SPECIES	*acuminata*
	balbisiana
	ornata
	paradisiaca
BIOLOGICALNAME	*Musa acuminata*
	Musa balbisiana
	Musa ornata
	Musa X paradisiaca

Bananas are extremely nutritious and they are exceptionally rich in potassium content [63].With a production of 100 million tons annually, banana is a staple food across the Asian, African and American tropics [64]. The fruit, leaf, trunk and flower are widely used for culinary and medicinal purposes. The banana pseudo stem is eco-friendly as it is biodegradable and it is widely used in the textile and packaging industry [65]. Moreover, the waste generated after the harvest is used in the cultivation of edible mushroom specifically oyster mushroom and therefore it acts as a fertilizer [66]. Inulin, a group of polysaccharide that occurs naturally can be found in the stem of banana. This is in agreement with the study by Meijer and Mathijssen [67], where most of the inulin is stored in the stem of chicory and Jerusalem artichoke. A preliminary study on treatment of spent coolant water showed that the inulin concentration in the banana stem was 1.22016 mg/mL [68]. Inulin has high bonding capacity and it is able to entrap more microfloc to form bridges on the polymer chain of inulin structure. As a result, bigger and heavier flocs that will easily settle down through the sedimentation process are formed. Studies show that the removal of COD, SS and turbidity by banana stem juice was efficient at a pH 7, where the percentages were at 83.9, 84.1, and 90.9%, respectively. Turbidity removal percentages showed marginal difference in which more than 98% removal was achieved. At a dosage of 90mL, the highest COD removal percentage was 80.1% and the suspended solid removal percentage was 88.6%. This shows that banana stem has the potency to act as a natural coagulant and it can be used in the pretreatment stage as a fine powdered coagulant. Further studies could be carried out in order to determine the effect of banana stem on dye removal, volume of floc produced and its efficiency as a bio-coagulant.

3.7. *Moringa Concanensis Nimmo*

Family *Moringaceae* in the plant kingdom that includes a wide variety of tree among which *Moringa oleifera* and *Moringa concanensis Nimmo* have been identified as significant species [69]. Moringa oleifera is commonly known as drumstick and Nimmo is called as kattumurungai by the tribal people of Tamilnadu. *Moringa oleifera* is indigenous to sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan [70] whereas Nimmo is widely distributed in Nilgiri Mountains [61] and locally sourced in the Veppanthattai and Kunnam taluk of Perambalur district of Tamil Nadu. In India, Nimmo could be located in Rajasthan, Madhya Pradesh, Gujarat, Goa and Andhra Pradesh [71]. The scientific classification of *Moringa oleifera* is given in Table 8.

The plant Kattumurungai has leaves and flowers that are larger in size and it differs entirely from the most abundant Moringa oleifera. In both the species of Moringa, the bark appearance exhibits a distinct feature [72] and studies indicate the presence of β-sitosterol in the bark. The bark is very smooth and very hard in both

Moringa oleifera and Nimmo. The medicinal properties of *Moringa concanensisNimmo* are higher when compared to *Moringa oleifera*. It is reported that twenty types of human ailments may be cured by using this plant with simple preparation of Nimmo [73]. However, studies show that *Moringa oleifera* supplies zeatin, quercetin, caffeoylquinic acid and kaempferol [74]. The General properties of M. concanensis are same as that of M. oleifera i.e., powerful tonic alternative, stomachic, laxative and asthma [75]**.** Roots of Moringa concanensis is used as substitute for Moringa oleifera. *Moringa oleifera* contains coagulant proteins that play a major role in surface water treatment [76]. On dosing extracts of *Moringa oleifera* that are soluble in water, turbidity was reduced to 5.9 NTU from 100 NTU in highly turbid water. Also 89-96% of coliform was reduced on using this natural coagulant [77]. Traditionally the seeds of Moringa oleifera were used in the treatment of rain water as it may lose its characteristics when collected in agricultural area [78]. This could be due to pesticide, aerial spraying, animal feces, dust, bird feces or other chemicals. Such contaminants might result in waterborne diseases such as cholera and typhoid. *Moringa oleifera* seedsare used for removal of hardness of the water and it also imparts beneficial properties to the water [79]. Hence further studies on the role of *Moringa oleifera* and *Moringa concanensis Nimmo* as natural coagulant would be of significant importance in treating effluent.

3.8. Mustard

Mustard plants include any of the wide variety of species that belong to the family *Brassicaceae* [80]and genus *Brassica* and *Sinapis*. In India, mustard is widely cultivated in Rajasthan, Madhya Pradesh and Haryana [81]. The seed of the mustard plant is used as a popular condiment worldwide. As a condiment, mustard averages approximately 5 calories per teaspoon [82]. The scientific classification of *Brassicaceae* is given in Table 9.

Table 8: Scientific classification of *Moringa oleifera*

KINGDOM	Plantae
ORDER	*Brassicales*
FAMILY	*Moringaceae*
GENUS	*Moringa*
SPECIES	*oleifera*
BIOLOGICALNAME	*Moringa oleifera*

Table 9: Scientific classification of *Brassicaceae*

KINGDOM	Plantae
ORDER	*Brassicales*
FAMILY	*Brassicaceae*
GENUS	*Brassica*
SPECIES	*juncea*
BIOLOGICALNAME	*Brassica juncea*

Some of the many vitamins and nutrients found in mustard seeds are selenium and omega 3 fatty acid [83]. It has been reported that intake of mustard with other condiments leads to lower risk of colon cancer [84]. Vision 2050 [85] was published by the Directorate of Rapeseed-Mustard Research (DRMR), established by the Indian Council of Agricultural Research to enhance the domestic oilseed production and to prioritize research work in this area.

Recently, mustard has been claimed as a potential water treatment agent as proteins responsible for imparting coagulation were found in mustard. Bradford method was used to determine the protein content and the molecular mass was determined by sodium dodecyl sulfate-polyacrylamide gel electrophoresis and peptide sequence. Analysis was performed by mass spectrometry. Mustard seeds such as Mustard Large (MusL; Brassica sp.), Mustard Small (MusS; Brassica sp.), Mustard Yellow (MusY; Sinapis sp.) belonging to Brassicaceae family and Cake (MusC) from an oil factory was assessed against synthetic clay solution and turbid pond water for their coagulation property. Experiments performed in India and Sweden during 2011, revealed the presence of thermo-stable coagulant protein in mustard even after heat treatment for 5 hours at 95°C from the extracts of MusL and MusS [86]. The coagulation activity of MusY and MusC significantly improved on heat treatment. Coagulant proteins with approximate sizes of 9kDa and 6.5kDa have been identified in mustard and presence of coagulant protein was confirmed by peptide sequence analysis. Extract of MusL and Moringa seed exhibited 70% and 85% coagulation activity after 90 min, respectively. Moreover, mustard seed extract showed higher (60%) activity compared to Moringa seed extract (50%). Moreover, a comparative study conducted to test the coagulation activity of more than hundred plants showed better scores for mustard. Hence, this study indicates that mustard could be used as a potential alternative to Moringa.

Thus, for various environmental, economic and performance reasons the above mentioned materials have been proposed to be potential effective bio coagulants. The following Table 10 summarises the physical characteristics and current applications of the above eight coagulant materials.

Table 11 gives the results of previous research work done on the materials, by studying their coagulation activity, in terms of removal of turbidity, colour, COD, etc…

Table 10: Description of plant species used for the derivatization of natural Coagulant

S.No	Species name	Common name/ local name	Description	Current applications	References
1	*Canna indica*	Kal Vazhai, Indian shot	It is a perennial growing to between 0.5 m and 2.5 m and has flowers which are hermaphrodites	Effluent treatment using C. indica wetlands	[29], [99]
2	*Tamarindus indica*	Tamarind	It is a leguminous tree which produces a pod like fruit with an edible pulp	Seed is used in removal of turbidity, COD and colour in various waste waters	[36], [37], [38]
3	*Typhaceae family*	Sambu, Cattail	These are large marsh herbs with two ranked leaves and brownish spike of flowers	T. orientalis is used to treat urban sewage using wetlands construction	[45]
4	*Adenanthera pavonina*	Aanai Kuntrimani	It is a perennial, non- climbing leguminous tree, with seed pods holding red seeds.	Traditional medicine, oil source	[53], [74]
5	*Azadirachta indica*	Neem	It is a tree in the mahogany family *Meliaceae* whose fruits and seeds are the source of neem oil	Neem oil, pesticide, siddha and Ayurveda, water treatment	[54]
6	*Musa genus*	Banana	It is an edible fruit produced by herbaceous plants in the genus Musa	Bio-fertilizer, bio-fiber, medicine, culinary, water treatment	[61], [65], [66]
7	*Moringa oleifera*	Drumstick	It is a tree that belongs to the family *Moringaceae*	Medicine, water treatment and culinary	[69], [93], [95]
8	*Brassica genus, Sinapis genus*	Mustard	These are plants that belong to the family *Brassicaceae*	Condiment, oil production	[80]

Table 11: Previous research outcomes based on natural coagulants

S. No	Species name	Form of coagulant	Sample treated	Experimental conditions	Outcomes	References
1	*Canna indica*	*Rhizome, aerial parts*	*Municipal wastewater*	Unsaturated and saturated wetlands	Unsaturated wetlands show higher nitrogen removal, partially saturated systems showed higher sulphate removal	[29]
2	*Tamarindus indica*	*Seed husk*	*Detergent wastewater*	1. Optimum mixing time of 3 minutes fast mixing and 15 minutes slow mixing 2. Optimum pH of 7.2	1. Turbidity and COD removal of 97.78% and 43.50% 2. Turbidity and COD removal of 97.01% and24.86%	[37]
3	*Typhaceae family*	*Fruit, flowers*	*Simulated urban sewage*	-	Efficiency of TP removal of 84.28%	[45]
4	*Adenanthera pavonina*	*Seeds*	*Water containing heavy metals like Copper*	Varying initial concentration of Cu	Maximum heavy metal removal was 10.917 mg/g at optimum contact time of 40 minutes	[101]
5	*Azadirachta indica*	*Seeds*	*Raw water and pond water in Chengalpattu district*	Different dosages	Reduction of 94% of fluoride with an optimum dosage of 2 gm/L Highest removal efficiency was in the range of 98 to 99%	[59], [60]
6	*Musa genus*	*Stem*	*Spent coolant waste water*	pH values were changed to determine highest removal percentage. Different dosages at pH 7	COD removal of 80.1% and SS removal of 88.6% at 90mL dosage At pH 7, COD, SS & turbidity removal was 80.1%, 88.6% and 98.5%	[68]
7	*Moringa oleifera*	*Seeds*	*Synthetic turbid water*	Higher, medium and lower turbidity range Dosage from 50 mg/L to 100mg/L	Turbidity reduced to 5.9 NTU from 100 NTU Coliform removal was 89-96%	[94]
8	*Brassica genus, Sinapis genus*	*Seeds*	*Synthetic clay solution and turbid pond water*	Heat treatment at 95ºC for 5 h	Thermal stability. The coagulation activity against turbid pond water was 60% compared to Moringa seed extract which was 50%	[86]

Conclusion

Plants surveyed in this review have remarkable properties and they could be adopted in effluent treatment. Although commercial coagulants are used in large scale for this purpose they have several limitations and often results in destabilization of the treated water such as change in conductivity and pH. The amount of sludge produced by conventional coagulants is very high and therefore sludge handling becomes a tedious process. Natural coagulants forms heavier flocs that settles quickly and the sludge volume is comparatively low and less toxic. The sludge produced is biodegradable and it can be used in agriculture as organic manure or as nutrient supplement for the growth of perennials. Therefore, the overall amount of waste that is generated is highly minimized. Natural coagulants are economical as they do not alter the conductivity of the treated water and thereby protects the operating channel against corrosion. The advantages stated above and the high coagulation efficiency of natural coagulants signifies its importance as alternatives to chemical coagulants. As a result of this considerable attention has been directed towards removal of dye in the effluent treatment, a preliminary step adopted in many effluent processing method using natural coagulants. Vegetables, cortex fruits and legumes have been extensively analysed for their application in water clarification. However, potential of many abundantly available plants and trees are still untapped and in-depth knowledge of these plant materials as active coagulants might improve the future prospect of commercialization of natural coagulants.

References

1. West, Larry (2006-03-26). "World Water Day: A Billion People Worldwide Lack Safe Drinking Water". Retrieved from thoughtco.com: https://www.thoughtco.com/water-pollution-causes-effects-and-solutions-1140786
2. Chan Y.J., *Chem. Eng. J.* 155 (2009) 1.
3. Forgacs E., Cserhati T., Oros G., *Environ. Int.* 30 (2004) 953.
4. Tang Shu Hui, Muhammad Abbas Ahmad Zaini, *Advances in Chemistry Research*, Nova, (2016).
5. Yagub M.T., *Adv. Colloid Interface Sci.* 209 (2014) 172.
6. Freitas TKFS, Almeida CA, Manholer DD, Geraldino HCL, de Souza MTF, Garcia JC, *Detox fashion, Springer,* 27.
7. Ouattara, *Int. J. Inno. Sci. Res.* 27 (2016) 303
8. Garcia JC, Simionato JI, da Silva AEC et al, *Sol. Energy.* 83 (2009) 316.
9. Xu XR, Li HB, Wang WH et al, *Chemosphere*. 59 (2005) 893.
10. Leme DM, Oliveira GAR, Meireles G et al, *Toxicol. In. Vitro.* 28 (2014) 31.
11. Ouattara, *Int. J. Inno. Sci. Res.* 27 (2016) 303.
12. Rudresh S., Technical report- Circular Economy Pathways for Municipal Wastewater Management in India (2017)
13. Boda M.A., *Int. J. Sci. Res. Dev.*2 (2017) 173.
14. Radzuan R.M., Radin Maya Saphira Radin Mohamed, Al-Gheethi A.A., Amir Hashim Mohd. Kassim, Integrated Water Protection Resources, Penerbit UTHM (2017)
15. Ghebremichael K.A., *KTH Land and Water Resource Engineering,* TRITA-LWR PHD (2004)
16. Lee K.E., *Chem. Eng. J*. 203 (2012) 370.
17. Bratby J., International Water Association- Coagulation and Flocculation in Water and Wastewater Treatment (2006).
18. Verwey E. J. W. and Overbeek J. T. G., Elsevier Amsterdam (1948).
19. Verma A.K., *J. Environ. Manage*. 93 (2012) 154
20. Obiora-Okafo I.A., Onukwuli O.D., Nigerian J. Tech. 36(2017) 482
21. Paula , *Acta Sci., Technol.* 38(2016) 57
22. Matilainen A, Vepsäläinen M, Sillanpää M, *Adv. Coll. Interface. Sci.* 159 (2010) 189.
23. Flaten P., *Brain Res. Bull*. 55(2001) 187
24. Muybi S.A., Birima H.A., Muhammed T.A., Noor M.J., IIUM Eng. J. 5 (2004) 25
25. Pavankumar P., Conference paper in ICGCSC 2017, Moodabidri, Karnataka.
26. Huang C., Chen Y., *J Chem. Technol. Biotechnol.* 66 (1996) 227.
27. ITIS report – *Canna indica*. Integrated Taxonomic Information System
28. Awosan, *Afr. J. Microbiol. Res.* 8 (2014) 2376
29. Saeed T., Sun G., *Chem. Eng. J*. 325 (2017) 332
30. Ali Esmail Al-Snafi, *Int. J. Pharmacol. Toxicol. Sci.* 5(2015) 71

31. Indrayan A.K., Bhojak N.K., Kumar N., Shatru A. and Gaura A., *Indian J. Chem.* 50B (2011) 1136
32. Atrooz O.M., Asian J. Biochem 7 (2012) 1
33. Atrooz O.M., Pak. J. Biol. Sci.12 (2009) 1063
34. Bachheti R.K., Int. J. PharmTech Res. 5 (2013)
35. ITIS report – *Tamarindus indica*. Integrated Taxonomic Information System
36. Chindu M., *Int. J. Res. Eng. Technol.* 5 (2016).
37. Saidat Olanipekun Giwa, *Int. J. ChemTech Res.* 9 (2016)771
38. Vijayakumar, *J. Water Res. Eng. Manage*. 1 (2014) 1
39. Sinchaiyakit P., *Nat. Prod. Commun.* 6 (2011) 829
40. Sinchaiyakit P., Naresuan Phayao Journal 4 (2011) 4.
41. EL-Siddig, Fruits for the future, revised. International centre for underutilized crops, Southampton (2006) 188
42. Datta A., Suhas P.W., Patil M., Tilak A.S., *Curr. Sci.*110 (2016) 1756.
43. Narayanan S., Nabi A., Hussain K., Khan F., Research on: Practical aspects of utilizing aquatic weeds in compost preparation (2017)
44. Sezik E, Yeşilada E, Tabata M, Honda G, Takaishi Y, Fujita T, Tanaka T, Takeda Y., *Econo.*
    a. *Bot.* 51 (1997) 195.
45. Liu W., Xu X., He H., Sun C., Comparison of treatment performances of simulated urban sewage in constructed wetlands planted with four types of wetland plant.
46. Prabhu P.C., Udayasoorian C.,*Paper Asia*23 (2007) 27.
47. *Trop. J. Pharm. Res.* 14 (2015) 1983
48. ITIS report – *Adenanthera pavonina L.* Integrated Taxonomic Information System
49. Sujit dash, Sunil K.K., Amaresh C.S., Mishra B.,*MIT Int. J. Pharm. Sci.* 3 (2017) 7
50. Dissanayake D.M.R.K., Wijayabandara M.D.J., Ratnasooriya W.D., *Int. J. Pharm. Res. Allied Sci.* 5(2016) 34
51. Lindamulage I.K.S., Soysa P., MC Complementary and Alternative Medicine 16 (2016) 1.
52. Wickramaratne, BMC Complementary and Alternative Medicine 16 (2016) 466
53. Md. Mujahid, J. Chem. Pharm. Res. 8 (2016) 586
54. Mohammad A. Hossain, Wafa A.S. Al-Toubi, Afaf M. Weli, Qasim A. Al-Riyami, Jamal N. Al-Sabahi *J., Taibah. Univ. Sci.* 7 (2013) 181.
55. Porter, A.H. (2006-04-17). *"Neem : India's tree of life"*.Retrieved from BBC news: http://news.bbc.co.uk/2/hi/south_asia/4916044.stm
56. Biren N., Shah A. S., The textbook of Pharmacognosy and Phytochemistry. Haryana: Elsevier (2010).
57. Bryan Yamasaki R.,James A. Klocke, Mark Lee S., Gregory A. Stone, Mark V. Darlington, *J. Chrom.* 356 (1986) 220.
58. Harish Kumar G., Vidya Priyadarsini R., Vinothini G., Vidjaya Letchoumy P., Nagini S., *Invest. New. Drugs.*28 (2010) 392.
59. Sowmeyan R., Santhosh J., Latha R., *Int. Res. J. Biochem. Bioinfo.*1(2011) 301.
60. Pamila Ramesh D., Dr. Vasanthi Padmanaban, Sivacoumar R., *Int. J. Eng. Res. Tech.*,3(2015) 972.
61. ITIS standard report - Musa X paradisiaca. Integrated Taxonomic Information System.
62. Policy note 2015-2016. (n.d.). *Policy note 2015-16 - TNAU agritech*. Tamil Nadu Agricultural University.
63. Kraft, Sy, *med news today* (2011).
64. Heslop-Harrison J.S., Trude Schwarzacher,*Ann. Bot-London.* (2007)
65. Vigneswaran C., Pavithra V., Gayathri V., Mythili K., *J. Text. App. Tech. Manage*. 9 (2015) 5.
66. Cristiane Suely Melo de Carvalho, Lorena Vieira Bentolila de Aguiar, Ceci Sales-Campos, Marli Teixeira de Almeida Minhoni, Meire Cristina Nogueira de Andrade, *Braz. J. Microb.* 43 (2012) 819.
67. Meijer W.J.M., Mathijssen E.W.J.M., *elsevier* (1992) 175.
68. Habsah Alwi, Juferi Idris, Mohibah Musa, Ku Halim Ku Hamid, *J. chem.*165057 (2013) 4.
69. ITIS report - Moringaceae. Integrated Taxonomic Information System
70. Jed W. Fahey, Sc.d., *Trees. Life*. 1 (2005).
71. Anu Elizabeth Joy, Shankar Bhat Kunhikatta, Shyamjith Manikkoth, *Arch. Med. Health. Sci. 1* (2013).
72. Balamurugan V., Balakrishnan V., *Int. J. Curr. Microbiol. App. Sci.* 2 (2013) 118.
73. Anbazhakan S., Dhandapani R., Anandhakumar P., Balu S., *Anc. Sci. Life.* 27 (2007) 43.
74. Farooq Anwar, Sajid Latif, Muhammad Ashraf, Anwarul Hassan Gilani, *Phyto. Res.*21 (2006) 17.
75. Kirtikar K.R., Basu B.D., *Indian medicinal plants* 27(1975) 46 .

76. Kebreab A. Ghebremichael, Gunaratna K.R., Hongbin Henriksson, Harry Brumer, Gunnel Dalhammar, *Elsevier*. (2005) 2338.
77. Asrafuzzaman Md., Fakhruddin A.N.M., Alamgir Hossain Md., *Int. Sch. Res. Netw.*632189(2011)6.
78. Joshua R., Vasu V., *Int. J. Life. Sci. Biotech. Pharma. Res.* (2013) 6.
79. Suleyman A. Muyibi, Lilian M. Evison, *Water. Res.* (1995) 1099.
80. *ITIS report - Brassica juncea.* Integrated Taxonomic Information System.
81. Agricultural statistics at a glance 2015, (2015).
82. *Basic Report 02024.* U.S.: USDA National Nutrient Database for Standard Reference (2016).
83. Muhammad Farhan Sarwar, Muhammad Haroon Sarwar, Muhammad Sarwar, Niaz Ahmad Qadri, Safia Moghal, *Acad. J.* (2013) 97.
84. Milner, Christine M., Kaefer, John A., *J. Nutr. Biochem*. (2008) 347.
85. Vision 2050. (2015). *Vision 2050 DRMR Rajasthan*. New Delhi: Indian Council of Agricultural Research.
86. Bodlund I., Pavankumar A.R., Chelliah R., Kasi S., Sankaran K., Rajarao G.K., *Int. J. Environ. Sci. Tech*. (2013) 1.
87. Vieira AMS, Vieira MF., Silva GF, Araújo AA, Agundes-Klen MR, Veit MT, Bergamasco R, *Water. Air. Soil. Pol.* 206 (2010) 273.
88. Wei, R.T.V., Houten, A.R., Borger, D.H., and Eikelboom, Y.F., *Water. Res.* 37 (2003) 4453.
89. J. Beltrán-Heredia, J. Sánchez-Martín, A. Delgado-Regalado, C. Jurado-Bustos, *J. Haz. Mat.* 170 (2009) 43.
90. Mohd Omar Fatehah, Md. Sohrab Hossain, Tjoon Tow Teng, *Int. J. Sci. Mod. Eng.* 1 (2013).
91. Jed W. Fahey, Sc.d., *Trees. Life*. 1 (2005).
92. Farooq Anwar, Sajid Latif, Muhammad Ashraf, Anwarul Hassan Gilani, *Phyto. Res.* (2006) 17.
93. Kebreab A. Ghebremichael, Gunaratna K.R., Hongbin Henriksson, Harry Brumer, Gunnel Dalhammar, *Elsevier*. (2005) 2338.
94. Asrafuzzaman Md., Fakhruddin A.N.M., Alamgir Hossain Md., *Int. Sch. Res. Netw. (2011)* 6.
95. Suleyman A. Muyibi, Lilian M. Evison, *Water. Res.* (1995) 1099.
96. ITIS report – *Canna indica*. Integrated Taxonomic Information System
97. ITIS report – *Tamarindus indica*. Integrated Taxonomic Information System
98. ITIS report – *Adenanthera pavonina L.* Integrated Taxonomic Information System
99. Jeyaraman V, Muthukkumarasamy S, Antony Joseph Velanganni A., *Ind. J. Nat. Sci.* 1(2011) 285.
100. Sezik E, Yeşilada E, Tabata M, Honda G, Takaishi Y, Fujita T, Tanaka T, Takeda Y., *Econo.*
    a. *Bot.* 51 (1997) 195.
101. Bahnika Sen, Sarma HP, Bhattacharyya KG., *Int. Org. Sci. Res. J. Env. Sci. Toxicol. Food.*
    a. *Techn.* 9 (2015) 1.
102. Katayon S., Ng S.C., Megat johari M.M.N., Abdul Ghani L.A., *Biotech. Biopro. Eng.* (2006) 489.
103. Vijayaraghavan G., Rajasekaran R., Shantha kumar S., *Int. J. Chem. Sci.*11 (2013) 1824.

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