Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2024; 13(5): 479-485
Received: 25-07-2024
Accepted: 20-08-2024

Harshal P Moon
Department of Pharmaceutical Sciences, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra, India

Snehal P Moon
Department of Pharmaceutical Sciences, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra, India

Nishikant A Raut
Department of Pharmaceutical Sciences, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra, India

Corresponding Author:
Nishikant A Raut
Department of Pharmaceutical Sciences, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra, India

Seeds, leaves and stems of *Eugenia jambolana* (*Jamun*) as a tool for water purification

Harshal P Moon, Snehal P Moon and Nishikant A Raut

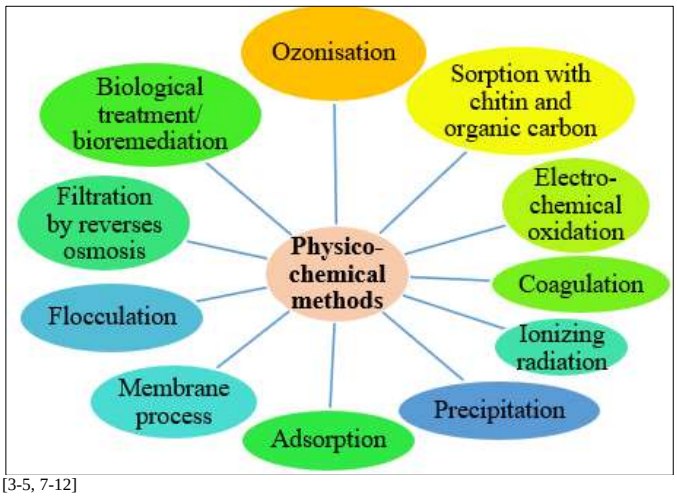
DOI: https://doi.org/10.22271/phyto.2024.v13.i5g.15114

Abstract
Eugenia jambolana vernacularly known as *Jamun*, *Jambul* or *Java Plum* has been traditionally used for variety of beneficial effects on human health. Its activities are experienced, studied and reported in several research articles along with its versatile therapeutic applications such as antidiabetic, anthelmintic, antidiarrheal, antibacterial, blood purifier, anti-infective, antimalarial, etc. it also has an important quality as *Grahi* (adsorbent). This review is focusing on the adsorbent properties of stem bark, leaves and seeds of *Jamun* as an alternative technique of water purification through adsorption of organic pollutants, dyes and heavy metals, parasites, toxins, etc. The stem bark, leaves and seeds of *Jamun* contain tannins that disrupt the oxidative phosphorylation process in waste-water parasites, interfering with their ability to produce energy. Also, the Ayurveda suggest the use of glass or tumbler made from wood of *Jamun* for drinking water as it has quality to adsorb toxins. The most important peculiarities of *Jamun* wood is that it does not degrade in water for longer period of time. If a piece of its wood is placed in the water tank, it prevents the formation of algae or green moss in water and minimize the frequency of tank cleaning. It is an effective alternative for adsorption on large industrial scale as that of activated charcoal. This biosorbent is 'Best out of waste', which can connect the roots of Ayurveda with the modern science. All these utilities indicate a novel approach for further useful and cost-effective natural adsorbent for water purification.

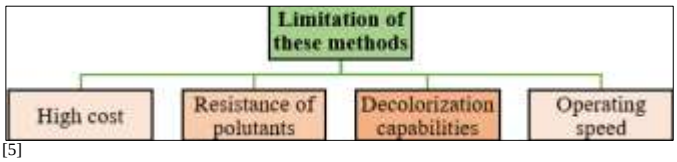
Keywords: Approach, further, ayurveda, phosphorylation

1. Introduction
The purification of waste-water is an essential and ultimate way of satisfying the daily routine demand of water. The disposal of contaminated water from various industrial sources such as paper, cosmetic, food, textile, plastic, leather, etc. to the communal sewage system is a serious issue and need special attention to work on it. This contamination is due to the presence of colouring agents, heavy metals, organic-inorganic pollutants and different synthetic dye stuffs. These dyes fall into three general categories: non-ionic (vat dyes and disperse dyes), cationic (basic dye) and anionic (reactive, direct, acid dyes). They are visually unpleasant and detrimental to the environment and human health. These are extremely toxic to both humans and animals because they can permanently damage eyes, causing itching, redness and pain to eye, redness of skin, respiratory tract irritation that can result in coughing and dyspnoea, causing gastrointestinal tract irritation that can cause nausea, vomiting and diarrhoea in people. It also acts as a mutagen for microorganisms. When heated to breakdown, it releases toxic compounds such as sulphur, nitrogen, and carbon oxides [1-3]. About 40,000 dyes containing 7000 complex chemical structures are resistant to biodegradation processes need adopting physico-chemical reactions for pretreatment and purification. These dyes are designed to be resistant to oxidising chemicals, light and water, hence they are difficult for breakdown followed by removal from aquatic systems [3-5]. Similarly, the production of medicines, dyes, pesticides, wood preservatives, paint, cement, mining, metallurgy waste, ceramic, electronics, petroleum refineries, glass processing, herbicides and pesticides used in agriculture/ forestry, landfill leachates, etc. are some of the ways that arsenic and other pollutant enters into the aquatic systems. Even at modest dosages, prolonged exposure of arsenic water can have negative effects on the skin, nasal passages, bone mineralization, and even the central nervous system, liver, kidneys, and prostate [6]. So there is imperative to design a cost-effective and highly potential method for waste-water handling [5]. There are several techniques such as reverse osmosis, distillation, boiling, chlorination, ion exchange, desalination, microfiltration, membrane technology, UV filter, activated carbon/charcoal, etc., which are routinely followed for separation of cationic, anionic and non-ionic materials from waste-water. The two most often utilised techniques among these are coagulation and adsorption; however, coagulation

produces large volumes of sludge, which turn into pollutants and have disposal issues of their own [5] results in significant expenses for disposal. In contrast, the adsorption process is a better method producing the good results by getting rid of different kinds of pollutants and colouring compounds [3, 13-15]. Several industrial processes utilize adsorption technique as it has a straightforward design, ease of operation, high efficiency, affordable cost for big adsorption, ease of disposal in landfills, and insensitivity to harmful pollutants [13-18].



[3-5, 7-12]



[5]

Many adsorbent materials are tested for adsorbing hazardous components such as stones, shells, sewage, municipal trash, agricultural waste, sludge, and nanocomposites from waste water [19-20]. To remove heavy metals from polluted water, some innovative techniques have been introduced, such as blending *Chenopodium quinosa* which was obtained from crop residue further activated with magnetic nanoparticles [20], preparing copper nanoflakes from the sol gel method, impregnating biochar composites with MnO and CuO, activated carbon, etc. Since activated carbon has a porous and sculpted surface that offers a wide surface area for adsorbing iron from waste water, it is the most effective adsorbent that is continuously utilised [21]. However, current research has focused on developing low-cost alternative adsorbent for highly expensive activated carbon.

All these attempts are ongoing to achieve two primary goals, first is to save money and second is to transform waste material into usable form, the first step is to replace activated carbon with less expensive alternatives. The second step is to convert various waste materials into usable form in order to save money [3, 22, 23]. The fortunate outcomes for treating coloured effluents with varying degrees of success are discovered, at least in laboratory base.

Cost effective bio-sorbents are mostly naturally obtaining, plant-based materials or agricultural wastes which processed biologically from fungi, bacteria, algae, kaolin [2], Neem leaves [24], bottom ash, de-oiled soya [25], jute sticks [26], rice husk [27], rice husk ash [28], home-made activated carbon [29] and bagasse fly ash [3, 30], seeds of mango, jackfruit, waste wool, used tea leaves [31], tea waste [32], waste from coconut bunch [23], activated carbon of coconut husk [33], pearl millet husk [34], garlic peel [35], sawdust, tree barks, papaya seed, Brazil nut shells, shell of wood apple [31], stem of pineapple [36], sunflower stalks [37], cotton and nut wastes, *Jamun*, *Amaltash*, etc. and are examined for their capacity to adsorb because of their safe chemical makeup [38]. The primary mechanism of plants function is their ability to adsorb or neutralise the harmful effects of heavy metals making them a potential substitute due to their affordability, reduced sludge production and environmental friendliness [8].

Present review has compiled the efficacy of the novel natural adsorbent prepared from *Jamun* (*Eugenia jambolana Lam.*) stem and seeds for removing different metals, dyes and pollutants from aquatic medium [39].

2. Materials and Methods

A. Plant Profile

- **Botanical name:** *Eugenia jambolana* Lam., also known as Syzygium jambolanum DC has another synonym as *Syzygium cumini* skeels
- **Common name:** Jamun, malabar plum, Java plum, black plum, Jam, Jamun, jaman, jambul or jambolana
- **Family:** Myrtaceae
- **Hight:** fast growing up to 30 m
- **Life:** long living (about 100 years)
- **Description:** It is an evergreen tropical tree plant highly dense foliage
- **Distribution:** throughout the warmest parts of the USA (Hawaii and Florida), Eastern Africa, Madagascar, South America, Ceylon-Malaya, and Australia [40]
- **Fruits:** during rainy season

B. Cultivation & collection

Jamun tree is typically grown along the major borders of orchards [41]. It blossoms once in a year, usually during the month of June-July on the Indian subcontinent. The tiny, sessile blooms of white colour with thin, membrane petals, and measure 7 to 12 mm. They often develop from the wounds of fallen leaves and are grouped primarily in threes. Fruit development takes around two months, during this time there are several changes to the phytochemical contents and proximate composition. The fruits do not mature at the same time and are found in clusters ranging from four to twenty. When the fruits are young, they are green; as they ripen, they become light-magenta; when they are fully ripe, they are either dark purple or black. The fully ripe fruit makes the tongue a purple hue with combines flavours that are sweet, somewhat tart and astringent. Every fruit has a central chamber that holds tiny seeds and is 1/2 to 2 inches long, with round, oblong, or ellipsoid shapes with tasty flesh. While the flesh of the desi *Jamun* fruit is sour and contains comparatively big seeds [41]. The ripe fruits fall to the ground or are consumed by bats, squirrels and monkeys if they are not picked, also the seeds remain on ground as waste [42].

C. Phytochemical constituents

According to the analysis, it contains free amino acids, glucose, fructose, mannose, sucrose, galactose and maltose; carbohydrates, alkaloids, flavonoids, terpenes, triterpenoids, anthocyanins, sterols, tannins, minerals, and glycosides; and water-soluble vitamins such as ascorbic acid, niacin, and thiamine [40, 41]. In addition, quercetin, betulinic acid, myricetin, myricitrin, n-nonacosane, n-hepatcosane, n-dotricontanol, mycaminose, n-hentriacontane, n-triacontanol, crategolic acid, noctacosanol, and flavonol glycosides have been identified in the leaves [42]. Stem bark contains gallic acid, gallotannin, ellagic acid, ellagitannin, kaempferol, myricetine, β-sitosterol, and β-sitosterol-d-glucoside [40]. The highly explored part of *Jamun* plant is the seed, which carry quercetin, ellagic acid, β-sitoterol, jambosine, gallic acid, corilagin, 1-galloylglucose, 3, 6-hexahydroxy diphenoylglucose, 3-galloylglucose, and 4,6-hexahydroxydiphenoylglucose in it [40, 43]. Along with that, some trace elements such as calcium, iron, copper, manganese, zinc, protein, fat, minerals and crude fibres were found in *Jamun* seed powder [44]. Due to the presence of abundance of phytoconstituents, about all parts of plant, particularly seeds has long been used in the folk medicinal systems [45].

D. Traditional Medicinal activity

It has been revered for its many medicinal qualities in the Unani and Ayurvedic medical systems. While the seeds are traditionally used as a diuretic and stop urine discharge, cardio-vascular disorder, control blood pressure, and gingivitis, whereas fruit acts as a live tonic and enriches blood, teeth, and gums. Collectively bark, fruit, leaves, and seeds of the plant are digestive, useful against bronchitis, asthma, control blood pressure, dysentery, ulcers, and wound healing [46, 47], anti-genotoxic, anti-allergic, anti-cancer, hepatoprotective, anti-HIV, anti-fungal, antiviral, antibacterial, anti-diarrheal, and anti-inflammatory properties [40, 48, 51]. Traditional healers used stem bark the most since it has antibacterial and anthelmintic properties [51, 52]. It is also helpful in the treatment of skin ulcer cause due to the diabetes mellitus [53]. Internally its *Grahi* (like absorbent) quality might occasionally result in constipation. However, this could be beneficial externally in the generalised water purification method for the adsorption of contaminants, ions, dyes, and other compounds.

E. Benefits of parts of plant

- **Fruits:** The ripen fruits are utilized to make wine, juices, toffees, jellies, squashes and other health beverages [40].
- **Leaves:** Used to treat metabolic illnesses such as diabetes mellitus, rheumatoid arthritis, cancer and liver disorders [54].
- **Bark:** Act as astringent, digestive and acrid according to Ayurveda, also helpful in the treatment of diabetes, ulcers, bronchitis, asthma, thirst, biliousness, and sore throats (40). The tumbler/glasses made from bark of *Jamun* are used to drink water for its health benefits.

- **Stem:** Used to prepare an adsorbent for the purpose of eliminating various metals, colours and contaminants from aquatic media [51].
- **Seeds:** The Large size of seeds make up around one-fourth of the fruit on the plant [55]. This provides an abundance of easily obtainable seed for the creation of bio-sorbents, which eliminate various metals, colours, and contaminants from aquatic environments [39]. Researchers showed that using bio-sorbents made from

seed biomass to remove arsenic from synthetic waste water had outstanding results, with 93% of the arsenic being removed. This suggests that bio-sorbent materials made from seed biomass might be produced at a cheap cost [6]. The approach might be optimised by adjusting the pH, adsorbent dosage, and arsenic content in wastewater. The efficiency of the adsorbent is assessed using methods such as FE-SEM, EDX, FTIR, XRD and ICP [6, 56, 58].

- **Wood:** The wood of plant is extremely robust and water resistant [51]. Because of its strength and resistance to water, its wood is utilised in furniture building [59].

F. Preparation of Adsorbent

The method of preparation of adsorbent was carried out by many scientists on laboratory scale and the same methods can be followed for large scale production. The specific procedure for preparation of adsorbents from different parts of plant are given below.

1. From saw dust of stem

The collected saw dust from any authentic sources is allowed to air dry in the presence of sunlight for 3-4 days, follow by oven drying at 60 ºC for about three hours. After that, grind the material to collect the final adsorbent [3].

2. From *Jamun* seeds

The seeds are collected from any reliable sources and soaked in a 10% ethanol solution for two hours to get rid of any colouring and germs. Then, the liquid is strained and the seeds are allowed to dry in the sun for three days. The material is kept in the oven for 16 hours at 70–80 °C. The dried material was crushed in the pin mill and converted into a fine powder (50 to 60 mesh) [60]. The process of preparing activated carbon involve activating *Jamun* seeds with KOH and then pyrolyzing them at 900 °C (61) or the powder is heated in a furnace having CARBOLITE tube, in presence of nitrogen gas at 40º, 50º, 60º and 75 ºC to produce adsorbent material [62].

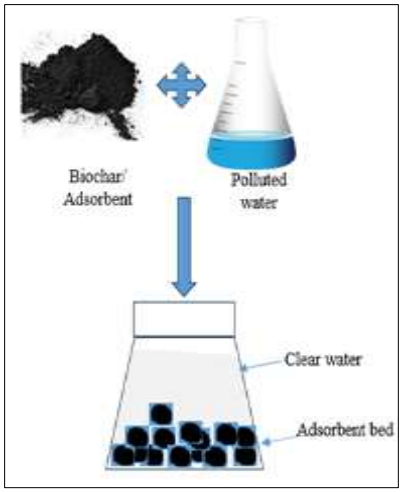
Other method for preparing adsorbent is by steeping the seeds in water for 48 hours followed by grinding up into little bits with a mill and pestle after drying up to 36 hours on 383 K in hot air oven. Further the seed pieces are crushed by mixer grinder to get a powder of 49 µm particle size and then screened it. Specific standardized sieves can be used to finish the screening process. Then this powder further pyrolyze for 60 minutes at 773 K in a pit type furnace reactor. After being removed from the reactor, the resulting *Jamun* seed powder biochar can be stored at room temperature in an airtight container [63].

3. From leaves

After washing the leaves demineralized water to make free from dirt and soil, they are kept in natural sunlight for around 7 days followed by grinding to obtain a powdered material. The concentrated sulfuric acid is added into the powder in the ratio 2:1 (Sulfuric acid: *Jamun* leaves powder) and kept in muffle furnace at 155-160 ºC temperature. The mixture is allowed to cool and then rinsed with water to remove the elemental acidic traces from it followed by drying in the hot air oven at 100-110 ºC. The sample changes its colour to black, which is then treated with 5% sodium chloride with continuous stirring for a day on magnetic stirrer and filtered using whatman filter paper. It is rinsed once with water, dried at temperature between 100-110 ºC to obtain particle size of 80 µm [64].

G. Mechanism of Adsorption

The powder of adsorbent is mixed in wastewater which quickly adsorbs pollutants, metals, etc. from water and gets settled down at bottom, leaving the pure water for further utilization. The tannins in the stem of *Jamun* interrupts the process of generating energy in parasites by uncoupling oxidative phosphorylation. It also gets bonded to glycoprotein on the cuticle or free proteins present in gastrointestinal tract of the parasite which cause death of worms (51). The FTIR study proved the appearance of amino, carboxyl, hydroxyl and carbonyl groups on the surface of the biomass in the adsorption of Chromium (IV), Cadmium (II) and Lead (II) [65].



3. Results and Discussion

A. Parameters for evaluation

There are several parameters such as particle size, pH of solution, concentrations of pollutants, agitation rate, dose of adsorbent, temperature and varying contact time, etc., which affect the efficacy of biosorbents and taken into consideration during the evaluation. The characterization is done by Iodine titration (micro-pores determination), Boehm titration (acidic and basic sites), determination of volatile matter, ash content, and porosity/bulk density, moisture content, pH, zero-point pH, elemental analysis, X-Ray Fluorescence (XRF Technique), XRD, EDS, FTIR, TGA and SEM [53, 64]. The results are then incorporated into the Temkin or Langmuir and Freundlich or Bohart-Adam isotherm model or Dubinin-Radushkevich model for assessment.

- **Particle size:** The adsorption rate decreases with increase in particle size. But when the particle size of adsorbent decreases, it ultimately increases the accessibility and surface area of pores followed by increase in rate of adsorption [26, 29, 30].
- **Adsorbent dose:** The higher dose of adsorbent increases the surface area which enhance adsorbent binding sites, hence the rate of adsorption increases with the amount of adsorbent [3, 26, 29, 30, 66].
- **Contact time:** As the contact time increases, adsorption rate also increases up to a constant value till the covering of all the available sites and absence of active sites for binding of pollutants on adsorbent surface. Primarily, large number of active sites are available for adsorption, but when few sites remains, there may be occurrence of difficulty in occupation caused by repulsive forces between the solid molecules of solute and bulk phase solution [3, 26, 28–30, 66].
- **Initial pH:** Studies revealed that the structure of some pollutants such as dyes get affected by the change in pH towards highly acidic or basic. While, *Jamun* stem powder easily removed dyes at neutral pH. The changes in initial pH causes destabilization of solution which is helpful for effective adsorption [3, 26, 28–30, 66].
- **Agitation rate:** The speed of agitation i.e. rotation per min is an important parameter to be considered. As the agitation rate increases up to 100 rpm, the adsorption rate increases due to chances of availability of binding sites. Agitation causes an increase in the external mass transfer coefficient, which speeds up the adsorption of pollutant molecules [26, 28–30, 66].
- **Temperature:** The effect of temperature has been assessed in the range of 10-80 ºC and the results of the studies reported that, *Jamun* stem powder showed maximum efficiency at 30 ºC. The adsorbent which removes harmful materials from water at normal temperature are good for acceptance [3, 26, 28–30, 66].
- **Chemical modification of adsorbents:** The organic solvents are used for the extraction of pigments, colours and resins from the adsorbents, so as to modify or increase its adsorption capacity. The polar organic solvents are preferred, because non-polar solvents such as benzene, carbon tetrachloride or chloroform does not improve the adsorption sites [3].
- **Bed depth:** The increase in bed depth causes decrease in adsorption capacity of biosorbent [67].
- **Flow rate:** The increase in flow rate of polluted solution causes decrease the adsorption rate of biosorbent [67].

B. Applications

Different parts of *Jamun* plant can be utilizes for variety of functions because of its richest phytoconstituents. The beneficial applications are enlisted according to the results of different studies as follows.

- The stem powder can be used in place of activated coal for removing Brilliant Green dye present in polluted water.
- Activated carbon derived from *Jamun* seed is beneficial in adsorbing fluorides from waste-water [61].
- *Jamun* seed biochar is proven useful in removing lamivudine with other organic components from polluted water and waste-water effluents [62].
- Biosorbent prepared from *Jamun* is use to form adsorbent bed, which adsorb Chromium (VI) ions from polluted aqueous solution. These biosorbent can be regenerated by desorbing it with 0.1 N sodium hydroxide solution and it provide sufficiently large breakthrough volumes up to 90%. This regeneration is beneficial in large scale purification such as industrial effluents and other wastewater [67].
- This adsorbent is supposed to be affordable clearing heavy metals from surplus water [65].
- The adsorbent from leaves powder are effective, ecofriendly and economical biomass for separation of dye from industrial effluents [68].

4. Conclusion

The efficacy of the *Jamun* stem, seeds, or leaf powder as a potent adsorbent for heavy metals, dyes, and various pollutants in water has been well-documented, with chemical modifications further enhancing its efficiency. This establishes *Jamun*-based adsorbents as an attractive eco-friendly substitute for conventional activated coal, in line with the principle of deriving value from waste materials. This convergence of traditional Ayurvedic knowledge with modern scientific methods not only enriches our understanding of natural remedies but also opens avenues for sustainable solutions to environmental challenges. The transformative journey of *Jamun* from a traditional remedy to a modern biosorbent exemplifies the harmonious blend of ancient wisdom and contemporary science, pointing towards a future where natural-inspired innovations lead us to a healthier, more sustainable world.

5. Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. References

1. Gao J, Yu J, Li Y, He X, Bo L, Pu L, *et al*. Decoloration of aqueous Brilliant Green by using glow discharge electrolysis. J Hazard Mater. 2006;137(1):431–436.
2. Nandi BK, Goswami A, Purkait MK. Adsorption characteristics of brilliant green dye on kaolin. J Hazard Mater. 2009;161(1):387–95.
3. Rehman R, Abbas A, Ayub A, Qurat-ul-Ain, Salman M, Mahmud T, *et al*. Comparative study of brilliant green dye adsorption from water by radish peels, jamun stem and coal. Electron J Environ Agric Food Chem. 2011;10(7):2531–43.
4. Klimiuk E, Filipkowska U, Libecki B. Coagulation of Wastewater Containing Reactive Dyes with the Use of Polyaluminium Chloride (PAC). Polish J Environ Stud. 1999;8(2):81–8.
5. Park C, Lee M, Lee B, Kim SW, Chase HA, Lee J, *et al*. Biodegradation and biosorption for decolorization of synthetic dyes by *Funalia trogii*. Biochem Eng J. 2007;36(1):59–65.
6. Giri DD, Jha JM, Tiwari AK, Srivastava N, Hashem A, Alqarawi AA, *et al*. Java plum and amaltash seed biomass-based bio-adsorbents for synthetic wastewater treatment. Environ Pollut. 2021;280:1–6.
7. Snider EH, Porter JJ. Ozone treatment of dye waste. J Water Pollut Control Fed. 1974;46(5):886-894.
8. Gupta GS, Prasad G, Singh VN. Removal of chrome dye from aqueous solutions by mixed adsorbents: Fly ash and coal. Water Res. 1990;24(1):45–50.
9. Safarik I. Removal of organic polycyclic compounds from water solutions with a magnetic chitosan based sorbent bearing copper phthalocyanine dye. Water Res. 1995;29(1):101–5.
10. Murphy OJ, Hitchens DG, Kaba L, Verostko CE. Direct electrochemical oxidation of organics for wastewater treatment. Water Res. 1992;26(4):443–51.
11. Lin SH, Peng CF. Treatment of textile wastewater by electrochemical method. Water Res. 1994;28(2):277–82.
12. Siddiqui SI, Chaudhry SA. A review on graphene oxide and its composites preparation and their use for the removal of As3+and As5+ from water under the effect of various parameters: Application of isotherm, kinetic and thermodynamics. Process Saf Environ Prot. 2018;119(October):138–63.
13. Olgun A, Atar N. Equilibrium and kinetic adsorption study of Basic Yellow 28 and Basic Red 46 by a boron industry waste. J Hazard Mater. 2009;161(1):148–56.
14. Crini G. Non-conventional low-cost adsorbents for dye removal : A review. Bioresour Technol. 2006;97(9):1061–85.
15. Robinson T, Mcmullan G, Marchant R, Nigam P. Remediation of dyes in textile effluent: A critical review on current treatment technologies with a proposed alternative. Bioresour Technol. 2001;77(3):247–55.
16. Gupta S, Baghel M, Bhuyan C, Ravishankar B, Ashok B, Patil P. Evaluation of anti-urolithiatic activity of Pashanabhedadi Ghrita against experimentally induced renal calculi in rats. AYU (An Int Q J Res Ayurveda). 2012;33(3):429.
17. Senthil Kumar P, Fernando PSA, Ahmed RT, Srinath R, Priyadharshini M, Vignesh AM, *et al*. Effect of Temperature on the Adsorption of Methylene Blue Dye Onto Sulfuric Acid–Treated Orange Peel. Chem Eng Commun. 2014;201(11):1526–47.
18. Gaurav N, Sivasankari S, Kiran GS, Ninawe A, Selvin J. Utilization of bioresources for sustainable biofuels: A Review. Renew Sustain Energy Rev. 2017;73(June):205–14.
19. Agrafioti E, Kalderis D, Diamadopoulos E. Ca and Fe modified biochars as adsorbents of arsenic and chromium in aqueous solutions. J Environ Manage. 2014;146(December):444–50.
20. Imran M, Khan ZUH, Iqbal MM, Iqbal J, Shah NS, Munawar S, *et al*. Effect of biochar modified with magnetite nanoparticles and HNO3 for efficient removal of Cr(VI) from contaminated water: A batch and column scale study. Environ Pollut. 2020, 261(June).
21. Kouakou U, Ello AS, Yapo JA, Trokourey A. Adsorption of iron and zinc on commercial activated carbon. J Environ Chem Ecotoxicol [Internet]. 2013;5(6):168–71. Available from: http://www.academicjournals.org/JECE
22. Reddy SS. The removal of composite reactive dye from dyeing unit effluent using sewage sludge derived activated carbon. Turkish J Eng Environ Sci. 2006;30(6):367–73.
23. Hameed BH, Tan IAW, Ahmad AL. Optimization of basic dye removal by oil palm fibre-based activated carbon using response surface methodology. J Hazard Mater. 2008;158(2–3):324–32.
24. Bhattacharyya KG, Sarma A. Adsorption characteristics of the dye, Brilliant Green, on Neem leaf powder. Dye Pigment. 2003;57(3):211–22.
25. Mittal A, Kaur D, Mittal J. Applicability of waste materials-bottom ash and deoiled soya-as adsorbents for the removal and recovery of a hazardous dye, brilliant green. J Colloid Interface Sci. 2008;326(1):8–17.
26. Asadullah M, Asaduzzaman M, Kabir MS, Mostofa MG, Miyazawa T. Chemical and structural evaluation of activated carbon prepared from jute sticks for Brilliant Green dye removal from aqueous solution. J Hazard Mater. 2010;174(1–3):437–43.
27. McKay G, Porter JF, Prasad GR. The removal of dye colours from aqueous solutions by adsorption on low-cost materials. Water Air Soil Pollut. 1999;114(3–4):423–38.
28. Mane VS, Mall ID, Srivastava VC. Kinetic and equilibrium isotherm studies for the adsorptive removal of Brilliant Green dye from aqueous solution by rice husk ash. J Environ Manage. 2007;84(4):390–400.
29. Calvete T, Lima EC, Cardoso NF, Dias SLP, Ribeiro ES. Removal of brilliant green dye from aqueous solutions using home made activated carbons. Clean - Soil Air Water Water. 2010;38(5–6):521–32.
30. Mane VS, Mall ID, Srivastava VC. Use of bagasse fly ash as an adsorbent for the removal of brilliant green dye from aqueous solution. Dye Pigment. 2007;73(3):269–78.
31. Hameed BH. Spent tea leaves: A new non-conventional and low-cost adsorbent for removal of basic dye from aqueous solutions. J Hazard Mater. 2009;161(2–3):753–9.
32. Uddin MT, Islam MA, Mahmud S, Rukanuzzaman M. Adsorptive removal of methylene blue by tea waste. J Hazard Mater. 2009;164(1):53–60.
33. Tan IAW, Ahmad AL, Hameed BH. Adsorption of basic dye on high-surface-area activated carbon prepared from coconut husk: Equilibrium, kinetic and thermodynamic studies. J Hazard Mater. 2008;154(1–3):337–46.
34. Inbaraj BS, Selvarani K, Sulochana N. Evaluation of a carbonaceous sorbent prepared from Pearl Millet Husk for its removal of basic dyes. J Sci Ind Res (India). 2002;61(11):971–8.
35. Hameed BH, Ahmad AA. Batch adsorption of methylene blue from aqueous solution by garlic peel, an agricultural waste biomass. J Hazard Mater. 2009;164(2–3):870–5.
36. Hameed BH, Krishni RR, Sata SA. A novel agricultural waste adsorbent for the removal of cationic dye from aqueous solutions. J Hazard Mater. 2009;162(1):305–11.

37. Sun G, Xu X. Sunflower Stalks as Adsorbents for Color Removal from Textile Wastewater. Ind Eng Chem Res. 1997;36(3):808–12.
38. Yu B, Zhang Y, Shukla A, Shukla SS, Dorris KL. The removal of heavy metals from aqueous solutions by sawdust adsorption - Removal of lead and comparison of its adsorption with copper. J Hazard Mater. 2001;84(1):83–94.
39. Pepato MT, Mori DM, Baviera AM, Harami JB, Vendramini RC, Brunetti IL. Fruit of the jambolan tree (*Eugenia jambolana* Lam.) and experimental diabetes. J Ethnopharmacol. 2005;96(1–2):43–8.
40. Baliga MS, Bhat HP, Baliga BRV, Wilson R, Palatty PL. Phytochemistry, traditional uses and pharmacology of *Eugenia jambolana* Lam. (black plum): A review. Food Res Int. 2011;44(7):1776–89.
41. Noomrio MH, Dahot MU. Nutritive Value of Eugenia Jambosa Fruit. J Islam Acad Sci. 1996;9(1):9–12.
42. Mahmoud II, Marzouk MSA, Moharram FA, El-Gindi MR, Hassan AMK. Acylated flavonol glycosides from *Eugenia jambolana* leaves. Phytochemistry. 2001;58(8):1239–44.
43. Rastogi RP, Mehrotra BN, Sinha S, Pant P, Seth R. Compendium of Indian Medicinal Plants: 1985-1989. Vol. 4. Central Drug Research Institute and Publications & Information Directorate; c1990.
44. Ayya N, Nalwade V, Khan TN. Effect of jamun (*Syzygium cumini* L.) seed powder supplementation on blood glucose level of type-II diabetic subject. Author(s). CAB Direct. 2015;6(2):353–6.
45. Bhandary MJ, Chandrashekar KR. Diversity and use of ethnomedicinal plants in coastal Karnataka, India. Biodiversitas. 2014;15(1):89–93.
46. Mutalik S, Chetana M, Sulochana B, Devi PU, Udupa N. Effect of Dianex, a herbal formulation on experimentally induced diabetes mellitus. Phyther Res. 2005;19(5):409–15.
47. Ravi K, Rajasekaran S, Subramanian S. Hypoglycemic effect of *Eugenia jambolana* seed kernels on streptozotocin-induced diabetes in rats. Food Chem Toxicol. 2005;43(9):1433–1439.
48. Teixeira CC, Rava CA, Mallman Da Silva P, Melchior R, Argenta R, *et al*. Absence of antihyperglycemic effect of jambolan in experimental and clinical models. J Ethnopharmacol. 2000;71(1–2):343–7.
49. Muruganandan S, Srinivasan K, Chandra S, Tandan S., Lal J, Raviprakash V. Anti-inflammatory activity of *Syzygium cumini* leaves. Fitoterapia. 2001;72(4):369–75.
50. Ravi K, Sekar S, Subramanian S. Hypoglycemic effect of *Eugenia jambolana* seed kernels on streptozotocin-induced diabetes in rats. Biol Trace Elem Res. 2004;99(8):145–55.
51. Sudeep HV., Ramachandra LY, Ganapathy PSS, Rai SP. In-vitro Anthelmintic and Antimicrobial Activities of Stem Bark of *Eugenia jambolana* Lam. Int J Biomed Pharm Sci. 2009;3(1):46–9.
52. Prajapati ND, Purohit SS, Sharma AK, Kumar T. A Handbook of Medicinal Plants. Agrobios publishers, Jodhpur, India; c2003 .p. 497–498.
53. Rehman R, Luqman W. Removal of Basic Blue-9 Dye from Water by *Eugenia jambolana* Seeds and *Citrullus lanatus* Peels. Asian J Chem. 2014;26(13):3827–32.
54. Eshwarappa RSB, Iyer RS, Subbaramaiah SR, Richard SA, Dhananjaya BL. Antioxidant activity of *Syzygium cumini* leaf gall extracts. BioImpacts. 2014;4(2):101–7.
55. Singh D, Jamal F, Pandey PK. Kinetic assessment and effect on developmental physiology of a trypsin inhibitor from *Eugenia jambolana* (JAMBUL) seeds on *Helicoverpa armigera* (HÜBNER). Arch Insect Biochem Physiol. 2014;85(2):94–113.
56. Kord Mostafapour F, Bazrafshan E, Farzadkia M, Amini S. Arsenic removal from aqueous solutions by *Salvadora persica* stem ash. J Chem. 2013;2013:1–8.
57. Hashemi F, Olesen JE, Jabloun M, Hansen AL. Reducing uncertainty of estimated nitrogen load reductions to aquatic systems through spatially targeting agricultural mitigation measures using groundwater nitrogen reduction. J Environ Manage. 2018;218(July):451–464.
58. Kumar K, Dasgupta CN, Das D. Cell growth kinetics of *Chlorella sorokiniana* and nutritional values of its biomass. Bioresour Technol. 2014;167(September):358–66.
59. Rehman R, Mahmud T, Anwar J, Waheed-Uz-Zaman, Moeen M, Zafar J. Biosorptive treatment of Acid Yellow-73 dye solution with chemically modified *Eugenia jambolana* seeds. J Chem Soc Pakistan. 2012;34(5):1120–1126.
60. Rehman R, Anwar J, Mahmud T. Thermodynamical and isothermal modeling of methylene blue dye batch biosorption on formalin modified *Madhuca longifolia* leaf powder. J Chem Soc Pakistan. 2012;34(2):460–7.
61. Araga R, Soni S, Sharma CS. Fluoride adsorption from aqueous solution using activated carbon obtained from KOH-treated jamun (*Syzygium cumini*) seed. J Environ Chem Eng. 2017;5(6):5608–16.
62. Ripanda A, Rwiza MJ, Nyanza EC, Bakari R, Miraji H, Njau KN, *et al*. Removal of lamivudine from synthetic solution using jamun seed (*Syzygium cumini*) biochar adsorbent. Emerg Contam [Internet]. 2023;9(3):100232. Available from: https://doi.org/10.1016/j.emcon.2023.100232
63. Kosale D, Thakur C, Singh VK. Use of Jamun seed (*Syzygium cumini*) biochar for the removal of Fuchsin dye from aqueous solution. J Serbian Chem Soc. 2023;88(6):653–67.
64. Chavan FI, Husain M, Paul SS, Mohammad I. Domestic Wastewater Treatment Using Jamun Leaves As Adsorbents. Int J Innov Eng Sci. 2021;6(10):1–6.
65. Shanmuganathan V, Manivannan R. Removal of Heavy Metal From Waste Water By Adsorption Using Chem-Bio Modified Bio Degradable Waste With the Help of Silver Nano Particles From. Int J Creat Res thoughts. 2018;6(2):1298–318.
66. Anwar J, Shafique U, Waheed-uz-Zaman, un Nisa Z, Munawar MA, Jamil N, *et al*. Removal of chromium on *Polyalthia longifolia* leaves biomass. Int J Phytoremediation. 2011;13(5):410–20.
67. Deka S, Bhattacharyya KG. Column Studies on Chromium (VI) Adsorption onto Kala Jamun (*Syzygium cumini* L.) Seed Powder (KSP). Int J Adv Chem Eng Biol Sci. 2017;4(1):93-97.
68. Khan MI, Zafar S, Azhar MF, Buzdar AR, Hassan W, Aziz A, *et al*. Leaves Powder of *Syzygium cumini* as an Adsorbent for the Removal of Congo Red Dye From Aqueous Solution. Fresenius Environ Bull. 2018;27(5A):3342–50.