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Removal of Dyes Using Various Organic Peel-based Materials: A Systematic Review

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Abstract: This review recapitulates the recent adsorption study literature regarding the activated biochar and nanocomposites of agricultural peel-based bio-adsorbents for the removal of dyes from wastewater. The use of agricultural peel in decoloration technology is promising for efficiency, cost-effectiveness, and eco-friendliness. Various types of bio-adsorbents have been studied in the literature, such as orange peel, potato peel, banana peel, cucumber peel, Pomelo peel, and rambutan peel, respectively. The equilibrium data and kinetics were analyzed, and they fit known models are also summarized. This review article will help to know the applicability and potential of various peel-based bio-adsorbents in wastewater treatment. The conclusion has been drawn from the literature review, and few suggestions for further future studies are also proposed.

Keywords: peel-based bio-adsorbent; dyes; adsorption.

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1. Introduction

The current situation demonstrates the contamination of water as a major cause of increasing concern with fleet urbanization. The groundwater and surface water turn out to be contaminated as a result of agricultural discharges as well as untreated domestic and industrial wastes[1–3]. The prime components present in polluted wastewater are mostly organic chemicals like pesticides, fertilizers, dyes, and heavy metal ions, which arise from textiles, metallurgy, mining, tanning, chemicals, etc. Most of these pollutants are non-biodegradable, leading to further complications in the clean-up process[4,5].

The discharge of dyes into the surrounding territory is a reasonable source of eutrophication, aesthetic pollution, and disturbance in aquatic life. Several azo dyes and their degradation products, e.g., aromatic amines, are extremely carcinogenic[6] and pollute the watercourses[7–10]. These dyes are highly stable in the aquatic environment, and it becomes very difficult to take away those from water bodies [11]. This problem leads the way to an exhaustive search for the finest technology which could be employed to remove and decontaminate the dyes[12–15]. Furthermore, it treats industrial sewage, which is a vital goal for industries as well as environmental protection. Figure 1 illustrates various treatment processes such as, flocculation, filtration, ion exchange, chemical precipitation, adsorption, and membrane separation [6,11] to remove these carcinogenic agents [16,17] from contaminted water.

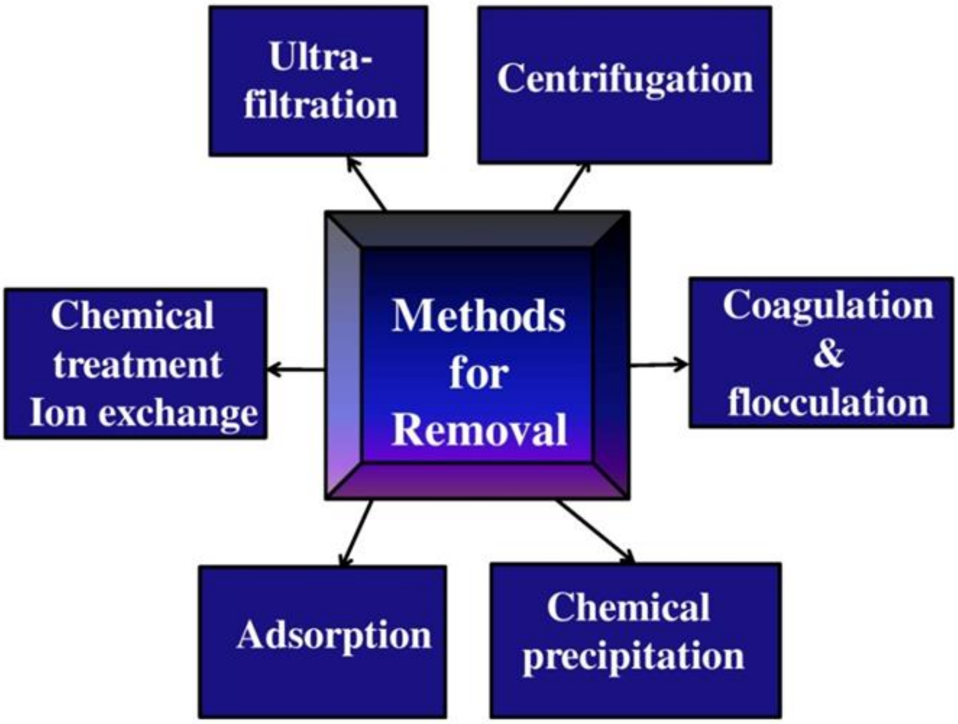

Figure 1. Various dye removal Methods.

When we consider the insufficient dye removal, sludge production, and cost, some limitations arise in the above treatment processes[15,18,19]. But among those, adsorption by natural adsorbents is proved to be highly proficient[20–22], and scientists notice. The merits of adsorption are subjected to remediation approaches like simplicity, efficiency, high selectivity, performance, cheap recovery of adsorbent and adsorbate, and efficient removal of pollutants[23]. In this case, activated carbon is a well-organized adsorbent for eliminating various types of carcinogenic dye pigments, though it is very high-priced. Hence, natural resources such as agriculture-based bio-adsorbents are more eye-catching as their effectiveness has been renowned well for different types of dye adsorption [13]. Different processes have been employed to modify adsorbents, which is very efficient in increasing adsorption [14].

Over the past few decades, there has been an increasing interest observed among scientists in the production of inexpensive and eco-friendly adsorbents for wastewater treatment. Recent researches reveal a number of low-cost adsorbents derived from agricultural ravage that are intensively investigated for the removal of dyes and heavy metals from wastewater[24].

Now, peels have given away their potential in the direction of being an eco-friendly and cost-effective bio-adsorbent material in working out the water contamination problem [25–29]. The agricultural wastes which are locally available are easily transformed to their respective carbonized (charcoal) forms, or activated carbons have been studied in this review.

2. Classification of Dyes

Generally, dye is a colored organic compound that unites itself over the surface or fabric to which it is applied. Most of the dyes are organic complexes and are also resistant to the action of detergent, soap, and the effect of temperature, sunlight, and atmospheric pressure[30–32]. Synthetic dyes are broadly applied in many advanced technology fields [26,33,34] like various textile, leather tanning, paper, food processing, rubber, cosmetics, plastics, dye manufacturing, printing, etc. These artificial dyes are also engaged in sewage, wastewater treatment and determining the cross-section area of activated sludge[35–37].

A huge number of outlets releasing water pollutants and various dyes is generated from the textile industry zone, which badly affects environmental conditions. So it is obligatory to employ effective management methods by using some unique adsorbents or other recent technologies to remove the blot of water by liberating them into water bodies. Commercial dyes can be classified in many ways, such as color, structure, and application methods[33]. On the other hand, so many complexities are found on considering the study of color and nomenclature. Therefore, classification according to application methods is mostly favorable. Furthermore, dyes are classified according to the charge on their particle when dissolved in an aqueous medium, i.e., anionic (acid, direct, reactive dyes), cationic (all the basic dyes), and dispersed or non-ionic dyes.

2.1. Cationic dyes.

The cationic dyes can be defined as the colored pigments which, when dissociated in an aqueous solution, split up into positively charged ions along with some complex ions[38–40]. Furthermore, when they are applied on the surface of a fabric, they interact with those anionic groups present on the fabric's surface[41–43]. These cationic dyes are prepared based on basic (alkaline) dyes. The stained concept for cationic dye is that they color the fiber's surface by combining with anionic acidic groups in the 3rd monomeric form of acryl on, resulting in very high effectiveness andrapidity[44–48]. These dyes are generally used in coloring the leather, silk, cotton, paper, and ink manufacturing industries. Hence, the significance of these cationic dyes has greatly been increased to develop textile, synthetic fibers, paper, tanning, etc.

The important examples of cationic dyes are Astrazon red, Astrazon pink, Basic yellow, Basic orange, Basic red, Basic orange, Methylene blue, etc.[43,48–50]. These cationic dyes are very harmful to human health. Some of those may lead to Quadriplegia, Heinz body formation, increased heart rate, vomiting, cyanosis, jaundice, shock, and tissue necrosis in the case of human beings.

2.2. Anionic dyes.

Anionic dyes are also known as acid dyes which are water-soluble. These dyes contain acidic groups such as COOH and SO_3H, which, when applied on silk, wool, and nylon, an ionic bond is formed among protonated NH_2 (fiber) and the acid group (dye)[51,52]. The acid leads to cation generation on the fabric surface, and the temperature substitutes the negative batch component of acid with the molecule of anionic or acid dye[53,54]. Acid dyes are usually applied to fabric material at a very low pH. Various examples of anionic dye include Reactive Blue 4 (RB4), Acid Blue 25(AB25), Acid Yellow 36 (AY36), Acid Orange 7(AO7), Acid Orange 52 (AO52), Acid Red 151(AR151), Acid Blue 78 (AB78)[21,55].

Table 1. Advantages and disadvantages of Various dye removal methods.

Methods	**Advantages**	**Disadvantages**
Adsorption by remaining /departed bacterial biogas.	Convinced dyes have a specific attraction required with bacterial classes.	No operative for entirely dyes.
Photochemical.	No slush is formed, and obscene odors are greatly condensed.	Developments of by-products.
Particle exchange.	Renewal: No adsorptive damage.	Non-operative for entire dyes.

Methods	Advantages	Disadvantages
Chemical behaviors. Oxidative procedure.	Easiness of submission.	(H_2O_2) agents need to stimulate by roughly resources slush group.
Irradiation.	Operative corrosion at lab measure.	Involves many liquified O_2.
Mixed bacterial cultures.	Decolorized in 24-30 hours.	Below aerobic surroundings, azo dyes are not eagerly absorbed.
Membrane separation.	Eliminates dye kinds entirely.	Intense slush manufacture.
Biotic behaviors pale by silver-rot yeasts.	Silver-rot yeasts are capable of reducing dyes with S incentives.	Incentive manufacture has similarly been exposed to be undependable.
Anaerobic fabric- dyes bio-treatment arrangements.	Permit azo and extra aquatic- miscible dyes to be bleached.	Anaerobiotic collapse produces methane and hydrogen sulfides.
Sodium hypo chloride (NaOCl)	Pledges and hurries azo bond breaking.	Production of aromatic amines.
Electro-kinetic coagulation.	Economically possible.	High slush manufacture.
Physical behaviors Adsorption by stimulated carbon.	Decent exclusion of inclusive different dyes.	Identical exclusive.
Electrochemical devastation.	No ingesting of chemical and no slush accumulation.	Comparatively, increased current charges reason a straight reduction in dye exclusion.

2.3. Non-ionic dyes.

Non-ionic or dispersed dyes are characterized by sulfide and anthraquinone composite structures having –NH, -C=O, and aromatic groups. Reactive dyes are more stable as compared to dispersed dyes due to the presence of azo dyes. These dyes possess very low solubility in water. These are mainly used for the pigmentation of polyester fiber surfaces. Some examples are Disperse Yellow 3(DY3), Disperse Blue 3(DB3), Disperse Orange 13(DO13), Disperse Yellow 54(DY54), Disperse Red 54(DR54), etc.

3. Dye Removal Methods

An enduring, efficient and sustainable dye removal method must be established to eliminate the major issue of sewage water treatment. Before release, dye contaminated water should be purified first to minimize its carcinogenic effect on the surroundings. Hence, the existing research for the dye removal techniques is extended to three types of biological, chemical, and physical methods. Though there are numerously tested and tried methods to carry out dye removal, most methods show a common demerit, i.e., secondary pollutant generation towards the environment.

The biological method is a typical technique that is used extensively in several countries for wastewater treatment[56–58]. Generally, it is a conventional method that includes a permutation of the aerobic and anaerobic processes [59,60]. This combined process is very cheap in the case and can be easily accomplished. Various biological methods include dye removal by Fenton reaction, Ozonation, Oxidation, Ultraviolet, and Photochemical irradiation (Figure 1).

Commercially, the processes of chemical dye removal are very ill-favored and require précised equipment as well as a high amount of electrical energy. This process also has a demerit, i.e., large-scale chemical consumption is needed, which leads to the origination of secondary pollution at the end of the removal process[61].

A mass transfer mechanism commonly accomplishes physical methods for dye removal. Various physical dye removal methods include coagulation or flocculation, irradiation, ion-exchange, adsorption, membrane filtration, reverse osmosis, and nano/ultrafiltration[62]. These are very simple and cost-effective methods and require the least amount of chemicals compared to biological and chemical methods. It is considered more predictable as it does not deal with living organisms[63].

Furthermore, in the midst of all physicochemical methods, the most approved and favorable ones are flocculation, adsorption united through ozonation, electro-kinetic process, flotation, ion exchange, coagulation, oxidation, membrane filtration, and precipitation[22,64,65]. But there are some limitations observed for these processes such as (i) in ozonation process, the half-life is very brief (ii) in case of ion-exchange process essential renewal, and removal ability is needed (iii) in the process of coagulation, manufacturing of huge particles as well as high slush is required (iv) in the oxidation process, production of energy outlets and huge particles are needed (v) in the filtration process, manufacturing of concentrated slush is required. Therefore, adsorption has been well-fit for removing dyes from sewage water as it is cost-effective, eco-friendly, and efficient. Table.1 shows the various dye removal methods with their merits and demerits.

4. Bio-Sorption Models

To develop an accurate and effective model for the adsorption of polluting agents such as dyes present in aqueous media, adsorption thermodynamic, kinetics, and equilibrium studies are needed. Adsorption isotherm study is one of the very useful tools for giving information about q_{max} and feasible interactions between adsorbate and adsorbent surfaces. When someone considers the adsorption isotherms, the major isotherms used in the batch adsorption process are Langmuir[66] and Freundlich models, which describe the monolayer and heterogeneous surface, respectively, with linear and non-linear expressions. Furthermore, kinetic studies are mostly used to predict optimum conditions[67] batch adsorption techniques in full scale. The kinetic study infers about adsorption mechanisms[15,68] and possible rate-controlling steps such as chemical reaction methods or mass transport. Several kinetic models include pseudo-first-order and pseudo-second-order, Elovich, and Weber–Moris. The most established kinetic models are pseudo-first and pseudo-second-order kinetic models [68]. When we consider the thermodynamic studies, we infer that these are used to determine the adsorption, the adsorbent nature, spontaneity, and adsorbate at equilibrium conditions [66]. Also, thermodynamic studies provide information on whether the reaction is favorable or unfavorable by determining the temperature range [69,70]. The main thermodynamic parameters are change of Gibbs energy (ΔG^o), adsorption enthalpy (ΔH^o), and entropy (ΔS^o). Those parameters can be calculated by fitting data obtained by adsorption experiments at different temperatures [63].

5. Agricultural Peels for Dye Adsorption

In this section, all published adsorption results regarding the dyes treatment by various agricultural peels are presented. The basic categories of dyes are discussed in detail. The isotherm model, kinetic model, maximum uptake capacity (q_{max}), optimum pH, and contact time are tabulated in Table 2. The detailed study of various isotherm and kinetic models were very limited in almost all the reported articles but most of the authors fitting Langmuir or Freundlich in isotherm and pseudo-first-order and pseudo-second-order in the kinetic model.

5.1. Potato peel.

Samarghandy *et al*. (2011) [71] studied the removal of reactive black 5 using acid-modified bio-mass of potato peel waste. Various adsorption, isotherm, and kinetic studies were performed in this experiment. The experiment was well-fitted for Langmuir adsorption isotherm and pseudo-first-order kinetics with a percentage removal of 85.5%.

Gupta *et al*. (2011)[72] studied the adsorption of MB and MG from wastewater using potato peel biomass. The experiment was well-defined by pseudo-first-order kinetics and Freundlich adsorption isotherm. The various batch equilibrium experiments were also performed along with the thermodynamic parameters.

Malekl *et al*. (2013)[73] investigated the efficiency of potato peel towards the removal of reactive red 198. The experiment was well-established for Langmuir adsorption isotherm with a capacity 93 mg/g. Various batch adsorptions have also performed to this extent, such as pH=11 and contact time 150min.

5.1.1. Adsorbent preparation.

Potato peels were collected and dried for 5-7 days at room temperature. Then the dried peels were carbonized with 0.01 M HCl modification at 90 ^oC (24h). Then the carbonized bio-mass was crushed to 40-45 mesh size[71].

Potato peels were dried at 60^0C (45min), and carbonized potato peel bio-mass was ground to 100-150 mm size. The pH was neutralized at 7 throughout the experiment[72].

Potato peel bio-mass adsorbent was prepared by carbonizing it at 170^0C for (24h) and then modifying it with H_2SO_4 and NaOH. Then again carbonized at 70^0C (48h) and crushed to 225-575 µm in size[73].

5.2. Banana peel.

Moubarak *et al*.[74] investigated the removal of MB using the powered form of banana peel. They studied the batch adsorption equilibrium processes such as temperature, contact time, agitation, pH, and adsorbent dosage. The contact time was found to be 40 min, and the removal efficiency was observed to be 90%. The experiment was well-established for Langmuir adsorption isotherm.

Amel *et al*. (2012) and Liu (2014)[75,76] reported the adsorption of MB using the nanocomposite of banana peel at pH =8; the activated banana peel shows a maximum adsorption capacity of 19.671mg/g. The experiment was well-suited for Langmuir adsorption kinetics and pseudo-second-order rate equation.

Pishgar *et al*. (2013) [77]studied the removal of basic blue 159 (BB159) from an aqueous solution using activated biochar of banana peel. The experiment was well-fitted to pseudo-second-order kinetics and Freundlich adsorption isotherm. Batch equilibrium conditions were as pH=9, 0.4g adsorbent dosage, 200rpm, and contact time 60min.

5.2.1. Adsorbent preparation.

The adsorbent was washed with distilled water to remove dirt content. Then it was dried at 105^0C. The carbonized form was sieved to 0.315mm in size. Then it was mixed with NaOH (0.1M) with a ratio of 1:5 and again carbonized and sieved to the same size[76].

5.3. Rambutan peel.

Ahmad *et al*. (2011) [78] adsorbed the malachite green (MG) using the bio-adsorbent of Rambutan peel. The experiment for activated carbon of Rambutan peel (RPAC) was carried out under different batch equilibrium conditions. The experiment was well-suited for Freundlich adsorption isotherm as well as pseudo-second-order kinetics.

In 2012, Alrozi *et al*. [79] studied the removal of Remazol Brilliant Blue R (RBBR) dye using the nano-structure of Rambutan peel. The batch adsorption conditions were observed to be at pH 2-12 and dosage 0.05-1.2. The equilibrium was well-established by Langmuir adsorption isotherm with q_{max} value 112.69 mg/g. And the batch adsorption was followed by pseudo-second-order kinetics with a good correlation.

Another researcher, Njoku *et al*. (2014) [80], investigated the removal of acid yellow 17 (AY17) using a novel nanosheet of Rambutan peel. To this extent, the adsorbent was prepared by modifying the activated carbon with KOH as a precursor. The adsorption capacity was studied under different batch conditions such as pH, contact time, adsorbent dosage, etc. The experiment followed Langmuir adsorption isotherm and pseudo-second-order kinetics with q_{max} value 215.05 mg/g.

5.3.1. Adsorbent preparation.

Firstly, the Rambutan peel was washed and dried at 378K (24 h) for the removal of moisture. The carbonized Rambutan peels were crushed to the size of 1–2 mm. The biochar was mixed with KOH at a ratio 1:2.9. Distilled water was added to the composite to dissolve the KOH pellets. Then the mixture was dehydrated at 378K (24 h) to remove out the moisture. 0.1 M HCl was added until the pH reached 6.5–7[78].

The collected Rambutan seed materials were cleaned with boiled water and deionized water to remove any adhering dirt. Then it was dried in the oven at 60^{o}C (24 h). Then the carbonized Rambutan peel was ground and sieved to obtain 250–355μm particle size[79].

The RP was rinsed with distilled water and carbonized in the oven at 105 °C (24 h) to remove moisture content. The carbonized sample was crushed to a size of 0.5–1.0 mm. The inert atmosphere was continuously maintained by passing nitrogen (99.99 %) through the system (during the heating (150 cm^3 min^{-1}) and cool-down intervals (100 cm^3 min^{-1}))[80].

5.4. Cucumber peel.

Akkay and Guzel (2014) [81] studied the efficiency of cucumber peel (CP) for the bio-adsorption of methylene blue (MB) dye from wastewater. They also compared the removal of methylene blue (MB) on Parsley stalks (PS) and watermelon seed hull (WSH). The adsorption of MB was inferred in the batch condition of pH (2-10), temperature (293-333K), initial dye concentration (25-450mg/L), ionic strength (0.0-1.0 mol/L NaCl). The adsorption capacity of CP, PS, and WSH was reported to be 111.11,400 and 57.14 mg/g at pH_{zpc} 6.42, 6.26, and 6.83, respectively. The experiment was well-fitted to Langmuir adsorption isotherm followed by pseudo-second-order kinetics for PS and pseudo-first-order kinetics for CP and WSH. In this experiment, the desorption ability and effectiveness of the adsorbent were also enhanced by treating with HCl and H_3PO_4.

5.4.1. Adsorbent preparation.

In this experiment, a nano-structural bio-adsorbent of cucumber peel was prepared. The bio-adsorbents were rinsed with deionized water. Then it was dried at 70^{0}C (24h) for carbonization. The carbonized form was ground to 500mm size and used as a nanocomposite to remove MB dye[81].

5.5. Pomelo peel.

Jayranjan *et al*. (2011)[82] studied the removal of Congo Red (CR) using Pomelo fruit peel as bio-adsorbent. The experiment was carried out using batch adsorption conditions such as pH (5.99-8.73), temperature (30^0-60^0C), and adsorbent dosage of 1.0-3.0 gL^{-1}. The Pomelo peel bio-adsorbent experiment was well-suited for Langmuir adsorption isotherm with an adsorption capacity of 1.08 to 0.75 mg/g.

Furthermore, in 2014, Argun *et al*.[83] investigated the adsorption of reactive blue 114 (RB114) from wastewater using Pomelo nano-porous composite as bio-adsorbent. The batch equilibrium was carried out with conditions such as pH=2, temperature =303 K, and the contact time = 90 min. The experiment was well-explained by Langmuir adsorption isotherm with q_{max} value 16mg/g.

5.5.1. Adsorbent preparation.

The Pomelo peels were washed with distilled water and air-dried in the oven at 40^0C (48h). The carbonized peel was ground up to 0.840m/m in size. The pH of the adsorbent was adjusted by a small amount of 0.1M HCl or NaOH[82].

Collected Pomelo peels were cleaned using distilled water to remove the interference effect of external dirt. The washed peels were cut into tiny pieces up to 0.5–1.0 cm. then it was carbonized (after drying in the sun for 4-5 days) at 60.8^0C (48h). The resulting carbonized form was crushed up to a particle size of 500 mm for the adsorption experiment[83].

5.6. Orange peel.

EI-Said *et al*. (2013) [84]considered orange peel to remove direct red 79 and direct yellow 27 from wastewater. The batch adsorption was carried out by investigating pH, the ratio of solid/liquid, initial dye concentration, and contact time. The experiment followed Freundlich adsorption isotherm and pseudo-second-order kinetics.

Khafuoui *et al*. (2014)[85] investigated the adsorption of MB using orange peel bio-adsorbent. They also studied the temperature dependence on adsorption and inferred that with increasing temperature, adsorption capacity increases. The experiment followed Langmuir adsorption isotherm with q_{max} value 9.74 mg/g and pseudo-second-order kinetics.

Ahmed *et al*. (2012) studied the adsorption of reactive blue 19 (RB19) using modified orange peel. The experiment was carried by reporting various batch equilibrium studies. The experiment was well-established for Freundlich adsorption isotherm and pseudo-first-order kinetics[86].

Table 2. List of isotherm, maximum adsorption capacity, optimum pH/time, and kinetic models for describing the removal of heavy metals on RH-based adsorbent.

Peel-based bio-adsorbent	**Dye Adsorbed**	**Isotherm Model**	**q_{max}(mg/g)**	**Kinetic Model**	**Optimum pH/Time**	**Reference**
Orange Peel	Reactive Blue19	Langmuir, Temkin	45.5	Pseudo First order	4/120 min	Ahmed *et al*. 2012
Modified with NaOH orange peel	Reactive Blue 19	Langmuir, Temkin	25.0	Pseudo First order	4/120 min	Ahmed *et al*. 2012
Orange Peel	Direct Red 79	Langmuir, Freundlich	151.50	Pseudo Second order	3/60 min	Mansour *et al.* 2012

Peel-based bio-adsorbent	Dye Adsorbed	Isotherm Model	q_{max}(mg/g)	Kinetic Model	Optimum pH/Time	Reference
Orange Peel	Direct Yellow 27	Langmuir, Freundlich	153.85	Pseudo Second order	3/60 min	Mansour *et al.* 2012
Potato Peel	Methylene blue	Langmuir	33.55	Pseudo Second order	8/60 min	. Oktem *et al.* 2012
HCL treated Potato Peel	Reactive Black 5	Langmuir	3.61	Pseudo Second order	3/120 min	Samarghandy *et al.* 2011
Banana Peel	Basic Blue 119	-	-	Pseudo Second order	9/60 min	Pishgar *et al.* 2013
Banana Peel Activated Carbon	color from palm oil mill effluent	Redlich-Peterson	135.14	Pseudo Second order	2/30 hour	Mohammed *et al.* 2014
Pomelo Peel	Reactive Blue 114	Langmuir	16.3	Pseudo Second order	2-11/90	Argun *et al.*, 2014
Activated carbon from Rambutan Peel	Malachite Green	Freundlich	329.49	Pseudo Second order	8/2-3 hour	Ahmad, *et al.*, 2011
Cucumber Peel	Methylene Blue	Langmuir	111.11	Pseudo First order	7-10/-	Akkaya, *et al.* 2014

5.6.1. Adsorbent preparation.

Orange peels were collected and washed with distilled water. It was carbonized at 150^{0}C (36h)and sieved to a particle size of 3.35mm[84].

The orange peel was collected, washed with distilled water. It was dried at 105^{0}C (24h) and carbonized at 550^{0}C (2h). The carbonized OP was crushed to form 0.315mm in size[85].

Orange peel was washed and carbonized at 70^{0}C (24h). Then it was modified with 1L NaOH for 24h. After decantation and filtration, the pH was balanced to 7.0 by washing with distilled water[86].

6. Conclusion

In this review literature, the application of agricultural peel wastes as bio-adsorbents for the adsorption of various dyes was discussed. The pH of the solution was affecting the adsorption process very strongly, and the conclusion depends upon the “nature” (basic/ cationic or acid/reactive) of organic dyes and the charge contained by the adsorbents (functional groups and pHpzc). According to the classification of maximum adsorption ability for monolayer, agricultural peels give a high value of $q_{m,}$ showing their greater potential for adsorption. Most of the experimental conditions were well-established by Langmuir adsorption isotherm and Pseudo-second order kinetics. Thermodynamic studies were evaluated and carefully discussed to eliminate possible flaws. This review literature infers that a more detailed and systematic study is needed to decontaminate wastewater using peel-based bio-adsorbent.

7. Future Scope

After cautious contemplations on variously described review objectives for removing carcinogenic dyes contaminants in the past few decades, this systematic review also predicted a small number of research gaps for further exhaustive and comprehensive studies and technological development, which are necessary for current systems. So various recommendations for future scope are discussed below in major cases of review analysis. The appliance of untreated solid bio-wastes as adsorbents can lead to the production of many organic compounds. These organic compounds which are leached in the experimental analysis must be studied carefully; otherwise, it may infer some invalid results. Till now, the adsorption processes are at the step of laboratory-scale batch studies. So furthermore, a study is needed in this area to stretch its extent up to an industrial scale by designing various techniques. Mostly the research methodologies are focused on the adsorptive efficiency of the adsorbent materials. But more study is needed on the sustainable valorization of post-sorption materials, which could be taken as the alternative for chemical products like catalysts, fertilizers, feed additives, etc. A reasonable study on more cost-effectiveness of bio-adsorbent for wastewater management must be carried out for practical use on an industrial scale.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the study's design, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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