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Sustainable Sorbent Materials Obtained from Orange Peel as an Alternative for Water Treatment

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Additional information is available at the end of the chapter

Abstract

The presence of pollutants in water promotes negative impacts on aquatic organisms. Among the methods of wastewater treatment, the use of sorbent materials is one of the most outstanding due to its efficiencies and easy implementation. Orange peels had become value-added products for these purposes. Activated carbon as a sorbent material was prepared using orange peel as a precursor. The resulting material was physicochemically characterized by scanning electron microscope (SEM) and Fourier transform infrared radiation (FTIR); structural changes were identified and related to sorption capacity using a model pollutant. Results of sorption indicated natural dried orange peel which presented a sorption capacity of 149.26 mg/g, while sorbent-activated carbon presented a sorption capacity of 2342.91 mg/g. The recovery of orange peel to obtain potential interest materials provided benefits for wastewater treatment.

Keywords: orange peel, sorbent material, activated carbon, valorization, wastewater treatment

1. Introduction

The industry of agricultural products processing, or agribusiness, is defined as the economic activity that combines the agricultural productive process with the industrial processing to obtain food or semi-processed raw materials. Among the industrialized products are fruits, vegetables, seeds, tubers and pods; some are marketed fresh and others are transformed into nectars, juices, jams, flours, oils, and wines, among others.

After the processing of these products, agroindustrial waste is obtained. Agroindustrial waste is solid or liquid materials generated from the direct consumption of primary products or its industrialization. Those residues are no longer useful for the process that generated them, but they are susceptible to transformation to obtain another product with economic value, of commercial and social interest [1].
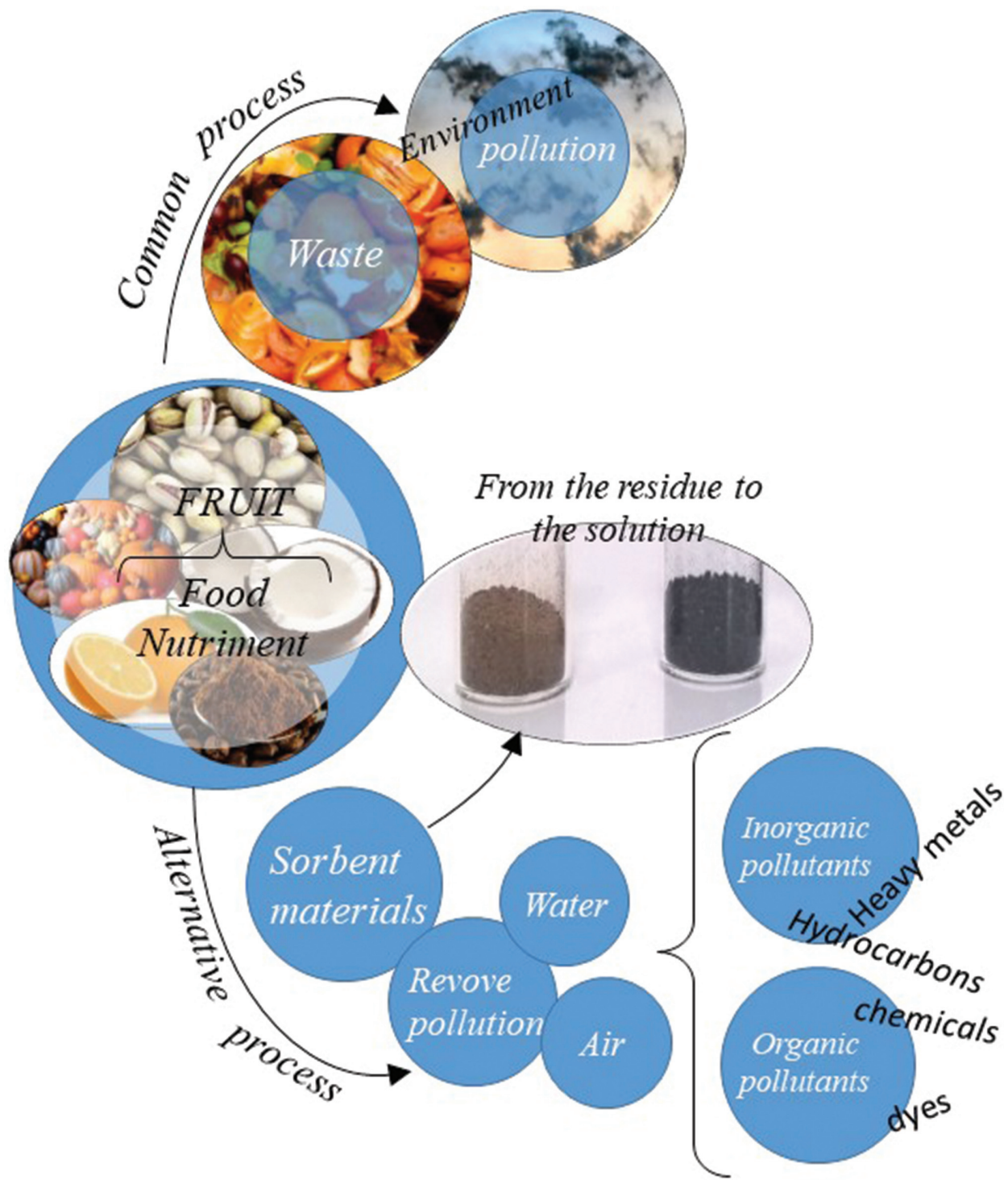

Figure 1. Alternatives for organic residue waste management.

The food industry is characterized by a considerable generation of waste and byproducts. Despite the environmental repercussions that this represents, the amount of agroindustrial waste has increased continuously. Orange peels represent a clear example of agroindustrial waste, which is the result of fruit processing for the production of juices. Due to the large volume of generation and the environmental risk they represent, some investigations have focused on the valorization of this waste through extraction of value-added products or even transformation to other materials.

Valorization of waste is an attractive approach that offers potentially useful alternatives to treat waste, instead of disposal or landfill deposition. In general, agroindustrial waste possesses varied characteristics, which depend on the raw material and the process that generated those residues; however, they share a similar characteristic, that is the organic matter content, constituted by different percentages of cellulose, lignin, hemicellulose, and pectin. The valorization of food waste components could give numerous possibilities for obtaining value-added products [2]. **Figure 1** represents different alternatives for organic residue waste management, on the one hand, the common use of waste that implies it's wasted, and even its contribution to the environment and, on the other hand, some possibilities to use them as materials for environment protection from the use of sorbent materials.

2. Orange fruit

In the orange Mexican harvest, the volume of production has averaged 4.3 million tons in the last 6 years. The national market is the main trade of Mexican orange; an average of 67.53% of the supply of fresh oranges is destined for national production; most of them are designated to homes, restaurants, street vendors, and hotel chains, among others [3, 4].

Since orange has a high production in the country, as well as in the world, and serves as the main raw material for agroindustrial processing, the amount of fruit marketed to the juicing industry has increased [3].

The orange processing industry accommodates a small percentage of 32% in the last years [4]. Since 2004, the percentage of fruit destined to the juice agroindustry increased significantly due to government programs which allowed the recovery of the freight and collection costs of the fruit marketed to the Mexican agroindustry of oranges (**Table 1**). Simple juice and concentrated juice are the main products in the processing of citrus fruits [3].

Production	2011	2012	2013	2014	2015	2016
Mexico	83	151	126	159	165	170
EUA	681	607	476	438	383	355
Brazil	1263	980	1230	1006	848	1222

Table 1. Main producing countries of orange juice, considering 1000 metric tons at 65° BRIX.

The oranges processed in the industry are destined in its majority to the juice export market (**Table 2**). Studies show that Mexico, in comparison with large producing countries, has been increasing the amount of juice produced over the years. Mexico has had a great inclusion in the international market, satisfying the demand of countries such as the United States, Canada, and Japan, among others [3, 4].

Production	2011	2012	2013	2014	2015	2016
Mexico	2011	2012	2013	2014	2015	2016
EUA	79	143	121	153	158	163
Brazil	110	114	113	81	66	65

Table 2. Export data of orange juice, considering 1000 metric tons at 65° BRIX.

3. Orange peels

Orange peels are waste generated mainly by the juicing industry that can cause environmental problems due to its large volume of generation and physicochemical characteristics, such as soil and water pollution. For this reason, the recovery and transformation of orange peels has become a topic of interest for recent investigations; one important alternative is the preparation of sorbent materials.

The waste material of the orange industry is constituted mainly by peels, shells, seeds, and capillary membranes. When leaving the industry, the orange peels have a high level of organic matter and low pH; such indicators demonstrate the potential polluting. Since the composition of orange peels can be transformed to use as raw material for the production of national interest products, in this way, value-added products can be obtained due to the valorization process, and, at the same time, it is possible to reduce the environmental impact [5, 6].

3.1. Physicochemical composition of orange peel

The chemical composition of orange peels, shown in **Table 3**, makes them an attractive source of industrial products. Soluble sugars present in orange peels are composed mostly of sucrose, glucose, and fructose, while organic acids are composed of citric, oxalic, and succinic acid. The fiber is the portion of the shell where the pectin is contained. The pectins contained in the orange fiber are soluble and insoluble in the form of protopectin [5].

However, resent investigations of citrus waste focus on the recovery of a single component, such as d-limonene, pectin, or bioethanol [8].

Recent investigations have shown that orange peel is a potentially valuable resource that can be transformed into value-added products; the most common alternatives have reported the use of this material as livestock feed, source of heat generation, biomethanization, and compost [9, 10].

Parameter	Value
Soluble solids (°Brix)	7.10 ± 1.2
pH	3.93 ± 0.003
Acidity[1]	0.29 ± 0.003
Formaldehyde	34.00 ± 2.4
Moisture (%)	60.5
Ash (%)[2]	3.29 ± 0.19
Fat content (%)[2]	0.2
Protein (%)[2]	1.5
Carbohydrates (%)[2]	89.00 ± 1.1
Pectin (%)[2]	170.00 ± 5
Lignin	3.20 ± 0.4
Essential oils (mL/kg)	1.45 ± 0.16

[1]g of citric acid/100 mL.
[2]db = dry basis.

Table 3. Physicochemical composition of the orange peel [7].

4. Sorbent materials obtained from orange peels

The elaboration of high-quality sorbent materials from agroindustrial waste opens an effective path for the conversion of these residues into high value added products [11].

Activated carbons are commonly used as sorbent materials due to their sorption capacity; those activated carbons are produced from a wide variety of carbon-based materials. Those materials used for the production of activated carbon are carbon-based organic materials, such as coal, lignite, and wood. Although natural coal is the most used precursor, agroindustrial waste is considered as a good alternative; in this way, the activated carbon produced from waste would reduce the demand of forests since wood is also used for this purpose [12].

According to International Union of Pure and Applied Chemistry (IUPAC), an activated carbon is a porous carbonaceous material that has been subjected to gas reaction, sometimes with chemical agents, during or after carbonization process in order to increase its sorption properties.

The use of carbon-based materials goes so far back in history, since charred wood and mineral coal or simply partially volatilized coal materials were already used for similar purposes.

From 1901, several patented methods of activated carbon production were registered. In this way, R. Von Ostrejko patented two methods to produce activated carbon: one based on the carbonization of lignocellulosic materials with metal chlorides (the basis of chemical activation) and the second method based on a gentle gasification of coals with water vapor or carbon dioxide (basis of physical activation) [13].

Nowadays the activated carbons are prepared from a carbon precursor such as lignite, wood, or synthetic precursors, mainly of polymeric type such as resins.

A typical carbonization process produces around 20–30% carbonization yield, where the activating agent is a dehydrating compound, which would increase the amount of active sites, favored by the thermal degradation of the precursor, modifying in this way the porosity of the obtained material. Precursors such as lignocellulosic materials reflect the botanical texture of the precursor [14].

Many of the laboratory uses and industrial applications of activated carbons are based on the high sorption capacity of the material. This capacity depends on the physical properties of the coal, as well as its chemical structure [15].

4.1. Chemical structure of activated carbons

The structure of the activated carbon is considered as a continuous descent in the degree of ordering of the planes in the graphite. However, activated carbon also has a three-dimensional structure of carbon atoms in flat sheets of hexagonal rings. However, unlike graphite, there is no crystallographic order in the third dimension, and the cross-linking of the plates can occur [13].

The spaces between the graphite planes of crystals create the microporous structure, with a high internal surface area [16]. According to IUPAC, pores of activated carbons can be classified into micropores (pore diameter <2 nm), mesoporous (pore diameter between 2 and 50 nm), and macropores (pore diameter >50 nm) [13].

In addition to the porous structure, activated carbons have a chemical structure, since they contain small amounts of heteroatoms. The presence of heteroatoms (O, N, H, S, etc.) attached to the edges of the graphene layers gives rise to a variety of surface functional groups [16], which allow polar substances to be weakly retained on the surface of activated carbon. This is because the carbon atoms located at the edges of the planes have a high available activity, since they are not saturated with carbon atoms and have free electrons [13].

Oxygenated functionalities are the most important due to their surface properties and can also be developed spontaneously through the exposure of the material to the inert atmosphere. Chemisorbed oxygen can only be removed from the surface as CO or CO_2 at temperatures above 120°C. The unsaturated carbon atoms at the edges of the basal crystal planes are associated with high concentrations of mismatched electrons, which play a very important role in the chemisorption process [16].

Oxygenated functional groups are not formed exclusively by the reaction with oxygen; these groups can also be the results of the reaction with other oxidizing gases (O_3, N_2O, CO_2) and oxidizing solutions (HNO_3, H_2O_2). In addition, the electron density π of the basal carbon planes is considered as chemically active [16]. The surface chemistry of activated carbon has an amphoteric nature due to the coexistence of acidic and basic surface groups. An activated carbon is globally acidic or basic depending on the surface concentration of these groups and also on the strength of acidic or basic compounds [13]. Therefore, the oxygenated surface groups are classified into the categories mentioned in the following sections.

4.1.1. Basic surface groups

These groups are formed when the oxidized surface is reduced by an inert or hydrogen atmosphere, at high temperatures. The decomposition of acidic groups creates active sites at the edges of graphene plates, which can attract oxygen during the cooling stage in an inert atmosphere, and after a process of reexposure to air, forming basic functional groups such as chromene and pirona.

4.1.2. Acidic surface groups

These groups are formed when the carbon surface is exposed to oxygen through reactions with oxidizing agents in solutions or the gas phase; this process can be carried out at room temperature or even at high temperatures, these parameters are responsible for the amphoteric characteristic of the activated carbons, which depend on the pH of the aqueous phase.

4.1.3. Hydrogenated groups

Hydrogen atoms are usually present in the surface of activated carbons such as chemisorbed water, as part of other surface groups such as carboxylic acids, phenols, amines, or even directly attached to carbon atoms as part of aromatic or aliphatic structures.

4.1.4. Phosphorus groups

Phosphorus atoms contained in activated carbons generally come from the phosphoric acid used as an activating agent in the preparation stage. Once phosphorus is located in the carbon matrix, it can be stable between 500 and 1000°C; this atom can be found as red phosphorus or chemically bonded as —C—P— or —C—O—P—. Phosphorus-containing species can be formed during carbonization at low temperature ranges [16].

4.1.5. Activated carbon preparation

The physicochemical properties of each activated carbon depend mainly on the source of the starting material, since it essentially determines the structural characteristics of the resulting material [14].

Through the carbonization process, it is possible to obtain a low surface area, as elements such as oxygen and hydrogen are eliminated by decomposition of the starting material in an inert atmosphere, usually nitrogen. The resulting material is formed by unions of elementary graphitic microcrystals, usually plugged by tars and carbonization residues, which notably decrease the sorption capacity. In order to increase the sorption capacity of this coal, it will be necessary to resort to some method that allows eliminating tars, by means of some oxidizing agent as the activating agent [14]. There are two activation processes, called physical activation and chemical activation, described below [13].

4.1.6. Physical activation

This method consists of an oxidation step that is usually carried out in the presence of water vapor, carbon dioxide, or air; the activation treatment is carried out at high temperatures

(>700°C) [15]. These agents are capable of extracting carbon atoms from the porous carbon structure according to the following stoichiometry equations; these equations describe the endothermic reactions. This method of activation is known as physical or thermal activation [14].

$$C + CO_2 \rightarrow 2CO \tag{1}$$

$$C + H_2O \rightarrow CO + H_2 \tag{2}$$

In this process, two differentiated stages can be considered: a first one, in which all the disorganized materials are burned, and a second one, in which the pores that were initially closed or blocked are opened. As a result of that, a new material with a high surface is produced, due to the presence of large porosity [17].

4.1.7. Chemical activation

Chemical activation involves the carbonization of the precursor in the presence of an alkali, hydroxides (KOH, NaOH), or inorganic acids (H_3PO_4, HNO_3, H_2SO_4) [16].

The yield of activated carbon prepared by chemical activation method is usually higher than those activated carbons prepared under physical activations. In order to compare physical and chemical methods, it is possible to emphasize that, while in the physical activation method, the development of pores is mainly promoted by the removal of carbon atoms by a gasification process; in the chemical activation method, the activation agents promote dehydrogenation reactions in the precursor that promote bonds' formation between carbon atoms and also the creation of pores on the surface.

Unlike physical activation, the preparation of activated carbons by chemical activations is carried out in a single stage; the carbonization and activation process are carried out simultaneously. Chemical activation requires lower carbonization temperatures than physical activation. In addition, chemical activation leads to a better formation of the porous structure.

As a result of the carbonization and activation processes, activated carbons with porous characteristics are obtained which are determined by various factors such as starting material (precursor), size of the precursor particles, activating agent, activation temperature, heating rate, temperature and carbonization time, etc. [12, 16].

4.2. Sorption on solid surfaces

The forces that hold a solid bonded to the surface of activated carbons produce a field force around each ion, atom, or molecule. At the surface of the solid, these forces cannot suddenly disappear, and due to these unsaturated and unbalanced forces, the solid has the tendency to attract and retain on its surface molecules and ions of other substances with which it is in contact. Thus, when the surface of the solid is in contact with a gas or a liquid, the concentration of the gas or liquid is always greater in the surface of the solid than in the interior of the gas or liquid phase. The substance adhered to the surface is called sorbate, and the material in which it is sorbed is called sorbent. Depending on the nature of the forces involved, the sorption process is classified into two main types [18]:

4.2.1. Physical sorption

The sorbate is bounded to the surface of the activated carbon by relatively weak Van der Waals forces, identical to the molecular forces of cohesion that are involved in the condensation of vapor on liquids.

4.2.2. Chemical sorption or chemisorption

This process involves electron exchange between the sorbate molecules and the surface of the sorbent, resulting in a chemical reaction. The bond formed between the sorbate and the sorbent is essentially a chemical bond and is stronger than in a physical sorption.

The nature of the forces involved in each of the sorption processes is significantly different. In the physisorption process, no activation energy is required; therefore, the sorption rate is higher even at low temperatures. While chemisorption requires activation energy, the sorption rate is low and depends on the sorption temperature [18].

In the study of new sorbents, it is essential to establish the most appropriate sorption equilibrium correlation, which is indispensable for the reliable prediction of sorption parameters and the quantitative comparison of the sorbent behavior for different sorbent systems, for varied experimental conditions [19].

The most common way to study the behavior of activated carbon is through kinetic and sorption equilibrium models. The first model is related to the study of the kinetics, while the second type is related to the studies of isotherm processes [16].

As a result of activation and carbonization processes, activated carbons with porous characteristics are obtained, which are determined by factors such as starting material, temperatures and carbonization and activation times, heating rate, particle size of the starting material, and so on [12].

In the preparation of an activated carbon, it is necessary to look for the appropriate ratio, as can be deduced from the information earlier, between the transport pores and the sorption pores, that is, it is necessary to achieve a rapid transport of the sorbate to the internal surface and, at the same time, obtain an internal surface sufficiently developed to ensure a high sorbent capacity. In each case, the properties of activated carbon will depend on the raw material, its previous treatment, and activation conditions [17].

Nowadays, a strong demand for activated carbons can be expected in two very important fields in developed countries: atmospheric pollution and wastewater, they are also used for other applications such as elimination of organic matter and toxic substances from industrial gases and drinking water, elimination of chlorine from water, etc. This promising future of activated carbons requires the development of alternative materials that may face the requirement of sorbent materials in the depollution area, especially as regards the search for new raw materials and obtaining very selective activated carbons. Actually, activated carbons with properties like molecular sieve are being prepared in recent years; the object of these materials is the selective sorption of molecules of specific size, a process in which the activated carbons

are displacing the zeolites, used frequently for this purpose. Another important application, which takes advantage of the properties of a molecular sieve of activated carbons, is the retention of nitrogen oxides (NOx) from different sources and sulfur that coals and oils contain and that when heated is transformed into toxic products, such as sulfur dioxide (SO_2), hydrogen sulfide (SH_2), carbon sulfide (S_2C), and so on [17].

Recently, fruit husks as agroindustrial waste have been implemented in the production of activated carbons; investigation of sorption about selective specific size molecules has been done regarding these materials. The use of agroindustrial residues is a new alternative that provides a proposal of integral valorization, taking advantage of the waste abundance and the low cost of the material [17].

Table 4 shows the results of some reports from which activated carbons have been elaborated; elaborating parameters as well as surface areas are shown. It is possible to see surface area values from 200 to 1800 m^2/g; these values are comparable to those reported in literature for lignite of 1300 m^2/g [23], as well as 1853 m^2/g [24]. These values are also comparable to commercial materials: PET activated carbons have 1170 m^2/g [25], Darco KB-B of 1608 m^2/g [26], Fluka 05120 of 1110 m^2/g [26], activated carbon MT40 of 528 m^2/g [27], activated carbon BW of 300 m^2/g [27], and Fluka 03866 of 179 m^2/g [26].

4.3. Activated carbons obtained from orange peels

Some studies have been done for the preparation of activated carbon from orange peel, **Table 5** shows some reports and it is possible to appreciate the different activating agents used, temperature, and time of carbonization, as well as the surface area reported for those materials.

Some studies for the elaboration of activated carbons from orange peel are described below; these materials have been used for the removal of metals, dyes, among others. These reports indicate sorption capacities from 7.9 to 982 mg/g.

Quijano and Mejía [31] elaborated activated carbons from the residue obtained after pectin extraction from orange peels; they analyzed the effect of time and carbonization temperature on the carbonization percentage, using a 2^2 factorial design. They determined that temperature has significant influence on the carbonization yield; the optimum condition was obtained at 400°C and 0.5 h for a 34.8% yield and a sorption capacity of methylene blue of 149.4 mg/g.

Annadurai et al. [32] prepared low-cost sorbents from orange peels for the sorption of several dyes in aqueous solution. The concentrations of dye and pH were varied and after the study they determined that sorption capacities decrease as follows: methyl orange > methylene blue > rhodamine B > red congo > methyl violet > black amino 10B, from 20.5 to 7.9 mg/g.

Khaled et al. [33, 34], in different studies, evaluated different conditions to obtain activated carbon; they used H_2SO_4 as an activating agent; a solution of this acid was in contact with the material for 96 h at 105°C; after that, the sample was carbonized at 120°C and 180°C. Obtained activated carbons were evaluated using direct blue dye-106 and direct yellow-12, for which sorption capacities were 107.5 and 75.8 mg/g, respectively.

Material[a]	Particle size (mm)	Temperature (°C)	Time (h)	Activation	Agent	Temperature (°C)	Time (h)	Surface area (m^2/g)	Pore volume (cm^3/g)	Pore size (nm)	Sorption capacity (mg/g)	Reference
Grapefruit	—	450	2	CH	KOH	450, 800	1.5, 2.5	1892.1	1.095	1.92	680	[20]
Banana	—	1000	8		ZnCl	—	—	1650	1.26	3.01	—	[11]
Yaca	—	350	0.5		H_3PO_4	350	0.5	5	—	—	—	[12]
						450	0.5	1033	0.664	1.7	—	
						550	0.5	1260	0.733	2	—	
Almond	1–5	300	1	P	CO_2	—	1	322	19.5	8–12	288.5	[21]
		700	1			—	1	385	16.92	10		
		1200	1			—	1	342	15.5	15–25		
Orange		300	1			—	1	225.6	14.5	7–14	166.7	
		700	1			—	1	248	15	10		
		1200	1			—	1	240	13.5	12–14		
Rice	6×10^{-3}	650	1	CH	NaOH	—	—	253.4	0.17	2.62	0.17	[22]

[a]Materials were considered as the husks of the mentioned fruits. CH: chemical activation and P: physical activation.

Table 4. Organic waste used for the production of activated carbon.

Activation type	Agent	Atmosphere	Temperature (°C)	Carbonization time (h)	Time of mixing material-agent	Surface area (m²/g)	Reference
Physical	CO_2	Nitrogen	700	1 h	—	248	[21]
Chemical	H_3PO_4	Autogenerated	850	1 h	—	1090	[28]
Chemical	H_3PO_4	Nitrogen	450	2 h	2 h	1203	[29]
Chemical	ZnCl	Nitrogen	550	1 h	36 h	1477	[30]

Table 5. Preparation of activated carbon using orange peels.

Fernandez et al. [35] studied the effect of H_3PO_4 as an activating agent to prepare activated carbon; the carbonization procedure was carried out at 475°C in 0.5 h. Authors report surface areas of 1090 m²/g for the obtained materials. Methylene blue and rhodamine B were used to characterize sorption capacities and the values obtained were 320 and 522 mg/g, respectively.

Li et al. [20], studied the effect of KOH as an activating agent and the process of carbonization in an inert atmosphere, at 800°C; the activated carbon obtained had a surface area greater than 1800 m²/g, and a sorption capacity of 680 m/g was obtained using methyl orange as a model pollutant.

Ashtaputrey and Ashtaputrey [36] prepared activated carbon from orange peels by chemical activation using HCl; they also varied the carbonization temperature from 300 to 500°C for 1 h. They analyzed the sorption capacity of iodine, and finally, they concluded that a carbonization temperature of 300°C promotes a sorption capacity of up to 983 mg/g.

5. Preparation and characterization of orange peel-activated carbon

Our results of the preparation of activated carbon from orange peel let us characterize the material. This material was prepared under the following conditions: activation agent, H3PO4, carbonization temperature of 400°C, and carbonization time of 1 h. Methyl orange was used as
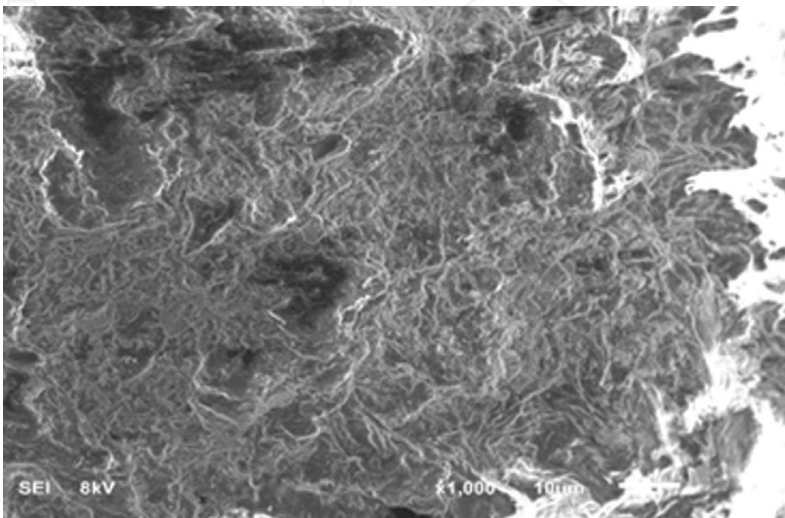

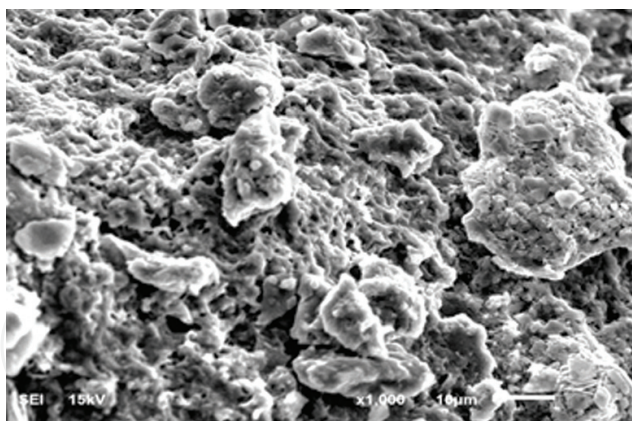Figure 2. SEM micrography of orange peel at 1000×.

Figure 3. SEM micrography of activated carbon obtained from orange peel at 1000×.

the model pollutant in order to analyze sorption capacity of 2342.91 mg/g. This result was compared to dried orange peel that showed a sorption capacity of 149.26 mg/g.

Figures 2 and **3** show a comparison of the surface morphology of orange peel and activated carbon obtained from orange peel. It can be seen that after the carbonization treatment the surface was modified, given by the thermal process and by the activation agent. The carbonization process promotes the formation of new surface sites.

On the other hand, Fourier Transform Infrared Spectroscopy (FTIR) was used to identify the surface groups of activated carbon obtained from orange peel. **Figure 4** shows the comparison of orange peel and activated carbon. It is possible to appreciate that the intensity of some signals decreases after carbonization process. **Table 6** identifies functional groups associated with the FTIR spectra of **Figure 4**.
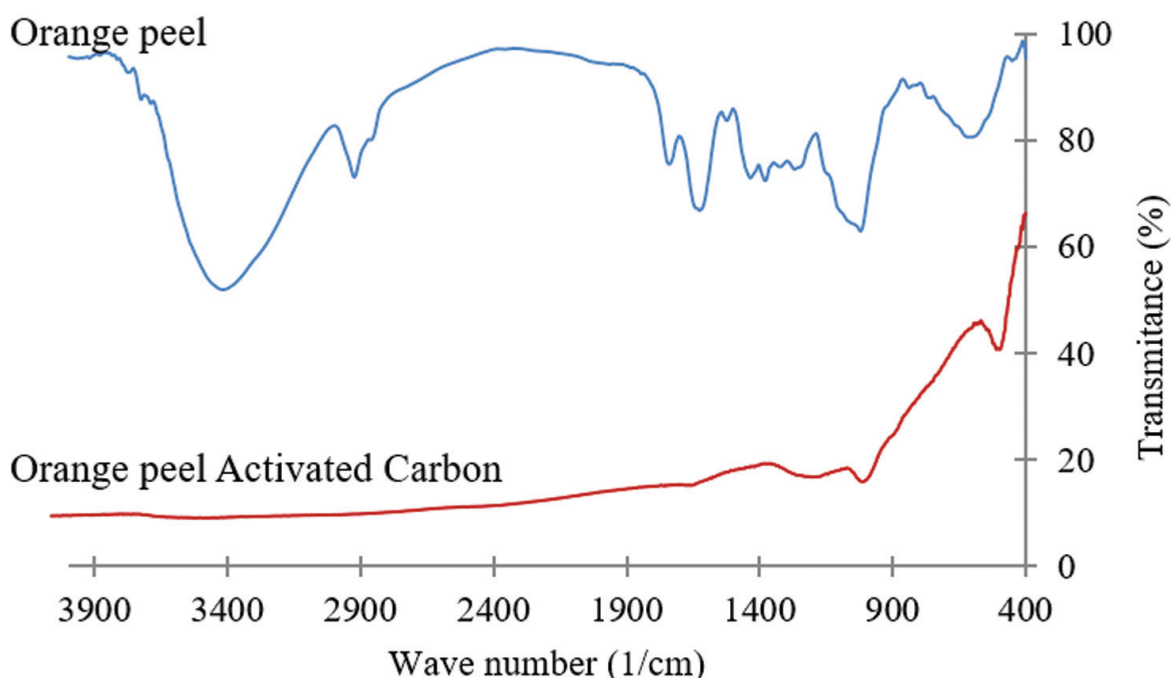

Figure 4. Comparison of the FTIR spectrum of orange peel and orange peel-activated carbon.

Wave number (1/cm)	Functional group
3422.8	—OH
2925.62	C—H
1741.27	C=O
1626.83	C=C
1435.53	—CH$_2$ —CH$_3$ O—CH$_3$
1379.24	C—O
1070	P—O
1020.77	C—O—H C—O—R
596.19	C—H

Table 6. Functional groups of FTIR spectrum.

Activated carbon prepared from orange peel has higher sorption capacity compared to the precursor (dried orange peel), which means that the transformation of a residence is a great advantage. The resulting material possesses the ability to be used for the treatment of water contaminated with colorants as an alternative principal.

However, it is necessary to continue the study of this material for the removal of heavy metals, organochloride compounds, and so on in order to provide greater alternatives for better care for the environment.

6. Sustainable materials

The concept of sustainability arises in 1987, when the World Commission on Environment and Development from the United Nations published a report titled "Our common future" [37], that is focused on the idea of sustainability or sustainable development.

Sustainability is a process that aims to find a balance between the environment and the use of natural resources. Humanity has degraded natural resources in such a way that currently it is necessary to conscientiously procure and plan its consumption to guarantee the existence to future generations.

That is why the use of innovative alternatives for the development of materials allows us to offer better conditions for the care of the environment. Therefore, if a strategy is generated to collect, characterize, and even take advantage of waste materials that currently contribute to the contamination of the environment, in the future, people tend to think of integral use of consumption products. It represents a change in how our society thinks about the use of natural resources and environmental protection.

This is the case of agroindustrial waste, since they have a physicochemical composition that can be used for different purposes, both for the recovery of different raw materials and for their transformation into sustainable materials useful to reduce water pollution.

7. Conclusion

Orange peels are good alternatives as raw materials for the production of activated carbons. Activated carbons obtained from this precursor have high surface areas and high sorption capacities, compared to commercial materials used for water treatment.

Orange peel-activated carbon is a sustainable alternative to replace activated carbons obtained from lignite materials that come from non-renewable sources.

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