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Research Article

THE POTENTIAL OF THE CIRCULAR ECONOMY OF ORGANIC WASTE STREAMS FROM PINE BARK

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Abstract

The process is presented in the management of solid waste of pine bark, which includes the recovery to obtain various products such as: compost, bio-solvents, ethanol and pellets. It is estimated that the conifers to which the pine belongs reach a volume of more than 230 million cubic meters and in the northern hemisphere, its surface is estimated at more than 4 billion hectares, of all this volume 10% comprises the bark. Likewise, it is a species of commercial interest due to its potential uses, therefore the technologies used to treat this organic waste is the chemical / biological transformation of sawdust and pine bark that accumulate in sawmills as waste from the production of sawn wood, and the obtaining of useful products to society such as compost and animal feed, among others, while contributing to environmental sanitation by eliminating this waste. Sawdust, chips, sprouts, among others, are stored in large hills or burned in boilers, without having a greater added value or achieving greater energy efficiency (Soto and Núñez, 2008). Although it forms a high volume as waste its low calorific value, due to its low density, is not included in the generation of energy, however due to its physical-chemical characteristics, according to the information analyzed, there are several studies that demonstrate its effectiveness in the use as substrate, compost, fertilizer, bio-absorbents and even the production of bio ethanol. There are several species used in the tests, of which *P.radiata, P. caribaea and P. tadea* stand out, however, studies also indicate that although they have similar characteristics, it is necessary to know their chemical composition before being applied as a substrate or as compost. In the production of compost, its efficacy with other compounds proved to be May. In the present study, the characteristics of pine bark and its valuation in three types of products were evaluated.

Keywords: Pine, Solids, Energy, Substrate, Compost.

INTRODUCTION

Solid waste is those substances, products or by-products, in a solid or semi-solid state, that its generator disposes of (MINAM, 2015). In Peru, forestry activity is an important generator of waste, since its main usable product is wood, mainly discarding the bark of various species, due to the low demand for the product in the vicinity of the exploitation or transformation centers (FAO, 2014). In addition to the natural forest, in the country, plantations are sources of forest raw material, the largest forest area in the country is covered by exotic species such as pine and eucalyptus, the first with a high potential for generating bark as waste solids from the forestry industry (ADEX, 2019). The generation of forest residues adds more than in this regard, solid residues are classified according to their generating source and according to their characteristics; In the case of pine bark, its generating source is the wood transformation industry or timber extraction, therefore, it is classified as industrial solid waste, generated by the activity of production, as well as by its characteristics. they are classified as organic waste (Jakubus and Graczyk, 2019). According to FAO 2021, more than 240 million cubic meters of forest residues are generated worldwide, of which 10% is generated in South America and the rest mainly between Europe, Asia and North America, these data indicate the enormous potential that have forest residues, mainly coniferous residues that are the largest part of production. The barks are a class of woody forest residues obtained as material removed by debarking the stem in primary transformation plants (FAO, 2014; SERFOR, 2021) ; It constitutes a residue in those sawmills that have a debarker, but frequently the wood is sawn with bark.

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However, where bark is generated as waste, it accumulates in the form of piles, out in the open, contaminating the environment. Chemical substances accumulate in these deposits, which, when properly treated, can be transformed into useful products (Rivas Flórez, 2010); globally, however, more than 95% of the total volume of pine residues, coming from plantations, is profitably recycled. Most of the pine waste is used for power generation purposes (Jakubus and Graczyk, 2019) compost, ethanol or products such as pellets. The regulatory framework for the forestry sector in Peru is framed in the Forestry and Wildlife Law Law 29763 and Supreme Decree No. 020-2015-MINAGRI, which approves the Regulations for the Management of Forest Plantations and Agro forestry Systems In this sense, the Forestry and Wildlife Service - SERFOR and the Forestry and Wildlife Administrations - ARFFS promote the use of forest residues resulting from the use of forest plantations, agroforestry systems and transformation plants that establish mechanisms to promote its use (El Peruano, 2021 and MINAM, 2015), likewise, the strategy for the promotion of commercial forest plantations 2021-2050 (SERFOR, 2021) was recently approved. In Peru, there are currently approximately 60,000 ha of plantations with 05 species of the genus Pinus, commonly known as "pine", it is estimated that by the year 2030 the area of plantations should increase to 250,000 ha, which is the projected demand (ADEX, 2019; SERFOR, 2021), installing "pine" plantations, an exotic species, introduced in Peru since the 1960s, with the purpose of afforesting and reforesting the area, mainly in the mountains of Peru, where the Wood-derived products were in high demand, mainly firewood and poles, and thus also reduce the pressure that the population had been putting on native forests (ADEX, 2019). Currently, the largest area of pine plantations is found in the regions of Cajamarca, Cusco and Apurimac. Cajamarca has more than

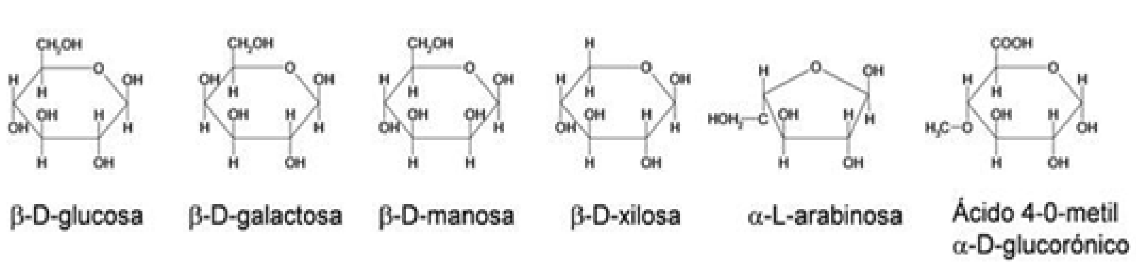
15,000 ha of Pinus radiata and Pinus Pátula plantations, in growth and production, with ages ranging from 5 to 25 years (SERFOR, 2021). This forest residue can be differentiated according to its use phase and it is because in its extraction phase residues such as branches, bark, stump-roots, leaves, fruits are generated and in the transformation phase, the generated residues can be mainly: bark, edging, non-commercial wood and sawdust (Mellouk *et al.,* 2016a). Worldwide, in recent years, the use of forest residues, mainly pine bark, has been gaining importance for use as substrates or growth media; although most of the wood waste is used for energy purposes, unfortunately, the bark has a low energy value (21 MJ/kg) and is not a very attractive material for the wood industry (Jakubus and Graczyk, 2019). ; Therefore, due to the large volume that is produced, various studies have been carried out since the 1990s to determine the physical and chemical properties of pine bark for its evaluation mainly as a substrate (compost), fertilizers, biol, for various agricultural, forestry crops, for restoration, remediation, reclamation, bioadsorption of metals, production of pellets, bioethanol, etc. (V.Arrieta and V. Terés, 1993, (Cutillas-Barreiro *et al.,* 2014; Mellouk *et al.,* 2016b; Montes-Atenas and Schroeder, 2015; Núñez-Delgado *et al.,* 2017; Randall *et al.,* 1974; Rivas Flórez, 2010). Obtaining the Caribbean pine substrate is carried out by mechanical debarking of felled trees, using a debarking machine with a diameter cutting capacity of 8-12 cm/post, with a debarking capacity between 400 - 500 posts/day (ECASO model JE PP450 N: 0707. 1997, 12 horsepower). Subsequently, the bark is ground or crushed to homogenize the material, with a particle size (sieve) between 7 - 8 mm (a PD-S Pinheiro hammer crusher was used. 7.5 horsepower motor) (Rivas Flórez, 2010).

Pine bark is characterized by being a material with a high aeration capacity, therefore being suitable for crops that are sensitive to root asphyxia; Likewise, the percentage of easily available water in the pine bark is low, a characteristic that decisively conditions irrigation management; the slightly acid character of the bark is not a limiting factor for most crops. The rest of the chemical characteristics are adequate for its use mainly as a culture substrate. V. Arrieta and V. Teres, 1993.

In general, in the case of the chemical components present in pines and conifers, carbohydrates make up most of the biomass of the plant stem (bark, wood, branches and leaves); compounds that cannot be separated without affecting the physical structure of the cell wall. The carbohydrate fraction, holocellulose (68 to 90%). Figure 1 shows the polysaccharides composed of more than one type of monomer linked by β bonds (1-4) that form a branched linear chain together with cellulose and, in turn, are part of the network of microfibrils that make up the cell wall of the tissues (Escoto García *et al.,* n.d.).

After polysaccharides, lignin is the most abundant organic polymer in the plant world (15 to 35%), it acts as an interfibrillar cement, responsible for gluing and joining, provides rigidity to the cell wall and resistance to tissues, preventing the attack of microorganisms and the penetration of destructive enzymes. The fraction of extractables in pines is composed of resin acids (60 - 75%), fatty acids (15 - 20%) and a volatile or turpentine fraction (5 - 10). Pine bark is rich in phenolic compounds, particularly condensed tannins, which are polyphenols present in most plants. Thanks to its chemical makeup, the bark could be used in a variety of fields, from pharmaceuticals and bioactive compounds to green polymers and biobased materials. Unfortunately, the concentration of these compounds can negatively influence vegetation when raw bark is used as fertilizer. For this reason, composting of the bark is recommended before its application, since its compounds such as lignin (approx. 33%) and cellulose (approx. 25%), are poorly mineralizable and can be broken down by fungal enzymes (Jakubus and Graczyk, 2019).

Coarse pine bark compost had the highest percentage of PA aeration porosity. Pine bark composts could be aerating components in a substrate formulation. The pH values obtained were found between 4.7 to 8.7 and EC between 0.09 to 5.55 dS m-1 (Barbaro *et al.,* 2019). Composting has been presented as an environmentally friendly alternative applied to the management and recycling of organic waste; In this process, organic matter is stabilized through aerobic decomposition based on microbiological activity, and the main products of its transformation include fully mineralized compounds such as CO2, NH4, H2 O, and humified organic matter (Jakubus and Graczyk, 2019; Rivas Flórez, 2010). However, it is important to recognize that composted pine bark presents highly variable characteristics, depending on the degree of decomposition and the size and distribution of the particles. Its use is recommended after a high degree of composting; fresh material has a high carbon:nitrogen (C:N) ratio and may contain toxic substances for plants, such as phenols, resins and tannins (Oberpaur *et al.,* 2010). Pine bark could also be an excellent biosorbent with the potential to increase the retention of heavy metals in contaminated media, especially in countries with relevant forestry production; However, although world statistics for wood production are available, those for bark are almost non-existent, despite its importance, since globally, it is estimated that approximately 1900 million m3 of wood is consumed each year (approximately 10 % of this amount is bark); and, according to the FAO (2020), annual wood consumption is expected to increase to 3 billion m3 by 2050 (Cutillas-Barreiro *et al.,* 2014). Regarding the production of ethanol from lignocellulose biomass, it is an option to reduce society's dependence on the use of fossil fuels such as oil and reduce environmental pollution. Mellouk *et al.,* 2016b argues.



Author: Chapa, 2011.

Figure 1. Fraction of carbohydrates

Lignocellulosic waste materials represent an interesting source of chemical products due to their abundant and renewable origin, as well as the qualities found in their components, making them a promising alternative resource. The metal-retaining capacity of pine bark is attributed to its high organic matter content (91.4% on a dry weight basis), which immobilizes metals through adsorption and complexation with carboxyl, hydroxyl, or other active functional groups, (Cancelo-González *et al.,* 2017). Among all types of compost available on the market, pine bark compost (PBC) is of interest due to its high permeability, reactivity and adsorbent capacity, together with its low metal content and affordable cost. In addition, its availability is high, because the bark of the Pinus species is one of the most abundant forest debris, mainly in the northern hemisphere, and bark composting is easily carried out in low-tech facilities with low environmental impact (Cancel-González *et al.,* 2017; Rivas Flórez, 2010).

VALORIZATION

A. Pine bark for use as a substrate for crops

Sawdust and pine bark are waste from the forestry industry that can be used as substrates (Sánchez-Córdova *et al.,* 2008). Lignocellulosic waste is often composted or belongs to compost mass components. Its utility value is determined by a series of physical-chemical factors (Bohacz, 2018). The bark of various species of pine can be used to make compost through aerobic decomposition processes from microorganisms existing in the same bark, under favorable conditions of temperature and relative humidity (Aries and Lignum, 1997). The pine substrate presents appropriate physical-chemical characteristics compared to the properties of the ideal substrate. The analysis carried out on the pine bark used indicates that it contains 0.24 nitrogen; potassium 0.58; calcium 1.29; Magnesium 0.14 (Rivas, 2010 and Bohacz, 2018) determined that the pine bark composts tested were not phytotoxic, because they did not inhibit the root growth of the test plant, Lepidium sativum L., and demonstrated a very good phytosanitary status. , especially the one that contained more hard grade lignocellulosic residues. They were also safe from a sanitary point of view, because they did not contain E. coli bacteria or parasitic eggs. Furthermore, the physical properties (field water capacity, bulk density, total porosity) of the composts were well aerated, which in turn provided a light product, which is important in production. Another form of composting is the use of pine bark with fish, which allows a significant reduction in the volume of by-products and fishing residues. Compost stability and maturity are essential for its successful application, particularly for compost used in agriculture. The compost used in the experiment was prepared from (w/w) 80% fish waste and 20% pine bark (10-15 mm chip size) as bulking agent and carbon source. The experiments performed indicate that the compost product is not phytotoxic, is mature, stable and suitable for use in agriculture, its use increased the yield of ice lettuce (L. sativa L.) leaves and had a significant effect on increasing of the content of nitrogen, phosphorus, potassium, sodium, calcium and magnesium in the leaves of the test plant. (Radziemska *et al.,* 2019).

B. Pine bark for use as a bioabsorbent

Pine bark could be an interesting biosorbent to be used as a low-cost alternative to the more expensive technologies traditionally used to retain heavy metals in contaminated soils and waters. In addition, this use would facilitate an environmentally sound recycling for a by-product (Cutillas-Barreiro *et al.,* 2016). Given the importance of the volume of bark generated by the forestry industry, intensive research is currently being carried out to develop new options for reusing this residue. Lignocellulosic residues such as pine bark have been proposed for use as biosorbents in the removal of metals and metalloids from contaminated water and wastewater, because the polyphenolic polyhydroxy groups present in tannin and lignin have a high potential sorption capacity. by ionic exchange and chelating processes (Cutillas-Barreiro *et al.,* 2016; Montes-Atenas *et al.,* 2014).

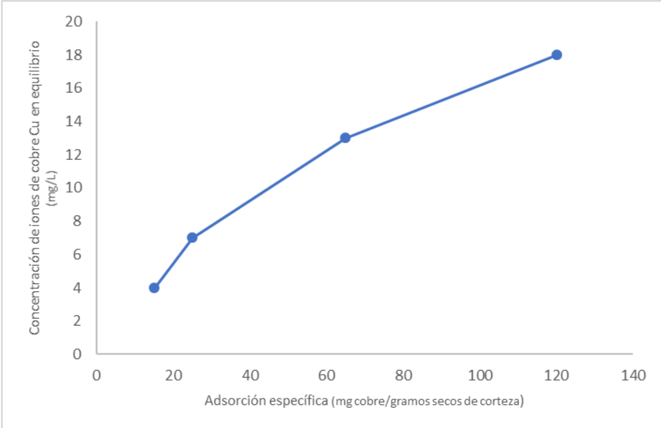


Figure 2. Copper (II) ion adsorption isotherm on washed pine bark at pH 5, 10 g/L pulp density

Figure 2 presents the equilibrium concentration in solution and the specific adsorption of copper (II) ions using washed pine bark. Some authors state that one of the promising sorbents is pine bark, which, as raw material, has practically zero cost. Since the bark releases coloring agents, polyphenols during contact with water, it is proposed to pre-treat the bark with solutions of acids or their mixture with formaldehyde for surface polymerization of bark particles. the convenience of treating pine bark with urea solution to improve the chemical stability of the bark and improve its adsorption properties with respect to heavy metals (Khokhotva, 2010). In his tests, the researcher used Pinus sylvestris pine bark containing 90% of the bark itself and 10% of the wood fibers having a particle size of 0.05–4 mm, applied with a solution of 5% urea at room temperature as a result showed that pine bark inhibits cation exchange processes and prevents acidification of treated water; forming nitrogen-containing groups on the surface of the cortex due to the interaction of urea with carbonyl and carboxyl groups that contributes to the formation of additional metal-binding active centers (Khokhotva, 2010).

Research is currently being carried out that includes new technologies for the absorption of heavy metals that include the use of organic products such as pine bark, since lignocellulosic waste materials represent an interesting source of chemical products. Their abundant and renewable origin as well as the qualities found in their components make them a promising alternative resource (Maimoonaa *et al.,* 2011).(Mellouk *et al.,* 2016). The sustainability of the wood processing industry can be improved through the use of by-products, the adoption of new technologies that maximize the profitability of the process, such as the use of microwave extraction for the extraction of solvents from the bark of forest species such as pine (Mellouk *et al.,* 2016).

C. Biol from Forest Biomass Residues (Pine)

Biol is a source of phytoregulators resulting from the anaerobic decomposition of organic waste that can be obtained by two methods: As a liquid affluent resulting from anaerobic decomposition or biodigestion of organic matter that appears as liquid residue resulting from the methanogenic fermentation of waste organic, generally in a biodigester whose main objective is the production of biogas (Cordero, 2010). According to Cordero *et al.,* 2010, they argue that the specific preparation, generally artisanal, whose main purpose is to obtain this fertilizer, a biostimulant, rich in nutrients, and can be obtained by filtering by separating the liquid part from the solid part. According to Cordero *et al.,* 2010 determines that in the case of the production of biol (as a by-product) from the biodigester to produce biogas, the proportions of solid-liquid matter established must be respected so as not to harm biogas production, in addition to The import of certain solid matter could delay the process of obtaining biogas, so in many cases biol is a by-product of the biodigester of waste (pine sawdust, animal manure (bovine, guinea pig, pig) with a portion of water, all this in order to achieve a good functioning of the digester, taking care of the quality of raw material or biomass, the digestion temperature, the acidity and the anaerobic conditions of the digester that occurs when it is hermetically closed.

Conclusion

The main energy source for biol fermentation, it favors the multiplication of microbiological activity, it feeds the microorganism that decomposes the different biol materials, it is rich in potassium, calcium and magnesium, it also contains micronutrients, mainly boron, potassium, magnesium and calcium (Lamb *et al.,* 2010). The analyzed evaluations allow us to point out that the pine bark is very suitable for the formulation of substrates for cultivation and is widely used in the production of humus, it can also be used in soil rehabilitation and land restoration. Among the benefits of pine bark we can find that it can be used in various fields from substrates for agricultural production, pharmaceuticals and bioactives to green polymers and bio-based materials. The use as a substrate and compost has been well studied, however, research continues in relation to increasing its efficiency with the use of other organic products, in such a way as to contribute to the reduction of organic waste and generate recovery. Pine bark could also be an excellent biosorbent with the potential to increase the retention of heavy metals in contaminated media, especially in countries with relevant forestry production; however, although world production statistics for wood are available, those for bark are almost non-existent, despite its importance since it is global. Work is being done on the inclusion of new technologies, which would increase its efficiency as a substrate and as a bioabsorbent and even as a solvent for various products that generate pollution. In the case of Bioethanol, we conclude that the pretreatment with alkaline sulfite/anthraquinone is a more effective method in the removal of lignin and hemicelluloses from radiata pine chips than the pretreatment with acid sulfite, allowing better saccharification in enzymatic hydrolysis. Regarding the production of ethanol from lignocellulose biomass, it is an option to reduce society's dependence on the use of fossil fuels such as oil and reduce environmental pollution. More research on processing and special attention to economic feasibility are required, and this is due to the fact that it is necessary to make full use of other by-products such as lignin and proteins contained in the pine bark, as well as other co-products generated during the process. It is also necessary to establish strict policies and regulations regarding the use of forest residues in a sustainable manner, to avoid overexploitation of this resource and deforestation, as well as base the production of bioenergy on various sources of biomass in synergy with forest residues such as the case of Pine and wood.

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