

CASHEW TREE TANNINS: A BIO-RENEWABLE SOURCE FOR A NEW GENERATION OF WOOD ADHESIVES: A LITERATURE REVIEW

TANINOS DO CAJUEIRO: FONTE BIO-RENOVÁVEL PARA UMA NOVA GERAÇÃO DE ADESIVOS PARA MADEIRA: REVISÃO DE LITERATURA

TANINOS DEL ANACARDO: FUENTE BIORRENOVABLE PARA UNA NUEVA GENERACIÓN DE ADESIVOS PARA MADERA: REVISIÓN DE LA LITERATURA



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ABSTRACT

Tannins are natural polymers of plant origin distributed in leaves, bark, fruits, and other plant tissues, characterized by their high chemical reactivity. This characteristic is associated with their structure rich in phenolic groups, which gives tannins functional properties relevant for various industrial applications. Among the different plant sources, tannins extracted from the cashew tree (*Anacardium occidentale* L.) have been gaining prominence as a promising bio-renewable alternative for the development of sustainable materials, especially wood adhesives. Cashew tannins have a high concentration of polyphenols, which favors condensation and crosslinking reactions, essential for the formation of polymeric networks with good mechanical resistance and stability. These properties allow their use as partial or total substitutes for synthetic adhesives based on petroleum derivatives, such as phenolics and urea-formaldehyde, contributing to the reduction of dependence on fossil resources and the emission of toxic compounds. From an environmental and socioeconomic perspective, the use of cashew tannins promotes the valorization of by-products from the cashew supply chain, traditionally exploited mainly for the production of cashew nuts and juice. This approach encourages the integral use of biomass, reduces waste, and generates new opportunities for the development of higher value-added products. Thus, the application of these tannins in ecological adhesives fits within the context of the bioeconomy, aligning technical efficiency, environmental sustainability, and conservation of natural resources, in addition to reinforcing the potential of renewable raw materials in the innovation of materials for the timber industry.

Keywords: Cashew. Tannin-Urea-Formaldehyde. Bioeconomy.

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RESUMO

Os taninos são polímeros naturais de origem vegetal distribuídos em folhas, cascas, frutos e outros tecidos das plantas, caracterizando-se por sua elevada reatividade química. Essa característica está associada à sua estrutura rica em grupos fenólicos, que confere aos taninos propriedades funcionais relevantes para diversas aplicações industriais. Entre as diferentes fontes vegetais, os taninos extraídos do cajueiro (*Anacardium occidentale* L.) vêm ganhando destaque por constituírem uma alternativa bio-renovável promissora para o desenvolvimento de materiais sustentáveis, em especial adesivos para madeira. Os taninos do cajueiro apresentam elevada concentração de polifenóis, o que favorece reações de condensação e reticulação, essenciais para a formação de redes poliméricas com boa resistência mecânica e estabilidade. Essas propriedades permitem sua utilização como substitutos parciais ou totais de adesivos sintéticos à base de derivados do petróleo, como os fenólicos e ureia-formaldeído, contribuindo para a redução da dependência de recursos fósseis e da emissão de compostos tóxicos. Sob a perspectiva ambiental e socioeconômica, o aproveitamento dos taninos do cajueiro promove a valorização de subprodutos da cadeia do caju, tradicionalmente explorada principalmente para a produção de castanhas e suco. Essa abordagem incentiva o uso integral da biomassa, reduz resíduos e gera novas oportunidades para o desenvolvimento de produtos de maior valor agregado. Assim, a aplicação desses taninos em adesivos ecológicos insere-se no contexto da bioeconomia, alinhando eficiência técnica, sustentabilidade ambiental e conservação dos recursos naturais, além de reforçar o potencial de matérias-primas renováveis na inovação de materiais para a indústria madeireira.

Palavras-chave: Caju. Tanino-Ureia-Formaldeído. Bioeconomia.

RESUMEN

Los taninos son polímeros naturales de origen vegetal distribuidos en hojas, cortezas, frutos y otros tejidos de las plantas, caracterizándose por su elevada reactividad química. Esta característica está asociada a su estructura rica en grupos fenólicos, lo que confiere a los taninos propiedades funcionales relevantes para diversas aplicaciones industriales. Entre las diferentes fuentes vegetales, los taninos extraídos del anacardo (*Anacardium occidentale* L.) han adquirido relevancia como una alternativa biorrenovable prometedora para el desarrollo de materiales sostenibles, especialmente adhesivos para madera. Los taninos del anacardo presentan una alta concentración de polifenoles, lo que favorece reacciones de condensación y reticulación, esenciales para la formación de redes poliméricas con buena resistencia mecánica y estabilidad. Estas propiedades permiten su uso como sustitutos parciales o totales de adhesivos sintéticos derivados del petróleo, como los fenólicos y los de urea-formaldehído, contribuyendo a la reducción de la dependencia de recursos fósiles y de la emisión de compuestos tóxicos. Desde una perspectiva ambiental y socioeconómica, el aprovechamiento de los taninos del anacardo promueve la valorización de subproductos de la cadena productiva del anacardo, tradicionalmente explotada principalmente para la producción de nueces y jugos. Este enfoque fomenta el uso integral de la biomasa, reduce residuos y genera nuevas oportunidades para el desarrollo de productos con mayor valor agregado. De este modo, la aplicación de estos taninos en adhesivos ecológicos se inserta en el contexto de la bioeconomía, alineando eficiencia técnica, sostenibilidad ambiental y conservación de los recursos naturales, además de reforzar el potencial de las materias primas renovables en la innovación de materiales para la industria maderera.

Palabras clave: Anacardo. Tanino–Urea–Formaldehído. Bioeconomía.

1 INTRODUCTION

Environmental concerns have encouraged the development of sustainable products to reduce the use of fossil resources and formaldehyde, promoting sustainability in the production of wood panels, which are made from the reconstitution of sheets, battens, particles or fibers joined by adhesives (Iwakiri; Trianoski, 2020). The adhesives most commonly used in the production of wood panels, such as phenol-formaldehyde and urea-formaldehyde, offer good mechanical performance and ease of use, but they contain formaldehyde, a toxic and potentially carcinogenic substance, and are derived from petroleum, making bonding one of the most expensive steps in the manufacture of these panels.

Seeking alternatives for the syntheses of adhesives, aiming at the use of renewable raw material, tannins are a favorable option (Luckeneder et al., 2016). In addition to applications in the production of adhesives and anticorrosives in the wood industry, tannins can also act in the absorption of minerals, precipitation of proteins, production of iron-gas paint, recovery of uranium from seawater, removal of mercury and methylmercury from solution, and as a significant element in leather tanning (Aires, 2020).

Tannins are conceptualized as natural polymers, present in several places, such as in the polyphenolic secondary metabolism of higher plants, soft tissues, such as leaves, needles and bark (Morisada et al, 2011; Hernes and Hedges, 2004; Arbenz; Averous, 2015). Found in several plants, they are mainly known for their ability to react with proteins and metals, which gives them unique properties. Recently, they have gained prominence as a promising bio-renewable source for the development of a new generation of sustainable polymers.

As phenolic compounds of plant origin, tannins have high availability, biodegradability and low environmental impact. These characteristics make them excellent candidates to replace synthetic polymers derived from petroleum, whose production is highly polluting and non-renewable. In addition, the chemical versatility of tannins allows for structural modifications that can provide mechanical, thermal, and chemical properties suitable for various industrial applications.

Tannin-based polymers can be used in various sectors, such as sustainable packaging, adhesives, paints, foams, and even materials for the automotive and construction industries. Its ability to form resistant and flexible polymer networks expands the range of possibilities, promoting eco-friendly materials without compromising technical performance.

Therefore, investing in the research and application of tannins as a renewable raw material for polymers represents a significant step towards the green economy. Not only do they help reduce dependence on fossil fuels, but they also minimize environmental impact,

paving the way for innovative and sustainable products that meet the current and future demands of the global market.

2 DEVELOPMENT

2.1 CASHEW TREE

The cashew tree, the popular name of the *Anacardium occidentale* It is a plant species native to the Brazilian Northeast that is widely used by the population, since many parts of the plant can be used from the cashew tree for various purposes, whether medicinal or food. The peduncle, its pseudofruit, is called cashew (Figure 1), and has varied color in shades of yellow to red. Next to it, there is the cashew nut almond that, inside, stores the nut. Cashews and nuts are appreciated in northeastern cuisine, both in natura and in other food products (Novaes; Novaes, 2021).

The species has about 60 to 80 genera and 600 species distributed pantropically, but with some genera in the temperate regions of the North and some native to the semi-arid coasts of Brazil, so it is economically important (Lima et al., 2010). The cashew tree produces a yellow resin in its trunk, known as cashew gum, which can replace the gum arabic used in the paper and pharmaceutical industries. Cashew wood is durable and pinkish in color, and can be used in civil construction, carpentry, among others (Brasil, 2019).

Figure 1

Cashew



Source: [https://www.amazon.in/Creative-Farmer-Anacardium-Occidentale Cashew/dp/B071V2HT2S](https://www.amazon.in/Creative-Farmer-Anacardium-Occidentale-Cashew/dp/B071V2HT2S)

The species is mainly cultivated in India, Vietnam, Côte d'Ivoire, Guinea-Bissau, Tanzania, Benin, Brazil, and other countries in Central and West Africa and Southeast Asia,

South Africa, and Australia (Global Cashew Council, 2021). Brazil is among one of the largest producers of cashew in the world, and industrialized products are the main form of consumption of the fruit inside and outside the country, both the nut (true fruit) and the peduncle (false fruit), which favors the growth of Brazilian fruit growing for the economy (Queiroz et al., 2010).

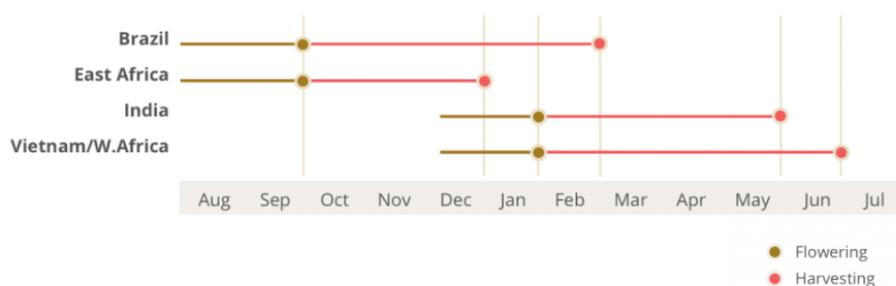
World cashew nut production currently ranges between 720,000 and 790,000 metric tons per year (2015/16-2019/20 seasons), with India, with an annual production of 170,000-195,000 tons, taking the top spot, followed by Côte d'Ivoire, Vietnam, and Tanzania, with figures of 149,000; 82,000, and 53,000 MT, respectively (Oliveira et al., 2020; Global Cashew Council, 2021).

One of the management procedures applied to cashew trees is pruning, which according to Embrapa (2021) Young cashew orchards should be managed in such a way that it forms a compact canopy, with a large productive surface, free of tangles and weed competition, mainly to facilitate mechanized harvesting. Fertilization and liming, which can be performed manually or mechanically, must be performed as needed, as well as the inspection of the irrigation system when the crop is irrigated. Commonly, these prunings are limited to removing parts of the tree attacked by insects or diseases, along with dry and broken branches.

Flowering occurs from December to April in the northern hemisphere and from June to December in the southern hemisphere, mainly in the period from September to November, according to Figure 2. Harvesting takes place during dry weather and nuts are harvested only when the fruit is fully ripe (Global Cashew Council, 2021).

Figure 2

Flowering and harvest period graph



Source: Global Cashew Council, 2021.

2.2 TANNINS

The word tannin originates from the ancient Celtic word for oak and was introduced by the Seguin, which explained the ability of plant extracts to convert into leather skin (Hagerman, 2002). Tannins (Figure 3) are natural polymers, which are present in several places, such as in the polyphenolic secondary metabolism of higher plants, soft tissues such as leaves, needles and bark (Morisada et al, 2011; Hernes and Hedges, 2004; Arbenz; Averous, 2015). After cellulose, hemicellulose, and lignin, tannins are considered one of the most abundant compounds extracted from biomass, leaves, roots, bark, seeds, wood, and fruits (Arbenz; Averous, 2015; Khanbabaee; Van Ree, 2001).

Figure 3

Tannins



Source: <https://afreitasvilar.com/taninos-2/>

Tannins are present among foods, such as grapes, blackberries, strawberries, walnuts, cashews, hazelnuts, mangoes, and tea (Clifford and Scalbert, 2000). In plants, they function as defenders, protecting trees from fungi, pathogens, insects, and herbivorous animals (Hagerman et al., 1998; Khanbabaee; Van Ree, 2001; Sharma, 2019). Tannins are mainly used in leather tanning, beverage manufacturing, pharmaceuticals, water treatment, as natural preservatives for wood, and also to produce adhesive (Shirmohammadli et al., 2018).

Usually, tannins are divided into two main groups, namely condensed tannins and hydrolyzable tannins. Condensed tannins are composed of flavonoids (flavan 3-ol or flavan 3,4-diol) without a sugar core, however, hydrolyzable tannins are composed of ellagic and gallic acids with a sugar core mainly glucose (Khanbabaee; Van Ree, 2001; Sharma, 2019).

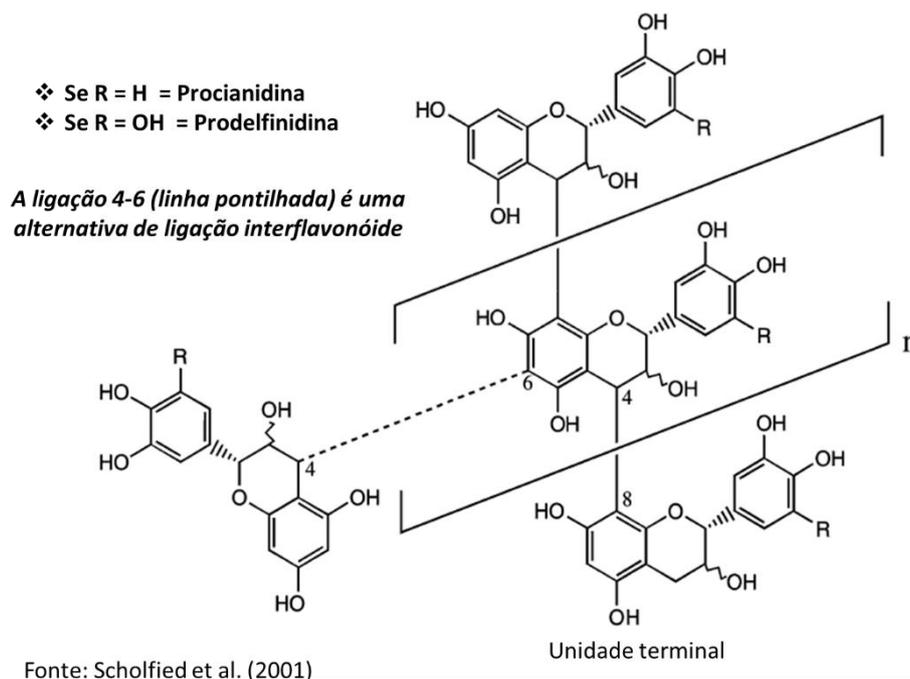
Comparing these two groups of tannins, the hydrolyzables have limited sources in nature compared to condensed tannins (Haslam, 1982; Hillis, 1985). Therefore, condensed tannins are dominating the world market consisting of more than 90% of the total commercial tannins (Filgueira et al., 2017).

Condensed tannins, as shown in Figure 4, are made up of units C₆, C₃ and C₆ of the flavonoid system, composed of two aromatic rings, joined by a pyran ring. The chemical

properties of condensed tannins are largely determined by three factors: (1) the hydroxylation pattern in the flavanol unit; (2) the stereochemistry in the three chiral centers present in the heterocyclic ring; and (3) the location of the interflavonoid bond (Tahir et al., 2019).

Figure 4

Condensed tannin structural model



Source: Scholfield et al., 2001.

The yield, purity and composition of the extracts generally depend on several parameters such as: the plant source, technique used, extraction time, temperature (Bacelo et al., 2016). Thus, the extraction of tannins is a process that is a fundamental key point for its reuse, valorization and sustainable production (Bacelo et al., 2017).

According to Pizzi (1983) The main salts used for tannin extraction are sodium sulfite (Na_2SO_3), sodium carbonate (Na_2CO_3), sodium hydroxide (NaOH), sodium disulfite ($\text{Na}_2\text{S}_2\text{O}_5$) and sodium bisulfite (NaHSO_3). Sulfitation is one of the oldest and most common methods of tannin extraction, and is especially suitable for the production of tannic extracts for the synthesis of phenolic adhesives. However, it is also known that the use of sodium sulfite as well as other inorganic salts are of great importance in the extraction process because they increase the hydrophilic sites of tannins, thus providing greater extraction of tannins (Silva, 2001).

The main characteristics of tannins correspond to their phenolic nature, because their antioxidant capacity is linked to the phenolic rings present in their structure, which can act as electron scavengers for Trap ions and radicals (Hoyos-Martínez et al., 2019).

2.3 TANNIN-BASED ADHESIVES

Tannin and lignin are considered renewable natural resources, and are of particular interest in phenolic resins due to their chemical structure (Faris et al., 2016), and can be used from modification to the synthesis of adhesives. Synthesis occurs through the polyphenolic structure and nucleophilic sites present (Wu et al., 2023). This polyphenolic structure of tannins provides their application in the adhesive industry.

Tannins are being used as a partial substitute for phenol to synthesize and reduce the rate of phenol use, as modifiers, or to replace some urea to synthesize tannin-urea-formaldehyde (TUF) condensation resins, which likewise improve the adhesive strength of UF resin adhesives as well as reduce UF formaldehyde emission (Peng et al., 2022; Zhang et al., 2014).

Beyond the purpose from the use of tannins in the synthesis of conventional formaldehyde-based resins, tannins are able to strongly complexify with proteins through hydrophobic interactions or non-covalent hydrogen bonds thus forming a well-cross-linked network through intermolecular interactions between the phenolic hydroxyl groups of tannins and proteins (Han et al., 2020; Van Buren; Robinson, 1969).

The high reactivity with formaldehyde occurs together with the A ring, resorcinolic or phloroglucinolic ring, and can reach faster reaction rates under similar conditions than those of phenol, achieving reactions 10 to 50 times faster (Pizzi, 2003). The aldehyde commonly used in the preparation, adjustment, and curing of tannic adhesives is formaldehyde. It is typically added to the tannin extract solution at the required pH, preferably in its para-formaldehyde polymer form, which is capable of reasonably rapid depolymerization under alkaline conditions (Kim, 2009).

Adhesives produced from tannins release relatively low levels of formaldehyde when compared to phenol formaldehyde (petrochemical compound), due to its high reactivity due to its structure (Pizzi, 2003; Hoong et al., 2011). In addition to their potential to reduce formaldehyde emissions, tannins have the characteristic of being resistant to fungal attacks (Krung; Tobisch, 2010). And the tannin sulfitation technique is a viable method for the production of adhesives, due to the process reducing the viscosity of tannic extracts and also increasing their solubility in water (Pizzi; Mittal, 1994).

3 FINAL CONSIDERATIONS

The application of cashew tannins in the development of adhesives for wood bonding represents an important technological and environmental advance. These tannins, because

they have reactive phenolic groups, can form stable chemical bonds with wood components, resulting in adhesives with good mechanical strength and durability.

In addition, compared to formaldehyde-based synthetic adhesives, they are less toxic, biodegradable, and come from renewable sources, aligning with the principles of sustainability. Thus, the use of cashew tannins in the formulation of adhesives contributes not only to the development of ecological and high-performance products, but also to the valorization of Brazilian natural resources and to the reduction of dependence on petrochemical derivatives in the timber industry.

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