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The potential of using chilean biomass to develop insulating biocomposite material

El uso potencial de biomasa chilena para desarrollar material biocompuesto aislante

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Abstract

The rise in greenhouse gas emissions, particularly CO2, has significantly contributed to global warming, with the residential and commercial building sectors playing a key role. Improving building energy efficiency through enhanced insulation is a crucial strategy for reducing CO2 emissions. However, conventional insulation materials have a high embodied carbon footprint, which limits their effectiveness in mitigating climate change. Biocomposites have emerged as an eco-friendly alternative to conventional materials. Countries like Chile, with their abundant agricultural fibers, show significant potential for fabricating biocomposites. This paper identifies the most produced fibers in Chile, including eucalyptus bark, wheat straw, rice husk, corn stalks, and walnut shells, and explores their potential use in the creation of sustainable biocomposite insulation materials.

Keywords: Greenhouse gas emissions; CO2; natural fibers; biocomposites; insulation materials.

Resumen

El aumento de las emisiones de gases de efecto invernadero, en particular de CO2, ha contribuido significativamente al calentamiento global, y los sectores de la construcción residencial y comercial desempeñan un papel clave. Mejorar la eficiencia energética de los edificios mediante un mejor aislamiento es una estrategia crucial para reducir las emisiones de CO2. Sin embargo, los materiales aislantes convencionales tienen una alta huella de carbono incorporada, lo que limita su eficacia para mitigar el cambio climático. Los biocompuestos han surgido como una alternativa ecológica a los materiales convencionales. Países como Chile, con sus abundantes fibras agrícolas, muestran un potencial significativo para la fabricación de biocompuestos. Este artículo identifica las fibras de mayor producción en Chile, entre las que se incluye, la corteza de eucalipto, la paja de trigo, la cáscara de arroz, los tallos de maíz y las cáscaras de nueces, y explora su uso potencial en la creación de materiales aislantes biocompuestos sostenibles.

Keywords: Emisiones de gases de efecto invernadero; CO2; fibras naturales; biocompuestos; materiales aislantes.

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1. Introduction

The amount of greenhouse gases (GHGs) released into the atmosphere as a result of human activity has significantly increased in recent decades (Mikhaylov et al., 2020). It has been demonstrated that GHGs have a direct impact on the increase in Earth's temperature and are, therefore, one of the major contributors to global warming (Filonchyk et al., 2024). There are several GHGs, with carbon dioxide (CO2) being the main contributor due to its abundance (Yoro and Daramola, 2020). In this context, as demonstrated in the Paris Agreement, the reduction of CO2 has become a global priority (UNFCCC, 2015), especially for the most polluting sectors. One of the sectors that contribute most to CO2 emissions is the residential and commercial sector, primarily due to fossil fuels burned for heating and the use of gases for refrigeration and cooling in buildings (Zhang et al., 2023), as well as the inadequate insulation of building envelopes and the high carbon embodied in related to conventional insulation materials (Grazieschi et al., 2021). In fact, the building sector contributes around 33% of global CO2 emissions (Lawrence, 2015).

One effective way to reduce the CO2 contribution of the residential and commercial sectors is by increasing the energy efficiency of buildings, particularly through enhanced envelope insulation (Kapoor and Singhal, 2024). Insulation plays a critical role in minimizing heat loss, which is a major factor in the energy consumption of buildings. By enhancing the insulation of walls, roofs, floors, and windows, buildings can maintain a more stable indoor temperature, reducing the consumption of energy. In fact, (Paraschiv et al., 2021) have shown that the installation of external insulation on building walls can reduce energy consumption by 13%–16%, depending on variations in outside air temperature. However, it is important to note that conventional insulation materials also have a high embodied carbon footprint, generating significant CO2 emissions during production and transportation (Tettey et al., 2014), which can undermine efforts to mitigate global warming. Therefore, utilizing alternative insulation materials with low carbon embodied content can significantly contribute to reducing CO2 emissions generated by the building sector.

On the other hand, the lack of affordable housing worldwide is becoming a global crisis. According to the OECD, a significant number of people cannot access housing, with reports indicating that 1 in 8 people out of every thousand lack this access (Salvi Del Pero et al., 2015). In Chile alone, the current housing deficit is estimated at approximately 550,000 units (Ministry of Housing and Urban Planning, 2024). Projections from (Chile's Construction Chamber, 2022) indicate that between 2019 and 2035, 2.7 million new housing units will be needed. Given that the housing sector is a significant contributor to CO2 emissions, addressing this housing need could further increase emissions if not managed sustainably. Therefore, a key challenge in housing development is to enhance the efficiency of thermal insulation while utilizing insulation materials that possess low or even negative embodied carbon.

2. Background

The most prevalent methods for enhancing thermal insulation in buildings involve the use of synthetic insulating materials, such as phenolic foam, polyisocyanurate (PIR) boards, expanded polystyrene (EPS), and mineral wool. Although these materials exhibit excellent thermal properties, their energy supply chains require significantly greater quantities of fossil fuels compared to alternatives like plant-based biomaterials (Tettey et al., 2014). Therefore, if insulation aims to reduce CO2 emissions, the high embodied carbon of these materials could be counterproductive. (Table 1) shows the thermal conductivity and embodied carbon of these materials. By utilizing a common R-value of 3 $m^2·K/W$ for all materials, the embodied carbon values can be normalized, considering that thermal conductivities differ and various thicknesses of material will be necessary to achieve the same thermal resistance.

(Table 1) illustrates the trade-off between thermal performance and embodied carbon across various insulation materials. While phenolic foam exhibits the lowest thermal conductivity, providing excellent insulating properties, it also carries the highest embodied carbon footprint (7.02 Kg CO2eq/kg), resulting in considerable emissions when normalized to achieve an R-value of 3 $m^2·K/W$ (17.06 Kg CO2eq/m^2). In contrast, wood fiber board, despite its higher thermal conductivity, presents a negative embodied carbon value (-1.06 Kg CO2eq/kg) and substantial carbon savings when normalized (-26.58 Kg CO2eq/m^2), owing to its ability to absorb and sequester CO2 (Lawrence, 2015). Due to this, there has been growing interest in the use of ecological thermal insulation capable of absorbing CO2, with a particular focus on biocomposites.

Biocomposites, also known as natural fiber composites (NFCs), are fabricated from a combination of biomass, primarily natural fibers, and binders such as gypsum-based materials, lime-based substances, thermosetting resins, or thermoplastic polymers (Osugi et al., 2009); (Kim et al., 2006). The fibers used in NFCs come from a variety of natural sources, including jute, flax, hemp, kenaf, sisal, coir, wool, silk, and others. These composites are characterized by their low density, high specific properties, biodegradability, and cost-effectiveness compared to conventional solid fiber-reinforced composite materials (Zhao et al., 2021).

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Table 1. Thermal Conductivity, Embodied Carbon of Wall Insulation Materials, and the Embodied Carbon Associated with Achieving R = 3 $m^2 \cdot K/W$

Insulation Material	Thermal Conductivity (W/m K)	Embodied Carbon $KgCO_2eq/kg$	Embodied carbon (R=3m^2K/W $KgCO_2eq/m^2$
Phenolic foam	0.020	7.02	17.06
EPS	0.038	4.21	14.40
Mineral Wool	0.036	1.13	15.50
PIR board	0.027	4.26	12.78
Woodfibre board	0.044	-1.06	-26.58

Note: Adapted from Densley Tingley et al., (2015)

In recent decades, various bio-based materials, particularly hemp-lime composites—commonly known as hempcrete—have been extensively studied for their beneficial properties (Demir and Doğan, 2020). These materials offer excellent insulation, high renewability, and the ability to absorb and sequester CO2 when used in building envelopes (Arrigoni et al., 2017). Hempcrete has been increasingly utilized in Europe since the early 1990s and has gained popularity in North America, especially in Canada (Dhakal et al., 2017). However, the commercial production of hemp remains illegal in many countries, including Chile, due to its cannabis nature (Ahmed et al., 2022). Consequently, Chile cannot take advantage of this material, which creates an opportunity to identify other forms of agricultural waste with similar properties to hempcrete that can be used effectively within the country.

Chile has enormous potential for the use of plant waste in the creation of biocomposites. The country's extensive coastline, varied topography, and diverse climate zones offer ideal growing conditions for a wide range of vegetation, including wheat, corn, almonds, walnuts, and rice, among others (Bazile et al., 2014). To process these plants, a large amount of waste is generated, which can be repurposed for other applications such as the creation of new types of construction materials (Román-Figueroa et al., 2017). With the proper scientific research and technology, Chile can benefit from its agricultural industry to develop novel biocomposite materials for thermal, reducing both embodied and operating energy of buildings.

Therefore, the existence of legal barriers to growing hemp, added to the high availability of other plant fibers in some countries, makes it attractive to explore alternatives that can exhibit optimal performance as insulating materials for buildings, especially residential housing, with similar properties or better compared to hempcrete. In Chile, there exists a diverse range of natural fibers that have not been thoroughly investigated for their potential use in construction. These fibers could be obtained from industries that process plant-based materials, such as wood and the food industry (Azócar et al., 2019). Furthermore, even though research has increased lately in the field of sustainable materials, there is still much to be investigated about the use of natural fibers as novel biocomposites, both in Chile and in the world (Hamada et al., 2023).

3. Properties of natural fibers and the matrix

3.1 Chemical, physical and mechanical properties of natural fibers

The fibers are essentially composed of rigid, crystalline cellulose microfibrils embedded in an amorphous matrix of lignin and/or hemicelluloses (Djafari Petroudy, 2017). Most plant fibers, except for cotton, consisting of cellulose, hemicelluloses, lignin, waxes, and some water-soluble compounds. Their natural hollow microstructure, defined by the formation of various walls and a central lumen (Pereira et al., 2015) (see (Figure 1)), provides NFCs with lower thermal conductivities compared to composites made from inorganic fibers (Liu et al., 2012). This low thermal conductivity makes NFCs highly effective for thermal insulation. Additionally, the use of natural fibers supports sustainability by utilizing renewable resources and reducing reliance on non-renewable materials.

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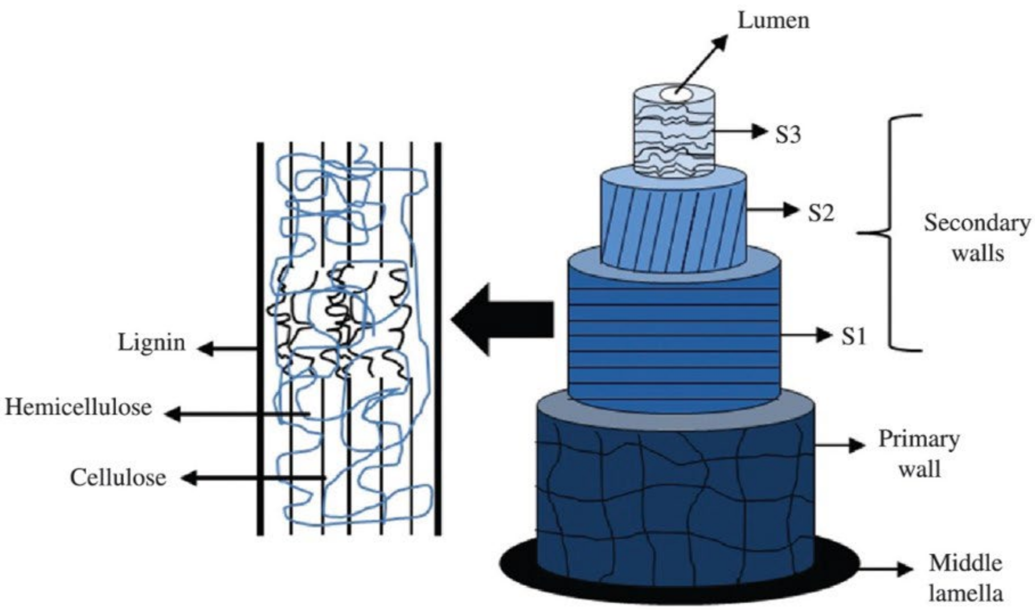

Figure 1. Microstructure of natural fibers (Pereira et al., 2015a)

The chemical composition of the fiber plays a significant role in determining the properties of the resulting composite material (Kumar and Prasad, 2014). Cellulose, a primary component of plant fibers, contributes to the strength, stiffness, and stability of the composite. Lignin acts as a chemical adhesive within and between fibers, and in composites, a high amount of lignin can enhance flexibility and ductility due to its nature (Banik et al., 2017). Hemicellulose and pectin are typically considered non-structural components, and their presence can affect the bond between the fiber and the matrix. The ranges of the chemical properties are 26%-91% for cellulose, 0.6%-45% for lignin, 3.00%-38.5% for hemicellulose, 0.45%-10% for pectin, 0.09%-4% for wax, 3.08%-12% for moisture, and 0.6%-8% for ash (Chokshi et al., 2022).

As noted previously, natural fibers such as wheat straw, jute, flax, sisal, and hemp are commonly used as reinforcement in composites. This is not only because they are renewable and sustainable, but also because of their chemical, physical, and mechanical properties. The density of plant fibers ranges from 800 to 1600 kg/m³ (Pereira et al., 2015), which endows the NFCs with low densities that allow for good thermal and acoustic properties. Their tensile strength varies according to the specific fiber, but in general can vary from 190 to 1100 MPa with an elongation at the break that varies between 1.2% to 8%, while Young's modulus ranges from 8 to 70 GPa (Djafari Petroudy, 2017b).

3.2 Pre-treatment of Fibers for Biocomposites

Although the use of raw fibers can enhance some properties of the composite, it has been shown that chemically and physically treating the fibers can significantly improve their effectiveness as reinforcement in composites by enhancing the adhesion between the fibers and the binder (El Mechtali et al., 2015). Chemical treatments involve modifying the surface chemistry of the fibers to improve their adhesion to the matrix material, reduce moisture absorption, and enhance their mechanical properties. There are different types of chemicals that can be used in chemical treatments, such as alkalis, acids, and coupling agents.

Alkali treatments increase the surface roughness, resulting in better mechanical interlocking. Also, it increments the amount of cellulose exposed on the fiber surface (Valadez-Gonzalez et al., 1999). Physical treatments include washing, cleaning, and drying the fibers to remove impurities and increase their strength. Heating treatment is used to remove the wax and the moisture content of the fibers, increasing the resistivity of the composite (Venkatachalam et al., 2016). Even though chemical treatments present improvements in the fibers, they may introduce some negative aspects such as the risk of manipulation, cost, and increased carbon footprint among others (Angelova-Fischer et al., 2014); (Hardwicke et al., 2012).

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3.3 Matrices of biocomposites

In biocomposite materials, the matrix, also referred to as the binder, plays a crucial role in holding the fibers together, transferring stress between them, and protecting the reinforcing material (Manu et al., 2022). These matrices can be classified into polymeric and inorganic types, each with distinct advantages. Polymeric matrices are typically derived from either renewable resources or fossil fuels (Guna et al., 2018). Polymeric matrices are often biodegradable, but it is important to note that not all of them are derived from renewable sources. For instance, polycaprolactone (PCL), a biodegradable polymer, originates from fossil fuels, while more recent efforts have aimed at producing conventional polymers, such as polyethylene (PE) and polypropylene (PP), using renewable monomers (Nagalakshmaiah et al., 2018). Polymeric matrices are generally categorized into three groups based on their source: renewable, mixed, or fossil fuel-based. The choice of matrix has a significant impact on the overall sustainability and performance of the biocomposite.

Beyond polymeric binders, inorganic binders such as gypsum offer a viable alternative for natural fiber composites. Gypsum, widely known for its use in construction, provides several advantages when used as a binder in biocomposites (Bumanis et al., 2020). It is a low-cost, abundant material with relatively low embodied carbon compared to polymeric matrices, making it an attractive option for eco-friendly applications (Quintana et al., 2018). Additionally, gypsum exhibits excellent fire resistance and enhances the thermal and acoustic insulation properties of the composite (Doleželová et al., 2018); (Mutuk et al., 2023). By incorporating gypsum as a binder, biocomposites can achieve a higher degree of sustainability while maintaining desirable mechanical and insulating characteristics, making it a suitable choice for applications such as sustainable building materials

4. Properties of biocomposites

Composites are materials made by combining two or more constituent materials with significantly different properties (Christian, 2019). For instance, fibre-reinforced polymers (FRPs) are composites in which fibers are embedded in a polymeric matrix. Biocomposites are defined as composite materials that consist of biodegradable natural fibers serving as reinforcement, combined with biodegradable (or non-biodegradable) polymers as the matrix. The most commonly available biopolymers include starch, cellulose, soy, polylactic acid, and polyhydroxyalkanoates (Ferrari et al., 2022).

The density of biocomposite materials can vary widely depending on the type of matrix material and reinforcement used. In general, composite materials have lower densities than traditional materials like metals and concrete, which can make them attractive for applications where weight reduction is important such as modular construction. Typical commercial insulation materials, such as glass wool, stone wool, glass fiber, and expanded polystyrene, have densities that vary from 30 to 160 kg/m3. Biocomposites made with plant fibers have been shown to have similar densities compared to traditional insulation. For instance, biocomposites made with hemp, jute, rice husk, and eucalyptus bark fibers have densities that fluctuate between 25 to 600 kg/m3 (Ricciardi et al., 2014); (Demir and Doğan, 2020). Furthermore, it has been shown that increasing the percentage of natural fibers within the matrix causes the density of the composite to decrease, as well as its mechanical resistance, due to their innate hollow microstructure (Benmansour et al., 2014).

The mechanical properties of biocomposites can vary significantly depending on the specific type and processing of the plant fibers, as well as the type and quantity of the matrix material used. In general terms, NFCs fabricated with a polymer matrix exhibit good mechanical properties, such as high strength and stiffness. For instance, composites made with bamboo fibers and walnut shells at 40 wt% of fibers have shown a tensile strength ranging from 19.1 to 35.1 MPa, a flexural strength ranging from 34.1 to 41 MPa, and Young's modulus ranging between 3.66 to 17.6 GPa (Okubo et al., 2004); (Ayrilmis et al., 2013). Furthermore, it has been shown that increasing the percentage of fiber replacement generally decreases the tensile strength and flexural strength of the composite. In an investigation carried out by (Bisht et al., 2020), it was shown that increasing the rice husk fiber in the composite from 10 wt.% to 30 wt.% decreased the tensile strength by 15%, while the flexural strength decreased by 42%.

NFCs exhibit good thermal properties compared to synthetic insulating materials, including low thermal expansion and good insulation properties. Typical thermal insulation materials, such as stone wool, glass wool, and expanded and extruded polystyrene, possess a thermal conductivity range from 0.031 to 0.050 W/mK, depending on the density of the material (Schiavoni et al., 2016). On the other hand, the thermal properties of composites reinforced with plant fibers such as hemp, jute, coir, and eucalyptus bark fibers can have thermal conductivities that range between

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0.038 and 0.049 W/mK (Casas-Ledón et al., 2020). These thermal properties make biocomposites suitable for use in applications where thermal insulation is critical. In general, it has been shown that thermal conductivity, thermal diffusivity, and effusivity decrease as the proportion of natural fibers in the composite matrix increases.

Another important aspect of NFCs is their hygrothermal properties. These properties are crucial due to the porous nature of the material and its application in building construction. By understanding how moisture interacts with the biocomposite, researchers can manage moisture movement, optimize thermal performance, and enhance durability. It has been shown that NFCs can attenuate the oscillations of the external environment and reduce energy consumption in winter when compared to conventional materials (Maalouf et al., 2014). These properties are essential for designing energy-efficient, sustainable buildings that effectively utilize biocomposites. For instance, the moisture buffering potential could help to smooth indoor relative humidity variations and improve occupant comfort (Colinart et al., 2020). Therefore, studying the hygrothermal behavior of these materials is fundamental.

Finally, it is important to highlight some aspects related to the durability of biocomposites. Although the literature suggests that biocomposites are generally durable, the final behavior and long-term durability will depend on several factors, the most important of which are the exposure conditions (Chang et al., 2020). Specifically, in the case of hempcrete, this material exhibited good durability against biodeterioration, salt exposure, and freeze-thaw cycles (Walker et al., 2014). Although the durability of biocomposites has been studied, the knowledge of their long-term behavior under adverse conditions is still limited.

5. Availability and chemical properties of Chilean fibers

Several types of natural fibers are available in Chile for potential use in the fabrication of biocomposites. The following provides a brief description of some promising options:

5.1 Eucalyptus Bark

Eucalyptus plantations are the predominant type of industrial fast-wood plantation in the Southern Hemisphere, covering over 20 million hectares worldwide (Ferreira et al., 2019). These plantations are found in several countries, including Australia, Spain, Portugal, Kenya, Brazil, Uruguay, and Chile. In Chile, Eucalyptus accounts for 34% of the total forest plantations (Fuentealba et al., 2016). Eucalyptus bark refers to the outer protective layer of the Eucalyptus tree, which is removed in the cellulose industry to produce pulp for paper and other cellulose-based products. In this sense, the eucalyptus bark has been considered industrial waste, representing 9.2% of the total volume of the tree (Mansilla et al., 2022). It is estimated that around 1.2 million cubic meters of Eucalyptus bark are produced in Chile per year, which corresponds to approximately 0.6 million tons (Casas-Ledón et al., 2020).

5.2 Wheat Straw

Chile produces approximately 1.3 million tons of wheat straw each year, which is frequently disposed of by burning the stubble (Azócar et al., 2019b). This practice not only contributes to atmospheric pollution but also increases the likelihood of wildfires. In 2014, Chile experienced its worst year in recent history, with over 8,000 fires burning approximately 130,000 hectares (Úbeda and Sarricolea, 2016). It has been shown that around 16% of the fires produced in the south of Chile were caused by agricultural activities, mainly associated with crop stubble-burning practices (Gómez-González et al., 2019). The utilization of wheat straw as a reinforcing material presents a promising prospect, not only in terms of repurposing a discarded material but also in avoiding the risk of wildfires.

5.3 Rice Husk

Rice (Oryza sativa) is a primary source of food for billions of people and one of the major crops in the world, covering around 1% of the Earth's surface (Arjmandi et al., 2015a). Rice husk is an inexpensive byproduct of rice processing and is separated from the rice grain during the rice milling process. It is estimated that the production of rice husks worldwide was approximately 759.6 million tons in 2017 (Bisht et al., 2020). In Chile, around 25,000 hectares are cultivated annually, which corresponds to a production of 163 thousand tons of rice and 32.6 thousand tons of husk (Gobierno de Chile, 2021). Rice production in the country is expected to increase in the coming years, creating an opportunity to reuse rice husk as reinforcement for composite materials.

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5.4 Chilean Corn Stalks

Corn (Zea Mays) is the most-produced cereal worldwide, surpassing wheat and rice (Jarabo et al., 2013). During the processing of corn, various wastes are generated, including corn stalks, stover, cobs, and husks. The corn stalk has a chemical composition like that of hardwood, and its fibers exhibit good strength properties. Therefore, corn stalk fibers can be considered a potential lignocellulosic agricultural waste that could serve as a reinforcement fiber source in the production of composites (Flandez et al., 2012). There are more than 23 maize races in Chile, with the Choclero type being the only local variety cultivated on a large scale in the country. About 11,500 hectares, which correspond to 13.6% of the total area destined for vegetable production, are cultivated mainly with Choclero, with an annual production of 101 million units on average (Salazar et al., 2017). It is estimated that 55 thousand hectares of corn are cultivated per year, which is equivalent to 0.56 million tons of production (ODEPA, 2021).

The following table (Table 2) presents a summary of production per year and the chemical properties of natural fibers that are highly available in Chile.

Table 2. Summary of fibers with high availability in Chile and their chemical properties

		General Chemical Composition of Fibers					
Organic Fibers	Annual Chilean Production (thousands of tons)	Cellulose (%)	Lignin (%)	Hemicellulose (%)	Holocellulose (%)	Ash (%)	Cite
Eucalyptus Bark	600	49.91	17.60	18.12	-	7.62	(Mansilla et al., 2020)
Quinoa Husk	NR*	NR*	NR*	-	-	NR*	NR*
Wheat Straw	1300	38.6	14.1	32.6	-	5.9	(Ghaffar, 2017)
Rice Husk	32.6	30.0	28.5	19.5	-	16	(Arjmandi et al., 2015b)
Corn Stalks	566	39	7.3	42	-	24.9	(Daud et al., 2013)
Walnut Shells	53.6	26.51	49.18	-	47.78	2.13	(Ayrilmis et al., 2013b)
Almond Shells	13.2	21.7	36.1	27.4	-	6.85	(Qaiss et al., 2015)

* Not reported in literature

6. Potential applications of fibers in biocomposites

The chemical composition and annual availability of these fibers are critical factors in assessing their potential as reinforcement materials in biocomposites. The fibers listed, such as eucalyptus bark, wheat straw, rice husk, corn stalks, walnut shells, and almond shells, demonstrate significant annual production rates, particularly wheat straw at 1,300 thousand tons and eucalyptus bark at 600 thousand tons. This high availability of agricultural by-products not only indicates a sustainable source of raw materials but also aligns with circular economy principles by utilizing waste products that would otherwise contribute to environmental pollution.

As outlined in this article, the chemical properties of these fibers are vital in determining their suitability for biocomposite applications. A key consideration is the cellulose content, as higher cellulose percentages have been shown to positively affect the mechanical properties and structural stability of biocomposites. For instance, eucalyptus bark and wheat straw contain 49.91% and 38.6% cellulose, respectively, indicating strong potential as reinforcing materials in composite formulations. Lignin, which varies significantly among fibers, influences the flexibility and ductility of biocomposites. For example, a biocomposite made with walnut shells, which have a high lignin content (49.18%), is expected to be more flexible than one made with wheat straw (14.1%)

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While cellulose is a primary contributor to the tensile strength and stiffness of biocomposites, other components, such as hemicellulose and ash content, also play critical roles. Hemicellulose, in particular, affects the compatibility and bonding between the fiber and the polymeric matrix. The variation in hemicellulose percentages among fibers, with corn stalks exhibiting 42%, suggests that they may provide additional benefits in terms of matrix bonding. However, limited information exists regarding the effects of chemical composition on the thermal properties of biocomposites. Therefore, further studies are necessary to explore this relationship and its implications for optimizing biocomposite performance.

7. Conclusions

In conclusion, the global challenge of decreasing greenhouse gas emissions, particularly CO2, underscores the urgent need for sustainable solutions in the building sector. The potential of biocomposites, especially those derived from agricultural fibers, offers a promising alternative to conventional insulation materials. This study identifies several Chilean fibers with significant annual production rates, including eucalyptus bark, wheat straw, rice husk, corn stalks, walnut shells, and almond shells. By harnessing these agricultural by-products, it becomes possible to develop sustainable insulation solutions that transform waste materials into valuable resources while mitigating environmental pollution.

The chemical composition of these fibers is crucial for their suitability in biocomposite applications. High cellulose content enhances mechanical properties and structural stability, while hemicellulose contributes to toughness and compatibility with polymeric matrices. Lignin content influences flexibility and ductility. Future studies must focus on conducting experimental work to evaluate the feasibility of using these fibers for fabricating biocomposites and analyzing their thermal properties. Understanding the impact of various chemical components, including ash content, is essential for optimizing formulations to achieve superior thermal insulation while maintaining structural integrity. This knowledge will enable researchers to effectively utilize fibers like eucalyptus bark, wheat straw, and corn stalks to create sustainable building materials that meet environmental and insulation needs.

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