European Journal of Wood and Wood Products (2026) 84:80
https://doi.org/10.1007/s00107-026-02441-1

REVIEW ARTICLE

Technological properties and uses of wood from *Paulownia fortunei* and its hybrids: a systematic review

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Received: 30 December 2025 / Accepted: 13 May 2026 / Published online: 1 June 2026
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Abstract

Paulownia fortunei, the species native to China, stands out as one of the fastest-growing trees in the world. Due to this characteristic and the wide variety of uses of its wood, its plantations, already significant in Asian countries, are expanding to other regions. The quality of the wood, determined by its anatomical, chemical, physical, and mechanical properties, is fundamental to guiding its applications. Furthermore, its performance in processing operations, such as sawing, drying, and machining, is crucial for industrial use. This systematic review aimed to gather and analyze available studies on the properties of *P. fortunei* wood and its hybrids, its behavior in industrial processes, and its potential applications, with an emphasis on higher value-added solid products. The methodology was structured in three stages: (i) searching the selected databases based on the defined research questions and keywords; (ii) screening articles according to inclusion and exclusion criteria; and (iii) systematic analysis of eligible studies and synthesis of their main results. The studies analyzed demonstrate that *P. fortunei* wood has broad application potential, varying according to the cutting age, and that its low density is a central characteristic, favoring uses that demand lightness. However, a scarcity of research focused on processing stages was observed, especially sawing, machining, gluing, and the production of solid wood panels.

1 Introduction

One of the main characteristics of interest in forest species intended for homogeneous plantations is the growth rate, due to the increasing global demand for raw materials in different industrial sectors, such as pulp, paper, energy, saw timber, panels, furniture, etc. *Paulownia* species and their hybrids have stood out for their rapid growth (Jiménez et al. 2005; Stimm et al. 2013). An average annual diameter growth rate of 40 mm/year was reported for the *P. elongata* x *P. fortunei* hybrid in plantations in Spain (Fos et al. 2023), and average diameters exceeding 40 cm were found for 6-year-old *P. fortunei* trees from plantations in Iran (Kiaei 2013). In more favorable locations, an annual increase of 8 to 9 cm in DBH and 0.2 m³ in production volume is obtained (Rai et al. 2000). Currently, *Paulownia* species are found growing under cultivation conditions in various parts of the world, including China, Japan, Southeast Asia, Europe, North America, South and Central America, Australia, and South Africa (CABI 2022; Carvalho 1998). Species of the genus are extremely adaptable to wide variations in edaphic and climatic factors and grow well in lands considered marginal (Yadav et al. 2013; Hoef and Hill 2003; Rodrigues et al. 2021).

The genus *Paulownia* is native to China and includes species such as *P. albiphloea*, *P. australis*, *P. catalpifolia*, *P. elongata*, *P. fargesii*, *P. fortunei* (Seem.) Hemsl. (WFO 2025), *P. kawakamii*, and *P. tomentosa* (Zhao-Hua et al. 1986). Of these, the most popular are *P. fortunei*, *P. tomentosa*, and *P. elongata*, and numerous hybrids, supposedly resistant to local conditions, are most frequently developed from them (Lachowicz and Giedrowicz 2020). The original *Paulownia* species that have been introduced worldwide are increasingly being replaced by superior clones, such as

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Cotevisa 2 (*P. elongata* SY Hu × *P. fortunei* (Seem.) Hemsl.), Shan Tong (*P. tomentosa* (Thunb.) Steud. × *P. fortunei*), and 9501 (a natural hybrid of *P. fortunei*), among others (Zuazo et al. 2013; Dżugan et al. 2021; Zhao et al. 2022).

According to Jakubowski (2022), the main objective of cultivating *Paulownia* in short cycles is the production of woody biomass for the energy and pulp industries, as well as for other industries related to wood processing, the creation of composites and biopolymers, wood gasification, etc. On the other hand, Fos et al. (2023) cite that new *Paulownia* plantations established in different regions of the world have as their main objective the production of high-quality wood in very short rotations for use in value-added products. In general, for obtaining solid wood, the cycles vary from 8 to 10 years, while for energy and biomass, around 3 to 4 years, varying according to the species, variety, or hybrid (Sá 2023).

The proper use of wood depends directly on knowledge of its technological properties, including its anatomical, chemical, physical, and mechanical characteristics, and, especially for use in solid products, it is essential to evaluate the material's behavior during sawing, drying, and machining. *Paulownia* wood is generally described in traditional literature as light, soft, light blond in color with a silky sheen, easy to process and dry, strong and stable, resistant to warping and chipping, with numerous applications (Cui et al. 2015).

Differences in chemical, physical, anatomical, mechanical, and processing characteristics have been reported for several species of the genus *Paulownia*; this work focused on the species *P. fortunei* and its hybrids. Among the species that compose the *Paulownia* genus, *P. fortunei* stands out for its scientific and technological relevance. According to a comprehensive bibliometric analysis covering 820 scientific articles published between 1971 and 2021, *P. fortunei* is the second most studied species worldwide in wood-related research, surpassed only by *P. tomentosa* (Lugli et al. 2022). In addition, recent review studies indicate that the hybrids currently most cultivated, such as in vitro 112, Cotevisa 2, and Shan Tong, are predominantly derived from crosses involving *P. fortunei* with *P. tomentosa* or *P. elongata* (Jakubowski 2022), reinforcing its central role in breeding programs and commercial plantations. The species also concentrates a substantial portion of research addressing wood technological properties and performance in industrial processing. Nevertheless, no systematic review has been dedicated specifically to *P. fortunei* and its hybrids, which limits the consolidation of available knowledge. Therefore, the selection of this species as the focus of the present review is justified by its representativeness in the literature, its applied relevance, and the need to critically integrate and synthesize existing studies.

Although several studies have been developed in research centers in different countries, the evidence available in the literature has not yet been systematized. Thus, this systematic review aims to gather and critically analyze studies on the properties of *P. fortunei* wood, its performance in industrial processes, and its potential applications, with emphasis on its use in higher value-added solid products.

2 Method

The systematic review was developed in three stages. The first stage consisted of planning, where the research questions, databases, search strategies, and selection criteria for the analyzed works were defined. The second stage was the screening and selection of articles, and the third was the systematic analysis and discussion of the results of the selected works. The following research questions were defined:

(a) What evidence is available regarding the technological properties of *P. fortunei* wood and its hybrids?
(b) What are the main characteristics of the species in sawing, drying, and machining processes? And what are the main recommendations?
(c) What are the industrial applications of this wood, with an emphasis on solid products?

Two databases were defined, Scopus and Web of Science, and search strategies were defined for each of them. For Scopus the search strategy was TITLE-ABS-KEY ("Paulownia fortunei" OR "Paulownia fortunei var. Mikado") AND TITLE-ABS-KEY (wood OR timber) AND TITLE-ABS-KEY (properties OR characteristics OR "wood technology" OR sawing OR drying OR machining OR workability OR utilization OR "solid wood products" OR furniture OR panels OR "industrial applications") and for Web of Science the strategy was TS=("Paulownia fortunei" OR "Paulownia fortunei var. Mikado") AND TS=(wood OR timber) AND TS=(properties OR characteristics OR "wood technology" OR sawing OR drying OR machining OR workability OR utilization OR "solid wood products" OR furniture OR panels OR "industrial applications").

To ensure the consistency and relevance of the systematic review, inclusion and exclusion criteria were defined for the studies. Original articles published in peer-reviewed scientific journals that specifically addressed *P. fortunei* wood (including varieties, hybrids, and clones) were included. The selected works evaluated technological properties of the wood (anatomical, physical, chemical, or mechanical), its performance in industrial processes (sawing, drying, machining), or its industrial applicability (solid wood, panels, and pulp). Studies published in English and Spanish,

or in another language, were considered, if translation was possible. There was no initial restriction on the period, if they were available in full text.

The exclusion criteria were also defined to ensure the consistency and reproducibility of the review. All studies that did not provide information on the anatomical, chemical, physical, mechanical, or processing properties of *Paulownia fortunei* or its hybrids were excluded, as well as those whose primary focus was not wood, such as research dedicated exclusively to physiological, silvicultural, ecological, growth, or genetic improvement aspects. Studies related to biomass, bioenergy, or energy properties were also excluded because they do not address wood in its solid form or its derived products. Articles without full-text access, duplicates retrieved across different databases, and documents that did not constitute primary scientific literature, including technical reports, promotional materials, book chapters, conference abstracts, and extension notes, were also removed. Narrative or systematic reviews were excluded since the objective was to compile only primary research studies. Finally, studies focusing on *Paulownia* species that did not involve *P. fortunei* or its hybrids were discarded.

The study selection process followed the recommendations of the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Initially, all records identified in the databases (Scopus and Web of Science) were exported to a reference manager, where duplicates were removed. In the screening stage, titles and abstracts were evaluated according to the previously established inclusion and exclusion criteria. Potentially relevant articles were then analyzed in full to confirm eligibility. The study selection flow is presented in PRISMA flowchart format, indicating the number of studies removed at each stage. In addition to the systematic search conducted in the databases, studies identified through complementary searches were also considered. This step included verifying the reference lists of the selected articles (snowballing) and identifying relevant works not retrieved in the initial search, but which fully met the established inclusion criteria. All additional studies were evaluated based on the same eligibility criteria applied to the records obtained in the systematic search. In the PRISMA flowchart, these articles were recorded in the category "additional records identified through other sources," ensuring the transparency of the selection process.

3 Results

3.1 Context of studies on wood *P. fortunei*

The initial search in the databases resulted in 59 studies, of which 15 were removed due to duplication. After a complementary analysis of the articles' reference lists, 14 studies were included for the initial screening, totaling 58 articles that were analyzed by title and abstract. After screening by title and abstract, 18 articles were excluded for not meeting the selection criteria and addressing other aspects of the species *P. fortunei*, or for dealing with other species of the genus *Paulownia*, or for not specifying which species they were referring to. Thus, 40 articles went to the second stage of screening, eligibility, where a complete reading of each article was carried out. Of these, 9 studies were excluded because they did not address the subject of the review, i.e., they were outside the scope, because they did not have a translatable full text (two articles only available in Chinese), or because they were published in conference proceedings and not in journals (Fig. 1). Finally, 31 articles were selected for this review.

Considering the articles accepted for this study, published between 2000 and 2025, it is observed that interest in *P. fortunei* wood has increased over the years. The percentage of publications was lowest between 2000 and 2004, increasing to 26.5% between 2010 and 2014, followed by a decline between 2015 and 2019. In recent years (2020–2025), the number of publications has increased significantly, representing almost half of the evaluated articles (Fig. 2).

From the general analysis of the articles, it was observed that most of the work was conducted in Spain with the species *P. fortunei* and the clone Cotevisa 2, which was formed through natural hybridization between the species *P. elongata* and *P. fortunei*. Clone 112 in vitro, an artificial hybrid between *P. fortunei* and *P. elongata*, and the tri-hybrid *P. fortunei* x *P. tomentosa* x *P. elongata* were also identified, although less frequently. Iran then stood out, accounting for 28% of the publications, with a focus on the variety *P. fortunei* L. (Fig. 3). In China, the selected works addressed the greatest diversity of clones, evaluating up to 19 clones with *P. fortunei*, including the clone Oxytree (*P. elongata* x *P. fortunei*). In Poland, the focus was on the clone Shan Tong, a hybrid between *P. tomentosa* and *P. fortunei*. The BIO125 clone (*P. elongata* × *P. fortunei*) was studied exclusively in Italy, while the Revotropix clone (a commercial variety of *P. fortunei* developed by Gain-Green) was studied in Italy. Malaysia, highlighting the adaptability of different clones to the specific edaphoclimatic conditions of each region.

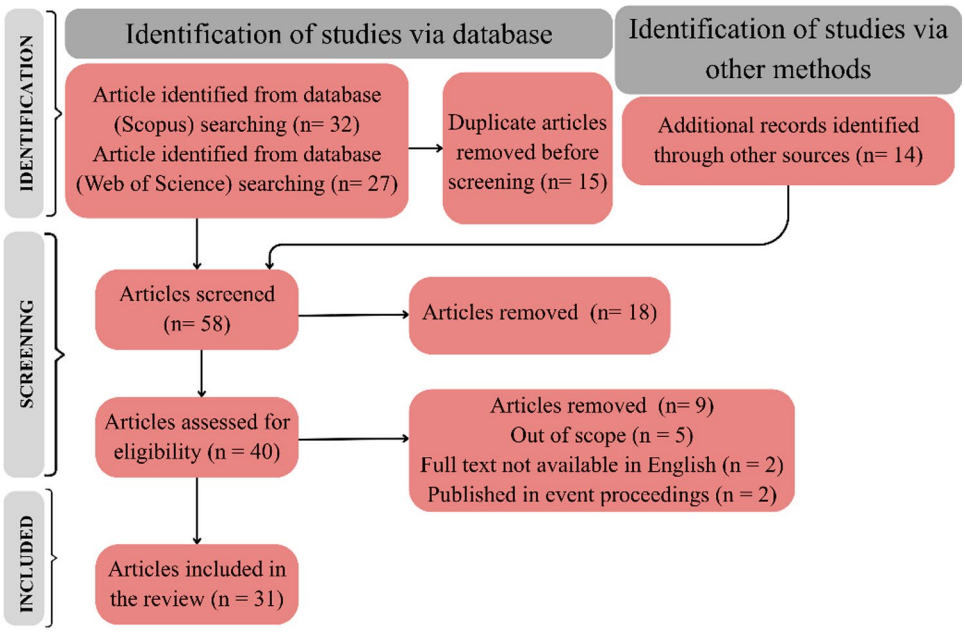


Fig. 1 PRISMA flowchart for systematic literature search and study selection, including publications from 2000 to 2025

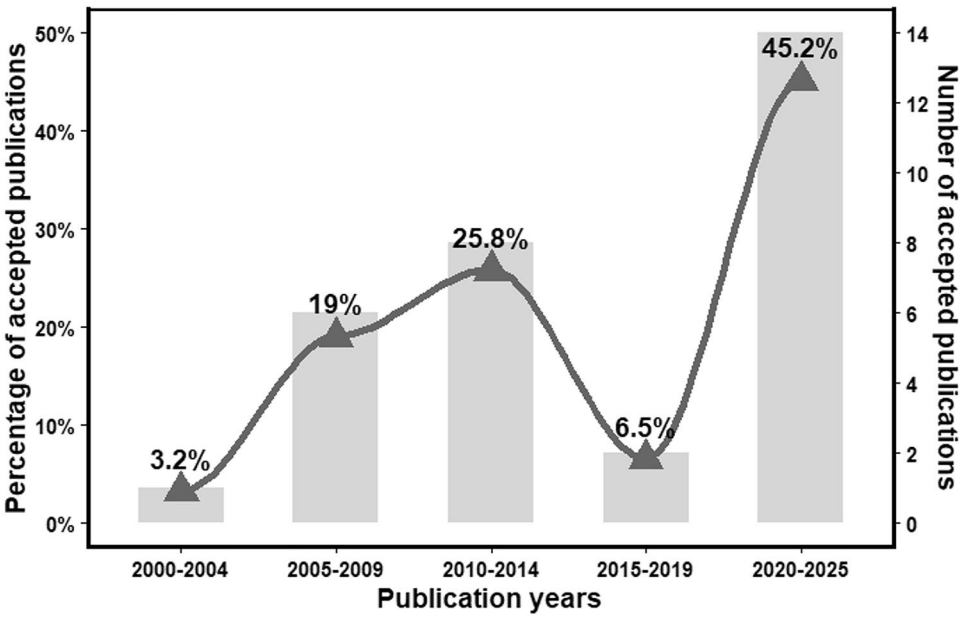


Fig. 2 Trend of publications on the properties of *P. fortunei* wood and its hybrids over time

3.2 Anatomical characteristics

3.2.1 Macroscopic structure of wood

P. fortunei trees, as well as their hybrids, have thin bark, hollow pith along their entire length, and are generally eccentric, and the boundary between heartwood and sapwood is not clearly defined visually. The trunk tends to be irregular only at the base and becomes cylindrical and regular along the length of the tree (Fos et al. 2023; Kozakiewicz et al. 2020). The bark thickness was determined to be 3 mm for the Cotevisa 2 clone (*P. elongata* x *P. fortunei*) in commercial plantations in Spain, while the pith had an average width of 16 mm with an eccentricity ratio of 1.6 (Fos et al. 2023). The three-year-old Shan Tong variety (*P. tomentosa* x *P. fortunei*) from Poland had a pith wider than 15 mm (Kozakiewicz et al. 2020).

The growth rings of the species are visible in cross-section and tend to be larger in the first years due to very rapid growth in the first years after planting, with subsequent gradual reduction and stabilization around five years of age (Fos et al. 2023). The wood of the Shan Tong hybrid growing in Poland, at two years of age, showed annual rings with an average width between 5.9 mm and 6.8 mm (Tomczak et al. 2023). The same variety at three years of age showed a greater width of annual growth rings, on average,

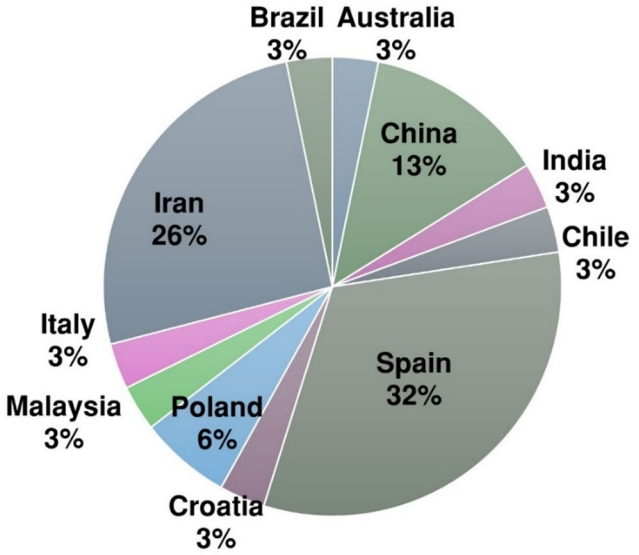


Fig. 3 Percentage of publications accepted by country on the properties of *P. fortunei* wood and its hybrids. The classification by country refers to the location where the experiments or plantations evaluated in the studies were conducted

of 13.3 mm (Kozakiewicz et al. 2020). The wood of the Cotevisa 2 hybrid, at seven years of age, showed the first ring with an average of 42 mm, and the fifth ring onwards with values around 10 mm per year (Fos et al. 2023).

In general, studies show that the wood of *P. fortunei* and its hybrids predominantly exhibits a light color with high L or whiteness values, indicating high luminosity, which can be considered an advantage for decorative uses. Studies have demonstrated that the color of *P. fortunei* wood, especially whiteness, differs between clones of hybrids; for example, 5-year-old clones planted in Hubei, China, designated B01, B05 (natural hybrids) and MB04 (artificial hybrid *P. fortunei* x *P. tomentosa*), presented whiteness values of 71.13, 68.91, and 72.27, respectively (Feng et al. 2020). In another study conducted at the same location on trees of the same age, the clone designated 204, obtained from selection of *P. fortunei* seedlings, presented values for the parameters L, aeb of 79.51, 3.66, and 14.34, and the clone designated 605 (artificial hybrid *P. fortunei* x *P. tomentosa*) presented values of 79.52, 3.85, and 14.17 (Cui et al. 2015). Through visual analysis, the seven-year-old Cotevisa 2 hybrid had its heartwood classified as ranging in color from light yellow to light gray (Fos et al. 2023). Although the color difference between the heartwood and sapwood is not pronounced, the 15-year-old *P. fortunei* growing in Iran presented a cream coloration in the heartwood and a slightly lighter sapwood (Taghiyari et al. 2014b).

3.2.2 Microscopic structure of wood

The structural elements of *P. fortunei* wood include vessels, fibers, parenchyma, and rays. This species presents a significant proportion of parenchyma cells and vascular elements compared to denser species, which are predominantly fibrous. The parenchyma is well-developed around the vessel, with cell walls thinner than those of the fibers, contributing to the lightness of the wood (Ashori and Nourbakhsh 2009). The wood structure is ring-porous, but tends towards diffuse porosity, with larger vessels concentrated in the annual ring region, and the others uniformly distributed in other areas (Ashori and Nourbakhsh 2009). The hybrid Cotevisa 2, cultivated in Spain at seven years of age, presents a semi-annular-porous structure, with solitary and multiple radial vessels, with solitary vessels being predominant (Fos et al. 2023). The number of vessels tends to gradually increase along the growth rings, going from 7 vessels·mm^{-2} in the 1st ring to 10 vessels·mm^{-2} in the 6th ring (Fos et al. 2023). Similarly, the Shan Tong clone, cultivated in Poland at two years of age, also has a semi-annular-porous structure, with vessels of fairly homogeneous diameters distributed throughout the width of the annual rings (Tomczak et al. 2023).

A few studies have quantified the dimensions of vessel elements and determined that for 15-year-old *P. fortunei* wood cultivated in Iran, average diameters were 143 µm in latewood and 298 µm in earlywood in the sapwood region, while in the heartwood these values were 153 µm and 318 µm, respectively (Taghiyari et al. 2014a). In a complementary study with the same wood, the authors observed that, in the sapwood, the average lumen area of the vessels was 0.030 mm², with 11.2% of the area occupied by vessels and a frequency of 3.8 vessels·mm^{-2}. In the heartwood, these values increased to 0.038 mm², 19% of the area occupied, and 5.1 vessels·mm^{-2} (Taghiyari et al. 2014b). Similarly, the Shan Tong clone, grown in Poland at two years of age, showed a tendency for increasing vessel size along the growth rings, with length varying from 212 µm in the first ring to 246 µm in the fourth, and diameter from 147 µm to 170 µm, respectively (Tomczak et al. 2023).

Table 1 shows the dimensions of the wood fibers of *P. fortunei* and its hybrids described in different studies. The analyzed results showed that a characteristic of this species is its relatively short fibers, with lengths ranging from 809 µm to 1,420 µm. The shortest value was recorded for the Shan Tong clone, cultivated in Poland at three years of age, while the longest was observed in *P. fortunei* growing in India at two years of age (Table 1). In young trees of the Shan Tong hybrid, a tendency for increasing fiber length with age was identified, ranging from 748 µm in the first ring to 871 µm in the fourth, with the value presented in the table

Table 1 Fiber dimensions of *Paulownia fortunei* and hybrids

Species/hybrid	Age	Local	Fiber length (µm)	Fiber width (µm)	Cell wall thickness (µm)	Lumen width (µm)	Author
Paulownia fortunei	2	India	1,420	30	–	–	Rai et al. (2000)
Paulownia fortunei L.	6	Iran	1,002	35.44	6.47	26.49	Ashori and Nourbakhsh (2009)
Paulownia fortunei L.	5	Iran	996	30.55	5.25	25.30	Kiaei (2013)
Shan Tong (*Paulownia fortunei* × *Paulownia tomentosa*)	3	Poland	809	–	–	–	Tomczak et al. (2023)
Cotevisa 2 *(Paulownia elongata* × *Paulownia fortunei*)	5	Spain	985	29.50	1.70	26.1	Kulak et al. (2024)

being an average of these data (Tomczak et al. 2023). Fiber width varies between 29.5 µm and 35.44 µm, with the highest value recorded for *P. fortunei* cultivated in Iran, and the lowest for the Cotevisa 2 clone originating from Spain. The cell wall thickness is relatively thin, ranging from 1.7 µm to 6.5 µm, which contributes to the lightness of the wood. The lumen width, however, is considerably large and varies little between *P. fortunei* and the hybrids (Table 1). The thin walls and wide lumens result in fiber morphology similar to the structure of a honeycomb (Ashori and Nourbakhsh 2009).

Considering the fiber width and cell wall thickness values (Table 1), it can be estimated that the cell wall proportion for *P. fortunei* and its hybrids is low, between 5.8% and 18.25%, with the lowest value for the Cotevisa 2 hybrid, studied by Kulak et al. (2024). However, Fos et al. (2023) observed that the cell wall proportion of this hybrid gradually increases from the 1st ring (14%) to the 5th and 6th rings (18% and 19%). A similar value was found for *P. fortunei* L. cultivated in Iran, which presented a cell wall proportion of 17.41% (Kiaei 2013).

Based on fiber dimensions, fundamental indices are obtained to evaluate their suitability for pulp and paper production. Among these, the Runkel index (2x wall thickness/lumen width) stands out, indicating favorable pulp strength properties at values less than 1. Another relevant parameter is the flexibility coefficient, obtained as a percentage of lumen width over fiber width, implying the degree of bonding between the fibers. According to Kiaei (2013), *P. fortunei* wood cultivated in Iran at five years of age presented a Runkel index of 0.426, a flexibility coefficient of 82.6, and a slenderness ratio of 33.1. Meanwhile, wood from the Cotevisa 2 hybrid planted in Spain showed a lower Runkel index (0.139), a higher flexibility coefficient (87.9), and a very similar slenderness ratio (34.96), in addition to a stiffness index of 6.03 (Kulak et al. 2024). The wood of *P. fortunei*, which also grows in Iran at six years of age, showed the lowest values for slenderness ratio (29.32) and flexibility (75), and an intermediate Runkel index (0.34) (Ashori and Nourbakhsh 2009).

In addition to indices derived from fiber dimensions, another highly relevant structural parameter for industrial applications is wood porosity. This characteristic is directly related to the material's lightness and influences properties such as thermal insulation, acoustic absorption, and drying behavior. Several studies have quantified porosity in different clones and growing regions. Kozakiewicz et al. (2020) evaluated the acoustic properties of Shan Tong clones grown in Poland and reported a porosity of up to 85% associated with good thermal insulation properties, high ultrasonic radiation damping, and low resistance to ultrasonic wave propagation. The Cotevisa 2 clone grown in Granada, Spain, showed porosity ranging from 80.44% to 87.27% (Lachowicz and Giedrowicz 2020). In Valencia, Spain, a reduction in porosity from 86% in the 1st ring to 81% in the 5th and 6th rings was observed (Fos et al. 2023). Similarly, *P. fortunei* L. cultivated in Iran showed a porosity of 82.59% (Kiaei 2013). In general, it is observed that the wood of *P. fortunei* and its hybrids consistently exhibits porosity greater than 80%.

Another striking anatomical characteristic of *P. fortunei* wood is the high incidence of tyloses in the vessels, structures that form from the axial parenchyma and partially or totally obstruct the vascular lumen (Taghiyari et al. 2014a; Xu et al. 2019). In trees cultivated in China, Xu et al. (2019) observed the presence of tyloses in 60.95% of the vessels in the sapwood and 72.02% in the heartwood, while in 15-year-old *P. fortunei* specimens from Iran, the occurrence was 48% in the sapwood and 74% in the heartwood (Taghiyari et al. 2014b). This high frequency of vessels obstructed by tyloses can compromise the permeability of the wood, hinder the penetration of preservative solutions, and reduce the efficiency of treatments that depend on fluid flow, such as impregnation with chemicals or controlled drying.

This partial or total obstruction of vessels by tyloses has direct implications for wood permeability, especially in the heartwood, where its concentration is higher. Gas permeability for 15-year-old *P. fortunei* growing in Iran was evaluated after drying with three drying programs, and the highest permeability was found in the sapwood after a moderate drying program, while the lowest permeability was observed in the heartwood using a milder drying program with lower temperatures and higher RH% (Taghiyari et al.

2014a). Similarly, Taghiyari et al. (2014b), evaluating the same wood after diffusion drying under three different initial moisture contents, observed higher gas permeability in the sapwood under an intermediate moisture content (~75%), while the lowest occurred in the heartwood under the highest initial moisture content (~113%). Liquid permeability, however, did not show a difference between the sapwood and the heartwood. The results of the studies indicate that the permeability of *P. fortunei* wood is influenced by its anatomical structure, such as the frequency and size of the vessels, but mainly by the presence of tyloses, generally with a higher concentration in the heartwood, which significantly reduces the flow of gas and liquids, as well as by external factors, such as the parameters of the drying process and the initial moisture content before drying (Taghiyari et al. 2014a, b; Xu et al. 2019).

Despite the high tyloses content present in *P. fortunei* vessels, it has been proven that it is possible to significantly reduce the amount of tyloses and increase vessel opening, especially in the heartwood, through treatment with supercritical CO_2, which promotes an increase of up to 64% in wood permeability, potentially favoring processes such as modification, preservation, and staining on an industrial scale (Xu et al. 2019).

3.3 Chemical composition

The chemical properties of wood essentially comprise its composition of cellulose, lignin, extractives, pH, and ash. Table 2 presents the results of the chemical composition of *P. fortunei* wood and its hybrids, according to the studies analyzed. It can be observed that the holocellulose content – the fraction formed by hemicelluloses and cellulose varied from 57% to 81%, with the lowest value for two-year-old *P. fortunei* cultivated in Spain and the highest for the same species at six years of age, cultivated in Iran. The maximum content of α-cellulose (52.6%) was recorded for *P. fortunei* at six years, while glucan values ranged from 34% to 44%, with the *P. fortunei* x *P. tomentosa* x *P. elongata* clone showing the highest content (Table 2).

The diversity in methods for quantifying cellulose among the studies is noteworthy: some used the determination of α-cellulose, others reported only the glucan content, and one study adopted the Seifert method, which is less common in the literature. Furthermore, there are variations in the presentation of the data, with some studies reporting only the total holocellulose content, others only the cellulose content, and some not specifying either.

The amount of lignin in the wood varied from 22.75% for the Cotevisa 2 hybrid, grown in Spain at five years of age, to 34% for the *P. elongata* x *P. fortunei* hybrid at four years of age, originating from Chile. Most studies, however, reported values between 27% and 29% for the *P. fortunei* species and its different hybrids, levels considered high compared to other hardwood species used in the pulp and paper industry. The most used quantification method was Klason's (Table 2).

The results obtained by Rencoret et al. (2009) from the characterization of lignin in three-year-old *P. fortunei* wood, collected in Spain, using pyrolysis coupled to gas chromatography and mass spectrometry (Py-GC/MS) and two-dimensional nuclear magnetic resonance (2D NMR), indicated a predominance of guaiacyl (G) units in relation to syringyl (S) units, with a molar composition of H:G:S of 1:59:40, an S/G ratio of 0.66, and a predominance of condensed structures. The combination of these characteristics suggests lower chemical reactivity in pulping and

Table 2 Chemical characteristics of *Paulownia fortunei* and hybrids

Species/hybrid	Age	Local	Holocellulose/ αCellulose (%)	Lignin (%)	Extractives (%)	pH	Ash (%)	Author
Paulownia fortunei	2	India	69.56	28	3.05[7]	–	–	Rai et al. (2000)
Paulownia fortunei L.	6	Iran	81.2/52.6	24.6	11.9[4]/10[3]/14.7[8]	–	–	Ashori and Nourbakhsh (2009)
Paulownia fortunei L.	1~2	Spain	69/34.2[1]	27.2	–		1.6	Feria et al. (2009)
Paulownia fortunei	1~2	Spain	56.9/34.2[1]	27.2	–	–	–	Franscisco et al. (2010)
Paulownia fortunei × *Paulownia tomentosa* × *Paulownia elongata*	3	Spain	65.2/44[1]	27.8	4.6[7]	–	0.9	García et al. (2011)
Paulownia fortunei	–	Iran	69/45.1	29.3	6.8[4]/5.3[3]	5.7	3.6	Salari et al. (2012)
Paulownia fortunei L.	5	Iran	80.1/51	23.5	11.8[4]	–	–	Kiaei (2013)
Paulownia elongata × *Paulownia fortunei*	4	Chile	–	34.41	9.28[5]	–	1.32	Pegoretti et al. (2020)
Cotevisa 2 (*Paulownia elongata* × *Paulownia fortunei*)	5	Spain	48.15[2]	22.75	3.8[4]/2.3[3]/ 5.5[6]	4.8	0.40	Kulak et al. (2024)

[1]Glucan content; [2]Cellulose, Seifert method; [3]Cold water; [4]Hot water; [5]Total extractives; [6]Ethanol; [7]Benzene ethanol; [8]1% NaOH

delignification processes when compared to species with lignins richer in syringyl units (Rencoret et al. 2009).

The extractive content in cold water ranged from 2.3% to 10%, respectively, for the Cotevisa 2 hybrid and *P. fortunei*. With hot water, the value ranged from 3.8% to 11%. The extractives in ethanol benzene were similar between the *P. fortunei* x *P. tomentosa* x *P. elongata* hybrid (4.6%) and *P. fortunei* (3.1%), and a slightly higher value was obtained for extractives in ethanol only (5.5%) in the Cotevisa 2 hybrid (Table 2).

Regarding the pH of wood, the value ranged from 4.8 to 5.7 for the Cotevisa 2 hybrid and *P. fortunei*, respectively (Table 2). Considering that the urea-formaldehyde-based adhesive, widely used in the manufacture of reconstituted panels, has a pH between 5.5 and 6.0 (Salari et al. 2012), the values recorded for *P. fortunei* and its hybrids demonstrate chemical compatibility with this type of binder. This compatibility favors the formation of an efficient glue line between the wood particles, contributing to the physical and mechanical performance of the panels.

The ash fraction showed wide variation among the studies analyzed, ranging from 0.4% for the Cotevisa 2 hybrid at five years of age, originating from Spain, to 3.6% for *P. fortunei* cultivated in Iran, without mention of age (Table 2).

3.4 Physical and mechanical properties

One of the most relevant physical properties of wood for defining its industrial uses is density, a parameter determined by the ratio between the mass and volume of a sample. Density can be classified as basic, when considering the dry mass of the wood and the saturated volume (in a state of maximum moisture), or as apparent, when considering the mass and volume at a given moisture content. This property is directly related to the mechanical strength, durability, workability, and industrial yield of wood, and is widely used as a selection criterion for different applications.

The results obtained in different studies demonstrate the ultralight density of this species and its hybrids planted in different regions and ages. The basic density ranged from 198 kg/m³ to 265 kg/m³ for clone 112 in vitro (*P. fortunei* × *P. elongata*) at 9 years of age, cultivated in Spain, and Cotevisa 2 at 7 years of age, also in Spain, respectively. With similar ages, the hybrids Cotevisa 2 and Shan Tong showed very similar basic density values to each other and to the variety *P. fortunei* var. Mikado (Table 3).

The normal density (density at 12% moisture content) ranged from 210 kg/m³, recorded for the Shan Tong clone at three years of age in Poland, to 370 kg/m³ for *P. fortunei* cultivated in Iran, whose age was not specified. The anhydrous density (density at 0% moisture content) showed values between 215 kg/m³ for the clone 112 in vitro at nine years of age in Spain, and 285 kg/m³ for the clone Cotevisa 2 at seven years of age, also in Spain (Table 3). Although clones 112 in vitro and Cotevisa 2 both originate from hybridization between *P. fortunei* and *P. elongata*, significant differences in density can be attributed to the distinct genetic selection processes and commercial objectives of each clone. The

Table 3 Wood density of *Paulownia fortunei* and hybrids

Species/hybrid	Age	Local	Normal density(kg/m³)	Anhydrous density (kg/m³)	Basic density (kg/m³)	Author
Paulownia fortunei	10	Australia	–	260	–	Beel et al. (2005)
Paulownia fortunei	–	Iran	370	–	–	Akhtari et al. (2012)
Paulownia fortunei L.	5	Iran	291	261	242	Kiaei (2013)
9501 ((*Paulownia fortunei* × *Paulownia elongata*) × (*Paulownia fortunei* × *Paulownia tomentosa*))	4	Croatia	–	249	233	Sedlar et al. (2020)
Shan Tong (*Paulownia fortunei* × *Paulownia tomentosa*)	4	Croatia	–	237	220	Sedlar et al. (2020)
Paulownia fortunei	–	Malaysia	325	–	–	Latib et al. (2020)
112 in vitro (*Paulownia fortunei* × *Paulownia elongata*)	9	Spain	231.6	215.1	198.3	Koman and Feher (2020)
Cotevisa 2 (*Paulownia elongata* × *Paulownia fortunei*)	5	Spain	270	233	216	Lachowicz and Giedrowicz (2020)
Shan Tong (*Paulownia fortunei* × *Paulownia tomentosa*)	3	Poland	–	246	–	Kozakiewicz et al. (2020)
Oxytree Clone (*Paulownia elongata* × *Paulownia fortunei*)	–	China	249	–	–	Mania et al. (2022)
Shan Tong (*Paulownia fortunei* × *Paulownia tomentosa*)	3	Poland	210	–	–	Tomczak et al. (2023)
Cotevisa 2 *(Paulownia elongata* × *Paulownia fortunei*)	7	Spain (Valencia)	–	285	265	Fos et al. (2023)
Paulownia fortunei var. Mikado	4	Brazil	262	238	218	Corrêa et al. (2024)

Anhydrous density: density at 0% humidity; Normal density: density at 12% humidity

in vitro clone 112 was developed by the Spanish company In Vitro SL, focusing on the production of a sterile, fast-growing variety adapted to the European climate, aiming at the production of lightweight wood (In Vitro 2023). On the other hand, the Cotevisa 2 clone was the result of more than a decade of genetic improvement conducted by the company Cotevisa, also in Spain, intending to obtain a highly productive variety, resistant to cold and drought, and with higher density and quality wood for industrial use (iPaulownia 2023). These differences in the development process explain the higher density values observed for Cotevisa 2, when compared to the in vitro clone 112, despite both sharing the same hybrid origin.

Samples collected at breast height tend to be denser than samples from the soil section. Tomczak et al. (2023) observed, for three-year-old trees in Poland, densities between 193 and 210 kg/m³ for samples collected at the base of the trees and 229 kg/m³ for samples collected at breast height. Besides the sampling position, another factor influencing density is the proportion of juvenile and adult wood. Fos et al. (2023) noted, for the Cotevisa 2 clone, a considerable difference (41 kg/m³) between the density of the first four annual rings and the fifth and sixth rings.

In general, the density values reported for *P. fortunei* and its hybrids are considered low, which was expected since these are fast-growing species. This characteristic is associated with anatomical features, such as a smaller proportion of cell walls and a greater presence of lumen in the fibers, in addition to the high incidence of parenchyma cells, resulting in lighter and more porous structures.

Due to its low density and consequent high porosity, the maximum moisture content also tends to be high. *P. fortunei* cultivated in Iran showed a maximum moisture content of 349.72% (Kiaei 2013), while the Cotevisa 2 clone, cultivated in Spain, showed values of over 400%, especially in the 1st ring, and a gradual and significant decrease to values between 317% and 308% in the 5th and 6th rings, respectively (Fos et al. 2023).

Aiming to increase the density of *P. fortunei* wood, the study conducted by Mania et al. (2022) investigated a thermal densification process using ammonia plasticization followed by compression pressing. This technique promoted a structural reorganization of the cell walls, resulting in an increase of over 180% in wood density compared to the control sample. The results demonstrate the potential of physical modification as an alternative to broaden the range of applications for *P. fortunei* wood, especially in contexts requiring higher density and mechanical strength.

Table 4 presents the main results regarding the dimensional stability of *P. fortunei* wood and its hybrids. Tangential and radial shrinkage ranged from 4.9% to 5.7% and 1.9% to 3.2%, respectively. Volumetric shrinkage ranged from 6% for *P. fortunei* at 10 years to 8.5% for clone 112 at 9 years and *P. fortunei* var. Mikado at 4 years, which showed the same value.

The influence of radial position on the dimensional stability of wood has been reported, with significant variations between growth rings. Tangential shrinkage showed the highest value in the first ring (5.9%), progressively decreasing until the fifth and sixth rings, with 4.5% and 4.4%, respectively. Radial shrinkage maintained lower values in the first four rings (2.1%–2.4%), increasing in the last two to 2.7% and 2.9%. Volumetric shrinkage followed a similar pattern, with the highest value in the first ring (8.4%), reducing to 7.4% in the second and stabilizing around 7.2% until the sixth ring (Fos et al. 2023). It should be noted that the values presented in Table 4 for the Cotevisa 2 clone, cultivated in Spain at seven years of age, correspond to the average of these data.

The wood of *P. fortunei* and its hybrids exhibits low total shrinkage values in individual anatomical directions, reflecting its low tendency for volumetric shrinkage during the drying process. This characteristic results in minimal volume reduction between green and dry wood, favoring industrial yield and reducing losses during processing.

Table 4 Stability of wood *Paulownia fortunei* and hybrids

Species/hybrid	Age	Local	Volumetric contraction (%)	Tangential contraction (%)	Radial contraction (%)	Author
Paulownia fortunei	10	Australia	6	–	–	Beel et al. (2005)
Paulownia fortunei L.	5	Iran	7.45	–	–	Kiaei (2013)
9501 ((*Paulownia. fortunei* × *Paulownia. elongata*) × (*Paulownia fortunei* × *Paulownia tomentosa*))	4	Croatia	7.62	4.95	2.35	Sedlar et al. (2020)
Shan Tong (*Paulownia fortunei* × *Paulownia tomentosa*)	4	Croatia	7.81	5.30	2.47	Sedlar et al. (2020)
112 in vitro (*Paulownia fortunei* × *Paulownia elongata*)	9	Spain	8.5	5	3.2	Koman and Feher (2020)
Cotevisa 2 (*Paulownia elongata* × *Paulownia fortunei*)	5	Spain	7.23	5.19	1.99	Lachowicz and Giedrowicz (2020)
Cotevisa 2 (*Paulownia elongata* × *Paulownia fortunei*)	7	Spain	7.6	4.9	2.5	Fos et al. (2023)
Paulownia fortunei var. Mikado	4	Brazil	8.5	5.7	2.5	Corrêa et al. (2024)

Based on the relationship between tangential and radial shrinkage, it is possible to calculate the anisotropy coefficient, an indicator of the dimensional stability of wood during the drying process. According to Koman and Feher (2020), clone 112 presents a favorable coefficient of 1.6, lower than that of many tree species, which represents an advantage in terms of drying quality and less tendency to deformation. In contrast, clone Cotevisa 2 presented an anisotropy coefficient of 2.72, as reported by Lachowicz and Giedrowicz (2020), indicating a greater difference between shrinkages in anatomical directions. Although tangential shrinkage was similar between clones, radial shrinkage was lower in Cotevisa 2, which increased the disparity between directions and raised the coefficient. However, according to Fos et al. (2023), the anisotropy coefficient in clone Cotevisa 2 decreases progressively with the growth rings, from 2.7 in the first ring to 1.6 in the sixth, suggesting an improvement in dimensional stability with advancing cambial age.

Regarding the hygroscopic behavior of wood, Tomczak et al. (2023) evaluated the dimensional swelling of the Shan Tong clone cultivated in Poland. The results indicated variations according to the anatomical direction: 0.28% in the longitudinal direction, 1.99% in the radial direction, and 5.67% in the tangential direction.

The mechanical properties of wood are important for its use in solid products and determine whether a material is suitable for structural uses. Table 5 shows the results for the mechanical properties of *P. fortunei* and its hybrids, obtained from the analyzed articles. It can be observed that the modulus of elasticity (MOE), which can be understood as the stiffness of the wood, varied from 3129 MPa for *P. fortunei* var. Mikado, cultivated in Brazil at 4 years old, to 5153 MPa for the Cotevisa 2 clone at 5 years old, in Spain. Furthermore, clone 112 growing in Spain showed an MOE very close to that of *P. fortunei* wood cultivated in Iran. The Cotevisa 2 clone from Spain, however, showed a value more similar to *P. fortunei* wood from Malaysia (Table 5). In a complementary study, the three-year-old Shan Tong variety from Poland showed an MOE of 4050 MPa evaluated by the non-destructive ultrasound method (Kozakiewicz et al. 2020).

All the studies analyzed presented the MOE and MOR values in the static bending test, except for Tomczak et al. (2023), who, evaluating the properties of the three-year-old Shan Tong hybrid using microtome samples, found a higher MOE value in the tensile test parallel to the fibers for the breast height region (3025 ~ 3034 MPa) compared to samples from the base of the trees (2049 ~ 2147 MPa).

The modulus of rupture (MOR) ranged from 21.8 MPa to 47 MPa, with higher values observed for *P. fortunei* wood from Malaysia, followed by the same species growing in Iran. The lowest value was observed for wood from Brazil. Regarding compression parallel to the grain, the values showed a wide variation, ranging from 14 MPa to 33 MPa, observed in *P. fortunei* wood grown in Brazil and Iran, respectively. While shear, also parallel to the grain, ranged from 3.8 MPa to 8 MPa, with the lowest value for *P. fortunei* growing in Brazil, which even presented a value very close to clone 112 with a higher age, and the highest value was recorded for *P. fortunei* from Malaysia (Table 5). As for hardness, values between 500 N and 2877 N were observed; however, the lowest value observed for *P. fortunei* from Australia may be associated with the adapted method used in the study by Beel et al. (2005), while the highest value was observed for clone MB04 (*P. tomentosa* x *P. fortunei*) originating from China.

In general, the species *P. fortunei* exhibits low mechanical properties due to its low density, and hybrids follow the same trend. As with other wood species, *P. fortunei* and its hybrids tend to show a positive correlation between density

Table 5 Mechanical properties of wood *Paulownia fortunei* and hybrids

Species/hybrid	Age	Local	MOE (MPa)	MOR (MPa)	Compression (MPa)	Shear (MPa)	Hardness (*N*)	Author
Paulownia fortunei	10	Australia	–	–	–	–	500[1]	Beel et al. (2005)
Paulownia fortunei	–	Iran	3882.5	40.4	33.17	–	2600	Akhtari et al. (2012)
Paulownia fortunei L.	5	Iran	3740	41.07	14.61	–	–	Kiaei (2013)
Paulownia fortunei	–	Malaysia	5145	47.25	26.48	8.10	1960	Latib et al. (2020)
112 in vitro (*Paulownia fortunei* × *Paulownia elongata*)	9	Spain	3800	32.3	19.9	4.0	–	Koman and Feher (2020)
Cotevisa 2 (*Paulownia elongata* × *Paulownia fortunei*)	5	Spain	5153.3	38.6	24.7	–	–	Lachowicz and Giedrowicz (2020)
9501 ((*Paulownia. fortunei* × *Paulownia. elongata*) × (*Paulownia fortunei* × *Paulownia tomentosa*))	5	China	–	–	–	–	1923	Feng et al. (2020)
MB04 (*Paulownia tomentosa* × *Paulownia fortunei*)	5	China	–	–	–	–	2877	Feng et al. (2020)
Paulownia fortunei var. Mikado	4	Brazil	3129	21.80	14.20	3.80	1029	Corrêa et al. (2024)

[1]Janka hardness adapted method. MOR and MOE values refer to the static bending test

Table 6 Processing operations applied to *P. fortunei* wood and its hybrids

Species/hybrid	Age	Local	Operation	Author
P. fortunei	10	Australia	Sawing, drying, machining, gluing, and finishing	Beel et al. (2005)
P. fortunei	15	Iran	Drying	Taghiyari et al. (2014a)
P. fortunei	15	Iran	Drying	Taghiyari et al. (2014b)
P. fortunei	-	Malaysia	Machining, gluing, and finishing	Latib et al. (2020)
BIO125 (*Paulownia elongata* × *Paulownia fortunei*)	6	Italy	Veneer production/ lamination	Nocetti et al. (2025)
P. fortunei	6–8	Iran	Veneer production/ lamination	Sedighizadeh et al. (2023)

and the mechanical properties of the wood. For example, the Shan Tong hybrid growing in Poland showed a strong positive correlation between density and MOE (0.75) and maximum strength in the parallel tensile test (0.54) (Tomczak et al. 2023).

Regarding wood modification, Akhtari et al. (2012) investigated the effects of impregnation with aqueous nanofluids of silver, copper, and zinc oxide on the mechanical properties of *P. fortunei*. The results showed that MOR, MOE, and parallel-grain compression strength increased in all cases, but it should be noted that the increase was not statistically significant in the case of MOE and parallel compression, and that for the hardness property, the best performance was obtained for the control, showing that depending on the end use of the wood, impregnation with these nanofluids may not be beneficial. Mania et al. (2022) evaluated the Brinell hardness of wood from Clone Oxytree (*P. elongata* x *P. fortunei*) growing in China and found values of 10.61, 5.63, and 5.46 for the longitudinal, tangential, and radial directions, respectively. After densification of the wood with ammonia plasticization and pressing, the values increased to 41.55, 22.51, and 20.51.

3.5 Features in unfolding, drying, machining, finishing, and gluing operations

In relation to the behavior of *P. fortunei* wood and its hybrids in sawing, drying, machining, finishing, and gluing operations, few studies were found (Table 6). The only reported sawn timber yield is 55% of the green log volume, obtained by Beel et al. (2005). High yields are expected for this species due to the regular shape of the logs and the low density, which facilitates cutting. However, the near absence of research on this stage of solid wood processing is one of the main gaps identified in this review.

Regarding drying, Beel et al. (2005) classified the wood in Class "E" of AS/NZS 4787:2001 after using a conservative schedule, indicating suitability for uses in which dimensional movement should be minimized. Taghiyari et al. (2014a, b) did not evaluate post-drying quality but rather its permeability, concluding that mild schedules (T6E3) and high initial moisture contents (>60%) favor impregnation processes. Despite the relevance of these findings, sample-size limitations and the absence of analyses on the effects of drying schedules on wood properties prevent conclusions applicable to industrial practice.

Regarding machining, *P. fortunei* shows good performance in cutting, planning, sanding, and drilling operations, although it requires sharp tools and high cutting speeds (Beel et al. 2005). In the planning test (15° cutting angle; 0.8 mm feed), about 90% of the samples were classified as Grades 1 and 2 under ASTM D1666, with minimal defects, and the fuzzy grain, typical of low-density woods, was easily removed by sanding (Latib et al. 2020). The species also showed 19% of samples classified as Grade 1 in the molding test and intermediate performance in drilling, with an average force close to 1.6 N, indicating adequate fastener-holding capacity (Latib et al. 2020).

In gluing tests, *P. fortunei* showed 100% wood failure when bonded with PVA adhesive, indicating excellent adhesion (Beel et al. 2005). Latib et al. (2020) also reported high shear strength (16.1 N/mm²) and 98% wood failure, demonstrating good structural cohesion. However, the behavior with other adhesives has not yet been investigated.

Regarding finishing, the best appearance was achieved with transparent coating, while staining resulted in a blotchy surface (Beel et al. 2005). The tape pull-off strength was 2.19 N/mm² for varnish and 1.72 N/mm² for paint; the lower density and higher porosity explain the reduced gloss and the need for additional coating layers (Latib et al. 2020).

In lamination, Nocetti et al. (2025) reported that the hybrid *P. elongata* × *P. fortunei* (BIO125) requires greater veneer thicknesses (1.5–2.2 mm) compared with poplar due to cracking associated with the porous growth ring. The veneers showed good overall quality despite the high incidence of cracks (54%). Sedighizadeh et al. (2023) produced 2 mm veneers dried at 120 °C to 6±1% moisture content, but no normative quality classification was performed, as the study focused on panel production.

3.6 Wood applications

P. fortunei has a long history of use in Asia in furniture, musical instruments, decorative moldings, ceremonial objects, and lightweight items such as boxes, linings, and

shoe heels (Yadav et al. 2013; Stuepp 2013). Over time, its applications have expanded to carved objects, utensils, plywood, pulp, and paper products (Latib et al. 2020; Snow 2015; Nocetti et al. 2025). Its low density, dimensional stability and good machining behavior further reinforce its suitability for lightweight solid wood products.

Recent studies highlight the promising performance of the species and its hybrids for both traditional and modern uses. Kozakiewicz et al. (2020) showed that clones cultivated in Poland exhibit acoustic properties suitable for musical instruments. In the pulp and paper industry, research from India, Spain, and Iran reports good delignification and high pulp yield, although higher extractives and lignin contents may increase chemical demand. Blending with long fibers is generally recommended (Rai et al. 2000; Jiménez et al. 2005; Hosseini and Afra 2005; Kiaei 2013; Ashori and Nourbakhsh 2009; Kulak et al. 2024). Caparrós et al. (2007, 2008) reported satisfactory performance in organosolv pulping, and the trihybrid *P. fortunei* × *P. tomentosa* × *P. elongata* showed adequate strength and viscosity in both organosolv and alkaline pulps for lightweight papers (García et al. 2011; Franscisco et al. 2010).

The technological potential of *P. fortunei* for solid wood applications is further supported by its behavior in sawing, drying, machining, gluing, and finishing, although these processes have been addressed in relatively few studies. Beel et al. (2005) recommended the wood for wall and ceiling coverings, decorative moldings, blinds, doors, windows, and substrates for veneered components such as table tops. Latib et al. (2020) reported good performance in shaping, planing, and bonding, supporting its use in lightweight furniture, curved pieces, and glued components. Koman and Feher (2020) also emphasized its potential in the packaging sector due to its low density.

For panel products, low density and favorable pH provide advantages for adhesion. Salari et al. (2012) confirmed its suitability for OSB and reported mechanical improvements through the addition of nano-SiO_2. Nocetti et al. (2025) produced mixed plywood panels combining poplar and hybrid paulownia, which maintained adequate mechanical performance while reducing weight. Sedighizadeh et al. (2023) developed flexible plywood with high bending resistance, and Bayatkashkoli and Faegh (2014) observed improvements in OSL and LSL properties after incorporating nanoclay.

The Cotevisa 2 clone shows potential for sawmilling, veneer and plywood production, packaging, insulation, furniture and appliance components, and wood-based panels (Fos et al. 2023; Lachowicz and Giedrowicz 2020). Its low density, however, limits structural applications (Lachowicz and Giedrowicz 2020; Kiaei 2013). Fos et al. (2023) recommend cutting cycles of at least 10 years to improve log quality and industrial yield, which is particularly relevant for solid wood applications.

4 Research gaps and limitations of current knowledge

The integrated analysis of the studies reveals significant gaps in the literature on *P. fortunei* and its hybrids. Most research relies on very young material: anatomical and chemical properties are typically evaluated in trees between 1 and 6 years old, physical and mechanical properties in trees between 3 and 10 years old, and processing-related analyses in trees between 6 and 15 years old. This heterogeneity in age among studies addressing complementary wood properties limits the possibility of establishing robust correlations. The predominance of juvenile wood further affects anatomical and chemical traits, as well as density, shrinkage, mechanical properties, and permeability, making it difficult to establish consolidated technological parameters.

Moreover, investigations have been conducted under highly diverse environmental conditions, including Europe, Asia, and the Middle East, introducing substantial genetic and climatic variation into the results. Considerable differences are also observed in the methodologies applied to anatomical, chemical, and mechanical characterization, along with a lack of standardization in drying and machining procedures, which hinders direct comparison among studies. Finally, there is a scarcity of research evaluating the technological performance of the species in solid wood products, particularly regarding sawmilling, industrial drying, machining, gluing, finishing, and panel behavior.

5 Conclusion

This systematic review allowed us to synthesize and analyze the available knowledge on the technological properties of *Paulownia fortunei* wood and its hybrids, as well as its performance in industrial operations and its potential applications. The main conclusions of this review are as follows:

1. Regarding the properties of wood, the literature converges on low density values, high porosity, and an anatomical structure typical of light hardwoods, conditions that favor rapid drying, good workability, and ease of machining, but limit mechanical performance for structural uses.
2. Regarding performance in industrial operations, *P. fortunei* wood exhibits satisfactory behavior in the sawing, drying, planning, shaping, and gluing stages, resulting in good-quality surfaces. In engineered composites,

performance is limited by their low density, but can be improved through nanostructured reinforcements, adhesive modifications, and hybrid configurations with other species.

3. Regarding applications, evidence points to the use of *P. fortunei* in lightweight, higher value-added products such as furniture, decorative components, packaging, mixed plywood, musical instruments, and insulation. In the pulp and paper industry, various studies confirm its potential as an alternative raw material, although blending with long fibers is recommended to optimize strength properties.

Overall, this review indicates that, although there is a growing body of studies on *P. fortunei* wood, important limitations remain, particularly related to methodological variability, the diversity of genetic materials, and the predominance of juvenile wood, often derived from very young trees. These factors, combined with differences in testing procedures and the lack of standardized protocols, hinder the establishment of consistent and comparable technological parameters. Finally, the importance of factors such as rotation age, genetics, and growth conditions is highlighted, as they significantly influence wood quality. Future research should prioritize the standardization of testing methods, the evaluation of hybrids or commercial varieties at ages representative of industrial use, and the development of applications that strategically exploit the low density and high workability of the species. In addition, aspects such as sawmilling, industrial drying, machining, finishing, gluing, and performance in solid wood panels remain underexplored, highlighting the need for further studies to support the development of more efficient and industry-relevant production chains.

Author contributions CAC, ABC, and MAB came up with the idea for the article; CAC, SSS, TFC, TMR, GOS, and LLR conducted the literature search and data analysis; CAC wrote the paper; and HCV, PDR, and ABC critically reviewed the work.

Funding The Article Processing Charge (APC) for the publication of this research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) (ROR identifier: 00x0ma614).

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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