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Research article

Property Comparison of Different Standard Wood Pallets for Possible Local Sourcing

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Abstract

The global expansion of freight transport across business types has impacted supply chain logistics in terms of coordinating the storage and delivery of goods and services across the supply chain. Wooden pallets are in high demand due to their price and environmental impact; however, the wood raw materials needed for making pallets are in short supply. This research was aimed at analyzing the possibility of using local wood instead of imported wood in the production of standard industrial pallets. Industrial pallets were designed using local acacia wood to replace some or all of the imported Radiata pine. This local acacia wood was utilized to prepare and construct pallets of the standard dimensions that were in accordance with the designs. Pallets made from the same type of wood and mixed woods were heat treated to meet the criteria of the ISPM 15 protocol for export. Flat pallet testing was conducted in accordance with industrial standards for the evaluation of the finished products. All types of pallets, including pallets containing local wood components, showed no visible damage during drop tests and compression strength assessments. However, the variability in diagonal span rates was influenced by the wood used in the fabrication process. Pallets frabricated from both partial and full acacia wood exhibited increased bending rates of 2081 and 2650 MPa, respectively, due to the higher levels of cellulose and lignin found in acacia wood. Our research suggests that there is an opportunity to manufacture standard pallets using locally sustainable wood resources, with some modifications to current industrial processes required.

Keywords: acacia; industrial process; process management; radiata pine; standard pallet; wooden pallet

1. Introduction

Freight transport forwarding continues to increase in line with global business growth. Logistic services in supply chain management provide international and domestic air, sea, and land freight services. These services cover a wide range of businesses including warehouses and distribution centers. Goods distribution and freight transport require

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pallets as a base for utilizing goods for packaging, warehousing, protection, and transportation in the supply chain (Bilbao et al., 2011; Handoko et al., 2021). Therefore, pallets play an important role in the business transportation process. Coherent Market Insights (2023) publish a report stating that the global pallet market size was valued at $57.4 billion in 2010 and is expected to reach $130.5 billion by 2032. The pallet market size in Asia is expected to surge at a CAGR of 5.8% over the forecast period of 2023-2030. The Asian pallet industry has grown at a compound annual rate and is projected to continue growing strongly over the next ten years. According to the latest estimates, there exist significant growth opportunities, and market is estimated to expand by about 1.9 times current volume (Future Market Insights, 2023). Furthermore, the expansion of e-commerce has had an impact on the flow and cost of goods and thus on supply chain logistics. Pallets play an important part in the supply chain; thus, the growing demand for pallets for e-commerce-based logistics has led to pallet market growth (Mynewsdesk, 2021). At present, the use of wooden pallets has been increasing as their use is consistent with eco-friendly business approaches. However, other features such as strength, lightness, and price also affect the customer decisions about pallet material.

A pallet is an upright support platform that helps move goods in a safe manner. Pallets are a necessary part of business performance (Handoko et al., 2020), with three main objectives associated with their use, i.e. product protection; versatility in storage, and flexibility in product distribution (Karaçali & Ulguel, 2014). Pallet types can be classified by user applications, region, key market players, and material composition. However, material composition and design directly affect their user applications. Pallets can be made of a range of materials including wood, plastics, steel, etc. Wooden pallets are in high demand in the market because they are inexpensive. Moreover, they are easy to manufacture and repair compared to plastic pallets (Leblanc, n.d.). A wooden pallet is made from renewable biomass which refers to resources that have the capacity to naturally regenerate over time, making them sustainable for continuous use. Wooden plant resources are categorized as either softwood or hardwood based on the wood species and their specific physical and chemical compositions. Softwoods such as Douglas fir, pine, yew, and spruce are more commonly used in the manufacture of wooden pallets than hardwoods such as maple, oak, teak, mahogany, and walnut.

In the pallet market, the wood pallet sector is expected to generate the most revenue, while injection-molded plastics are expected to account for the highest share by material (Allied Market Research, 2023). The use of softwood or hardwood in the construction of pallets can be determined by a number of factors including the product, budget, availability, and location. Choosing a softwood does not automatically indicate a lower-quality product because pine is suitable for many uses, and choosing hardwood does not consistently indicate a higher cost. In Asia, standard pallets are produced from Pine radiata woods (*Pinus radiata*) in the form of a four-way entry pallet with dimensions of 1000 x 1200 mm, which are usually used in warehousing, transport, and product handling processes in the supply chain (Mead, 2013).

Nowadays, lumber prices have increased in recent years due to a number of factors, for example, the fluctuation of transportation costs and demand. This encompasses a rise in demand from China and other emerging nations, along with a reduction in the availability of wood (Expert Market Research, n.d.). Consequently, the production of customized wooden pallets has become more challenging and costly. The rising price of wooden pallets has had a huge impact on businesses. It has also made it harder to get the required pallets, which has led to delays in transportation and delivery and has made transportation more expensive, resulting in higher costs and lower profits.

The Thai National Shippers' Council as same as many other countries has chosen wooden pallets as the packing material of choice for export-oriented industries due to their durability for heavy shipments and due to them being of lower cost than plastic pallets (Rey et al., 2013). Pine wood is the main raw material used in Thailand's wooden pallet industry, and it is used to make standard pallets. It belongs to the Pinaceae family of pine trees. *Pinus radiata* grows quickly and has wood of medium-density. Because of limited local supply, about 60% of the wooden pallets produced in Thailand are made from pine imported from numerous countries in the world, but mainly from America, Finland, Sweden, Brazil, Russia, Australia, and New Zealand (Mead, 2013, Wattanasiriseth & Krairit, 2019; Rey et al., 2013). Additionally, the wood is a higher premium grade softwood, making it suitable for many applications, and the wood can be used as a material for home building and furniture making, depending on consumer needs. Because of this situation, Radiata pine wood prices and shipping costs are high, and the material is insufficient supply in some cases (Rey et al., 2013). To substitute imported wood in wooden pallets with locally sourced wood would be a benefit to local business. Wattanasiriseth & Krairit (2019) propose that the use of para rubber wood as an alternative primary wood for pallet production. However, due to the high price of native para rubber wood and logging, along with stringent regulations to preserve forest conservation, Thai pallet manufacturers rely on imports of tropical and temperate hardwoods to meet their business demand (Rey et al., 2013; Mead, 2013).

Earleaf acacia (*Acacia auriculiformis*) is a significant fast-growing tree in the Fabaceae family when planted according to its provenance (Harwood et al., 2015). It is an evergreen perennial plant that can be grown to create cover in degraded forest areas as part of forest management and is utilized to address global warming and energy issues (Kull et al., 2011). Acacia plants are globally important resources in the wood business, particularly in Southeast Asian countries, where they are utilized as a significant resource in global furniture production and in the pulping industries, and are essential to the wood industry (Huong et al., 2020; Viet et al., 2021; Haque et al., 2021). *Acacia auriculiformis* is an economic wood in Thailand that is suitable for use in the promotion of forest-based business due to the fact that it grows rapidly in every part of the country. Acacia plants are grown in Thailand and other Southeast Asian countries for utility wood manufacturing, especially for the furniture and pulp industries (Luangviriyasaeng, 2001). Ideally, it should be possible to replace or combine imported wood in wooden pallets with locally sourced wood, effectively eliminating or reducing supply shortages and the higher costs resulting from wood importation or wood from natural forests. Raw material inventory management is one of the key issues related to industrial production schedules and smooth delivery. Proper management of raw materials affects customer satisfaction as well as increases financial efficiency.

Different plant species have specific chemical biomaterial content in their woods, which affect physical properties such as strength and elasticity. Wood is made up of natural polymers of cellulose fibers (cellulose and hemicellulose) held together by lignin. The understanding of the chemical composition of wood is important for promoting the economic uses of wood from forest tree species (Nirsatmanto et al., 2017). Therefore, in this research, we proposed using local wood (Earleaf acacia) as an alternative wood to replace imported wood (pine). This study utilized local and imported wood timbers as bio-based resources to make wooden pallets. The local and imported woods were cut and assembled into pallet individually or as mixed woods. The assembled pallets were tested for quality according to industry standards to ensure their suitability for commercial use.

2. Materials and Methods

2.1 Raw materials

The local wood, (Earleaf acacia: *A. auriculiformis*), was used as a raw material to replace imported wood, (Radiata pine: *P. radiata*). The process of pallet production using local and imported woods as raw materials was performed according to industrial processes.

2.2 Strip preparation and pallet assembly

Pine was imported as timber that had already been undergone preservation, while acacia was locally transferred as logs into the industrial pallet plant. The pine wood and acacia wood were cut in dimensions (Thickness x Width x Length; 100 x 150 x 4800-6000 mm) using an industrial band saw machine (locally produced). The strips from local wood were deeply impregnated with CELBOR SP®, a boron-based wood preservative, under vacuum pressure conditions, for eliminating insect and fungi. The strips were cut into wooden pieces used to make pallets, depending on the pallet design. A thickness planer machine (Bigwood®, PL-400 model) was used to produce a board that was uniform in thickness along its entire length and smooth on both surfaces. The size parameters are shown in Figure 1. The size of these pallets was Width x Length x Height; 1200 x 1000 x 156 mm, and the pallets had 4 entry points. The wooden pieces were assembled into universal standard pallets using the Storti® system (GSI 150 AL model). Pallets were composed of the same kind of wooden pieces and mixed wooden pieces. A mixed pallet consisted of 6 pieces of pine and 5 pieces of acacia (size 90 x 22 x 1000 mm) forming the top deck, 2 pieces of acacia (size 120 x 22 x 1000 mm) and 3 pieces of pine (size 90 x 22 x 1000 mm) forming the bottom deck. This mixed pallet consists of six units of acacia wood blocks with dimensions of 90 x 90 x 200 mm, in addition to three units of acacia blocks with dimensions of 90 x 90 x 150 mm.

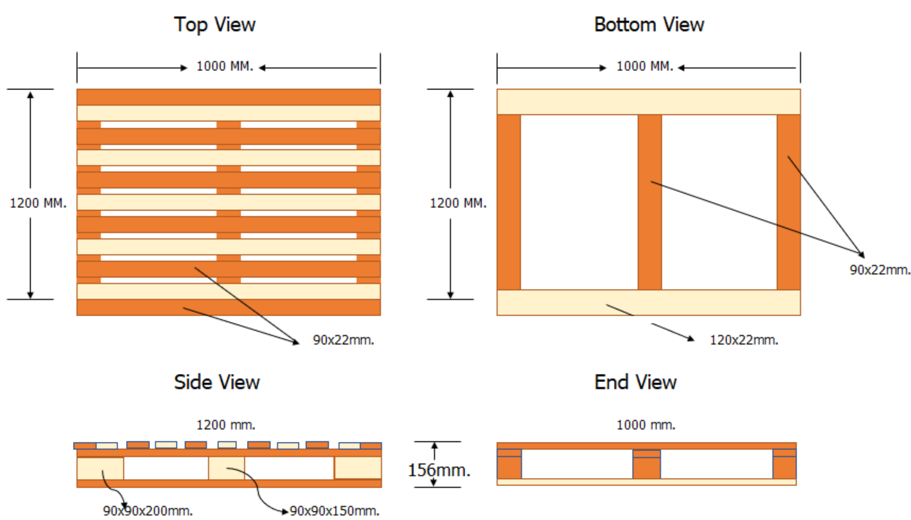

Figure 1. Pallet design and wood compositions. Orange bars are pieces of pine, yellow bars are pieces of acacia.

These prefabricated pallets were heat treated by raising the temperature in an industrial heat chamber to 70°C and methyl bromide fumigation was performed following the guideline of the International Plant Protection Conventions (IPPC) to remove wooden moisture and eliminate microorganisms (Barak et al., 2005). The dimensions, weight, and moisture content of these pallets were documented both pre and post thermal processing.

Images of the wood materials used in the creation of the pallet were depicted,using digital camera. Detailed visual depictions of the wood grain patterns were documented on each flat surface for further examination. Furthermore, the origins of the research data pertaining to these different types of timber were thoroughly scrutinized and organized according to their classification, biomaterial composition, and physical characteristics.

2.3 Industrial quality test of finished products

The fabricated pallets with three replicates underwent standardized procedures for flat pallets (JIS Z 0603-1988). Pallet drop test was executed at a drop height of 0.5 m. The diagonal measurement of each pallet was documented both before and after the drop test. The percentage change in the diagonal measurement, known as the rate of diagonal variation, was then calculated and recorded. Assessments of the pallet's compression and bending strength were performed at a compression speed of 12.7 mm/min. The application of compression load was evenly distributed across the entire upper surface of the pallet. The maximum allowable compression strength capacity specified in the standard testing protocol is 8500 kilograms-force (kgf). For bending strength test, load was applied to a supported wooden pallet to determine its bending capacity and rigidity. Data on the applied force during testing were captured at the maximum bending stress point. The testing protocols were implemented in a controlled environment set at a temperature of 23±2ºC and a relative humidity of 50±5%. Test data was analyzed in relation to chemical composition.

3. Results and Discussion

The different sources of raw materials affect the quality, price and transportation cost of pallets. Moreover, specific characteristics of raw materials affect management in the pallet production process at the industrial level. Different sources of wood raw materials were fed into the pallet production process (Figure 2). The moisture contents of imported woods arriving at the factory are variable and depend on the environmental conditions associated with each shipment, while the moisture levels of local raw materials to the factory also fluctuate in accordance with the prevailing environmental conditions. Nevertheless, the moisture content of the wooden strips gets reduced in accordance with industrial procedures.

In the scenario of timber that has been imported, it undergoes a procedure for the elimination of microbes at the location prior to its export to foreign countries and subsequent delivery to manufacturing facilities in the designated nation for the purpose of transformation into lumber and strips. On the other hand, local woods are delivered to the industrial plant in the form of logs, and subsequently transformed into lumbers and strips. The handling process of local wood strip has an extra process that involves treatment with a wood preservation prior to being cut for pallet assembly. The procedure for cutting into strips is the same for local and imported wood. The construction of pallets follows established patterns that are commonly employed in the Asian region.

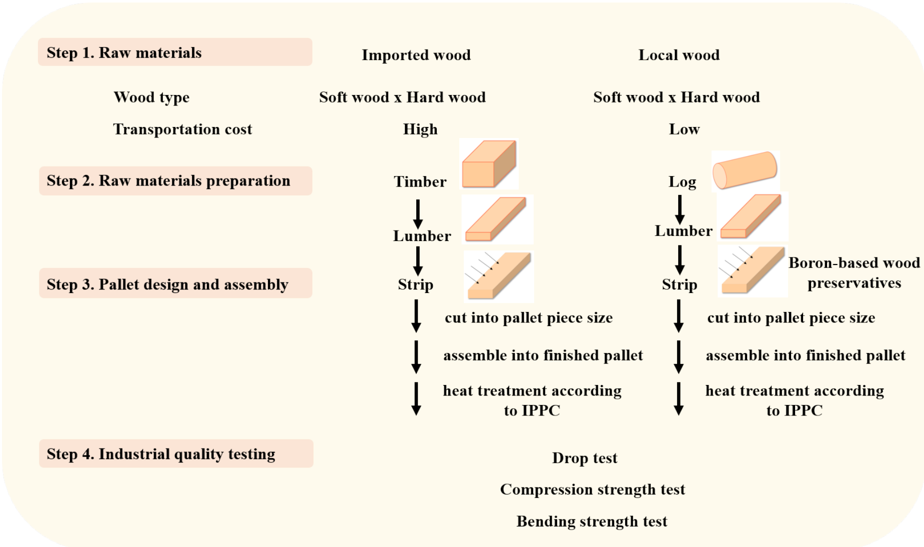

Figure 2. Comparative production process management of pallets assembled from imported and local woods

Wood planks were used for the assessment of wood grain characteristics, and the results are presented in Figure 3. The arrangement of wood fiber in specific plant species depend on their genetic controls and environmental regulation during plant growth and development. These factors affect the specific wood grain patterns. The heartwood of Radiata pine displayed a light brown hue and possessed a straight wood grain, with a texture that was characterized as medium and uniform. The end grain of the pine plank revealed medium-large resin canals, while the tracheid diameters were medium-large.

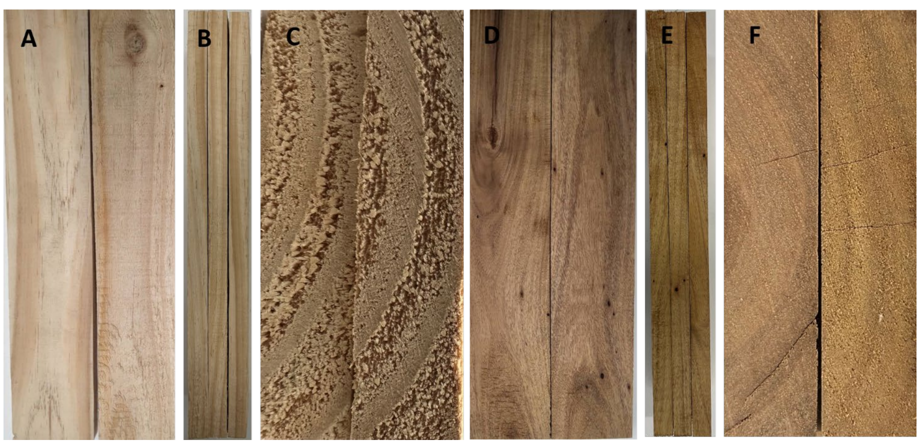

Figure 3. Wood grain of planks derived from Radiata pine and Earleaf acacia woods; A, D: plank surface (plain grain), B, E: length edge (quarter grain), C, F: width edge (end grain)

Acacia heartwood possesses a dense and durable characteristic. It exhibited an even texture and contained tinny wood pores on its surface resulting in a medium to coarse wooden grain. The grain pattern of acacia had the potential to display variations between straight and wavy patterns, while the color spectrum may encompass shades from light brown to reddish-brown. Radiata pine wood had longer and thicker fibers than Earleaf acacia, as shown in the cut edge (Figure 3C&F).

Earleaf acacia wood contained more cellulose and hemi-cellulose and less lignin than Radiata pine, while Radiata pine had a higher proportion of extractives (Table 1). Radiata pine softwood was imported from a high humidity area, and thus the moisture content of the wood was rather higher than Earleaf acacia hard wood. The industrial process of pallet manufacturing employs heat treatment to diminish the moisture content of the wood, and the strength of the wood depends on biomaterial compositions and the arrangement of their structure. The wooden composition of Earleaf acacia is denser compared to that of Radiata pine. The strength of the wood is influenced by the structure and quantity of cellulose fibers. The vessel elements play a role in the pores on the surface of Earleaf acacia. These substances cause the wood to darken, resulting in the distinct color and grain pattern of its species. Furthermore, they have an impact on its strength, flexibility, and hardness. As the sap dries up, mineral compounds known as extractives develop on the cell walls, the extractive content in Radiata pine is higher than that in Earleaf acacia.

Table 1. Biomaterial composition and physical properties of raw material woods

Composition and Properties	Radiata Pine	Earleaf Acacia	Reference
Biomaterial compositions	40% Cellulose 31% Hemicellulose 27% Lignin 2% Extractive 0.2 Ash	66% Cellulose 31% Lignin 16% Pentosan 1.5% Ash	(Dubey, 2021; Hanum & Meason, 1997)
Moisture content	20%	12-15%	(Hanum & Meason 1997; Hughes &Mackney, 1949; Forest Research and Development Office, 2023; Karen, 2015; New Zealand Forest Research Institute Ltd, 2023)
Strength			
- Modulus of Rupture: MOR	17.7-27.7 MPa	110.33 MPa	
Stiffness			
- Modulus of elasticity	8,000-10,050 MPa	1,325 MPa	
Hardness	3300 N	6916 N	
Density	428-510 kgm^{-3}	490-840 kgm^{-3}	

MPa: Megapascal pressure unit, Newtons: N, kgm^{-3}: kilogram per cubic meter

The raw material sources affected on quality, and the industrial process of pallet production. The moisture contents of the raw materials were different depending on environment. Subsequent to the heat treatment process, the moisture contents of flat woods (top and bottom deck parts) and block woods were observed to be 10-12% and 13-16%, respectively. All kinds of finished pallets had a standard size (WxLxH; 1200x1000x156 mm) with a tolerance of plus or minus 5 mm, which is an acceptable range for industrial quality use. The results of the drop test, compression strength, and bending strength tests are shown in Table 2 and Figure. 4.

Drop test analysis was conducted by carrying out free-fall drop tests, utilizing specific test methodologies designed for flat pallets. These tests were aimed at assessing the diagonal rigidity of the pallet's top deck and its ability to withstand impact. No visible damage was observed on three varieties of pallets. The average rates of variation in the diagonal range were 1.58%, 2.03%, and 2.69% for Radiata pine, Earleaf acacia, and mixed wood pallets, respectively. The variation in rates observed depend on the total weight and the specific type of raw material used. Among the different types of pallets, mixed pallets showed the highest variation in diagonal range, mainly due to more mass density of Earleaf acacia causing breakage in the Radiata pine components. Compression strength testing was conducted using a compression speed of 12.7 mm/min and a maximum compression strength of 8500 kgf. This research found that three different types of pallets exhibited the same compressive strength of more than 8500 kgf (Table 2). This result indicated that wood types did not differ in terms of the compressive strength of wooden pallets under industrial standard tests.

The bending strength test was conducted to assess the long-term durability of these pallets, revealing that the wooden pallets made from Earleaf Acacia wood exhibited the highest bending strength at 2682 MPa. When a combination of woods was used as the primary material for the production of the pallets, the bending strength decreased to 2059 MPa. Radiata pine wood pallets demonstrated the lowest bending strength at 1124 MPa. Nevertheless, Earleaf acacia wood pallets had the heaviest weight of 40.4 kg, followed by mixed wood pallets at 35.4 kg, and Radiata pine wood pallets at the lightest weight of 23.1 kg.

Figure4. Industrial quality tests of finished pallets, A: an example of compression strength, B-D: bending strength test of Radiata pine, Earleaf acacia and mixed wooden pallets, respectively, E: an example of drop test.

Table 2. Physical properties of wooden pallets composed of different types of wood

Raw Material Woods	Appearance	Variation rate of Diagonal Range (%)	Compression Strength (kgf)	Bending Strength (MPa)	Weight (kg)
Radiata Pine	No VD	1.58±0.15	>8,500	1124±467	23.1±2.3
Earleaf Acacia	No VD	2.03±0.28	>8,500	2682±268	40.4±4.6
Mixed Wood	No VD	2.69±0.37	>8,500	2059±345	35.4±3.8

No VD: No visual damage, kgf: kilogram force, MPa: Megapascal pressure unit

Pallets are commonly used as a platform for product storage, with wood being the predominant material of choice for their construction. Both softwoods and hardwoods are used, and various industries blend different wood types to create pallets (The Wood Data Base, 2003, Gerber et al., 2020). When selecting wood for pallet production, it is essential to consider factors such as timber quality and durability, particularly given the need for pallets to withstand heavy loads (Cameroon Timber Export, n.d.).

Pallets are usually discarded at the end of their transportation process. Pine softwood is often used in standard pallets because it tends to be more uniform in weight than hardwood. This gives the product a high strength-to-weight ratio. Pine wood is used as raw material in the manufacture of pallets in countries with a cold climate due to its availability, low cost and ease of drying (Mega Forest Product & Wooden Pallet, n.d.). Asian countries use pine wood to produce pallets to meet the shipping requirements of trading partners. Although the importation of pine wood for pallet production into Asian countries reduces some industrial steps such as bark removal and the process of protecting wood from microorganisms. However, imported pine wood as a raw material is subject to high fluctuations of freight shipping costs and currency exchange rate. Therefore, finished products made from imported wood have variable prices. The price of prefabricated pallets made from imported wood varies depending on the economic situation and the global crisis. Meanwhile, prefabricated pallets made from local wood are more stable in price and more convenient to handle in the process.

Earleaf acacia wood is composed of vessel elements, fiber and parenchyma, while Radiata pine contains long tracheid and parenchyma. Vessel elements, longitudinally hollow cells, are found only in Earleaf acacia wood but not in Radiata Pine. These vessel elements, fiber parenchyma and tracheid are combined in a vascular tissue system involving in water, mineral and nutrient transportation. Therefore, Radiata pine wood has a light-colored grain but Earleaf acacia wood has a dark pattern of wood grain. After many seasons, the living protoplasm within cells deteriorates and decays, and only the cell walls remain. Older sapwood becomes heartwood, which consists in cell walls composed mostly of cellulose fibers bound together with lignin. Highly cross-linked lignin precursors are formed while the cell is in the final stage of lignification and death (Zeng et al., 2017).

Earleaf acacia wood contains higher percentages of cellulose and lignin than Radiata pine wood. Therefore, wooden pallets composed of Earleaf acacia wood would have higher compressive strength and blending strength than pine wooden pallets. Cellulose is composed of elongated chains of glucose, forming a *para*-crystalline arrangement of multiple glucan chains and is classified as a (1—>4)- β-D-glucose polymer. On the other hand, hemicellulose is made up of shorter chains containing various sugar units (Carpita, 2011). Furthermore, hemicelluloses can exist as polymers with branches, in contrast to cellulose which is non-branched. The cellulose microfibril has the ability to interact more extensively with matrix polysaccharides like hemicellulose. Each type has unique composition and structure within plant cell walls, thereby influencing the strength of cell wall and wood (Höfte & Voxeur, 2017). The strength of the wood is certainly an important factor in its selection for assembling pallet production. The strength of the wood primarily depends on the chemical composition of solid wood, and specifically the composition of the fibers. Polymerization and orientation of cellulose influences the strength of wood fibers, while hemi-cellulose acts as cross-linking of cellulose microfibrils, enhancing the packing density and strength of the plant cell walls (Scheller & Ulvskov, 2010). Lignin plays a crucial role as a binder of cellulose, cross-linking within the fiber cell wall (Winandy and Rowell. 1984: Tarasov et al., 2018). Importantly, the lignin content was positively related to the cell wall elastic modulus, and variation in the mechanical properties of wood can be attributed to differences in the proportion and content of biomolecules, mainly cellulose, hemicellulose and lignin, although the wood pattern remains the same (Via et al., 2009; Landel & Nielsen, 1993; Tobolsky & Eyring, 1943).

Radiata pine and Earleaf acacia exhibited varying wood fiber compositions, and this research provides an overview of the wood composition and its effect on physical properties of wooden raw material and pallet finished product. High cellulose and lignin contents and their structural arrangements in Earleaf acacia affected strength, hardness and density of wooden raw material and also characteristics of the finished pallet product. As a result, Earleaf acacia wood demonstrated superior bending strength. Mixed pallets produced from two types of wood had bending strength values and weights in between Radiata pine and Earleaf acacia pallets. The acacia plant produces hardwood which is suitable for use as a substitute material for imported pine wood because this local plant grows quickly and is already being grown to replace degraded forests. Moreover, using this type of wood will reduce the raw material cost of the pallet by about 30-50% depending on the environmental and economic situation. In the United States, approximately 43% of pallets were constructed from hardwood, while only 15% were made from softwood (Gerber et al., 2020). Therefore, Earleaf acacia should be considered as an alternative biomaterial resource for wooden pallet fabrication in Asian area. Earleaf acacia and mixed pallets were heavier than standard pallets; therefore, such pallets should be used for ocean transportation, where weight has less impact on shipping cost.

4. Conclusions

In the study, both imported and local woods were employed to manufacture pallets as a bio-based resource. These pallets were constructed using the same type of wood and from wood type combination and conformed to the industry-standard pallet size. The research findings indicate that the characteristics of each pallet type varied in relation to the chemical and physical proportions of biomaterials in the wood. Subsequently, the pallets underwent analysis for potential industrial applications, particularly in the realm of logistics. Notably, Earleaf acacia (*A. auriculiformis* Cunn.) emerges as a promising alternative wood option for pallet construction.

5. Conflicts of Interest

No potential conflict of interest was reported by the author(s).

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