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POTENTIALS OF BINDERLESS BOARDS PRODUCTION FOR SUSTAINABLE BUILDING DEVELOPMENT IN NIGERIA: A REVIEW

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Abstract:
Nigeria, a developing nation with a population of about 200 million people, is currently experiencing a national housing deficit of approximately 17 million units. With an expected annual national population growth rate of about 3% and an annual urban population growth rate of about 4%, Nigeria's population is becoming more and more concentrated in metropolitan regions, towns, and cities where housing deficits are more pronounced. The high cost of construction materials contributes majorly to Nigeria's housing problems, prompting several researches into the use of local materials as alternative building materials. In Nigeria, lignocellulosic biomass resources such as forestry residues, agricultural wastes, and industrial remnants are available in large quantities and are being investigated for use in the production of wood-based panel boards. However, the formaldehyde-based adhesives used in their manufacture emit emissions that pollute the environment and harm human health. The goal is to create cheap, environmentally friendly binder-less boards from waste lignocellulosic materials. In pursuit of a sustainable built environment in Nigeria, this review investigates the potentials of binder-less board production from lignocellulosic biomass.

Key words: *lignocellulosic materials; binderless board; agricultural residues; synthetic resins; Nigeria.*

INTRODUCTION

Nigeria is located in West Africa, between $3^{0}15'$ and $13^{0}30'$ N and $2^{0}59'$ and $15^{0}00'$ E. It is in the tropics, where the weather is seasonally damp and humid. Nigeria is bordered on the West by the Republic of Benin, on the East by Cameroon and Chad, and on the North by Niger. The Gulf of Guinea borders it on the South. Nigeria has a population of approximately 200 million people and a land area of 920,000km^2. It has the largest population in Africa and the seventh largest population on the planet. According to Abubakar *et al.* (2022), Nigeria's population is projected to be 352.67 million by 2030, with a growth rate of 2%, and working with this figure; providing adequate and cost-effective buildings in Nigeria is a matter of uttermost national priority. Nigeria's housing deficit has gradually increased from 7 million units in 1991 to 12 million in 2007, 14 million in 2010, and finally 28 million units in 2022. A growing urban population, a lack of an efficient mortgage system, poverty, rising construction costs due to high building material costs, high inflation, and declining household income have all made it difficult for many Nigerians to obtain decent and affordable housing. According to the Central Bank of Nigeria in 2019, only 10% of Nigerians who want to own a home can afford it in 2019. When compared to 72% in the US and 78% in the UK, the estimate is grossly inadequate for the size of our economy (Shobowale 2022). Among the strategies used to combat Nigeria's housing deficit were the construction of 2,700 housing units in the short term to create 105,000 direct jobs per year and gradually increase to 10,000 housing units per year by 2020, as well as the construction of 20,000 pilot social housing units (Moore 2019). However, no discernible progress has been made in this area. The cost of building materials is one of the major constraints in achieving a sustainable housing infrastructure in the country, making research into building material development critical. The goal is to create materials that can be easily adapted from existing manufacturing processes using locally sourced raw materials and technology.

Wood-based panel products

Wood-based panels are specialised products that offer superior, long-term performance, and increased durability. They are cheaper to produce and use. In terms of structural and aesthetic applications,

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wood-based panels offer a wide range of options. The use of wood-based panels in residential construction is increasing due to their affordability, flexibility in design, construction, and renovation. Wood chips, strips, veneers, strands, or lignocellulosic fibres are used to make wood-based panels. Particleboard, medium-density fibreboard (MDF), high-density fibreboard (HDF), plywood, softboard, hardboard, and oriented strand board (OSB) are some examples. They are cost-effective due to the use of surface veneering technology on particleboard and medium density fibreboard in their production. Furthermore, they are moisture and temperature resistant, with improved shape stability when compared to solid wood. As a result, they are widely used in the construction, packaging, and shipping industries all over the world.

Particleboard is a wood-based composite composed of wood particles or lignocellulosic material particles bonded under high temperature and pressure. It is classified alongside plywood, medium density fibreboard, oriented strand board, softboard, and hardboard. These panel products are made from wood and other lignocellulosic biomaterials and are designed to overcome some of wood's limitations. For example, they have excellent strength and durability and are widely used for ceiling, cladding, roofing, flooring, and furniture applications. In addition, they are moisture and temperature resistant with improved shape stability compared to solid wood. Because of their high impact resistance and strength, they are an excellent packaging material, especially for long-distance transportation. The particle board market was estimated to worth $155.3 billion in 2021 and is expected to expand due to an increase in residential, commercial, and industrial construction worldwide (IMARC 2022). In addition to building construction, particle boards are used to create interior walls, floors, furniture, and work surfaces.

The main step in the manufacture of particleboard is the processing of raw materials, which includes the selection of acceptable lignocellulosic materials and pre-treatments (mechanical and/or chemical). Following the pre-treatments, the mixing with an adhesive, hot pressing, shaping into a board, cooling, and trimming take place. When it comes to major environmental issues, panel products share some characteristics, even though the production process varies from product to product. The main issues that are becoming more and more of a concern when producing wood panel products are formaldehyde, organic compound, and dust emissions. Particles smaller than 3mm can make up to 50% of the total dust measured due to dust emissions from the manufacturing of wood-based panels, causing health and environmental issues that are high on the environmental policy agenda. Fine particulate matter emissions contribute to these dust emissions (Bloomberg 2022).

In the production of wood composites, adhesive is crucial. Due to their widespread industrial use and favourable performance, formaldehyde-based adhesives are the most popular adhesives (Nasir *et al*. 2015; Asim *et al*. 2018). The most popular resin is urea formaldehyde because it cures quickly, has a clear colour, and is less expensive than other synthetic resins (Hashim *et al*. 2012). As the board cures, it creates a crosslink, producing particleboards with superior qualities. The only thing keeping the fibres together is this synthetic adhesive. It provides the required dimensional stability as well as the necessary mechanical and physical properties. However, in the last 30 years, formaldehyde emissions from urea formaldehyde-bonded panels have drawn attention as a public health issue and have been subjected to strict legislation. Synthetic adhesives may cause environmental pollution and have negative effects on people's health, including cancer and irritated eyes, noses, and throats (Okuda and Sato 2006). They are listed in the 1B category by the International Agency for Research on Cancer as being carcinogenic to humans (Domnguez-Robles *et al*. 2020).

Due to the lack of a suitable alternative, it is still used in developing countries despite being prohibited in many developed countries (Kim 2009). However, worries about formaldehyde-based products' effects on human health and the environment are becoming more and more significant. Additionally, as 10% of the dry weight of particleboard is used with urea formaldehyde resin, the cost of producing particleboard as a whole is burdened by the rising cost of synthetic adhesives (Pizzi 2015). This usage accounts for about 60% of the total cost of particleboard production (Okuda and Sato 2004). The need for binderless boards cannot be over-emphasized.

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Bio-based adhesives

According to Alvarez *et al*. (2011), new environmental regulations have increased the pressure on board manufacturers to look for alternative sources of lignocellulosic fibres, which means that producers of particleboard are under more pressure to stop using synthetic binders because of the aforementioned financial and health risks. Studies on particleboards that use natural adhesives and resins instead of synthetic ones, such as soy (Frihart *et al*. 2010; Frihart and Satori 2013), lignin (Ghaffar and Fan 2014), tannin (Li *et al*. 2019; Yang *et al*. 2020), gluten, starch (Monteiro *et al*. 2016) etc., have been done in this regard. One potential chemical component for encouraging lignocellulosic particles to achieve self-bonding has been suggested: starch (Hashim *et al*. 2011). Starch is similar to cellulose because it is a glucose-based carbohydrate polymer. Starch can dissolve in warm water to form paste, which is one of the ways it differs from cellulose. In addition to being used as an adhesive in the papermaking industry, starch is frequently used as glue in household applications. Additionally, starch and its derivatives are used as raw materials in the manufacture of synthetic resins (Onusseit 1993). Starch may be able to function as a natural binder to aid in the bonding of particles because of its adhesive properties. However, because producing bio-based adhesives is more expensive than producing conventional adhesives, research is being done on producing boards without binders.

Self-bonding mechanism of binder-less boards

Self-bonding boards without synthetic adhesives have attracted more engineering and research attention in recent times (Widyorini *et al*. 2005; Alvarez *et al*. 2011). Waste lignocellulosic materials are renewable and recyclable when making binderless board, and there are no synthetic binders to drive up the cost of the final product (Angles *et al*. 1999). Furthermore, because no adhesives are used, there is no need for a curing period (Angles *et al*. 1999), therefore there is reduction in production time which benefits both the environment and the economy.

Particleboards known as "BPB" (Anglès *et al*. 2001) have lignocellulosic materials bonded together without the use of synthetic adhesives. The right pre-treatment, hot-pressing conditions, and the type of lignocellulosic material can cause the reaction of the chemical components contained in the lignocellulosic itself, and together with the fibres crosslinking, can achieve the self-bonding between particles during the production of particleboard without synthetic adhesive (Hashim *et al*. 2011). Although numerous theories regarding the self-bonding mechanism of BPB have been put forth, research is still only being done on a small scale in laboratories (Suzuki *et al*. 1998; Okuda *et al*. 2006; Halvarsson 2005). The intricate processes involved in self-bonding during the hot pressing of particleboard are the cause. As a result, thorough research on the self-bonding mechanism is required for standardising the manufacturing process for an industrial application. In-situ lignin modification is another strategy to improve the self-bonding mechanism in addition to the study of fibre modification.

The lignin and glucose contents of boards decrease with rising pressing temperature, which is the basis for the self-bonding mechanism in particleboards. Cellulose, hemicellulose, and lignin make up the majority of lignocelluloses in nature. The polysaccharides are cellulose and hemicellulose, and the binder is lignin. When lignin is exposed to high temperatures, it changes structurally. According to a study by Bouajila *et al*. (2005), the lignin-lignin and lignin-polysaccharide cross-linking reactions, which are activated at high temperature and pressure, are what give BPB their mechanical strength. BPB may develop self-bonding reactions as a result of the chemical activation reactions and physical consolidation of particles under applied heat and pressure (Rashim *et al*. 2011). One of the key factors in the manufacturing process that affects the properties of the particleboard is the hot press. Binderless particleboard is primarily produced using naturally occurring components found within fibres rather than synthetic resin.

The breakdown of hemicelluloses and cellulose results in the production of simple sugar, which aids in the self-bonding of boards (Widyorini *et al*. 2005). Bonding may also result from the crosslinking of lignin and carbohydrate polymers (Okuda *et al*. 2006). Condensed organosolv lignin based (Nasir *et al*. 2013; Fahmy *et al*. 2017), soy-lignin based adhesive (Nasir *et al*. 2014), and lignin-furfural linkages (Yan *et al*. 1996; Suzuki *et al*. 1998) are a few of the theories that have been put forth. Also contributing to the self-bonding mechanism are the physical characteristics of lignin, such as its ability to plasticize at high temperatures and condense at low temperatures (Bouajila *et al*. 2005; Zhou *et al*. 2010). The pressing temperature had a significant impact on the properties of the binderless boards, according to many researchers (Mancera *et al*. 2010; Hashim *et al*. 2011). Other researchers discovered that during the self-bonding process' hot press stage, lignin and hemicellulose decomposed and underwent chemical changes (Fahmy and Mobarak 2013).

Potential resources for binder-less particle board production in Nigeria

Forest products and residues, agricultural wastes, aquatic biomass, and industrial remnants have all been identified as potential resources for binderless board production in Nigeria. Developing countries, including Nigeria, have an abundance of these resources, which have a variety of other potential applications. Wood and woody plants, non-woody forest resources, herbaceous biomass, aquatic biomass, and biomass mixtures are also categories. Forest residues include logging residues like tops and branches, as well as process residues like off-cuts and sawdust from wood industries and demolition wood wastes, wood pulp, paper board, particle board, plywood, sawn wood, printing and writing paper are among the forest products available in Nigeria (Simonyan and Fasina 2013). According to Zalfar (2019), the residues generated during the processing of wood into furniture account for approximately 45% of the wood. Considering the large body of water in Nigeria, there is a huge potential for the production of aquatic biomass, which includes marine or freshwater algae, macroalgae or micro algae, seaweed, kelp, lake weed, and water hyacinth (Tursi 2019). Kaur *et al.* (2013) stated that aquatic weeds have exceptionally high reproduction rates and are rich in cellulose and hemicellulose with a very low lignin content, which makes them relevant for fibre board production. Simonyan and Fasina (2013) noted that the three common fast-

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growing aquatic weeds in Nigeria are water hyacinth, water lettuce, and bracken fern which are potential resources of binderless board production.

Presently, waste from various sawmills across Nigeria is the primary source of feedstock for the production of particleboard. These wastes are derived from tropical hardwood species native to the country. Natural and artificial forests are resent throughout Nigeria, from the middle belt to the southern region, and they supply the nation's furniture and construction industries. Abura (*Mitragyna ciliata*), Afara (*Terminalia superba*), Araba (*Ceiba pentandra*), Aye (*Sterculia rhinopetala*), Idigbo (*Terminalia ivorensis*), and Iroko are just a few of the hardwood species that can be found in Nigeria (*Milicia excelsa*). Others are African mahogany (*Afzelia Africana*), Omo (*Cordia millenii*), Opepe (*Nauclea diderrichii*), Obeche (*Triplochiton scleroxylon*), Ofun (*Mansonia altissima*), Gmelina (*Gmelina arborea*), and Omo (*Cordia millenii*) (Falemara *et al*. 2012).

The nation is also blessed with a wide variety of grasses and shrubs with excellent lignocellulosic properties suitable for the manufacture of particleboard (Fig. 1). Like in other applications, the woody biomass's compact fibres are preferred to non-woody biomass's low bulk density, which has an impact on the logistics of non-wood raw materials (Rousu and Rousu 2002).

Other sources of feedstock include fruit fibress obtained from plant seeds, whose cellulosic content varies significantly depending on the type of plant (Mesquita 2018); cotton (Zhou *et al.* 2010; Fahmy and Mobarak 2013); *leaf fibres* resulting from a cutting process that occur to enable plant growth and cultivation and belong to the agricultural residues category (Rashid *et al.* 2014), date palm (Saadaoiu *et al.* 2013), plantain (Alvarez-Lopez *et al.* 2014); s*tem fibres*, collected from the surroundings of the plant's stem which are the highest consumed among plant fibres within the industrial application and lead to the production of particleboards of very good quality (Sam-Brew and Smith 2015; Battegazzore *et al.* 2018), kenaf (Wiyorini *et al.* 2005, Okuda *et al.* 2006a; Okuda *et al.* 2006b), s*talk fibres* include trees trunk as well as annual plant stems that are left over in fields after harvesting (Yang *et al.* 2017), tree trunks (Baskaran *et al*. 2015); *fruit shell/husk/hull fibres* collected from the protecting skin of the fruit from which fibres can be extracted and processed (Van-Dam *et al*. 2004; Araujo Jnr *et al*. 2018), rice husk (Suzuki *et al*. 1998), almond shell (Fernandez-Villena *et al*. 2019), walnut shell (Rivela *et al.* 2007).

Manufacturing process of binder-less particleboard

Particleboards are generally produced using two distinct processes: "wet-process" and "dry-process". The water-distributed cellulose fibres are pressed at high temperatures with or without adhesive in the wet process. Thus, the only bonding forces created throughout the wet-process of heating and drying processes are hydrogen bonding and lignin plasticizing (Stark *et al*. 2010). The primary drawbacks of the wet process are the decreased mechanical strength, poor water resistance and the colossal waste of water in the process. On the other hand, in the dry process, cellulosic fibres are dried first, then resins are added, and then pressed at curing temperature (Stark *et al*. 2010). The industry mostly uses dry-process production with the addition of synthetic resins.

However, BPB are made from raw materials high in lignin and hemicelluloses. Steaming, chemical, or enzyme pre-treatments alter the fibres composition, which is thought to play an essential role in self-bonding. Thus, the production of binderless boards comprises two basic processes: pre-treatment and hot pressing (Fig. 2). During hot pressing, the cellulosic components undergo too many changes and achieve self-bonding. Thus, the pressing parameters such as temperature, pressure and time are important factor to be studied in detail. The effect of pressing temperature has been studied on various biomass such as *Miscanthus sinensis* (Velásquez *et al*. 2003), oil palm fibres (Laemsak 2000; Hashim *et al*. 2010) and kenaf core (Okuda *et al*. 2006). It was discovered that some of the most essential production characteristics, such as pressing temperature, had an impact on board qualities. Boon *et al*. (2013) examined temperature, time, and pressure and reported that pressing temperature was the most influential component, although pressure and time were ineffective at a certain point. To avoid fibres burning, the temperature should be kept below 200^0C. Aside from these variables, fibres moisture is an important component in determining heat transmission during the pressing process. The moisture percentage range allowed is 5-20 percentage weight of fibres, with high moisture amounts having a detrimental effect on modulus.

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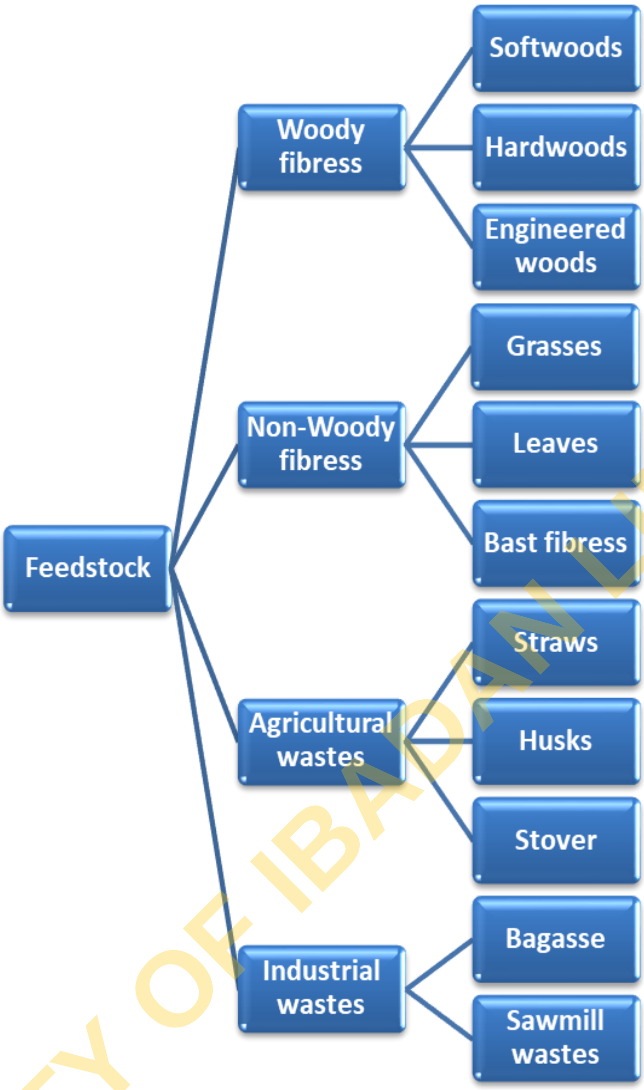

Fig. 1.
Different sources of raw material for Particleboard Production.

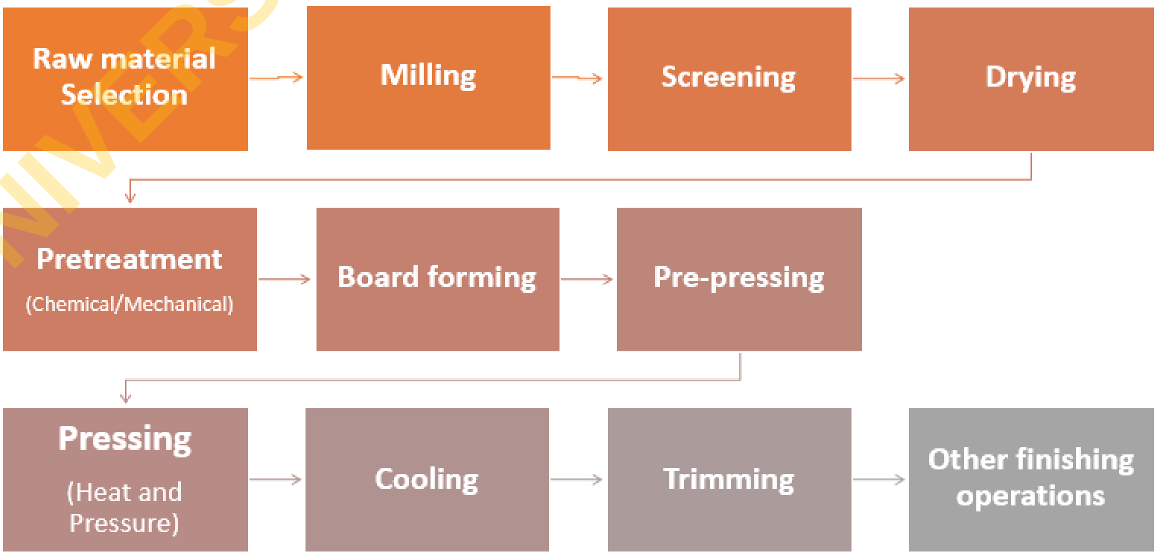

Fig. 2.
Dry binderless particleboard production process.

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Kinetics of binderless particleboard production: Reaction of Wood Components

The chemical composition of non-woody biomass varies, and some of it calls for particular pretreatment techniques. For instance, most plant leaves and grasses contain cellulose, lignin, hemicellulose, some terpenes, resins, inorganic elements, and fatty acids (Table 1), with cellulose's percentage composition ranging from 32.6 to 88% (Marques *et al*. 2010). (Baptist 2013). Additionally, the silicate, nutrient, and hemicellulose contents of non-wood fibres are higher (Judith, 1993). In producing BPB, chemical composition is a crucial consideration because the absence of a binder increases the impact of each component's percentage on the particleboard's properties. Depending on the type of material and frequently also the fibres sources taken into consideration, the chemical makeup of raw materials varies. The choice of feedstock for the production of binderless particle boards was influenced by the role of polysaccharides and lignin in self-bonding.

In many instances, pre-treatment may enhance the qualities of particleboard, particularly dimensional stability. It is well known that increasing the surface area of cellulose fibres improved binderless particleboard performance, and that hemicellulose hydrolysis increased water resistance (Zhang *et al*. 2019). Wood must deform to create wood-wood contact in order to achieve a strong adhesive bond.

Table 1

Chemical composition of biomass feedstock

Fibres	Cellulose %	Hemicellulose %	Lignin %	Extractives %	Ash %	Reference
Coconut husk	23-27	9.24	38.7-41.1	3.2-3.7	2.3-6.80	Araujo Junior *et al*. (2018)
Corn stalk	46.3	23.4	15.6	-	3.92	Kolajo and Onilude, 2019
Sunflower	40.9	15.5	21.6	-	-	Klimek *et al*., (2018)
Kenaf	37.16	34.31	23.29	3.12	-	Xu *et al*., (2004)
Sugarcane bagasse	37.73-55.52	16.0 – 27.38	20.03-25.3	17.03	0.59-1.1	Hoareau *et al*., (2006) Ribeiro *et al*., (2019)
Oil palm stalk	60.6	32.5	17.2	-	5.4	Hill and Abdul Khalil, (2000)
Coconut coir	32.0-43.0	25.0-25.0	40.0-45.0	-	2.0-10.0	Bismarck *et al*., (2005)
Rice straw	37.7	27.9	7.2	-	-	Domínguez-Robles *et al*. (2018)
Miscanthus sinensis	42.6	21.1	19.9	4.7	0.4	Velasquez *et al*., (2003)
Date palm	29.7-50.5	8.1-31.4	11.6	18.2	9.2-12.3	Saadaoui *et al*., (2013)

Hollocellulose

Numerous studies demonstrate the impact of the chemical composition of the feedstock on the properties of BPB as well as the impact of each component. First, it was discovered that less hemicellulose, which is hydrophilic and has a high moisture absorption rate, leads to a better resistance to water in the composite matrix (Pelaez-Samaniego *et al*. 2013). According to Alvarez-Lopez *et al*. (2014), the holocellulose are primarily responsible for moisture sorption and are biologically degraded. Although it promotes better fibres to fibres binding, low hemicellulose content may result in weak bonding strength (Nasir *et al*. 2019), necessitating the use of synthetic resins to create lignocellulosic particleboards (Zhang *et al*. 2015).

Lignin

This is the component that permits adhesion in wood structure, but it is also responsible for ultraviolet degradation (Angles *et al*. 2001) through the chromophore groups present in its matrix. The composition of cellulose and lignin in woody materials is typically higher than that of hemicelluloses (Table 1). However, the higher hemicellulose content of non-wood materials causes them to have poor dimensional stability (Zhang *et al*. 2015). Due to the hydrophobic nature of its large molecules, lignin resists water absorption, reducing the thickness swelling and absorption of water by particleboards. In addition, lignin, a naturally occurring component of cellulosic fibres, gave treated cellulose (activated fibre surface) more reactive sites, increasing the links between cellulose fibres. In a different experiment, Velasquez *et al*. (2003) discovered that pre-treatment of binderless particleboard made from steam-exploded non-wood fibres was improved by mixing kraft lignin.

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Extractives

Delamination may result from extractives evaporating during hot pressing (Migneault *et al*. 2011). According to Alvarez-Lopez *et al*. (2014), the development of the mechanical strength of self-bonded particleboards depends heavily on the extractable components of non-wood materials. In his study, organic extractives reduced the fibres surface's reactivity, which reduced bonding capacity and, as a result, reduced the mechanical properties of particleboards. Contrarily, during thermo-compression, water extractives act as catalysts for the fibre degradation reaction, causing covalent bonds to form and improving the mechanical properties. Therefore, the impact of extractives depends on the pathway through which the BPB are formed. While the thermo-chemical process accommodates extractives, the biochemical process repels the presence of extractives.

Pretreatment technique of BPB

Many chemical and enzymatic pre-treatment techniques have been devised and demonstrated their use in fibres-to-fibres bonding via diverse processes (Anglès *et al.* 2001; Schmidt *et al*. 2002; Quintana *et al.* 2009; Nasir *et al*. 2013). The majority of pre-treatments attempt to expose lignin and hemicellulose to the surface of cellulosic fibres, where they will participate in the reaction during hot pressing. Steam explosion, steam injection, chemical pre-treatments, and enzyme pre-treatments have lately gained a lot of interest since they are supposed to promote self-bonding in particleboards and are widely available in Nigeria.

EQUIPMENT REQUIREMENTS FOR BPB PRODUCTION

The equipment required for the production of BPB is determined by the required parameters, which are temperature and pressure. Various studies have investigated a variety of methods in this regard. According to Sugimoto *et al*. (2013), the physical properties of board made from oil palm trunk reached their peak at 200°C press temperature. Mobarak *et al*. (1982) investigated the production of moulded binder less boards from bagasse pith, rind, and whole bagasse portions using a hot-pressing system at pressures ranging from 15.7 to 25.5MPa and temperatures ranging from 175 to 185°C. Hashim *et al.* (2011) investigated the effect of temperature on binderless board production from oil palm trunk and concluded that as temperature increased, water absorption and thickness swelling properties improved. Ragil *et al.* (2005) compared the properties of steam-injection and hot-pressing boards. Binderless particle board production required hot pressing formed particles at appropriate temperature and pressure in all of these studies.

CONCLUSION

The availability of raw materials, technical knowledge, and equipment are critical factors in the production of binderless particleboard as a construction material in the Nigerian built industry. This review has brought to light the abundant availability of lignocellulosic biomass from various sources that is suitable for binderless particleboard production, as well as the technical knowledge as evidenced by several studies conducted locally. The equipment required is minimal and can be imported or locally built. As a result, there is a high prospect for the production of particleboard in Nigeria, which lowers production costs, relieves pressure on our local currency due to importation, improves the economy by providing jobs for the teeming populace, and is environmentally friendly.

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