Available online freely at www.isisn.org

Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

REVIEW ARTICLE BIOSCIENCE RESEARCH, 202219(2):1050-1066. **OPEN ACCESS**

Lignins as natural active ingredients for Cosmetics: A Review

Intan Nur Athirah Daud[1,2], Norhayati Mohamed Noor[1], Zaitul Iffa Abd Rasid[1], Hesham A. El Enshasy[1,2,3] and Nur Izyan Wan Azelee[1,2]*

[1]Institute of Bioproduct Development (IBD), Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, **Malaysia**
[2]School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, **Malaysia**
[3]City of Scientific Research and Technology Applications (SRTA), New Burg Al Arab, Alexandria, **Egypt**

***Correspondence: nur.izyan@utm.my** **Received 23-03-2022, Revised: 25-05-2022, Accepted: 27-05-2022 e-Published: 30-05-2022**

Renewable, natural and biocompatible characteristic of lignin portray a huge milestone in cosmeceutical applications. The wide availability of lignin which exist in abundance in nature and from low-cost biowaste has put this polymer as one of the highly promising elements to be explored for replacing the common chemical-based ingredients in cosmetics. This review briefly summarises the detection methods of lignin and several common extraction and isolation methods of lignin. Several potential applications of lignin in cosmetic products which include ultraviolet protection, anti-ageing, antimicrobial properties, and others are also discussed. The advancement in technology and the increased awareness in health and wellness has speed up the research among the experts in finding the most appropriate natural substances to be able to replace the harmful and toxic ingredients in cosmeceutical products. The positive findings obtained from various studies shown in this review has lighten the future of this complex heterogeneous macromolecule for a more sustainable lifestyle of human being.

Keywords: active ingredients, cosmetics, lignin, bio waste

INTRODUCTION

Issues regarding the uses of chemical ingredients in cosmetics products regardless of makeup or skincare, which causes numerous negative effects on human health, have caused arising concern among people. For instance, homosalate which is one of the bioactive ingredients commonly present in sunscreens and other skincare product which acts as sun protection have potential to cause endocrine disruption and studies in cells indicate that it may have an effect on hormones of the users (Schlumpf et al. 2010). Moreover, this ingredient also has been proven to enhance the number of pesticides absorption into the skins (Brand et al. 2003). A recent trend in cosmetics shows that people nowadays tend to use cosmetics that are produced from natural ingredients as people have becoming more aware on the toxic ingredients in conventional cosmetics. Thus, this has led to the great interest for many scientists to explore the potential of natural products in replacing the chemical ingredients in cosmetics that can cause many drawbacks to human being and environment.

As an alternative to this issue, lignin from lignocellulosic biomass is believed to have a great potential to become one of the natural sources for bioactive ingredient in cosmetics application. In most plants, besides hemicellulose, cellulose, pectin, and extractives, lignin is also known as one of the most important elements which is located in the plant cell wall. It is a natural product that possesses very complex biosynthesis produced by the phenylalanine or tyrosine metabolic pathway in plant cells. Moreover, lignin is a very intricate macromolecule because some features such as type of plant, species, age, growing and harvesting conditions, as well as the isolation procedure employed for its extraction will influence the structure and the bonds between various unit of the lignin (Torres et al. 2020). Lignin is so vital to the plant due to its various functions including-assisting plant growth, for tissue and organ development in plants, lodging resistance and the responses to a variety of biotic and abiotic stresses (Liu, Luo and Zheng, 2018). Besides, lignin also serves as a structural material that give strength and rigidity to the plant cell wall while act as important barrier in protecting the plant against pests and pathogen (Donaldson et al. 2017).

Table 1: The lignin yield from different types of edibles and non-edible plants

Type of plant	Scientific name	Part of the plant	Country of origin	Lignin yield	References
Edible plant					
Pineapple	*Ananas comosus* L.	Mixture of leaves, peel, crown and core	South America	12.37%	(Azelee et al. 2019)
Olive	*Olea europae*	Husk	Asia Minor	48%	(Ioelovich, 2015)
Wheat plants	*Triticum*	Straw	Southeast Turkey	14%	(Stone et al. 1951)
Maize	*Zea mays L.*	Grains	Mexico	5.5%	(Del Río et al. 2018)
Banana	*Musa*	Peels	Southeast Asia	6.0-12.1%	(HappiEmaga et al. 2007)
Corn	*Zea mays L*	Cob	Mexico	10%	(Ioelovich, 2015)
Banana	*Musa*	Leaf blade	Southeast Asia	24%	(Poletto, 2018)
Rice	*Oryza sativa*	Husk	South India	20%	(Gao et al. 2018)
Palm	*Elaeisguineensis*	Empty fruit bunch	West Africa	76.98%	(Yaakob, 2020)
Sugarcane	*Saccharum officinarum* L.	Bagasse	New Guinea	78.93%	(Ratanasumarn& Chitprasert, 2020)
Non-edible plant					
Kenaf	*Hibiscus cannabinus* L.	Core	Africa	22.22%	(Hazwan et al. 2019)
Jatropha	*Jatropha Cursas* L.	Seed coat	Mexico and Subtropical America	49.42%	(Yamamura et al. 2012)
Crataeva tapia	*Crataeva tapia* L.	leaves	Brazil	17.3%	(Arruda et al. 2021)

As mentioned by Chen (2015), study on lignin is currently divided into two groups which are, research on analytical, and industrial or application lignin. As for analytical lignin, the study focuses on quantitative and qualitative analysis of the lignin in the plant, meanwhile for the industrial lignin, it targets more on the utilization of the lignin from the plant for the society. Various studies have recorded that the amount of lignin in all plants are varied from each other. Table 1 below portrays several types of plant and their respective lignin yields.

2.0 Determination of Lignin

Several methods for determining the quantitative quantity of lignin in plants have been developed and updated throughout the years. There are many studies done to investigate the best method to quantify the percentage of lignin (analytical lignin) in many parts of the plants. Hatfield and Fukoshima (2008) and Fagerstedt et al. (2015) claimed that the most common and direct method used is Klason lignin method or known as sulphuric acid procedure. The method has also been supported by Emmanuel et al. (2018), where here the Klason lignin is a promisingly cheap, simple, and fast method that can be able to recover the lignin in plant biomass waste. According to Hatfield and Fukoshima (2008), Klason developed this method in the early 1990s, by using 64%-72% of sulphuric acid to dissolve all the polysaccharides, leaving lignin as the insoluble residue. Although this method has been claimed by many researchers as the common procedure used to determine the number of lignin, however, several drawbacks has been reported by some studies. As mentioned by Kirk and Obst (1988), other constituents such as proteins and suberins may condense and be identified as Klason lignin. In addition, Fagerstedt et al. (2015) also revealed that the lignin residue also might contain other non-lignin components such as tannins, proteins and non-extracted polysaccharides after the process. Due to these claims, the accuracy of lignin determination using the Klason lignin method could be decrease.

In addition, Acetyl Bromide (AcBr) method is also one of the methods used to quantify the amount of lignin in plant cell walls. As mentioned by Barnes and Anderson (2017), AcBr method has been revealed as the simplest and quickest methods evaluated to determine lignin in all tissues tested. Faust et al. (2018) mentioned the AcBr method is widely used in forest and animal ecology for lignin determination. The principle of AcBr method is based on the formation of acetyl derivatives in non-substituted OH groups and a bromide replacement of the α-C-OH groups to completely solubilize lignin under acidic conditions. Moreover, the solubilization of lignin and determination of absorbance at 280 nm are used in this procedure. (Moreira-Vilar et al. 2014). However, this lignin determination method also possesses its weaknesses. One of its drawbacks is structural polysaccharide of xylan has the potential to become an interfering factor during the procedure that would result in an overestimation of the total lignin concentration (Hatfield et al.1999).

Other method that is also known to quantify the amount of lignin in the plants are thioglycolic acid method. However, this method is considered as the least efficient compared to previous methods as it produced the lowest lignin recovery according to Moreira-Vilar et al. (2014). Thioglycolic acid has high specificity with the ether linkages found in many herbaceous plants while may underestimate the total lignin in other types of plants having many other linkages (Casaretto et al. 2019). This method works such that plant will be solubilized in the thioglycolic acid before purified in dioxane and ether. Different extracting methods resulted in different fine structures of lignin, that can clearly be seen from the differences in the composition of monolignols (Tao et al.2020). Nevertheless, although all these lignin determination methods are commonly used to measure the amount of lignin in the plant cell walls, each of them has their specific advantages and also disadvantages.

3.0 Extraction and Isolation of Lignin

While the previous section discusses on the analytical lignin, production of lignin for industrial application (industrial lignin) is covered in this section. As stated by Torres et al. (2020), industrial lignin is categorised into two types of lignin which are sulphur-free lignin and sulphur-containing lignin (Figure 1). The type of extraction and isolation methods used will determine the type of lignin produced. The most well-known sulphur-containing lignin is Kraft lignin and lignusulfonates, which derived from the commercial pulping process. In the contrary, soda, organosolv and steam explosion methods produce sulphur-free lignin (Mansouri and Salvado, 2006). Each of the isolation procedures has its advantages and disadvantages and thus having distinct usage preferences by manufacturers (Table 2). The utilization of microbes such as fungi has also been explored as the green technology to degrade lignin from biomass (Zin et al. 2022). Therefore, there are increasing studies on lignin from different plants and the parameters involved in the extraction method in yielding the highest lignin under reliable extraction method as summarised in Table 3.

4.0 Characterization of Lignin

The amount and composition of lignin varies widely among plant species, tissues, cell types, and cell wall layers, and is regulated by developmental and environmental factors. (Vanholme et al. 2019; Poletto, 2018). As complicated as it can be, lignin presumes to have a more complex structural compositions compared to hemicelluloses and cellulose. It mainly acts as a cementing material for cellulose fibers in plant cells (Mudgil and Barak, 2019). Lignin is made up from building blocks of plant polymer derived from phenyl propanoid pathways. It is a three-dimensional polymer composed of phenylpropane units that is laid down within the cell wall after tracheid elongation has stopped (McDonald & Donaldson, 2001). In molecular level, lignin polymer is biosynthesized by a cascade of oxidative radical couplings through a benzene ring attached to three carbon side chains lignin making it a heteropolymer consisting of three main precursors, namely, *p*-coumaryl (H), coniferyl (G), and sinapyl (S) monomers (Welker et al. 2015; Florian et al. 2019; Pereira et al. 2020). Figure 2 shows the structure of three monomers exist in lignin polymers. The lignin molecular weight, polydispersity value, and total phenolic content of lignin from various sources is detailed in Table 4.

5.0 Application of Lignin in Cosmetics

5.1 Ultraviolet (UV) absorber

High amounts of chemicals in sunscreen were detected in marine ecosystems which have caused marine pollution (Piccinino et al. 2021; Widsten, 2020). This is due to the annual washing and bathing activities, resulting in tons of sunscreen residues present in the wastewater. The limitation of wastewater pre-treatments has caused the small molecules of the chemicals in sunscreen products to enter the water system and caused negative effects to the marine habitats (Ramos et al. 2016). Oxybenzone and octinoxate are known as chemical ultraviolet (UV) absorbers that are widely used in sunscreen products and have been shown to cause toxicity to marine habitats. As a result, these sunscreen UV filters chemicals have been banned in many countries such as Australia and island regions such as Hawaii (Levine, 2020).

Extensive studies have been done to investigate the potential of lignin for human well-being as lignin is believed to have high potential in to pharmaceutical and industrial applications. A recent study has shown promising usage of lignin for cosmetics applications. Lignin has been proven to become an alternative ingredient in commercial sunscreen that portrays less side effects to the people and environment. Table 5 shows the chemical ingredients commonly used in sunscreen products and its adverse effects to human and environment.

A green alternative may be provided by the utilization of this nature-inspired lignin system as a replacement for some synthetic sunscreen ingredients (Qian et al. 2015). Nowadays, on-going research on eco-friendly sunscreen ingredients has been vastly studied to protect the environment. In addition, due to the circular economy and environmental concerns, the production of sunscreen formulations based on renewable and recyclable resources has attracted a lot of attention from many scientists.

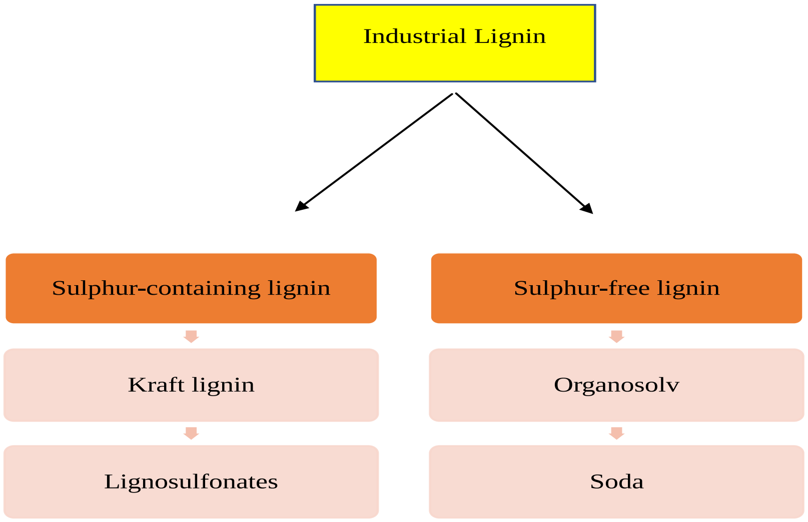

Figure 1 Two types of industrial lignin and its extraction methods

Table 2 : Advantages and disadvantages of different lignin isolation procedures

Types of isolation	Procedures	Advantages	Disadvantages	References
Kraft lignin	Treating wood material in an aqueous solution of sodium hydroxide and sodium sulphide	Contains a greater number of phenolic groups	Have impurities such as sulphur Low solubility	(Hu et al. 2018; Alzagameem et al. 2018)
Lignosulphonates	Treating wood at high temperatures with aqueous sodium sulphite	Water soluble	Higher sulphur contains A structural change of lignin and the low purity after isolation	(Tang et al. 2020)
Organosolv	In an aqueous ethanol or methanol solution, hardwood chips are batch cooked for predetermined times at optimum temperatures and pH	High purity and chemical reactivity Sulphur free and non-toxic	When compared to untreated lignin, the molar mass of extracted lignin is reduced by 36 to 56% Expensive	(Klett, 2017)
Soda pulping	Biomass treated with alkaline solution which is aqueous solution of sodium hydroxide at 150-200ºC	Absent of sulphur	Low pulp yield performance	(José Borges Gomes et al. 2020)

Table 3: lignin yield from different plant variety and the parameters involved in the extraction methods

Plant	Extraction method	Parameters studied				Lignin yield	Description	References
		Biomass (g)	Solvent/ ratio	Time	Temperature			
Sugarcane bagasse	Alkaline treated	0.5 g	Sodium hydroxide solution concentrations (3–7% w/v)	30–60 minutes	115–135°C	78.93%	The optimized parameters are solution concentration of 7% w/v with temperature of 135 °C, and time of 47.92 minutes	(Ratanasumarn and Chitprasert, 2020)
Coffee husk	Alkaline hydrolysis liquid solid extraction	5.0 g	Sodium hydroxide 10% (w/v)	60 minutes	120°C.	11%	Solvent used in liquid solid extraction : water, methanol, ethyl acetate and hexane	(Sarrouh et al. 2020)
Corn stover Prairie cordgrass Switchgrass	Organosolv pre-treatment	10.0 g	Liquid to solid ratio (%w/w) was 10:1.	20 minutes	140°C	<50%	Lignin extracted from switch grass was characterized as the purest	(Cybulska et al. 2012)
Wheat straw	Alkali extraction	7.0 g	Solid to liquid ratio is 1:10 (w/v)	45 minutes	120°C	22.4 %	Lignin is used as reducing, capping and stabilizing agent for silver nanoparticles	(Saratale et al. 2019)
Eucalyptus Aleppo pine	Kraft treatment	20.0 g	Solid to liquid ratio was 1:4 (w/v)	2 hours	170°C	24.5% 20.7%	Hardwood (Eucalyptus) showed higher lignin content that softwood (Aleppo pine)	(Cherif et al. 2020)

Table 4: Determination of molecular weight, polydispersity value, and total phenolic content of lignin from various sources

Lignin source	Molecular weight	Molecular weight distribution (polydispersity value)	Total phenolic content (TPC)	Reference
Rice husk	M_w: 1366 Da M_n: 784 Da	1.70	14.90 ± 0.7 µg GAE/g	(Lee et al. 2020; Singh &Dhepe, 2016; Gao et al. 2018)
Crataeva tapia leaves	M_w: 1246.8 Da M_n: 831.2 Da	1.50	189.6 ± 9.6 µg GAE/g	(Arruda et al. 2021)
Corn stalk	M_w: 6743 Da M_n: 2611 Da	2.58	12.76 µ GAE/g	(Wang et al. 2020; Wang & Chen, 2013)
Sugarcane bagasse	M_w: 3954 Da M_n: 2025 Da	1.95	69.41 ± 0.32 µg GAE/g	(Ratanasumarn&Chitprasert, 2020)
Wheat straw	Mw: 3570 Da Mn: 1970 Da	1.81	140.6 ± 5.6 µg GAE/g	(Saratale et al. 2019)
Bamboo	Mw: 4032 Da Mn: 1976 Da	2.04	1.47 GAE/g	(Wang et al. 2019)
Bangalay	M_w: 8848 Da M_n: 2052 Da	4.31	48.4 GAE/100 g	(Dos Santos et al. 2014)
Forest red gum	Mw: 8444 Da Mn: 1745 Da	4.84	50.2 GAE/100 g	(Dos Santos et al. 2014)
Empty fruit bunch (Palm oil)	Mw: 1564 Da Mn: 597 Da	2.62	1.79 GAE/100 g	(Tsouko et al. 2019; Faris et al. 2017)
Alfa grass	Mw: 7900 Da Mn: 2060 Da	3.83	0.67 GAE/g	(Hattali et al. 2002)
Olive tree	Mw: 7924 Da Mn: 1430 Da	5.54	14.18 GAE/g	(Erdocia et al. 2014)

Table 5: Harmful and adverse effects of chemical ingredients available in sunscreen products

Chemicals	Function	Adverse effects	References
Para-aminobenzoic acid (PABA) and its derivatives	Act as UVB filter	Allergic dermatitis. disrupts estrogenic and androgenic activity. bioaccumulation in the environment and the food chain.	(Gago-Ferrero et al. 2015)
Nanomaterial; micronized zinc oxide, nano zinc oxide, micronized titanium dioxide	UV-filters or preservatives	Inhalation of some nanoparticles may reach the brain.	(Oberdörster et al. 2002; Elder et al. 2006)
Octinoxate, also called Octyl methoxycinnamate or (OMC)	UV-filters	Octinoxate has been found in human urine , blood, and breast milk , indicating that humans are exposed to it systemically.	(Axelstad et al.2011)
Oxybenzone (benzophenone 3)	Organic filter (absorbs UVB and UVA rays)	Has antiandrogenic as well as proestrogenic and antiestrogenic effects.	(Schneider and Lim, 2019)

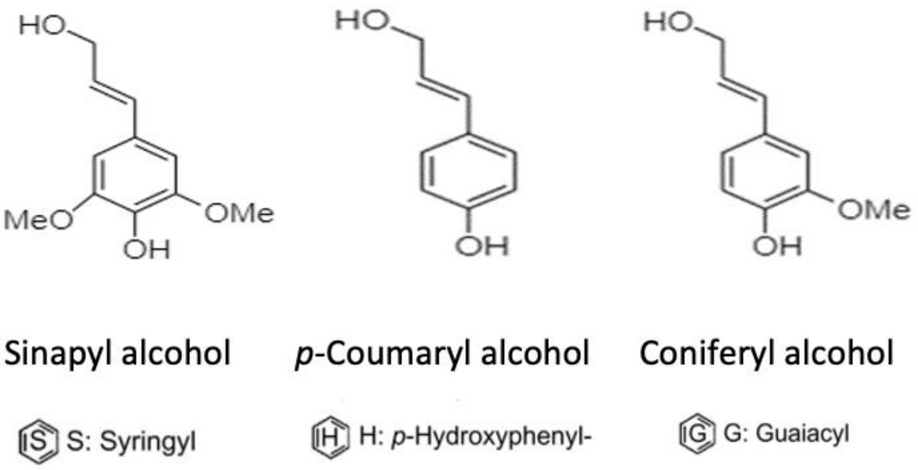

Figure: 2 Structure of three monomers in lignin polymers (Vavilala et al., 2019)

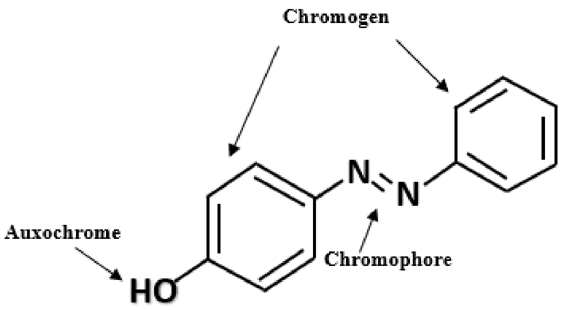

Figure 3 Different chromophores and auxochromic groups located in the lignin (Qian et al., 2015)

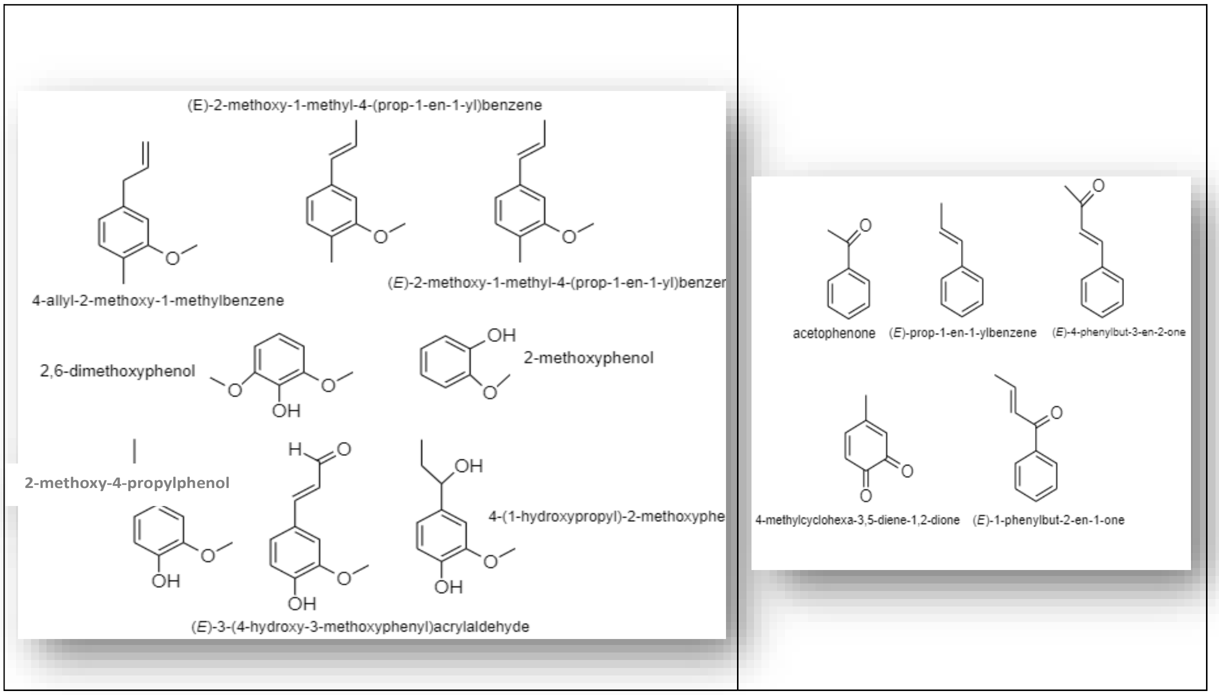

Figure 4 Classification and structural representation of lignin sub-units with antioxidant activities (Piccinino et al. 2021)

Lignin has been proven to become a safer and biodegradable substitute for synthetic UV absorbers in sunscreen (Yang et al. 2017).

Lignin is biomass consists of the most abundant polyphenols that contain UV absorbing functional groups such as phenolic, ketone and other chromophores. It became a suitable candidate as a broad-spectrum sunscreen ingredient because of the aromatic ring structure that has a phenylpropane base unit linked by ether and carbon bonds, containing various functional groups that are capable of absorbing UV radiation (carbon-carbon bonds, carbonyl and other chromophores). Auxochromes like hydroxyl groups and ethers plays an important role in the sunblock action of lignin (Lee et al. 2019; Qian et al. 2015). Study by Qian et al. (2015) and Piccinino et al. (2021) revealed that lignin can become an alternative active ingredient for commercial sunscreen products because there are two different chromophores and auxochromic groups located in the structure that function as UV absorber (as shown in Figure 3). The three-dimensional structure chromophore functional groups can absorb a broad spectrum of UV rays in the range of 250 - 400 nm, which prevents photodegradation of the amorphous parts of cellulose fibers (Sadeghifar and Ragaukas, 2020; Kim et al. 2017). In addition, these compounds possess the same function as homosalate which is a synthetic UV absorber. Owing to these facts, lignin can become a good alternative for chemical ingredients used in cosmetics which has been proved to give adverse effects on human health.

Qian et al. (2015) showed that lignin has significantly improved the sunscreen performance when it was introduced in lotion cream. It also attributed to certain synergistic effects between lignin and other sunscreen actives in the lotions (Qian et al. 2015). Study by Padilha et al. (2020) was in accordance with Qian et al. (2015) which has reported that drastic reductions in the transmittance values of moisturizing creams and sunscreen lotions and increased SPF values of a commercial sunscreen lotion were observed with the addition of organosolv lignin from the whitened organosolv lignin pretreatment of cashew apple bagasse (Padilha et al. 2020). Another study by Gordobil et al. (2020), revealed that isolated lignin from hazelnut and walnut shells that were blended in pure cream (NIVEA body milk) can act as UV absorber compounds when evaluated according to the in vitro SPF method based on UV spectrophotometric. The results demonstrated an increased in the UV absorbance with the increased in lignin concentration in the pure cream (Gordobil et al. 2020).

Widsten et al. (2020) invented safer bio-based sunscreens with lignin UV absorbers by altering the Kraft lignin, creating CatLignins with abundant phenolic hydroxyl auxochromes and catechol units and demethylation process to improve the regular lignin function as sunscreen UV absorbers in terms of sun protection factor (UVB–SPF) and UVA–UVB transmittance. The lignin was then modified to lignin nanoparticles (LNPs) to boost the UV absorption and photostability of lignin sunscreen. The results proved that sunscreens formulated with 10% lignin or LNPs could be applied as UV absorbers for dark-tinted SPF cosmetics that are environmentally friendly and safer for humans (Widsten et al. 2020).

5.2 Antioxidant and anti-ageing properties

A major contributor to skin ageing is due to oxidative damage initiated by ROS. Free radicals generated internally in the skin cells during normal oxidative metabolism or by external sources such as UV radiation (Rinnerthaler et al. 2015). The excessive production of ROS is due to the skin exposure to ionization and UV radiation quantities that can deplete tissue antioxidants and other oxidant degrading pathways. Uncontrolled ROS release is involved in the pathogenesis of most skin problems including premature skin ageing (Oresajo et al. 2009). To overcome this problem, sunscreen formulations are designed to protect the skin from UV radiation and other skin diseases such as cancer and melanoma (Piccinino et al. 2021). Due to this reason, antioxidant has become one of the important ingredients in all sunscreens. Lignin, the natural sources of UV absorber has also showed an excellent antioxidant property that can help for anti-ageing in sunscreen products (Qian et al. 2016; Spiridon, 2020). Alternative eco-friendly and natural antioxidants with less toxic effects are strongly recommended and expected in future cosmetic formulations.

A study by Espinoza-Acosta et al. (2016) reported that lignin is the important molecule that function to scavenge and prevent oxidation in all the living system as well as food that is caused by the free radicals. The hindered phenolic structure found in lignin allows it to function as a free radical scavenging antioxidant (Kabir et al. 2017). Functional groups and molecular weight determine the strength of antioxidant activity of lignin. Figure 4 describes the main phenolic sub-units of lignin that responsible for the radical scavenger activity (Piccinino et al. 2021). Hydroxyl group and methoxyl group are the main contributors to the antioxidant activity in lignin, while the existence of aliphatic hydroxyl and conjugated carbonyl moieties reduce it activities (Dizhibiteet al. 2004). The radical scavenging ability of lignin is reliant on its free phenolic groups which tend to form phenoxyl radicals and methoxyl group. The phenolic groups have a stabilizing effect on the formed phenoxy radicals during the scavenging process (Yearla and Padmasree, 2016; Meng et al. 2018). Via hydrogen donation, functional groups in lignin such as methoxy and phenolic hydroxyl groups may induce the termination of oxidative propagation reactions (Tang et al. 2020).

In addition, the efficiency of lignin as an antioxidant and UV protector is related to its structure, solubility, genetic origin and the isolation methods used (Mahmood et al. 2018; Yearla and Padmasree, 2016). Wei et al. (2021) have determined antioxidant activity in eucalyptus kraft lignin (EKL). The eucalyptus was firstly extracted using organosolv extraction to fractionate the EKL. The antioxidant activity of each lignin fraction was then assessed using DPPH radical scavenging activity, ABTS radical cation scavenging activity, and ferric reducing antioxidant power. The findings demonstrated that organic solvent fractional extraction is a viable method for improving the uniformity and antioxidant activity of kraft lignin. (Wei et al. 2021). Table 5 shows the list of research and findings on antioxidant properties of lignin.

A normal ageing process and UV stress can deplete the antioxidant system of the skin, leading to the generation of ROS and oxidative damage to proteins, lipids and nucleic acids in the skin. Thus, it is important to supplement skin with natural antioxidants to provide skin protection and slow down the ageing process (Oresajo et al. 2009). As study by Mahmood et al. (2018), revealed that lignin can slow down the ageing of biological system because the structure and solubility of lignin can influence its antioxidant effects. Interestingly, lignin showed higher antioxidant capacity as compared to the well-known commercial antioxidant; butylated hydroxytoluene (BHT) (Gordobil et al. 2018; Wei et al. 2021). *In vivo* toxicity study of the lignin has been done by assessing the lignin in embryonic zebrafish. The results proved that lignin is non-toxic and hence it is suitable to be used as a natural antioxidant in sunscreen products (Piccinino et al. 2021).

5.3 Antimicrobial properties

Antimicrobial properties are also one of the important features that is taken into consideration by researchers and dermatologist during the production of cosmetics. A study by Espinoza-Acosta et al. (2016) reported that lignin has been proved to possess as a green antimicrobial ingredient in the production of cosmetics and known as the main sources of the growth of many types of microorganisms due to the present of phenolic fragments that contain a C-C double bond together with methyl group in the y-position (Espinoza-Acosta et al. 2016). Owing to these properties, the phenolic compounds are capable to destroy and lysis the cell membrane of the bacteria (Solihat et al. 2021). However, other than the chemical structures of lignin, the effectiveness of the antimicrobial activity of the lignin relies on several factors such as the sources of lignin, the extraction method used to extract lignin and also the microorganism strain tested for the antimicrobial activity.

As reported by Piccinino et al. (2021), Kraft lignin (KL) and acid detergent lignin (AL) came up with different antimicrobial activities. KL is believed to fight against *Erwinia carotovora* and *Xanthomonas campestris*pv. *Vesicatoria*, meanwhile, AL is believed to destroy *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas*. In addition, according to the study by Alzagameem et al. (2019), lignin turns out to be more effective towards gram positive bacterial compared to the gram negative bacterial under 35°C and at low temperatures (0–7°C). Both gram positive bacteria that had been used during the study were *S. aureus* and *Listeria monocytogenes* which display positive inhibitory effects on the bacteria. Nevertheless, no results had been reported from the gram-negative bacteria used which is *E. coli*. Additionally, in similar study by Alzagameem et al. (2019), several sources of lignin have been chosen as the variables and the results demonstrated that organosolv of softwood lignin possess higher antimicrobial activity compared to the kraft of softwood lignin, but kraft of softwood lignin shows a better antimicrobial property than organosolv of grass. Lignin from breech-based sample indicates the highest antimicrobial activity.

In other study on the antimicrobial properties by using fungus *Aspergillus niger*, they discovered that two kraft lignins which are kraft spruce and kraft eucalyptus indicated higher antimicrobial activity than organosolv lignin (organosolv spruce and organosolv eucalyptus) with an inhibition value between 73-87% (Gordobil et al. 2018). Meanwhile, organosolv only portray moderate inhibition rate. According to the study, the differences of inhibitory effects between each lignin occurs due to the distinct carbohydrates content in both lignin samples where, lower carbohydrate content resulted in higher antimicrobial activity. Moreover, lignin also can be considered as a good antimicrobial agent due to its ability to act as a booster in order to increase the effectiveness of other antimicrobial agents which is silver nanoparticles. In the light of this issue, several studies have published in advance on the mechanism of lignin-coated silver nanoparticles as efficient antimicrobials (Luzi et al. 2021; Paul et al. 2021). Zhong et al. (2014) have reported that silver is well-known to inhibit cell division or cell proliferation by interacting with microorganism enzymes or proteins, thereby able to inactivate the microorganisms. However, according to the study, the performance of antimicrobial activity of the silver nanoparticles could be synergistically improved with lignin. Hence Zhong et al. (2015) have produced lignin-based silver nanoparticles via in-situ method and tested on gram negative bacteria which is *E. coli*

From the results obtained, lignin-based silver nanoparticle portrayed a great antimicrobial agent compared to silver nanoparticle alone. In other study by Slavin et al. (2021) have proved that silver nanoparticles that was capped with lignin (AgLNPs) showed higher antimicrobial activity compared to the commercial silver nanoparticles (AgNPs) against multidrug-resistant bacteria such as *Staphylococcus aureus, Staphylococcus epidermidis, Pseudomonas aeruginosa, Klebsiella pneumoniae,* and *Acinetobacter baumannii*. From all the reported studies, it is believed that lignin has a great potential to become a commercial green antimicrobial agent against many types of microbes and could replace the synthetic antimicrobial agents not only for cosmeceutical and medical field but also in industrial application. The main characteristics of lignin that have piqued the interest of many researchers to study its ability as antimicrobial agents are its high availability, environmental friendliness, renewable sources, low cost, and biodegradability (Lobo et al. 2021). Pertaining to that fact, the use of lignin as an antimicrobial agent has been found to be non-toxic to the environment.

5.4 Skin lightening properties

The global market for skin lightening or whitening, which was anticipated to be worth US$8.6 billion in 2020, is expected to grow further to US$12.3 billion by 2027 (Research Ltd, 2021). Nowadays, skin whitening products are widely used all around the world, with Asia being the largest market (Kim and Pangestuti, 2011). An even and light skin tone is connected with attractiveness in Asian countries such as India, China, Japan, and Korea (Desmedt et al. 2016). Inhibition of tyrosinase, which catalyses the rate-limiting phase of pigmentation, is the most popular method for achieving skin hypopigmentation (Kim and Pangestuti, 2011) or skin lightening. Until today, more than thousands of researches have been conducted on the tyrosinase inhibition activity either from both natural or synthetic sources including marine (Kim and Pangestuti, 2011), plant (Lan et al. 2013; Ticona et al. 2020; Wan Hassan et al. 2015; Wong et al. 2018) or synthetic or semi-synthetic ingredients (Lee et al. 2016; Masum et al. 2019; Zolghadri et al. 2019) for the target of skin lightening or whitening purposes.

Besides that, lignin has shown a great potential to be used for skin lightening or whitening as well as depigmentation (Wang et al. 2018; Wang et al. 2019). Antioxidant and anti-tyrosinase activity are increased in substances with more phenolic hydroxyls as reported by Zuo et al. (2018), suggesting that antioxidant and anti-tyrosinase activity in lignin could be correlated based on the phenolic hydroxyl group. Alkali lignin and organosolv lignin were both evaluated as tyrosinase inhibitors (Wang et al. 2018; Wang et al. 2019), with organosolv lignin having a stronger anti-tyrosinase activity than alkali lignin (Spiridon, 2020). It has ability to inhibit tyrosinase activity which enzymes required for melanin synthesis (Ratanasumarn and Chitprasert, 2020; Wang et al. 2019). In other study on the effects of sources and isolation processes of lignin, they found that corn stalk lignin (Gramineae plant) had contributed the strongest inhibitory impact of all the lignins tested (pine (softwood) and poplar (hardwood)), with an IC50 of 0.276 mg/mL, which is equivalent to the positive control p-hydroxy benzaldehyde (0.233 mg/mL) (G. Wang et al. 2018).

In other study on the lignin heterogeneity on anti-tyrosinase activity, they found that dichloromethane extraction can be used to separate the heterogeneous lignin with significant anti-tyrosinase activity (Wang et al. 2019). They have fractionated the organosolv ethanol lignin (OEL) into four fractions and found that the fraction with the highest phenolic hydroxyl content and the lowest molecular weight had the strongest tyrosinase inhibitory activity (Wang et al. 2019). Another approach to improve skin lightening or whitening is using enzymatic melanin decolonisation approach since enzymes show significant promise for selective melanin decolorisation with reduced cytotoxicity (Sung et al. 2019). The molecular structure of lignin, it is similar to that of melanin (Zhong et al. 2015) and furthermore having a high redox potential to oxidise veratryl alcohol. Lignin peroxidase is a promising catalyst for efficient decolorization of melanin (Sung et al. 2019). Based on the study, they observed that the in-situ production of hydrogen peroxide (H_2O_2) by glucose oxidase (GOx) from *Aspergillus niger* is particularly effective in preserving lignin peroxidase isozyme (LiPH8) and able to produce melanin decolorisation efficiency up to 63.3 ±2.4% within 1 h and continued to 84.0±1.8% in 8 h and remained constant maximally to 86.9 ± 1.8% until 24 h (Sung et al. 2019). These results suggest that the enzyme is suitable to be used topically for overnight application. Sadaqat et al. (2020) have also conducted a study to produce lignin peroxidase for skin lightening ingredients. They have successfully produced a cost-effective and efficient process lignin peroxidase from the white-rot fungus (*Phanerochaetechrysosporium*) and found that the optimum conditions for decolorization of melanin were at pH 3, 40°C, 15 IU/mL. A 10-hour incubation period with the addition of a mediator (veratryl alcohol) was also demonstrated and had effectively enhanced the efficacy of the melanin decolonization up to 92% (Sadaqat et al. 2020). As most of the skincare product having pH range of pH 4-7, the delivery of the lignin peroxidase in skin care product should be concern in order to sustain the effectiveness of the product on the skin. Based on the cytotoxicity result on shrimp larvae, the increase of lignin peroxidase concentration had no impact on the viability of the shrimp larvae for up to 80 µl/mL (~ 80 IU/mL1), suggesting its low cytotoxic activity. However, extra care should be taken as the mortality rate was 100% when a mediator is used (Sadaqat et al. 2020). In addition, more safety analysis such as *in vitro* 3D skin irritation or sensitisation should be done in order to obtain a safety profile for the ingredient used in cosmetic applications.

In a preliminary clinical study (single-center, open label, self-controlled prospective study) on 31 Chinese women (25-55 years of age, mean ± SD, 42.12 ± 8.37 years), who had melasma on both sides of the face were applied twice daily with lignin peroxide-based lotion for 8 weeks of a full-face product treatment. The result obtained found that after 28 days of treatment, the melasma area severity index (MASI) score was statistically decreased compared to the baseline (Zhong et al. 2015). This result showed that, lignin peroxidase-based product used together with activator H_2O_2 is effective in improving skin pigmentation (Zhong et al. 2015). Lignin peroxidase-based product could potentially be used in cosmetic ingredients for skin lightening or depigmentation and it has also been suggested that a greater number of volunteers should be used in the next clinical trial for a more reliable and convincing result. Another clinical study was conducted by comparing lignin peroxidase and hydroquinone-based product on 60 volunteers aged 18 to 65 years with mild to moderate facial dyspigmentation for 12 weeks in 2 cohorts (Cohort 1: lignin peroxidase on one side of the face and left the other side alone, Cohort 2: one side of the face with lignin peroxidase and the other with generic hydroquinone) and found that similar reduction in Melasma Area Severity Index (MASI) score in Cohort 1 and in Cohort 2 meaning, both products showed comparable results (Draelos, 2015).

Based on the results obtained from these studies, it showed that lignin-based derivatives could be potentially used as skin lightener or whitener in skin care products. Nevertheless, safety concern should be taken into account in order to confirm the effectiveness and long-term effect to the consumers.

5.5 Stabilizers and emulsifiers

Cosmetics formulation is a sophisticated study that includes following trials with mixed substances utilising various emulsifier systems, which may have an impact on steering the active component to the appropriate layer of the skin(Morganti and Cortelli, 2019; Wiechers et al. 2004). During cosmetic formulation, emulsions are thermodynamically unstable systems thereby, developing technical criteria for selecting optimal components and concentrations to ensure kinetic stability is a real challenge (Franzol et al. 2021). Therefore, this requires emulsifiers which are both hydrophilic and lipophilic, a substance that are used to lower surface tension, disperse oil in water, and can therefore form stabilized emulsions or solubilize scents. According to McClement et al. (2017), to be used in cosmeceutical applications, an emulsifier must possess a number of important features. Firstly, the ability to rapidly adsorb to the surfaces of the droplets formed during homogenization. Secondly, the ability to significantly reduce interfacial tension in order to facilitate further droplet disruption; and thirdly, the ability to form a protective coating around the droplets, preventing aggregation by generating strong repulsive forces such as steric or electrostatic repulsion (McClement, 2017).

The physicochemical properties of lignin interestingly contribute to its application as a surface-active agent where surfactants have been used to stabilize emulsions and suspensions (Alwadani and Fatehi, 2018). Therefore, growing interest in the development of lignin applications, replacing synthetic with natural and biodegradable emulsifiers and stabilizers have urged several studies to perform investigation on different types of lignins for this purpose (Sipponen et al. 2016; Chen et al. 2019; Czaikoski et al. 2020). This includes amphiphilic nature of lignin as an attractive property for large scale industrial applications requiring stabilization of interfacial systems (Sipponen et al. 2017). Lignin acts as an emulsifier by using the polar and nonpolar attraction of the hydrophilic phenolic/aliphatic hydroxyl groups and the lipophilic carbon backbone (Safian et al. 2022). In a dispersant for solid–liquid mixtures, the structure of polyphenolic lignin lowers interfacial tension between oil and water and stabilises liquid–liquid mixtures. Due to this, lignin was involved in the study of Pickering emulsion; an emulsion stabilized only by solid particles located at the oil-water interface (Yang et al. 2017).

Studies on lignin as stabilizers has recorded its competency to be used in high capacity as an emulsifier in different concentrations and pH to facilitate the use of this biodegradable material. Lignin nanoparticles have demonstrated to be efficient stabilizer and emulsifying agents (Yaqoob et al. 2021; Ghavidel et al. 2020; Bertolo et al. 2019; Dai et al. 2019). Lignin nanoparticles have stabilized the emulsion for months and lowered the interfacial tension to as low as 19.2 mN/m in a 0.1% concentration (Silmore et al. 2016). Also, modified lignin in colloidal form has shown to be effective emulsifying agents for pickering emulsions (Henn and Martinen, 2019). Nevertheless, an important characteristic of emulsifying agents in cosmetics is that to affirm in the toxicity test. A study by Czaikoski et al. (2020) reported the cytotoxicity of lignins to HT-29 and Caco-2 cells presented a dose-response relationship, establishing non-cytotoxic concentrations for emulsifiers capable of producing stable emulsions. The study has been supported by Yaqoob et al. (2021) that reported the in vitro and in vivo toxicological analyses in human umbilical cell line and Sprague Dawley rats shows lignin-based emulsifier as a non-toxic substance where it exerts no cytotoxic effect to those analyses.

CONCLUSION

To conclude, lignin has received a lot of attention from many researchers around the world due to its uniqueness and speciality. Lignin shows a great potential not only for industrial application, but also in pharmaceutical and cosmeceutical application. Lignin which contains, phenolic, carbonyl and other chromophore as its bioactive ingredient has been proved to give many benefits for human, especially in cosmetics application. Many studies have proved that these bioactive ingredients may contribute as a natural source of antioxidant, antimicrobial agent and natural UV filters in cosmeceutical products to replace the harmful chemical ingredients that are widely used in the market nowadays. It is believed that by incorporating research on lignin with nanotechnology could further enhance their effectiveness as cosmetic ingredients.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEDGEMENT

This work was financially supported by the Universiti Teknologi Malaysia (UTM) under the UTM Fundamental Grant, UTM-FR (20H88).

AUTHOR CONTRIBUTIONS

N.I.W.A. and I.N.A.D. developed the concept and outline of the review. N.M.N. and Z.I.A.R. contributed on the application of lignin in cosmetics. H.A.E.E gave conceptual advice and support. N.I.W.A. reviewed, gave comments, edited, and harmonized the manuscript. All authors have approved the final article to be submitted as a manuscript.

REFERENCES

Alwadani, N., Fatehi, P., 2018. Synthetic and lignin-based surfactants: Challenges and opportunities. Carbon Resources Conversion, 1(2), 126-138. https://doi.org/10.1016/j.crcon.2018.07.006

Alzagameem, A., Khaldi-Hansen, B.E., Büchner, D., Larkins, M., Kamm, B., Witzleben, S.,Schulze, M., 2018. Lignocellulosic biomass as source for lignin-based environmentally benign antioxidants. Molecules, 23(10), 2664.

Alzagameem, A., Klein, S.E., Bergs, M., Do, X.T., Korte, I., Dohlen, S., Schulze, M., 2019. Antimicrobial activity of lignin and lignin-derived cellulose and chitosan composites against selected pathogenic and spoilage microorganisms. Polymers, 11(4), 670.

An, L., Si, C., Wang, G., Sui, W.,Tao, Z., 2019. Enhancing the solubility and antioxidant activity of high-molecular-weight lignin by moderate depolymerization via in situ ethanol/acid catalysis. Industrial Crops and Products, 128, 177-185.

Arruda, M.D.M., Alves, S.D.P.L., da Cruz Filho, I.J., de Sousa, G.F., de Souza Silva, G.A., do Nascimento Santos, D.K.D., ... de Melo, C.M.L., 2021. Characterization of a lignin from *Crataeva tapia* leaves and potential applications in medicinal and cosmetic formulations. *International Journal of Biological Macromolecules*, *180*, 286-298.

Axelstad, M., Boberg, J., Hougaard, K.S., Christiansen, S., Jacobsen, P.R., Mandrup, K.R., Hass, U., 2011. Effects of pre-and postnatal exposure to the UV-filter octyl methoxycinnamate (OMC) on the reproductive, auditory, and neurological development of rat offspring. Toxicology and applied pharmacology, 250(3), 278-290.

Azelee, N.I.W., Adnan, S.A.M., Manas, N.H.A., Dailin, D.J., Ramli, A.N.M., Illias, R.M., 2019. Assessment of microwave-assisted pretreatments for enhancing pineapple waste delignification. In AIP Conference Proceedings (Vol. 2155, No. 1, p. 020003). AIP Publishing LLC.

Barnes, W.J., Anderson, C.T., 2017. Acetyl bromide soluble lignin (ABSL) assay for total lignin quantification from plant biomass. Bio-Protocol, 7, 2149.

Bertolo, M.R., Brenelli de Paiva, L.B., Nascimento, V.M., Gandin, C.A., Neto, M.O., Driemeier, C.E.,Rabelo, S.C., 2019. Lignins from sugarcane bagasse: Renewable source of nanoparticles as Pickering emulsions stabilizers for bioactive compounds encapsulation. Industrial Crops and Products, 140, 111591,https://doi.org/10.1016/j.indcrop.2019.111591

Brand, R.M., Pike, J., Wilson, R.M., Charron, A.R., 2003. Sunscreens containing physical UV blockers can increase transdermal absorption of pesticides. *Toxicology and industrial health*, *19*(1), 9-16.

Casaretto, R., Thomsen, F., Born, J., Holm-Nielsen, J.B., 2019. Determination of biogas process efficiency - a practice-oriented alternative to the biomethane potential test. Bioresource Technology Reports, 7, 100201. https://doi.org/10.1016/j.biteb.2019.100201

Chen, H., Chen, H., 2015. Lignocellulose biorefinery feedstock engineering. LignocelluloseBiorefinery Engineering, 1st ed.; Woodhead Publishing: Cambridge, UK, 37-86.

Chen, K., Qian, Y., Wu, S., Qiu, X., Yang, D., Lei, L., 2019. Neutral fabrication of UV-blocking and antioxidation lignin-stabilized high internal phase emulsion encapsulates for high efficient antibacterium of natural curcumin. Food & Function, 10(6), 3543-3555. https://doi.org/10.1039/c9fo00320g

Cherif, M.F., Trache, D., Brosse, N., Benaliouche, F., Tarchoun, A.F., 2020. Comparison of the physicochemical properties and thermal stability of organosolv and kraft lignins from hardwood and softwood biomass for their potential valorization. Waste and Biomass Valorization, 11(12), 6541-6553.

Cybulska, I., Brudecki, G., Rosentrater, K., Julson, J.L., and Lei, H., 2012. Comparative study of organosolv lignin extracted from prairie cordgrass, switchgrass and corn stover. Bioresource Technology, 118, 30-36.

Czaikoski, A., Gomes, A., Kaufmann, K.C., Liszbinski, R.B., De Jesus, M.B., & Cunha, R.L., 2020. Lignin derivatives stabilizing oil-in-water emulsions: Technological aspects, interfacial rheology and cytotoxicity. Industrial Crops and Products, 154, 112762. https://doi.org/10.1016/j.indcrop.2020.112762

Dai, L., Li, Y., Kong, F., Liu, K., Si, C., Ni, Y., 2019. Lignin-based nanoparticles stabilized Pickering emulsion for stability improvement and thermal-controlled release of trans-resveratrol. ACS Sustainable Chemistry & Engineering, 7(15), 13497-13504. https://doi.org/10.1021/acssuschemeng.9b02966

Del Río, J.C., Rencoret, J., Gutiérrez, A., Kim, H., Ralph, J., 2018. Structuralcharacterization of lignin from maize (*Zea mays L.*) fibers: evidence for diferuloylputrescine incorporated into the lignin polymer in maize kernels. Journal of agricultural and food chemistry, 66(17), 4402-4413.

Desmedt, B., Courselle, P., Beer, J.O. De, Rogiers, V., Grosber, M., Deconinck, E., and Paepe, K.D., 2016. Overview of skin whitening agents with an insight into the illegal cosmetic market in Europe. Journal of the European Academy of Dermatology and Venereology, 30, 943–950. https://doi.org/10.1111/jdv.13595

Dizhbite T, Telysheva G, Jurkjane V, Viesturs U., 2004. Characterization of the radical scavenging activity of lignins––natural antioxidants. Bioresource Technology, 95(3):309-317

Donaldson, L., Nanayakkara, B.,Harrington, J., 2017. Wood Growth and Development.In: Encyclopedia of Applied Plant Sciences, Elsevier, Amsterdam, 203-210.

Dos Santos, P.S, De Cademartori, P.H., Prado, R., Gatto, D.A., Labidi, J., 2014. Composition and structure of organosolvlignins from four eucalypt species. *Wood Science and Technology*, *48*(4), 873-885. https://doi.org/10.1007/s00226-014-0646-z

Draelos, Z.D., 2015. A split-face evaluation of a novel pigment-lightening agent compared with no treatment and hydroquinone. Journal of the American Academy of Dermatology, 72, 105–107. https://doi.org/10.1016/j.jaad.2014.09.011

El Mansouri, N.E., Salvadó, J., 2006. Structural characterization of technical lignins for the production of adhesives: Application to lignosulfonate, kraft, soda-anthraquinone, organosolv and ethanol process lignins. Industrial crops and products, 24(1), 8-16.

Emaga, T.H., Andrianaivo, R.H., Wathelet, B., Tchango, J.T., Paquot, M., 2007. Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. Food chemistry, 103(2), 590-600.

Emmanuel, G., Nour, S.A.R., Ali, H.A., Mahdi, M.A., Abbas, A.K., 2018. Klason method: aneffective method for isolation of lignin fractions from date palm biomass waste. Chem. Process Eng. Res, 57, 46-58.

Erdocia, X., Prado, R., Corcuera, M.Á., Labidi, J., 2014. Effect of different organosolv treatments on the structure and properties of olive tree pruning lignin. Journal of Industrial and Engineering Chemistry, 20(3), 1103-1108. https://doi.org/10.1016/j.jiec.2013.06.048

Espinoza-Acosta, J.L., Torres-Chávez, P.I., Ramírez-Wong, B., López-Saiz, C.M., Montaño-Leyva, B., 2016. Antioxidant, antimicrobial, and antimutagenic properties of technical lignins and their applications. BioResources, 11(2),5452-5481.

Esteves Costa, C.A., Coleman, W., Dube, M., Rodrigues, A.E., Rodrigues Pinto, P.C., 2016. Industrial Crops and Products, 92, 136-148. https://doi.org/10.1016/j.indcrop.2016.07.032

Fagerstedt, K.V., Saranpää, P., Tapanila, T., Immanen, J., Serra, J.A.A., Nieminen, K., 2015. Determining the composition of lignins in different tissues of silver birch Plants, 4(2), 183-195.

Faris, A.H., Rahim, A.A., Mohamad Ibrahim, M.N., Hussin, M.H., Alkurdi, A.M., Salehabadi, A., 2017. Investigation of oil palm-based Kraft and auto-catalyzedorganosolv lignin susceptibility as a green wood adhesive. *International Journal of Adhesion and Adhesives*, *74*, 115-122. https://doi.org/10.1016/j.ijadhadh.2017.01.006

Faust, S., Kaiser, K., Wiedner, K., Glaser, B., Joergensen, R.G., 2018. Comparison of different methods for determining lignin concentration and quality in herbaceous and woody plant residues. Plant and Soil, 433(1), 7-18.

Florian, T. D., Villani, N., Aguedo, M., Jacquet, N., Thomas, H.G., Gerin, P., Magali, D., and Richel, A., 2019. Chemical composition analysis and structural features of banana rachis lignin extracted by two organosolv methods. *Industrial Crops and Products*, *132*, 269-274. https://doi.org/10.1016/j.indcrop.2019.02.022

Franzol, A., Banin, T.M., Brazil, T.R., Rezende, M.C., 2021. Assessment of kinetic stability of cosmetic emulsions formulated with different emulsifiers using rheological and sensory analyses. Journal of Sol-Gel Science and Technology, 99(3), 469-481. https://doi.org/10.1007/s10971-021-05587-x

Gago-Ferrero, P., Díaz-Cruz, M.S., Barceló, D., 2015. UV filters bioaccumulation in fish from Iberian River basins. Science of the Total Environment, 518, 518-525.

Gao, Y., Guo, X., Liu, Y., Fang, Z., Zhang, M., Zhang, R., You, L., Li, T., Liu, R. H., 2018. A full utilization of rice husk to evaluate phytochemical bioactivities and prepare cellulose nanocrystals. Scientific Reports, 8(1). https://doi.org/10.1038/s41598-018-27635-2

Ghavidel, N., Fatehi, P., 2021. Interfacial and emulsion characteristics of oil–water systems in the presence of polymeric lignin surfactant. Langmuir, 37(11), 3346-3358. https://doi.org/10.1021/acs.langmuir.0c03458

Gordobil, O., Herrera, R., Yahyaoui, M., İlk, S., Kaya, M., Labidi, J., 2018. Potential use of kraft and organosolvlignins as a natural additive for healthcare products. RSC advances, 8(43), 24525-24533.

Gordobil, O., Olaizola, P., Banales, J.M., Labidi, J., 2020. Lignins from agroindustrial by-products as natural ingredients for cosmetics: chemical structure and *in vitro* sunscreen and cytotoxic activities. Molecules, 25(5), 1131.

Gregorová, A., Cibulková, Z., Košíková, B., Šimon, P., 2005. Stabilization effect of lignin in polypropylene and recycled polypropylene. Polymer Degradation and Stability, 89(3), 553-558.

Hatfield, R., Fukushima, R.S., 2005. Can lignin be accurately measured? Crop science,45(3), 832-839.

Hatfield, R.D., Grabber, J., Ralph, J., Brei, K., 1999. Using the acetyl bromide assay to determine lignin concentrations in herbaceous plants: some cautionary notes. Journal of Agricultural and Food Chemistry, 47(2), 628-632.

Hattalli, S., Benaboura, A., Ham-Pichavant, F., Nourmamode, A., Castellan, A., 2002. Adding value to alfa grass (*Stipa tenacissima L.)* soda lignin as phenolic resins 1. Lignin characterization. Polymer Degradation and Stability, 76(2),259-264. https://doi.org/10.1016/s0141-3910(02)00022-8

HazwanHussin, M., Aziz, A.A., Iqbal, A., Ibrahim, M.N., and Latif, N.H., 2019. Development and characterization novel bio-adhesive for wood using kenaf core *(Hibiscus cannabinus*) lignin and glyoxal. International Journal of BiologicalMacromolecules, 122, 713-722. https://doi.org/10.1016/j.ijbiomac.2018.11.009

Henn, A., Mattinen, M., 2019. Valued applications of lignin nanoparticles. Recent Progress in Materials, 1(2), 1-1. https://doi.org/10.21926/rpm.1902001

Hu, J., Zhang, Q., Lee, D.J., 2018. Kraft lignin biorefinery: A perspective. BioresourceTechnology, 247, 1181-1183.

Ibrahim, H.M., 2015. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. Journal of Radiation Research and Applied Sciences, 8(3), 265-275. https://doi.org/10.1016/j.jrras.2015.01.007

Ioelovich, M., 2015. Methods for determination of chemical composition of plant biomass. JSITA, 17(4), 208-214.

José Borges Gomes, F., De Souza, R.E., Brito, E.O., Costa Lelis, R.C., 2020. A review on lignin sources and uses. Journal of Applied Biotechnology & Bioengineering, 100-105. https://doi.org/10.15406/jabb.2020.07.00222

Kabir, A.S., 2017. Effects of lignin as a stabilizer or antioxidant in polyolefins. Electronic thesis and dissertation Repository. The University of Western Ontario.

Kim, S., Pangestuti, R.,2011. Potential role of marine algae on female health, beauty, and longevity. In S.-K. Kim (Ed.), Advances in Food and Nutrition Research (Vol. 64). Elsevier Inc. https://doi.org/10.1016/B978-0-12-387669-0.00004-1

Kim, Y., Suhr, J., Seo, H.S., Kim, S., Park, I.K., Ki, S.H., Lee, Y., Kim, K.J., Nam, J.D., 2017. All biomass and UV protective composite composed of compatibilized lignin and poly (lactic acid). Sci. Rep. 7, 43596.

Kirk, T.K., Obst, J.R., 1988. Lignin determination. Methods in enzymology, 161,87- 101.

Klett,A.S., 2017. Purification, Fractionation, and Characterization of Lignin from Kraft Black Liquor for Use as a Renewable Biomaterial. (Dissertation) Clemson University.

Lan, W.C., Tzeng, C.W., Lin, C.C., Yen, F.L., Ko, H.H., 2013. Prenylated flavonoids from *Artocarpus altilis*: Antioxidant activities and inhibitory effects on melanin production. Phytochemistry, 89, 78–88. https://doi.org/10.1016/j.phytochem.2013.01.011

Lee, S.C., Tran, T.M.T., Choi, J.W., Won, K., 2019. Lignin for white natural sunscreens. International journal of biological macromolecules, 122, 549-554.

Lee, S.C., Yoo, E., Lee, S.H., and Won, K., 2020. Preparation and application of light-coloredligninnanoparticles for broad-spectrum sunscreens. Polymers, 12(3), 699. https://doi.org/10.3390/polym12030699

Lee, S.Y., Baek, N., Nam, T., 2016. Natural, semisynthetic and synthetic tyrosinase inhibitors. Journal of Enzyme Inhibition and Medicinal Chemistry, 31(1), 1–13. https://doi.org/10.3109/14756366.2015.1004058

Levine, A., 2020. Sunscreen use and awareness of chemical toxicity among beach goers in Hawaii priorto a ban on the sale of sunscreens containing ingredients found to be toxic to coral reef ecosystems. Mar. Policy, 117, 103875

Liu, Q., Luo, L., Zheng, L., 2018. Lignins: biosynthesis and biological functions in plants. International journal of molecular sciences, 19(2), 335.

Lobo, F., Franco, A.R., Fernandes, E.M., Reis, R.L., 2021. An Overview of the Antimicrobial Properties of Lignocellulosic Materials. Molecules, 26(6), 1749.

Lu, Q., Zhu, M., Zu, Y., Liu, W., Yang, L., Zhang, Y., Zhao, X., Zhang, X., Zhang, X., Li, W., 2012. Comparative antioxidant activity of nanoscale lignin prepared by a supercritical antisolvent (SAS) process with non-nanoscale lignin. Food Chemistry, 135 (1), 63-67.

Luzi, F., Yang, W., Ma, P., Torre, L., Puglia, D., 2021. Lignin-based materials with antioxidant and antimicrobial properties. Lignin-Based Materials for Biomedical Applications, 291-326. https://doi.org/10.1016/b978-0-12-820303-3.00003-5

Mahmood, Z., Yameen, M., Jahangeer, M., Riaz, M., Ghaffar, A., Javid, I., 2018. Lignin as natural antioxidant capacity. Lignin Trends Application.

https://www.intechopen.com/chapters/59700 (Accessed: August 2021).

Masum, M.N., Yamauchi, K., Mitsunaga, T., 2019. Tyrosinase inhibitors from natural and synthetic sources as skin-lightening agents. Reviews in Agricultural Science, 7, 41–58.

McClements, D.J., Bai, L., Chung, C., 2017. Recent advances in the utilization of natural emulsifiers to form and stabilize emulsions. Annual Review of Food Science and Technology, 8(1), 205-236. https://doi.org/10.1146/annurev-food-030216-030154

McDonald, A., Donaldson, L., 2001. Wood, constituents of. *Encyclopedia of Materials:Science and Technology*, 9612-9615.https://doi.org/10.1016/b0-08-043152-6/01739-3

Meng, X., Parikh, A., Seemala, B., Kumar, R., Pu, Y., Christopher, P., Wyman, C.E., Cai, C.M., Ragauskas, A.J., 2018. Chemical transformations of poplar lignin during cosolvent enhanced lignocellulosic fractionation process, ACS Sustain. Chem. Eng. 6 (7), 8711–8718.

Moreira-Vilar, F.C.,Siqueira-Soares, R.D., Finger-Teixeira, A., Oliveira, D.M., Ferro, A.P., Da Rocha, G.J., Ferrarese, M.D., Dos Santos, W.D., Ferrarese-Filho, O., 2014. The acetyl bromide method is faster, simpler and presents best recovery of lignin in different herbaceous tissues than Klason and Thioglycolic acid methods. *PLoS ONE*, *9*(10), e110000. https://doi.org/10.1371/journal.pone.0110000

Morganti, P., Coltelli, M., 2019. A new carrier for advanced Cosmeceuticals. Cosmetics, 6(1), 10. https://doi.org/10.3390/cosmetics6010010

Mudgil, D., Barak, S., 2019. Classification, technological properties, and sustainable sources. Dietary Fiber: Properties, Recovery, and Applications, 27 58. https://doi.org/10.1016/b978-0-12-816495-2.00002-2

Ndaba, B., Roopnarain, A., Daramola, M.O., Adeleke, R., 2020. Influence of extraction methods on antimicrobial activities of lignin-based materials: A review. Sustainable Chemistry and Pharmacy, 18, 100342. https://doi.org/10.1016/j.scp.2020.100342

Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Lunts, A., ... Cox, C., 2002. Extrapulmonary translocation of ultrafine carbon particles following whole-body inhalation exposure of rats. J Toxicol Environ Health A, 65(20), 1531-1543.

Oresajo, C., Pillai, S., Yatskayer, M., Puccetti, G., McDaniel, D.H., 2009. Antioxidants and skin aging: A review. Cosmetic Dermatology, 22 (11), 563-570.

Padilha, C.E.D.A., Nogueira, C.D.C., Filho, M.A.O., Souza, D.F.D.S., Oliveira, J.A.D, Santos, E.S.D., 2020. Valorization of cashew apple bagasse using acetic acid pretreatment: Production of cellulosic ethanol and lignin for their use as sunscreen ingredients. Process Biochemistry, 91, 23-33

Paul, S., Thakur, N.S., Chandna, S., Reddy, Y.N., Bhaumik, J., 2021. Development of a light activatable lignin nanosphere based spray coating for bioimaging and antimicrobial photodynamic therapy. Journal of Materials Chemistry B, 9(6), 1592-1603. https://doi.org/10.1039/d0tb02643c

Pereira, M.A., Monteiro, C.R., Pereira, G.N., Júnior, S.E., Zanella, E., Ávila, P.F., Stambuk, B.U., Goldbeck, R., De Oliveira, D.,Poletto, P., 2020. Deconstruction of banana peel for carbohydrate fractionation. *Bioprocess and Biosystems Engineering*, *44*(2), 297-306. https://doi.org/10.1007/s00449-020-02442-1

Piccinino, D., Capecchi, E., Tomaino, E., Gabellone, S., Gigli, V., Avitabile, D., Saladino, R., 2021. Nano-Structured Lignin as Green Antioxidant and UV Shielding Ingredient for Sunscreen Applications. Antioxidants, 10(2), 274.

Poletto, M., 2018. *Lignin: Trends and applications*. BoD – Books on Demand.

Qian, Y., Qiu, X. Zhu, S., 2015. Lignin: a nature-inspired sun blocker for broad spectrum sunscreens. Green Chem., 17, 320-324.

Qian, Y., Qiu, X., Zhu, S., 2016. Sunscreen performance of lignin from different technical resources and their general synergistic effect with synthetic sunscreens. *ACS Sustainable Chemistry & Engineering*, *4*(7), 4029-4035.

Ralph, J., Lapierre, C., Boerjan, W., 2019. Lignin structure and its engineering. *Current Opinion in Biotechnology*, *56*, 240-249. https://doi.org/10.1016/j.copbio.2019.02.019

Ramos, S., Homem, V., Alves, A., Santos, L., 2016. A review of organic UV-filters in wastewater treatment plants. Environment international, 86, 24-44.

Ratanasumarn, N., Chitprasert, P.,2020. Cosmetic potential of lignin extracts from alkaline-treated sugarcane bagasse: Optimization of extraction conditions using response surface methodology. International Journal of Biological Macromolecules, 153, 138–145. https://doi.org/10.1016/j.ijbiomac.2020.02.328

Research Ltd, M., 2022. Skin Lighteners - Global market trajectory & analytics. Research and Markets - Market Research Reports - Welcome. https://www.researchandmarkets.com/reports/1056077/skin_lighteners_global_market_trajectory_and

Rinnerthaler, M., Bischof, J., Streubel, M., Trost, A., Richter, K., 2015. Oxidative stress in aging human skin. Biomolecules, 5(2), 545-589. https://doi.org/10.3390/biom5020545

Sadaqat, B., Khatoon, N., Malik, A. Y., Jamal, A., Farooq, U., Wang, Q., Huang, Z., 2020. Enzymatic decolorization of melanin by lignin peroxidase from *Phanerochaetechrysosporium*. Scientific Reports, 10(20240), 1–10.

https://doi.org/10.1038/s41598-020-76376-9

Sadeghifar, H., Ragauskas, A., 2020. Lignin as a UV light blocker—a review. Polymers, 12(5), 1134.

Safian, M.T., Sekeri, S.H., Yaqoob, A.A., Serrà, A., Jamudin, M.D., Mohamad Ibrahim, M.N., 2022. Utilization of lignocellulosic biomass: A practical journey towards the development of emulsifying agent. Talanta, 239, 123109. https://doi.org/10.1016/j.talanta.2021.123109

Saratale, R.G., Saratale, G.D., Ghodake, G., Cho, S.K., Kadam, A., Kumar, G., Shin, H.S., 2019. Wheat straw extracted lignin in silver nanoparticles synthesis: Expanding its prophecy towards antineoplastic potency and hydrogen peroxide sensing ability. International journal of biological macromolecules, 128, 391-400.

Sarrouh, B., de Souza, R.O.A., da Silva Florindo, R.H., Lofrano, R.C.Z., de Oliveira, A.M., 2021. Extraction and Identification of Biomolecules from Lignin Alkaline Hydrolysate from Coffee Husk.

Schlumpf, M., Kypke, K., Wittassek, M., Angerer, J., Mascher, H., Mascher, D., Lichtensteiger,W., 2010. Exposure patterns of UV filters, fragrances, parabens, phthalates, organochlor pesticides, PBDEs, and PCBs in human milk: correlation of UV filters with use of cosmetics.Chemosphere, 81(10), 1171-1183.

Schneider, S.L., and Lim, H.W., 2019. Review of environmental effects of oxybenzone and other sunscreen active ingredients. Journal of the American Academy of Dermatology, 80(1), 266-271.

Silmore, K.S., Gupta, C., Washburn, N.R., 2016. Tunable Pickering emulsions with polymer-grafted lignin nanoparticles (PGLNs). *Journal of Colloid and Interface Science*, *466*, 91-100. https://doi.org/10.1016/j.jcis.2015.11.042

Singh, S.K., Dhepe, P.L., 2016. Isolation of lignin by organosolv process from different varieties of rice husk: Understanding their physical and chemical properties. Bioresource Technology, 221, 310-317. https://doi.org/10.1016/j.biortech.2016.09.042

Slavin, Y.N., Ivanova, K., Hoyo, J., Perelshtein, I., Owen, G., Haegert, A., ... Bach, H., 2021. Novel Lignin-Capped Silver Nanoparticles against Multidrug-Resistant Bacteria. ACS applied materials & interfaces, 13(19), 22098-22109

Solihat, N.N., Sari, F.P., Falah, F., Ismayati, M., Lubis, M.A., Fatriasari, W., Santoso, E.B., Syafii, W., 2021. Lignin as an active biomaterial: A review. Jurnal Sylva Lestari, 9(1), 1. https://doi.org/10.23960/jsl191-22

Spiridon, I., 2020. Extraction of lignin and therapeutic applications of lignin-derived compounds. A review. Environmental Chemistry Letters, 18(3), 771-785. https://doi.org/10.1007/s10311-020-00981-3

Stone, J.E., Blundell, M.J., Tanner, K.G., 1951. The formation of lignin in wheat plants. Canadian Journal of Chemistry, 29(9), 734-745

Sung, H.J., Khan, M.F., Kim, Y.H., 2019. Recombinant lignin peroxidase-catalyzed decolorization of melanin using in-situ generated H_2O_2 for application in whitening cosmetics. International Journal of Biological Macromolecules, 136, 20–26. https://doi.org/10.1016/j.ijbiomac.2019.06.026

Tang, Q., Qian, Y., Yang, D., Qiu, X., Qin, Y., Zhou, M., 2020. Lignin-Based Nanoparticles: A Review on Their Preparations and Applications. Polymers, 12(11), 2471.

Tao, J., Li, S., Ye, F., Zhou, Y., Lei, L., Zhao, G., 2020. Lignin–An underutilized renewable and valuable material for food industry. Critical reviews in food science and nutrition, 60(12),2011-2033.

Ticona, L.A., Estrada, C.T., Sánchez, Á.R., 2020. Inhibition of melanin production and tyrosinase activity by flavonoids isolated from *Loranthus acutifolius*. Natural Product Research, 35, 4690-4693. https://doi.org/10.1080/14786419.2019.1709185

Torres, L.A.Z., Woiciechowski, A.L., de Andrade Tanobe, V.O., Karp, S.G., Lorenci, L. C.G., Faulds, C., Soccol, C.R., 2020. Lignin as a potential source of high-added value compounds: A review. Journal of Cleaner Production, 263, 121499.

Tsouko, E., Alexandri, M., Fernandes, K.V., Guimarães Freire, D.M., Mallouchos, A., Koutinas, A.A., 2019. Extraction of phenolic compounds from palm oil processing residues and their application as antioxidants. *Food technology and biotechnology*, *57*(1), 29-38. https://doi.org/10.17113/ftb.57.01.19.5784

Vanholme, R., De Meester, B., Ralph, J., Boerjan, W., 2019. Lignin biosynthesis and its integration into metabolism. *Current Opinion in Biotechnology*, *56*, 230-239. https://doi.org/10.1016/j.copbio.2019.02.018

Vavilala, S.L., Ghag, S.B., D'Souza, J.S., 2019. Lignin: Understanding and exploring its potential for Biofuel production. *Advanced Bioprocessing for Alternative Fuels, Biobased Chemicals, and Bioproducts*, 165-186. https://doi.org/10.1016/b978-0-12-817941-3.00009-7

Wan Hassan, W.N.A., Zulkifli, R.M., Basar, N., Ahmad, F., Che Yunus, M.A., 2015. Antioxidant and tyrosinase inhibition activities of α-mangostin and Garcinia mangostana Linn. pericarp extracts. Journal of Applied Pharmaceutical Science, 5(09), 37–40. https://doi.org/10.7324/JAPS.2015.50907

Wang, G., Chen, H., 201. Fractionation and characterization of lignin from steam-exploded corn stalk by sequential dissolution in ethanol–water solvent. Separation and Purification Technology, 120, 402-409. https://doi.org/10.1016/j.seppur.2013.10.029

Wang, G., Xia, Y., Sui, W., Si, C., 2018. Lignin as a novel tyrosinase inhibitor: Effects of sources and isolation processes. ACS Sustainable Chemistry Engineering, 6, 9510–9518. https://doi.org/10.1021/acssuschemeng.8b02234

Wang, R., Wang, G., Sui, W., Zhou, C., Li, S., Ji, Y., Si, C., 2020. Tyrosinase inhibitory performance of hydrolysate from post-washing liquor of steam exploded corn stalk and its fractionation enhancement. Industrial Crops and Products, 154, 112652. https://doi.org/10.1016/j.indcrop.2020.112652

Wang, R., Wang, G., Xia, Y., Sui, W., Si, C., 2019. Functionality study of lignin as a tyrosinase inhibitor: Influence of lignin heterogeneity on anti-tyrosinase activity. International Journal of Biological Macromolecules, 128, 107–113. https://doi.org/10.1016/j.ijbiomac.2019.01.089

Wang, G., Pang, T., Xia, Y., Liu, X., Li, S., Parvez, A.M., Kong, F., Si, C., 2019.Subdivision of bamboo Kraft lignin by one-step ethanol fractionation to enhance its water-solubility and antibacterial performance. International Journal of Biological Macromolecules, 133, 156-164. https://doi.org/10.1016/j.ijbiomac.2019.04.093

Wei, X., Liau, Y., Luo, Y., Shen, Z., Wang, S., Li, M., Zhang, L., 2021. Effect of organosolv extraction on the structure and antioxidant activity of eucalyptus kraft lignin. International Journal of Biological Macromolecules, 187, 462–470.

Welker, C., Balasubramanian, V., Petti, C., Rai, K., DeBolt, S., Mendu, V., 2015. Engineering plant biomass lignin content and composition for Biofuels and Bioproducts. *Energies*, *8*(8), 7654-7676. https://doi.org/10.3390/en8087654

Widsten, P., 2020. Lignin-Based Sunscreens—State-of-the-Art, Prospects and Challenges. Cosmetics, 7(4), 85.

Widsten, P., Tamminen, T., Liitiä, T., 2020. Natural sunscreens based on nanoparticles of modified kraft lignin (Cat Lignin). ACS omega, 5(22), 13438-13446.

Wiechers, J.W., Kelly, C.L., Blease, T.G., Chris Dederen, J., 2004. Formulating for efficacy. International Journal of Cosmetic Science, 26(3), 165-165. https://doi.org/10.1111/j.1467-2494.2004.00217_02.x

Wong, S.K., Tangah, J., Chan, H.T., Chan, E.W.C., 2018. Chemistry and pharmacology of artocarpin: An isoprenyl flavone from artocarpus species. Systematic Reviews in Pharmacy, 9(1), 58–63. https://doi.org/10.5530/srp.2018.1.12

Yaakob, M.N., 2020. Effect of catalysts on the yield and properties of lignin from microwave assisted acetosolv extraction of oil palm empty fruit bunch fibres. Journal of Oil Palm Research. https://doi.org/10.21894/jopr.2020.0076

Yamamura, M., Akashi, K., Yokota, A., Hattori, T., Suzuki, S., Shibata, D., Umezawa, T., 2012. Characterization of *Jatropha curcas*lignins. Plant Biotechnology, 29(2), 179-18 https://doi.org/10.5511/plantbiotechnology.12.0515b

Yang, W., Rallini, M., Wang, De-Y., Dominici, F., Torre, L., Kenny, J.M., Puglia, D., 2017. Role of lignin nanoparticles in UV resistance, thermal and mechanical performance of PMMA nanocomposites prepared by a combined free-radical graft polymerization/masterbatch. Composites, 107, 61–69.

Yaqoob, A.A., Sekeri, S.H., Othman, M.B., Ibrahim, M.N., Feizi, Z.H., 2021. Thermal degradation and kinetics stability studies of oil palm (ElaeisGuineensis) biomass-derived lignin nanoparticle and its application as an emulsifying agent. Arabian Journal of Chemistry, 14(6), 103182. https://doi.org/10.1016/j.arabjc.2021.103182

Yearla, S.R., Padmasree, K., 2016. Preparation and characterisation of lignin nanoparticles: evaluation of their potential as antioxidants and UV protectants. Journal of Experimental Nanoscience, 11(4), 289-302.

Zhong, J.F., Xu, L., Qin, X.L., 2015. Efficient antibacterial silver nanoparticles composite using lignin as a template. Journal of Composite Materials, 49(19), 2329-2335.

Zhong, S., Sun, N.A.N., Liu, H., Niu, Y., Wu, Y.A.N., 2015. Reduction of facial pigmentation of melasma by topical lignin peroxidase: A novel fast-acting skin lightening agent. Experimental and Therapeutic Medicine, 9, 341–344. https://doi.org/10.3892/etm.2014.2118

Zin, N.A., Badaluddin, N.A., Huat, J.T.Y., Khandaker, M.M., Khalit, S.I., Mohammad, H., Lokman, M.N., 2022. Assessment potential of Trichoderma spp. as biodecomposer agent of food waste. Bioscience Research, 19(1), 39-48.

Zolghadri, S., Bahrami, A., Khan, M.T.H., Munoz-munoz, J., Garcia-molina, F., Garcia-Canovasd, F., Saboury, A.A., 2019. A comprehensive review on tyrosinase inhibitors. Journal of Enzyme Inhibition and Medicinal Chemistry, 34(1), 279–309. https://doi.org/10.1080/14756366.2018.1545767

Zuo, A.R., Dong, H.H., Yu, Y.Y., Shu, Q.L., Zheng, L.X., Yu, X.Y., Cao, S., 2018. The antityrosinase and antioxidant activities of flavonoids dominated by the number and location of phenolic hydroxyl groups. Chinese Medicine, 13(51), 1–12. https://doi.org/10.1186/s13020-018-0206-9