Original Article
J. Korean Wood Sci. Technol. 2026, 54(1): 1-18
https://doi.org/10.5658/WOOD.2026.54.1.1

Journal of the Korean Wood Science and Technology
pISSN: 1017-0715 eISSN: 2233-7180
http://www.woodj.org

Influence of Toasting Levels on the Chemical Components of *Eucalyptus camaldulensis* Dehnh. Wood

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ABSTRACT

Barrel-making commonly involves wood toasting processes that improve the sensory profile of alcoholic beverages. This study aimed to determine the effect of toasting levels on the wood chemical components of *Eucalyptus camaldulensis* Dehnh., known as river red gum (RRG) using TAPPI and ASTM methods. Total phenolic and sugar contents and volatile components of this wood aged in a model spirit solution were measured using UV-Vis spectrophotometry and gas chromatography-mass spectrometry (GC-MS), respectively. Results showed that heavy toasting significantly reduced the lignin content of RRG wood from 31.91% to 28.40%. The GC-MS analysis showed that the thermal degradation of lignin formed new volatile compounds such as 3,5-dimethoxy-4-hydroxycinnamaldehyde, coniferyl aldehyde, syringaldehyde, syringylacetone and vanillin in the heavily toasted and charred RRG wood extracts. Furthermore, charring of RRG wood led to a decrease in total phenolic content from 398.49 mg GAE/L to 374.26 mg GAE/L. Hemicellulose was significantly decreased from 48.24% to 44.94% (heavy toasted) and 34.15% (charred), which was further confirmed with the increase in total sugar content of RRG wood extract from 186.29 mg Glu/L to 230.44 mg Glu/L (heavy toasted) and 342.87 mg Glu/L (charred). Additionally, results in Fourier transform infrared spectroscopy confirmed the thermal degradation of hemicellulose and lignin. Overall, the toasting treatment had a significant effect on the RRG wood chemical components, particularly on lignin and hemicellulose, leading to the formation of new sensory compounds that could add complexity and a unique sensory profile to alcoholic beverages likes distilled spirits.

Keywords: toasting levels, *Eucalyptus camaldulensis*, wood chips, alcoholic beverages, model spirit solution

1. INTRODUCTION

The use of wood barrels and wood chips plays an integral part in the quality and sensory profile of alcoholic beverages. Traditionally, the wood species considered best for making barrels is oak (*Quercus* genus). However, as a result of the huge demand for oak barrels, some countries have explored alternative wood materials, such as false acacia, cherry, European and American ash, and mulberry, for use in the aging and maturation of alcoholic beverages (Jordão and Cosme, 2022).

In the Philippines, winemakers, distillers, and brew-masters commonly use plastic, glass and stainless con-

Date Received June 18, 2025; Date Revised August 26, 2025; Date Accepted September 24, 2025; Published January 25, 2026
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tainers due to the unavailability and high costs of importing oak barrels.

The World Health Organization reported that spirits account for the majority of alcoholic beverage consumption in the Philippines (72%), followed by beer (27.3%) and wine (0.4%). With the increasing demand for these alcoholic beverages in the Philippines, the Department of Science and Technology – Forest Products Research and Development Institute (DOST-FPRDI) explored, studied, and developed non-oak wooden barrels made from locally available wood species such as *Sandoricum koetjape* (Burm. f.) Merr., *Swietenia macrophylla* King, *Acacia mangium* Willd., and *Eucalyptus camaldulensis* Dehnh. for wine aging purposes.

Among these, *E. camaldulensis* Dehnh. or river red gum (RRG) wood was studied further for its potential as alternative to oak for distilled spirit aging. This tree is native to Australia and widely introduced to the Philippines to serve as a plantation or reforestation species because of its invasive and highly adaptive characteristics that could withstand extreme environmental conditions such as drought and high soil salinity (Rojas-Sandoval and Acevedo-Rodríguez, 2019). Its appropriateness for spirit maturation is further supported by its successful use by several Australian distilling companies. For instance, Woodwater Distillery Pty Ltd's RRG-matured whisky received a bronze medal at the 2023 World Whisky Awards.

To determine the suitability of this local wood as an alternative to oak for maturing spirits, the effect of toasting levels on the macromolecule's components (cellulose, hemicellulose, lignin) and extractives of the RRG wood was initially investigated using ground wood samples and model spirit solution through various chemical methods and instrumental analysis. These chemical components are known to degrade as the temperature rises (Kim *et al*., 2018; Park *et al*., 2020) and hydrolyze at higher toasting temperature (> 200℃) to form into new aromatic and sensory compounds that could significantly improve the quality, complexity, and sensory profile of alcoholic beverages upon aging (Carpena *et al*., 2020).

This study will serve as a baseline knowledge for the suitability of different toasting level in *E. camaldulensis* for the wood industry, specifically for use as wooden barrels and wood chips for the aging of alcoholic beverages.

2. MATERIALS and METHODS

2.1. Sample preparation

Kiln dried RRG wood samples were prepared following the TAPPI T 257 method. Samples were cut to matchstick size, air-dried, and then ground using a Wiley mill (Wiley Mill Model N02, Arthur Thomas, Chadds Ford, PA, USA). The ground samples were then sieved in a mesh wire passing 40 mesh and retained at 60 mesh. The samples retained on the 60-mesh screen were used to determine chemical properties. Ground samples were then toasted in a convection oven at varying temperatures and durations (Fig. 1; Table 1).

Fig. 1. Ground river red gum wood samples with different toasting levels.

Table 1. Thermal treatment conditions of RRG wood for different toasting levels

Toasting level	Temperature and duration
Untoasted	No heat treatment
Heavy toasting	200℃, 25 min
Charred	250℃, 15 min

RRG: river red gum.

Then, the samples were subjected to proximate chemical analysis. For other chemical analyses such as total phenolic content (TPC), antioxidant, total sugar analysis and gas chromatography-mass spectrometry (GC-MS) analysis, 20 g/L RRG wood chips (untoasted, heavy, charred) were soaked in 40% ethanol for 1 month (Fig. 2) as an experimental spirit solution.

2.2. Proximate chemical analysis

Standard methods (with some modifications) were used for chemical analysis of wood components. All analyses were done in triplicate (Table 2).

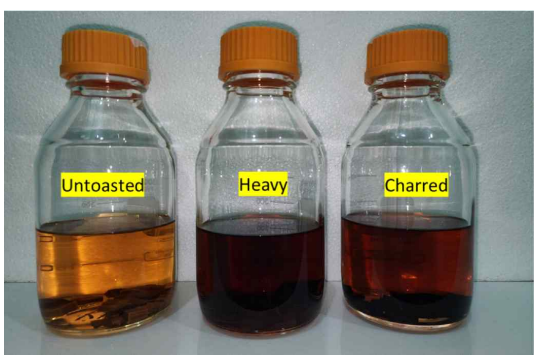

Fig. 2. Maceration of river red gum wood chips (20 g/L) in 40% ethanol for chemical analysis.

2.3. Total phenolic content

TPC was determined with the Folin-Ciocalteu reagent according to a procedure described by Singleton and Rossi (1965). Sample (0.5 mL) was added with 0.2 mol/L Folin-Ciocalteu reagent (2.5 mL) followed by 75 g/L sodium carbonate solution (2 mL). The absorbance readings were taken at 765 nm after incubation at 45℃ for 15 minutes using UV Vis spectrophotometer (UV-1700, Shimadzu, Kyoto, Japan). Gallic acid was used as a reference standard, and the results were expressed as milligram gallic acid equivalent (mg GAE/g) dried extract. The calibration curve ranged from 0.0−1,000 ug/mL. The data were presented as mean values ± SD (n = 3).

2.4. 2,2-Diphenyl-1-picrylhydrazyl radical scavenging assay

This test using 2,2-diphenyl-1-picrylhydrazyl (DPPH) was carried out following the method described by Sharma *et al*. (2018) with some modifications. The working solution was prepared using a methanolic solution (98 mg/L). A portion (950 μL) of the working solution was added to the concentrated extracts and standard solutions. The sample was incubated for 30

Table 2. Summary of analytical methods for determination of proximate chemical properties of RRG wood

Proximate chemical analysis	Test methods/Reference
Moisture content	TAPPI T 264 cm-07 (TAPPI, 2007)
Ash content	TAPPI T 211 om-12 (TAPPI, 2012)
Ethanol (40%) extractive content	Modified TAPPI T204 cm-07 (TAPPI, 2007; Balagot *et al*., 2024)
Hot water solubility	T 207 cm-08 (TAPPI, 2008)
1% Sodium hydroxide (NaOH) solubility	TAPPI T 212 om-12 (TAPPI, 2012)
Lignin content	Modified TAPPI T 222 om-15 (TAPPI, 2011; Balagot *et al*., 2024)
Holocellulose content	Erickson, modified TAPPI procedure (Erickson, 1962; Balagot *et al*., 2024)
Alpha-cellulose content	ASTM-D1103-60 (ASTM, 1968)
Hemicellulose content	Difference between holocellulose and alpha-cellulose content

RRG: river red gum.

minutes and absorbance was read at 515 nm using UV Vis spectrophotometer (UV-1700, Shimadzu). Trolox solutions were used for calibration, and antioxidant activity was expressed in mmol TE/g dried extract. The calibration curve ranged from 0.050−0.500 mM.

2.5. Cupric-reducing antioxidant capacity assay

The method used was from Apak *et al*. (2008) with some modifications. The analysis, three solutions were mixed in a test tube. Solution A was prepared by dissolving copper (II) chloride in distilled water to produce a solution containing 0.010 M Cu(II). Solution B contained ammonium acetate buffer pH 7.0, which was prepared by dissolving ammonium acetate in distilled water. Solution C contained 0.0075 M neocuproine (2,9-dimethyl-1,10-phenanthroline) in ethanol.

The reaction mixture was left for 30 minutes in the dark and then the absorption was measured at 450 nm using a UV Vis spectrophotometer (UV-1700, Shimadzu). Trolox was used as a reference standard. The results were expressed as Trolox equivalent antioxidant capacity (TEAC) or in mmol TEAC/g dried extract. The calibration curve ranged from 0.0−0.500 mmol/L.

2.6. Total sugar analysis

Total sugar content was quantified using the procedure published by DuBois *et al*. (1956). A 0.5-mL of extracts was put into a test tube and added with an equal amount of 5% phenol. The working solution was vortexed to ensure a complete reaction. Then, 2.5 mL of concentrated sulfuric acid was added and thoroughly vortexed. The solution was allowed to stand for 10 min before cooling in a water bath (25℃−30℃) for 20 min. The absorbance of the sample or standard was measured at 490 nm using a UV Vis spectrophotometer (UV-1700, Shimadzu). A calibration curve with a coefficient determination of 0.9974 was prepared using glucose solutions (0−0.10 mg/mL).

2.7. Fourier transform infrared analysis

The infrared spectra of untoasted, heavy and charred RRG wood samples were obtained using Fourier transform infrared (FTIR) spectrophotometer equipped with Single Reflection Diamond Attenuated Total Reflectance (ATR; IR Prestige 21, Shimadzu, Japan) in the range of 400−4,000 cm^{-1} and a resolution of 4 cm^{-1} with a total of 40 scans per sample (n = 5). The average spectra of each RRG wood sample were plotted using the Origin Pro 2025.

2.8. Gas chromatography-mass spectrometry analysis of extracts

2.8.1. Blank preparation

One mL of methanol was transferred into a 2 mL microcentrifuge. This was dried using a centrifugal vacuum concentrator along with the sample. After drying, the blank was reconstituted with 100 μL methanol, then dried with anhydrous sodium sulfate. This was then injected into the GC-MS for analysis.

2.8.2. Sample preparation

1 mL of the sample was transferred into a 2 mL microcentrifuge. This was dried using a centrifugal vacuum concentrator along with the blank. After drying, the sample was reconstituted with 100 μL methanol, then dried with anhydrous sodium sulfate. This was then injected into the GC-MS (8890 GC system; 5977B Mass Selective Detector, Agilent, Santa Clara, CA, USA) for analysis (Table 3).

2.9. Statistical analysis

One-way analysis of variation (ANOVA) was done to

Table 3. GC-MS parameters

Oven temperature program: Rate (℃/min)	Temp (℃)	Hold time (min)
	50	0
15	120	0
10	300	15

Injection volume: 1.0 μL; Injection mode: Splitless; Carrier gas flow rate: 1 mL/min.
MS parameters: MS ionization mode: Electron ionization (70 eV); Acquisition mode: Scan; Mass range: 50 to 550 amu.
GC-MS: gas chromatography-mass spectrometry.

determine significant differences in the group means. Treatments were evaluated using Tukey test. Statistical significance was set at $p < 0.05$.

3. RESULTS and DISCUSSION

3.1. Moisture and ash content

In this study, the effects of toasting on the chemical composition of RRG wood were determined. As presented in Fig. 3, heavy toasted and charred RRG wood exhibit moisture contents of 3.08% and 1.21%, respectively, in contrast to the 8.96% moisture level seen in untoasted RRG wood. This result showed an inverse relationship between the moisture content of RRG wood samples and the application of heat, indicating that moisture content diminishes as temperature rises. The weight loss during the toasting process is expected due to the evaporation of both free and bound water from the wood components (Chatonnet and Escobessa, 2007). Aside from water, other volatile components evaporate from wood when the toasting temperature rises, explaining the weight loss from heavy and charred RRG wood (Kainuma *et al*., 2024).

Moisture content of wood has a fundamental role in the oxygen diffusion coefficient of a barrel, which plays an oenological impact on the alcohol being aged (del

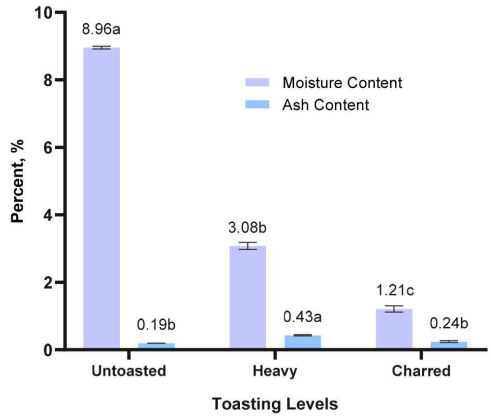

Fig. 3. Moisture and ash content of different toasting levels of ground samples of river red gum. [a–c] Means with the same letter are not significantly different.

Alamo-Sanza and Nevares, 2014; Junqua *et al*., 2021; Sorz and Hietz, 2006; Vivas *et al*., 2003). However, in this study, wood chips were toasted and not the barrel itself. Future studies will be done on the effect of wood barrel moisture content on the model wine and spirit solution.

The ash contents of the heavily toasted RRG wood sample exhibited the highest value among the varying toasting of wood samples. The closeness of ash content values (0.19%–0.43%) among the untoasted, heavy toasted, and charred RRG wood revealed that toasting treatment cannot degrade the inorganic components of the wood, which include minerals and heavy metals. These components are generally found in trees, having been absorbed from the soil via the roots and then distributed throughout different portions of the plant (Smailagić *et al*., 2021).

Given that wooden barrels and wood chips are in contact with the alcoholic beverages, the migration of these inorganic materials during maturity will be expected. These minerals and heavy metals are known to influence the maturation of spirits. It could play a crucial catalytic role in oxidation reactions involving phenolic compounds and other substrates in wine spirits.

However, its presence on alcoholic beverages raises toxicological or physiological concerns (Sofia *et al*., 2022). Future studies will determine the composition and contents of the RRG wood ash to make sure that spirit aged with RRG wood are safe for human health.

3.2. Extractives

As presented in Fig. 4, 1% NaOH solution extracted the highest amount of compounds, ranging from 13.20 ± 0.26% to 21.61 ± 0.35%, compared to the other two solvents: hot water (3.57 ± 0.29%–6.83 ± 1.61%) and 40% ethanol solution (5.18 ± 0.57%–7.41 ± 0.48%). This is due to the alkali hydrolyses of ester bond between polysaccharides and lignin which enhances the solubility and release of polysaccharides (Nor Nadiha and Jamilah, 2020). Furthermore, the toasting of RRG wood have a significant effect on the quantity of extracted compounds due to the degradation of these polysaccharides, particularly hemicellulose, that are readily extractable to alkali solution compared to hot water and organic solvents. These wood polysaccharides begin to degrade through heat treatment at around 180℃, with significant changes occurring around 250℃ (del Álamo *et al*., 2008; Esteves and Pereira, 2009) making it more soluble and extracted as new compounds (Kainuma *et al*., 2024) which explains the significant increase of extracted compounds in charred RRG using 1% NaOH solution.

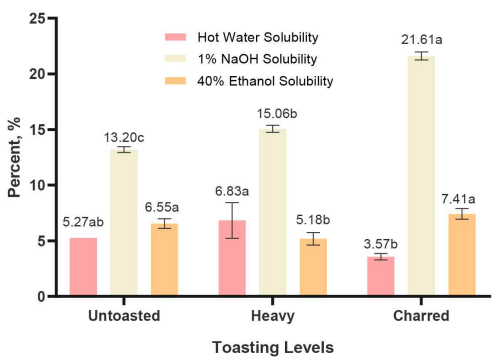

Fig. 4. Extractives content of different toasting levels of ground samples of river red gum. $^{a-c}$ Means with the same letter are not significantly different.

Hot water extracted tannins, sugars, dyes, and starches from the wood. The partial hydrolysis of hemicellulose occurs during the hot water extraction process, which results in the solubility of starch in hot water, and contributes to the hot water solubility content (Iswanto *et al*., 2021). However, as presented in Fig. 4, heavy toasting of RRG wood resulted in the increase of the extracted hot water-soluble compounds (6.83 ± 1.61%), which can be due to the partial breakdown of some hemicellulose and lignin components into new, smaller and more soluble compounds (Gašparovič *et al*., 2010; Petrozziello *et al*., 2020). The charred RRG had the lower extractable compounds in hot water solution which can be due to the thermal denaturation of these soluble sugars and transformed into volatile compounds (Le Floch *et al*., 2015) which possibly volatilized during the high toasting and high temperature extraction process.

A 40% ethanol solution was also used in the study as a model for a spirit beverage, as it can extract compounds similar to those found in alcoholic spirits during aging. As presented in Fig. 4, there was a significant difference between heavy toasted (5.18 ± 0.57%) and charred (7.41 ± 0.48%) RRG wood. This could be due to the extraction of water-soluble hemicellulose and lignin derivative compounds from the high toasting process. Future studies will measure these non-volatile compounds using high performance liquid chromatography (HPLC) to further determine the effect of toasting on individual polyphenols and other non-volatile compounds.

3.3. Celluloses and lignin

It is known that major wood components such as lignin and cellulose do not directly affect the sensorial

characteristics of the aged alcoholic beverages. However, pyrolysis or toasting of these wood components (Figs. 5 and 6) during wooden barrel and wood chips production, may lead to the formation of volatile phenols, phenolic aldehydes, ketones, and acids, which upon further dehydration, are converted to lactones (Tarko *et al.*, 2023).

Toasting likewise causes the release of hemicellulose

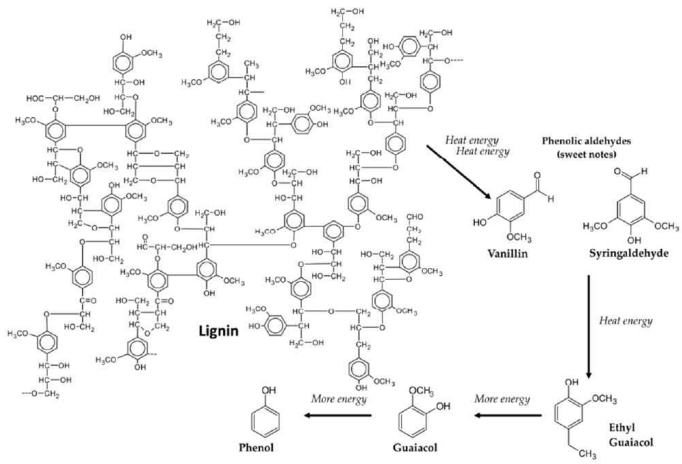

Fig. 5. Thermal degradation of lignin. Adapted from Spedding (2018) with permission of author.

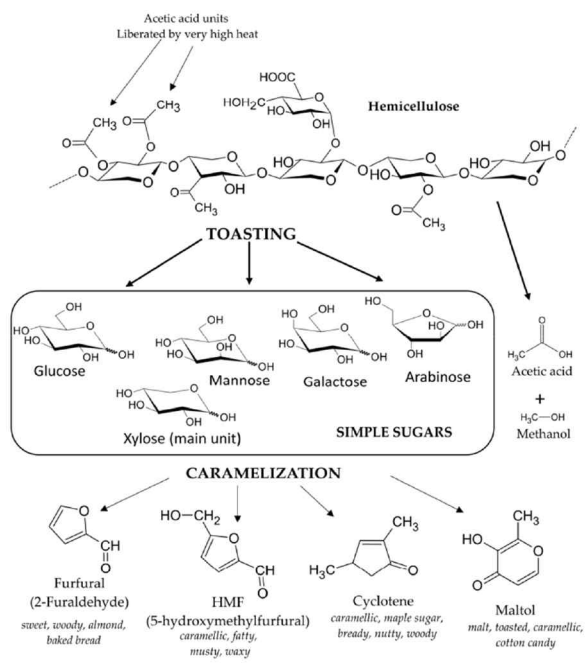

Fig. 6. Products formation during toasting and caramelization of hemicellulose. Adapted from Spedding (2018) with permission of author.

(simple sugars) leading to caramelization which gives the fruity, toasty, caramelized, and sweet aroma and flavors due to furfural, maltol, cyclotene and other sugar condensation products (Čabalová *et al*., 2018; González-Centeno *et al*., 2016; Nishimura, 1983; Prida and Chatonnet, 2010; Tarko *et al*., 2023). As presented in Fig. 7, results showed that the cellulose content decreases as the temperature increases due to thermal degradation of cellulose at higher temperatures.

Cellulose binds the wood together. However, during barrel aging, it does not directly affect the maturation of alcoholic beverages, but serves as a transporter of extractives from wood to the alcoholic beverages (Aylott, 2003; Spedding, 2018). The toasting treatment could affect the physico-mechanical attributes of wood or the wooden barrels. Further studies must be made for verification.

The hemicellulose content of different toasted RRG wood was also determined. This hemicellulose is mainly consists of pentoses (xylose and arabinose), hexoses (mannose, glucose, and galactose), and uronic acids (d-Glucuronic acid and d-Galacturonic acid).

As presented in Fig. 7, hemicellulose content significantly decreases as the temperature increases. It is known that amorphous cellulose is less thermally stable than crystalline cellulose which are susceptible to toasting (Mburu *et al*., 2008; Özgenç *et al*., 2017). It was also observed by Sikora *et al*. (2018) that mannose, galactose and arabinose decrease upon increasing the treatment temperature.

As presented in Fig. 8, the lignin content significantly reduced in heavy toasted RRG samples due to thermal degradation. However, the charred RRG exhibited a greater lignin concentration than anticipated. This is possibly due to the reaction between lignin and products of polysaccharide degradation during the extraction process forming an insoluble fraction (Borrega *et al*., 2011; Overend and Chornet, 1987).

Future studies will conduct acid soluble lignin determination to verify the hypothesis that at higher temperatures, lignin polymer are degrades to form new compounds. Overall, toasting treatments could significantly degrade the macromolecular components of RRG wood as well as minor components such as extractives.

3.4. Total phenolic content and total sugars of river red gum wood extracts

As mentioned, temperature increase breaks down lignin into new phenolic compounds (Hale *et al*., 1999;

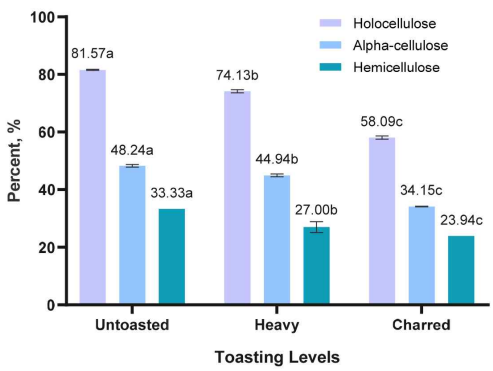

Fig. 7. Celluloses content of different toasting level of ground samples of river red gum. [a–c] Means with the same letter are not significantly different.

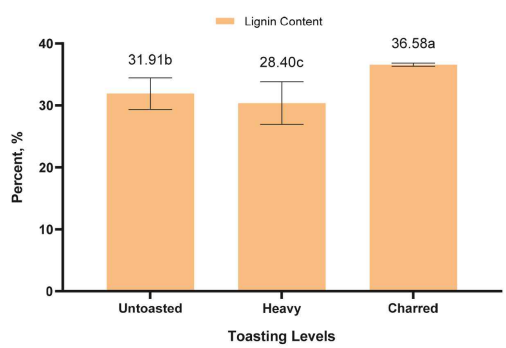

Fig. 8. Lignin content of different toasting level of ground samples of river red gum. [a–c] Means with the same letter are not significantly different.

Tarko *et al*., 2023). Studies showed that ellagitannin, which is abundant in wood, is degraded and converted into ellagic acid during toasting (Cadahía *et al*., 2001; Jordão *et al*., 2012; Tarko *et al*., 2023). This is the main reason for the observed increase in TPC after heavy toasting, as shown in Fig. 9. Subsequently, the decline in TPC in charred RRG wood is due to the intense toasting temperature that resulted in the degradation of these phenolic compounds.

Additionally, the interaction of the extracted phenolic compounds in the solution may result in polymerization, leading to the formation of new compounds that could ultimately reduce the phenolic content of the extracts (Ivanova *et al*., 2012).

The direct relation of total sugar increase and temperature rise is due to the breakdown of hemicellulose into simpler sugars (Fig. 6). This is correlated with the decrease of hemicellulose content in the heavily toasted and charred RRG wood samples as previously presented (Fig. 7).

The increase in extracted sugars, primarily attributed to the breakdown of hemicelluloses through heat, was also observed in the research conducted by Kainuma *et al*. (2024) with the effect of toasting temperature on French oak wood chips in extracted sugars. At higher temperatures (> 250℃), sugars are transformed into several aromatic compounds, such as furfural and 5-methyl furfural, resulting in reduced extracted sugars (Le Floch *et al*., 2015). Kainuma *et al*. (2024) found that these results indicate two possible scenarios on the effect of heat treatment on hemicellulose: it becomes more soluble when depolymerized by heat, and is transformed into new aromatic compounds. Therefore, toasting temperature considerably influences the quantity, content, and composition of extracted sugars (Kainuma *et al*., 2024). Further studies will measure these simple sugars by HPLC analysis.

Furthermore, as shown in Fig. 10, the toasting of the RRG wood samples led to a decrease in antioxidant activity. However, a significant difference in antioxidant activity was observed only in the DPPH assays of the RRG wood samples. This decrease was due to the degradation of some phenolic and bioactive compounds which are known to contribute to the antioxidant activity.

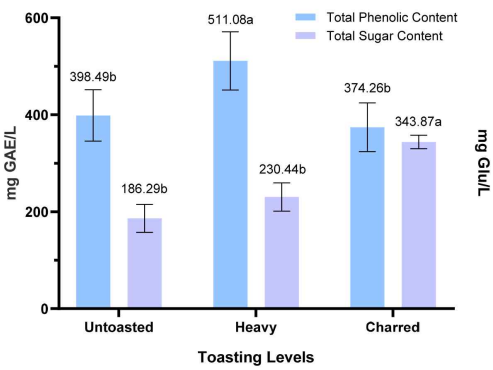

Fig. 9. Total phenolic content (mg GAE/L) and total sugars (mg Glu/L) of different toasting levels of RRG wood samples (20 g/L) macerated in ethanol solution (40%) for 1 month. [a,b] Means with the same letter are not significantly different. RRG: river red gum.

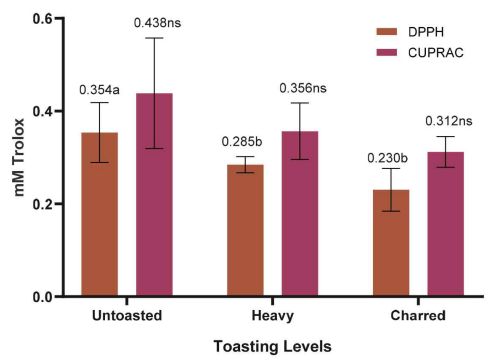

Fig. 10. Antioxidant activities of RRG wood samples (20 g/L) macerated in ethanol solution (40%) for 1 month. [a,b] Means with the same letter are not significantly different. [ns] not significant. DPPH: 2,2-diphenyl-1-picrylhydrazyl, CUPRAC: cupric-reducing antioxidant capacity, RRG: river red gum.

3.5. Fourier transform infrared analysis

As presented in Fig. 11, the toasting of RRG wood samples led to changes in the intensity of the bands in FTIR spectra. The band at 1,730−1,732 cm^{-1} increased after heavy toasting of RRG wood sample and decreased upon charring treatment. It has been reported that this band corresponds to C = O stretching vibrations of the acetyl groups of galactoglucomannan, carboxyl- and aldehydes, and aromatic/conjugated aldehydes and esters (Gérardin *et al*., 2007; Tjeerdsma and Militz, 2005).

Thus, the heavy toasting treatment made the hemicellulose component of RRG wood partly soluble in hot water while charring treatment made it degraded, confirming previous results (Fig. 7). Furthermore, the degradation of hemicelluloses leads to the decrease of numerous free hydroxyl groups in hemicelluloses which correlates to the decrease of the band intensity at 1,650−1,652 cm^{-1} (Akgül *et al*., 2007; Gérardin *et al*., 2007).

As also observed in Fig. 11, the bands' intensities at 1,504−1,508 cm^{-1}, 1,452−1,459 cm^{-1}, and 1,421−1,422 cm^{-1} increase upon toasting the RRG wood samples heavily compared to untoasted RRG wood samples. This could be due to condensation of lignin and splitting of aliphatic side chains in lignin during heating (Akgül *et al*., 2007; Kotilainen *et al*., 2000; Schulz *et al*., 2021). These changes in lignin during heat treatment were also reported in *Eucalyptus grandis* and *Pinus elliottii* wood (Gallio *et al*., 2019; Schulz *et al*., 2021). These bands also represent the C = C stretching of the aromatic skeletal vibrations which also represent the lignin content changes in heat-treated samples (Özgenç *et al*., 2017).

Overall, the FTIR results confirm the degradation of lignin and hemicellulose of RRG wood samples during heat treatment.

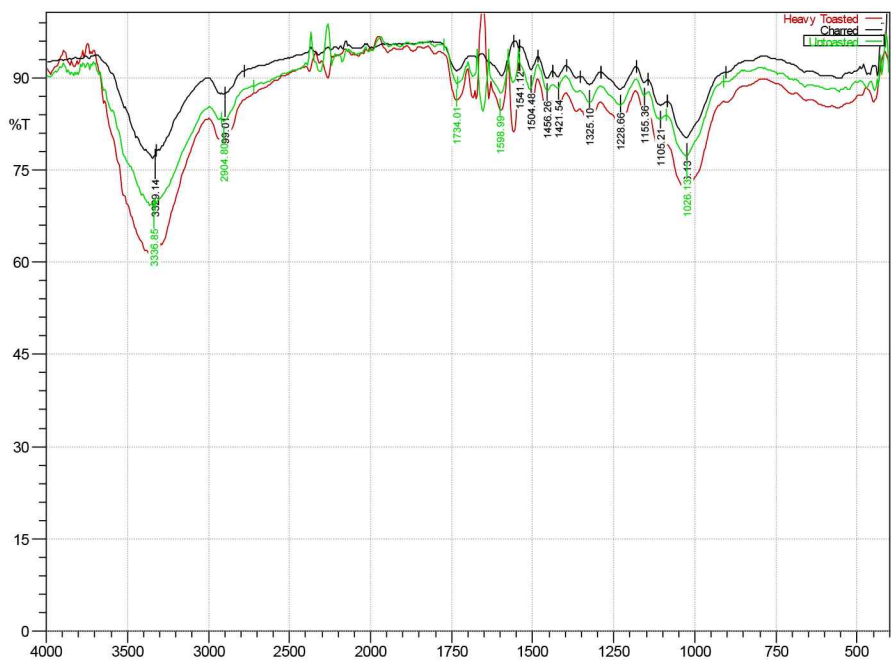

Fig. 11. FTIR analysis of RRG wood samples (untoasted, heavy and charred). FTIR: Fourier transform infrared, RRG: river red gum.

3.6. Gas chromatography-mass spectrometry analysis of river red gum wood ethanolic extracts

Ethanolic extracts from untoasted, heavily toasted and charred RRG wood were further subjected to GC-MS analysis to determine the volatile compositions which could give aroma to alcoholic beverages. As observed in Table 4, the main components of untoasted RRG wood ethanolic extract were furfural and eugenol with 39.18% and 26.22%, respectively. On the other hand, the main composition of ethanolic extract from heavy toasted RRG wood were 3,5-dimethoxy-4-hydroxycinnamaldehyde (28.76%), coniferyl aldehyde (28.10%), syringaldehyde (14.25%) and vanillin (8.16%). Lastly, the main components of ethanolic extract from charred RRG wood were 3,5-Dimethoxy-4-hydroxycinnamaldehyde (28.58%), syringaldehyde (21.50%), coniferyl aldehyde (11.43%), vanillin (5.99%) and syringylacetone (5.90%).

The results also showed that the toasting process and the increase in thermal temperature produce a greater number of volatile components from wood. Specifically, the heavily toasted RRG and charred RRG samples yielded 34 and 48 volatile components respectively, as shown in Tables 5 and 6, in contrast to the 11 volatile components seen in the untoasted RRG wood sample (Table 4). Furthermore, the main volatile components (coniferyl alcohol, syringaldehyde and vanillin compounds) of heavy and charred RRG wood extracts came from the degradation of lignin due to thermal treatment. They are known for their aromatic and sweet notes. Additionally, the dehydration of hemicellulose during aging leads to the formation of new compounds such as furfural and 5-hydroxymethylfurfural, which could provide roasted, fudge, and caramel profiles (Kelly *et al*., 2023). These compounds are commonly found in alcoholic beverages aged in oak barrels and wood chips.

Overall, *E. camaldulensis* wood and toasting treatment

Table 4. GC-MS analysis of untoasted RRG wood ethanolic extract

Peak No.	Retention time (min)	Area	Compound name	Composition (%)
1	3.14	1682528.1	Furfural	39.18
2	4.399	242208	2-Furancarboxaldehyde, 5-methyl-	5.64
3	6.608	58118.16	Terpinen-4-ol	1.35
4	6.751	191790.36	α-Terpineol	4.47
5	8.622	111124.16	Syringol	2.59
6	8.696	1126221.2	Eugenol	26.22
7	9.297	161653.03	Benzaldehyde, 3-hydroxy-4-methoxy-	3.76
8	10.871	76488.8	2(4H)-Benzofuranone, 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-, (R)-	1.78
9	12.267	139991.54	Syringylaldehyde	3.26
10	17.108	138164.61	Linoleic acid ethyl ester	3.22
11	17.148	366325.91	Ethyl oleate	8.53
		Total		100

GC-MS: gas chromatography-mass spectrometry, RRG: river red gum.

Table 5. GC-MS analysis of heavy toasted RRG wood ethanolic extract

Peak No.	Retention time (min)	Area	Compound name	Composition (%)
1	2.808	486602.34	3-Penten-2-one, 4-methyl-	0.53
2	3.089	658750.98	Furfural	0.72
3	3.152	3321868	2-Pentanone, 4-hydroxy-4-methyl-	3.64
4	4.296	69485.55	2-Furancarboxaldehyde, 5-methyl-	0.08
5	4.634	400088.51	N-Butyl-tert-butylamine	0.44
6	5.303	401940.78	γ-Ethoxybutyrolactone	0.44
7	7.1	2559903.4	5-Hydroxymethylfurfural	2.80
8	8.599	660670.06	Phenol, 2,6-dimethoxy-	0.72
9	8.691	178448.26	Eugenol	0.20
10	8.805	1198697.7	1,6-Anhydro-β-d-talopyranose	1.31
11	9.211	7456081.5	Vanillin	8.16
12	9.726	344842.37	3,5-Dimethoxy-4-hydroxytoluene	0.38
13	9.921	235762.37	p-Propylguaiacol	0.26
14	10.127	434348.79	D-Allose	0.48
15	10.253	364646.14	Apocynin	0.40
16	10.756	485829.63	Guaiacylacetone	0.53
17	10.865	140981.32	2(4H)-Benzofuranone, 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-, (R)-	0.15
18	11.111	559878.6	4-Vinylsyringol/Canolol	0.61
19	11.277	264651.9	1'-Hydroxyeugenol	0.29
20	11.397	1086402.3	Butyrovanillone	1.19
21	11.534	304538.19	trans-4-Propenylsyringol	0.33
22	12.101	1211325.9	2,6-Dimethoxyhydroquinone	1.33
23	12.204	13019283	Syringylaldehyde	14.25
24	12.684	454016.49	Homosyringaldehyde	0.50
25	12.85	130736.45	4-Hydroxy-2-methoxycinnamaldehyde	0.14
26	12.953	522827.2	2-Propanone, 1-hydroxy-3-(4- hydroxy-3-methoxyphenyl)-	0.57
27	13.039	25665539	Coniferyl aldehyde	28.10
28	13.394	659220.88	Syringylacetone	0.72
29	13.892	319059.18	Benzeneacetic acid, 4-hydroxy-3,5-dimethoxy-, methyl ester	0.35
30	13.966	487076.72	Butylsyringone	0.53
31	14.979	102317.86	Danielone	0.11
32	15.397	880089.96	Acethydrazide, 2-(2-benzothiazolylthio)-N2-(3-fluorobenzylideno)-	0.96
33	15.546	26272994	3,5-Dimethoxy-4-hydroxycinnamaldehyde	28.76
			Total	100

GC-MS: gas chromatography-mass spectrometry, RRG: river red gum.

Table 6. GC-MS analysis of charred RRG wood ethanolic extract

Peak No.	Retention time (min)	Area	Compound name	Composition (%)
1	3.037	258454.07	2-Pentanone, 4-hydroxy-4-methyl-	0.04
2	3.112	3816222.5	3(2H)-Furanone, 4-hydroxy-5- methyl-	0.60
3	4.622	1456244.9	N,N-Diamylmethylamine Phenol, 2-methoxy-	0.23
4	5.595	3684685.2	4-methoxyphenol	0.58
5	6.344	950389.73	Ethyl hydrogen succinate	0.15
6	6.51	212193.65	Monomethyl succinate, trimethylsilyl ester	0.03
7	6.774	3257223	Catechol	0.51
8	7.106	3516502.7	5-Hydroxymethylfurfural	0.55
9	7.317	188452.92	Succinic acid, monoethyl ester- (TMS)	0.03
10	8.055	658246.84	5-Acetoxymethyl-2-furaldehyde	0.10
11	8.176	1119874.1	2-Methoxy-4-vinylphenol	0.18
12	8.593	15517461	Phenol, 2,6-dimethoxy-	2.45
13	8.685	1096644.1	Eugenol	0.17
14	9.217	37957129	Vanillin	5.99
15	9.72	3944197.6	3,5-Dimethoxy-4-hydroxytoluene	0.62
16	9.783	3959583.2	trans-Isoeugenol	0.62
17	9.909	4293831.9	p-Propylguaiacol	0.68
18	10.241	4332582.5	Apocynin	0.68
19	10.384	10217722	β-D-Glucopyranose, 1,6-anhydro-	1.61
20	10.75	10594432	Guaiacylacetone	1.67
21	11.111	3518189	4-Vinylsyringol/Canolol	0.55
22	11.157	3468744.6	3-Hydroxy-4-methoxybenzoic acid	0.55
23	11.26	2695339	1'-Hydroxyeugenol	0.43
24	11.529	6465428.1	Methoxyeugenol	1.02
25	11.609	514435.76	Homosyringaldehyde	0.08
26	12.095	4697168	Benzenepropanol, 4-hydroxy-3- methoxy-	0.74
27	12.273	136328394	Syringylaldehyde	21.50
28	12.633	7908232.3	trans-4-Propenylsyringol	1.25
29	12.696	6503110.4	Escaline	1.03
30	13.085	72441823	Coniferyl aldehyde	11.43
31	13.428	37399478	Syringylacetone	5.90
32	13.972	8037456.5	1-Propanone, 1-(4-hydroxy-3,5- dimethoxyphenyl)-	1.27
33	14.647	5493518.9	Dihydrosyringenin	0.87
34	14.99	3247631.8	Danielone	0.51
35	15.637	181195778	3,5-Dimethoxy-4- hydroxycinnamaldehyde	28.58
36	19.105	8571323.4	6-Methoxyeugenyl isobutyrate	1.35
37	20.152	3753396.5	Phenol, 2,4-bis(1-methyl-1- phenylethyl)-	0.59

Table 6. Continued

Peak No.	Retention time (min)	Area	Compound name	Composition (%)
38	20.73	1923643.2	α-Amino-3'-hydroxy-4'- methoxyacetophenone	0.30
39	21.147	2754808.5	Phenol, 4-ethenyl-2,6-dimethoxy-	0.43
40	21.233	7249867.6	(E)-3,3'-Dimethoxy-4,4'- dihydroxystilbene	1.14
41	23.081	7645750.8	4-(4-Hydroxy-3-methoxystyryl)-2,6- dimethoxyphenol	1.21
42	24.306	1265466.7	Gomisin L1	0.20
43	25.262	3445410.4	4,4'-Stilbenediol, 3,3',5,5'- tetramethoxy	0.54
44	27.104	576657.39	γ-Sitosterol	0.09
45	29.072	560956.48	Phenol, 2,6-dimethoxy-4-[tetrahydro-4-(4-hydroxy-3-methoxyphenyl)-1H,3H-furo[3,4-c]furan-1-yl]-	0.09
46	29.765	2786328.9	Yangambin	0.44
47	32.157	264929.23	Syringaresinol	0.40
48	33.581	2297525.4		
			Total	100

GC-MS: gas chromatography-mass spectrometry, RRG: river red gum.

could also significantly improve the sensory profile of alcoholic beverages. Moreover, the locally available and fast-growing wood species will serve a sustainable alternative in the Philippine alcoholic beverage industry.

4. CONCLUSIONS

The toasting treatment had a significant effect on the macromolecules and extractives of RRG wood. Furthermore, GC-MS results showed that the degradation of these macromolecules leads to the formation of new compounds which could improve the sensory profile of alcoholic beverages. Future studies will focus on the quantitative determination of individual lignin-derived and hydrolyzed hemicellulose compounds through HPLC and GC analysis.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENT

This research was supported and funded by the Department of Science and Technology (DOST) - Forest Products Research and Development Institute (FPRDI). The authors would also like to acknowledge Engr. Jovito Elec and his team for the collection and sawmilling of wood logs, Engr. Caezar A. Cuaresma for the kiln drying of lumber, Mr. Audel V. Mosteiro and Mr. Rommar F. Guia for the assistance in the implementation of the study, Dr. Karen Laserna and De La Salle University – Laguna Campus for the GC-MS analysis of the RRG wood extracts.

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