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# EFFECTS OF PHOSPHORIC ACID AND DIAMMONIUM PHOSPHATE TREATMENTS ON THE PHYSICAL AND FIRE RETARDANT PROPERTIES OF FIVE NIGERIAN SELECTED WOOD SPECIES

***Jacob Mayowa OWOYEMI***
Assoc.Prof.Dr. - Federal University of Technology Akure, Department of Forestry and Wood Technology
E-mail: jacobmayowa@yahool.com

***Oyinkansola Mary IBRAHIM***
Research fellow - Forestry Research Institute of Nigeria, Forest Products Development and Utilisation Department
E-mail: ibrahimoyinkansola1@gmail.com

***Ayodeji Oyekanmi ADIJI****
Dr. - Forestry Research Institute of Nigeria, Forest Products Development and Utilisation Department
E-mail: adijiayodeji@gmail.com

***Abstract:***
*In this study, the effects of phosphoric acid and diammonium phosphate treatments on the physical and fire-retardant properties of Brachystegia laurentii, Khaya ivorensis, Pterygota macrocarpa, Celtis zenkeri and Terminalia superba wood were investigated. The basic physical properties of the selected wood species and effect of treatments on the physical and fire retardant properties were evaluated. Moisture content, density and weight loss due to leaching for Pterygota macrocarpa was 42.98%, 536.36 kg/m$^3$ and 20.28%; Terminalia superba had 34.11%, 461.79 kg/m$^3$ and 18.68%; Brachystegia laurentii had 29.84%, 695.76 kg/m$^3$ and 12.64% respectively while Khaya ivorensis and Celtis zenkeri had 29.45%, 807.04 kg/m$^3$and 7.43%; 22.49%, 737.43 kg/m$^3$ and 14.53% respectively. The fire-retardant treatments had significant effect on the physical and fire retardant properties of the wood species as sample treated with phosphoric acid had better resistance to fire than diammonium phosphate. For species treated with diammonium phosphate and phosphoric acid, Khaya ivorensis had the least absorption of 9.13% and 11.93%; weight loss after combustion of 9.23% and 5.63% respectively. Brachystegia laurentii had absorption of 12.53% and 12.24%; weight loss after combustion of 13.72% and 7.22%. Khaya ivorensis and Terminalia superba had least volumetric swelling of 5.53% and 6.46% when soaked in phosphoric acid while Pterygota macrocarpa had the highest absorption and volumetric swelling of 22.59% and 9.50% respectively when soaked in diammonium phosphate.*

***Key words****: wood, fire retardants, diammonium phosphate, phosphoric acid.*

## INTRODUCTION

The versatility nature, easy to work with, low energy consumption during processing and the inherent properties of wood, make it a choice material than other construction materials (Štefko *et al*. 2021). However, due to the inherent flammability of wood, they often contribute to unwanted fires, resulting in numerous injuries and fatalities. Fires in buildings cost millions of dollar every year and turn them into ruins in minutes. Moreover, if such accidents claim lives, the consequences are much more significant, people cannot be replaced, and those wounded spend many days in pain and often sustain lifelong injuries (Zang *et al.* 2024 and Pundalik *et al.* 2022). Wood becomes thermal degraded with great full of ignitable gas above 300℃, thus it catches fire easily and burns vigorously with flame (Shi and Chew 2013). The outbreak of fire in wooden structures has caused massive destruction of properties and loss of lives. The occurrence of outbreak of fire in building worldwide is about 17.5 million between 2012 and 2016 (Brushlinsky *et al*. 2018).Therefore, the use of wood is limited by various safety requirements and regulations pertaining to its flammability and spread of fire characteristics. To reduce flammability of wood, it must be treated with fire retardants which drastically reduces the rate at which flames travel across the wood surface and reduces the amount of potential heat (Won and Ran 2015; Park and Baek 2015; Lu *et al.* 2020 and Chen *et al.* 2019). Much research work has been done in these regard especially with primarily inorganic salts; halogen, boron, ammonium salts and metal foils in combination with intumescent products. However, the problem of leaching, corrosion and environmental concern still persist. Furthermore, Nitrogen, phosphorus and Borides has shown to be fire resistance, toxic-free, smoke-inhibiting and cheap (Ellis and Rowel 1989; Wu *et al.* 2021). Also, formulations containing silicon, nitrogen and phosphorus proved to be effective and efforts to

*Corresponding author

fixed silicon in the wood have been successful using micro-layers of silicon dioxide (Lowden and Hull 2013). Despite various kinds of flame retardants have been used for synthetic polymer materials, ideal flame retardants for wooden materials are still under development, and new technologies are urgently needed.

Therefore, this work focus, the effects of phosphoric acid and diammonium phosphate treatments on the physical properties and fire-retardant properties of *Brachystegia laurentii,* ***Khaya ivorensis, Pterygota macrocarpa, Celtis zenkeri and Terminalia superba with a view to have a stable and effectives fire retardant.***

## MATERIALS AND METHODS

### Study Area

This study was conducted at the Department of Forestry and Wood Technology, Federal University of Technology, Akure (FUTA). FUTA is located in Ondo State, South-Western Nigeria, between latitudes 07° 16' and 07° 18'N and longitudes 05° 09' and 05° 11'E.

### Preparation of Wood Samples

Five selected wood species; *Brachystegia laurentii, Khaya ivorensis, Pterygota macrocarpa, Celtis zenkeri* and *Terminalia superba* were sourced from a sawmill in Akure, Nigeria. It was cut into 20 × 20 × 60mm and 200 x 95 x10mm size for physical and fire-retardant properties test (ASTM, 2009).

### Determination of Physical Properties

The samples were weighed and measured to obtain their initial weights and dimensions, respectively, after which they were oven-dried at a constant temperature of 103±2°C until a constant weight was achieved and weighed. The following tests were carried out according to Owoyemi and Kayode (2007) method.

### Percentage moisture content

The initial weight and oven-dried weight of the wood samples were obtained while the percentage moisture content were determined using:

$$\text{Moisture content (\%)} = \frac{Wg - Wo}{Wo} \times 100 \quad \text{.................................. Eq. 1}$$

where: $W_g$ = Weight of green samples (gm)
Wo = Weight of dried samples (gm)

### Density

The weight and volume of the samples before and after the oven drying was used to calculate the density of the wood sample using:

$$\text{Density} = \frac{Mass\ of\ oven\ dried\ sample}{Volume} \quad \text{.........................................................Eq. 2}$$

### Volumetric swelling

The volumetric swelling of the five selected wood species was determined by taking the oven-dried dimensions of the wood, soak in water for 24, 48, and 72 hours, respectively, and taking the final dimensions.

$$\text{VS (\%)} = \frac{D2 - D1}{D1}\ X\ \frac{100}{1} \quad \text{...............................................................Eq. 3}$$

where: VS is the Volumetric Swelling (%); $D_1$ is green dimensions (mm), while $D_2$ is the final dimensions after oven drying (mm).

### Volumetric shrinkage

The volumetric shrinkage of the samples was determined by recording the volume of the wood samples at the green stage and at the end of the drying period. The initial volume of the samples (L x B x H) was taken at the green stage and at the end of the drying process. The final volume attained was measured.

$$\text{VS (\%)} = \frac{D1 - D2}{D1}\ X\ \frac{100}{1} \text{.............................................................................. Eq. 4}$$

where: VS is the volumetric shrinkage (%); $D_1$ is green dimension (mm); while $D_2$ is the final dimensions after oven-dry (mm).

**Weight loss due to leaching**

Wood sample of 20mm x 20mm x 60mm were used for a leaching test, which was conducted by soaking the samples in distilled water for 72 hours. The percentage weight loss due to leaching was determined.

$$\% \text{ Weight loss} = \frac{W2-W3}{W2} \times 100 \quad \text{……………………………………Equation 5}$$

where: $W_2$ = Initial weight after treatment (g) and $W_3$ = oven dried weight after soaking (g).

**Preparation of Fire Retardants and Testing**

The Diammonium phosphate and Phosphoric acid were prepared in the laboratory at varying concentrations. The fire retardant was prepared in concentration to water at 60% and 40% of Diammonium phosphate and Phosphoric acid respectively. The wood samples were soaked in the prepared solution for 72 hours to guarantee a good absorption of the retardants. For complete treatment, the withdrawn wood was dried in the oven at 103±2°C to ensure a faster curing process. The wood was reweighed to account for the percentage absorption and retention of retardant before it was subjected to test.

$$\% \text{ Absorption} = \frac{W2-W1}{W1} \times 100 \quad \text{……………………………… Eq. 6}$$

where: $W_1$ = Oven dry weight of the sample (g) and $W_2$ = Initial weight after treatment (g).

$$\text{Retention (kg/m}^3\text{)} = \frac{GC}{V} \times 10 \quad \text{………………………….. Eq. 7}$$

where: G = $W_2$-$W_1$, C = is the quantity of the treating solution in grams, V = volume of the wood samples ($cm^3$).

**Fire Test**

The construction of the test bench for the test of limited flame spread determination was made of materials resistant to heat and combustion products that were released during the test (Fig. 1). The test bench for the experiment consists of these parts: a propane gas cylinder with technical propane, a manifold gauge, gas burner, test samples, and the holder for the test specimen. The fuel source in the experiment was a pressure cylinder with a technical propane-butane mixture with a purity of at least 95%. Other devices required for the realization of the experiment were weighing balance used for mass measurement of the samples and time measurement devices for the measurement of flame exposure duration. The test specimen was placed in the device holder at an angle of 45° and exposed to the flame's effects for 5 minutes. Each wood sample was put in the desiccator immediately after being removed from the flame to prevent further burning.

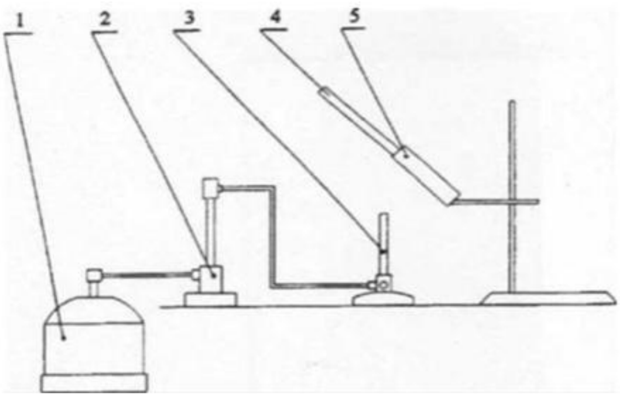


***Fig. 1.***
***Test bench (1- propane gas cylinder, 2- flow meter, 3- gas burner, 4- test specimen, 5- test specimen holder).***

The pressure gauge used to measure the gas flow rate was at 5psi throughout the experiment. For each measurement, the distance from the centre of the test specimen to the mouth of the gas burner was 50±1mm and also the distance of the height flame was 40±2mm. The fire test experiment was done according to (Fanfarová *et al.* 2017) for tests on fire behaviour. This laboratory method was developed in the Fire-chemical laboratory of the Department of Fire Engineering, Faculty of Security Engineering, and the University of Zilina as an internal document with the aim of becoming an STN standard. The methodology was created to evaluate the specimen combustion behaviour when exposed to a direct mid- height flame for a longer period.

**Experimental Design**

The experiment design was 5x2 factorial experiments in a completely randomized design (CRD). Data obtained was analysis with Statistical Package for Social Sciences (SPSS). The data were subjected to Analysis of Variance (ANOVA) and Duncan Multiple Range Test (DMRT) to determine the significant difference between various treatment and their interactions at 0.05 level of significance

## RESULTS AND DISCUSSION

**Result of Physical properties of the selected wood species**

Fig. 2 and Table 1 shows the result of the basic physical properties of the selected wood species. The result of the moisture content for the five selected wood species showed that it ranges from 22.49% to 42.98% with *Pterygota macrocarpa* had the highest percentage moisture content and *Celtis zenkeri* had the least value of 29.45%.

The Duncan multiple ranges test presented in Table 1, showed that in terms of the moisture content distribution of the wood species, samples obtained from *C. zenteri* are significantly different from those obtained other species, however, the value obtained for *Khaya ivorensis* and *Brachystegia laurentii* are not significantly different but significantly different from those obtained from *Terminalia superba* and *Pterygota macrocarpa* which recorded the least value.

The result of wood density of the selected wood species revealed that *Khaya ivorensis* had the highest density of 807.04 kg/m$^3$, following by *Celtis zenkeri* 737.43 kg/m$^3$, with *Brachystegia laurentii* having 695.76 kg/m$^3$, followed by *Pterygota macrocarpa* having density value of 536.36 kg/m$^3$, while *Terminalia superba* had the least value of 461.79 kg/m$^3$ it also showed that the five samples are significantly different in terms of the density distribution as samples obtained from *Khaya ivorensis* attained the highest density value among the five species.

For the volumetric shrinkage (VS), the results showed that *Terminalia superba* had the highest VS of 24.69%, following by *Pterygota macrocarpa* 15.76%, with *Brachystegia laurentii* having 14.29%, followed by *Celtis zenkeri* having VS value of 14.42%, and the least value of 10.29% was recorded for *Khaya ivorensis*. The Duncan multiple ranges test presented in Table 1, showed that the five samples are significantly different in terms of the VS distribution as samples obtained from *Khaya ivorensis* performed best which was significantly different from samples obtained from *Celtis zenkeri*, *Brachystegia laurentii, and Pterygota macrocarpa* that falls under the same category in terms of their performance which were highly significant different from those obtained from *Terminalia superba* which had the least performance.

The result of the percentage weight loss due to leaching showed that *Pterygota macrocarpa* had the highest weight loss of 20.28%, following by *Terminalia superba (*18.68%), with *Celtis zenkeri* having 14.53%, followed by *Brachystegia laurentii* having percentage weight loss value of 12.64%, and the least value of 7.43% was recorded for *Khaya ivorensis*.

The Duncan multiple ranges test presented in Table 1, showed that the five samples are significantly different in terms of the percentage weight loss distribution as samples obtained from *Khaya ivorensis* and *Brachystegia laurentii* performed best which were significantly different from samples obtained from *Celtis zenkeri* and *Terminalia superba,* that falls under the same category in terms of their performance which were not significant different from those obtained from *Pterygota macrocarpa* which had the least performance.

For the Volumetric Swelling (VSW), the result revealed that *Pterygota macrocarpa* had the highest average VSW values for 24, 48, and 72 hours at 8.48%, higher than *Celtis zenkeri* with VSW of 6.90%, follow by *Brachystegia laurentii* (6.72%), followed by Terminalia superba (6.04%), and the least was recorded for *Khaya ivorensis* with a VSW of 5.69%. The Duncan multiple ranges test presented in Table 1, showed that the samples obtained from *Pterygota macrocarpa* had the least performance which significantly from those obtained from *Khaya ivorensis, Brachystegia laurentii*, *Celtis zenkeri* and *Terminalia superba,* that falls under the same category in terms of their performance with not significant different.

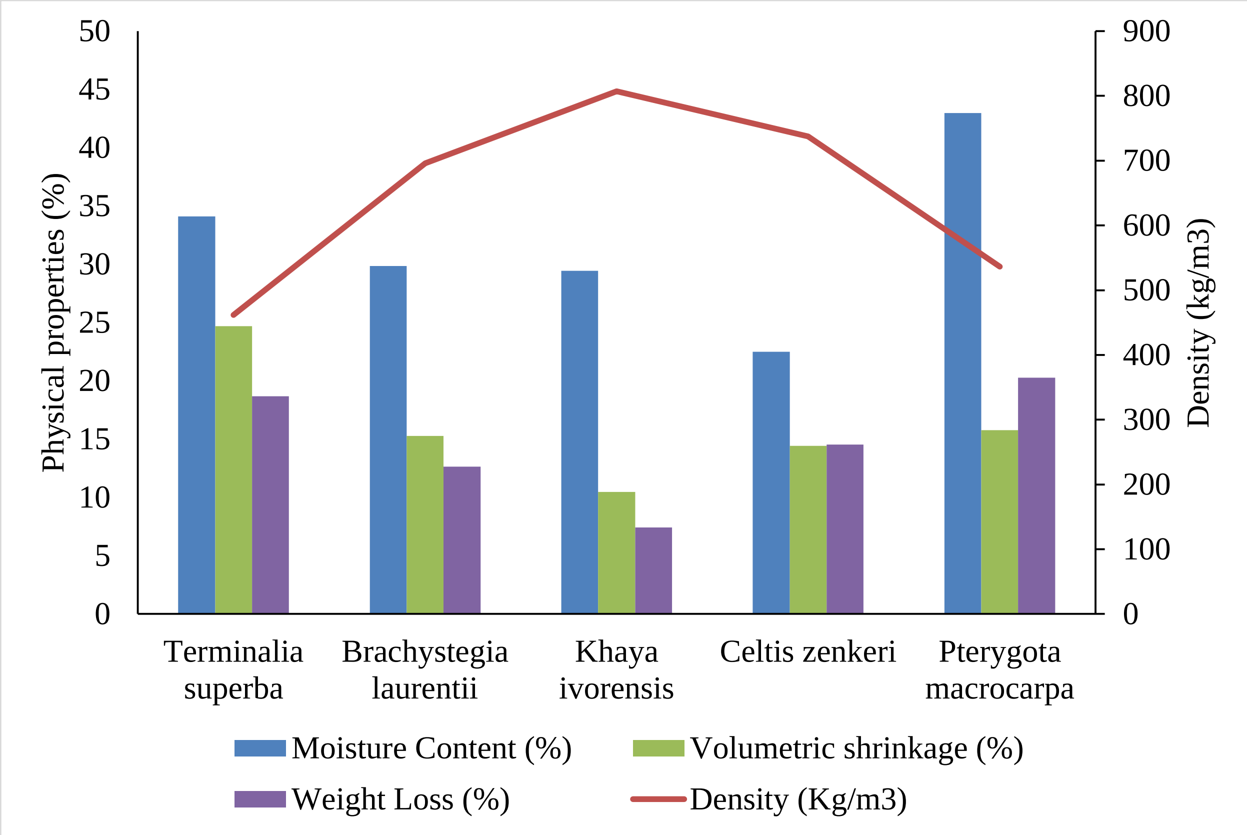


***Fig. 2.***
***Basic Properties of the selected Wood Species.***

*Table 1*

***Duncan's Multiple Range tests for the Basic Physical Properties***

| | Moisture content (%) | Density | VS (%) | VSW (%) | Weight Loss (%) |
|---|---|---|---|---|---|
| *Celtis zenkeri* | 22.49$^{d}$ | 737.43$^{b}$ | 10.47$^{a}$ | 6.90$^{a}$ | 14.53b$^{c}$ |
| *Khaya ivorensis* | 29.45$^{c}$ | 807.04$^{a}$ | 14.42$^{b}$ | 5.69$^{a}$ | 7.43$^{a}$ |
| *Brachystegia laurentii* | 29.84$^{c}$ | 695.76$^{c}$ | 15.29$^{b}$ | 6.72$^{a}$ | 12.64$^{ab}$ |
| *Terminalia superba* | 34.11$^{b}$ | 461.79$^{e}$ | 24.69$^{c}$ | 6.05$^{a}$ | 18.68$^{bc}$ |
| *Pterygota macrocarpa* | 42.98$^{a}$ | 536.36$^{d}$ | 15.76$^{b}$ | 8.48$^{b}$ | 20.28$^{c}$ |

*Alphabets with the same letter show that there is no significant difference; Alphabets with different letter show that there is significant difference.*

**Result of the physical properties of the treated wood sample**

The result of the physical properties of the treated wood was presented in Fig. 3-5 and Table 2. The result of the absorption of chemical by the five selected wood species showed that for the *T. superba, P. macrocarpa, C. zenkeri, B. laurenti, and K. ivorensis* absorbed 32.57% and 21.77%, 30.60% and 22.59%, 19.21% and 15.55%, 12.23% and 12.53%, and 11.92% and 9.13% of Phosphoric acid and Diammonium solution respectively during treatment (Fig. 3). For retention of the chemical preservatives on the five selected wood species, the result revealed that there are variations in the retention rates among the wood species. Phosphoric acid treatment exhibited moderate fire protection, with retention rates ranging from 14.20% in *Khaya ivorensis* to 29.43% in *Terminalia superba*. On the other hand, Diammonium phosphate treatment showed higher retention rates, with *Terminalia superba* having the highest rate of 38.52% and *Brachystegia laurentii* displaying the lowest rate of 18.37%. Wood species treated with diammonium phosphate generally had a higher retention rate in all the wood species except for *Brachystegia laurentii* compared to phosphoric acid treatments (Fig. 4).

The result of the volumetric swelling of the five selected wood treated with fire retardant revealed that T. superba, P. macrocarpa, C. zenkeri, B. laurenti, and K. ivorensis had 6.46%, 8.99%, and 5.10%, 7.33%, 9.50% and 9.32%, 7.25%, 6.85% and 13.16%, 7.04%, 6.75% and 7.39%, and 5.53%, 8.15% and 8.59% for samples treated with Phosphoric acid, Diammonium solution and control respectively (Table 2). However, there was a significant difference (i.e. P<0.05) in the volumetric swelling obtained for the selected wood species, soaking time, and in the two treatment of the wood treated with Phosphoric acid and diammonium solution. The volumetric swelling of the wood species treated with both Phosphoric acid and Diammonium solution were lower than the control group, indicating a reduction in swelling potential. Fig. 5, Fig. 6 and 7 present the result of the weight Loss due to Combustion of the selected wood species, it revealed that *T. superba, P. macrocarpa, C. zenkeri, B. laurenti*, and *K. ivorensis* recorded percentage weight loss of 8.43 %, 17.47%, and 36.90%, 6.40%, 17.64% and 37.05%, 7.20%, 14.68% and 27.43%, 7.22%, 13.72% and 19.85%, and 5.63%, 9.23% and 14.87% for samples treated with Phosphoric acid, diammonium solution and control respectively. However, there was a significant difference (i.e. P<0.05) in the weight loss of the wood treated with Phosphoric acid and diammonium solution.

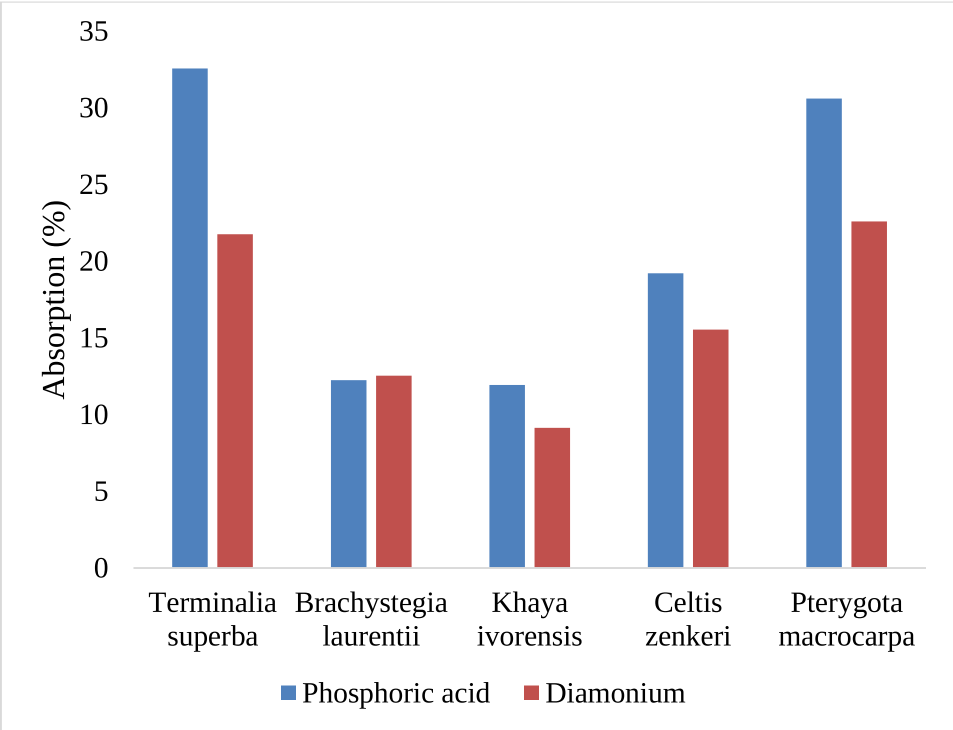


***Fig. 3.***
***Chemical absorption of the five selected wood species.***

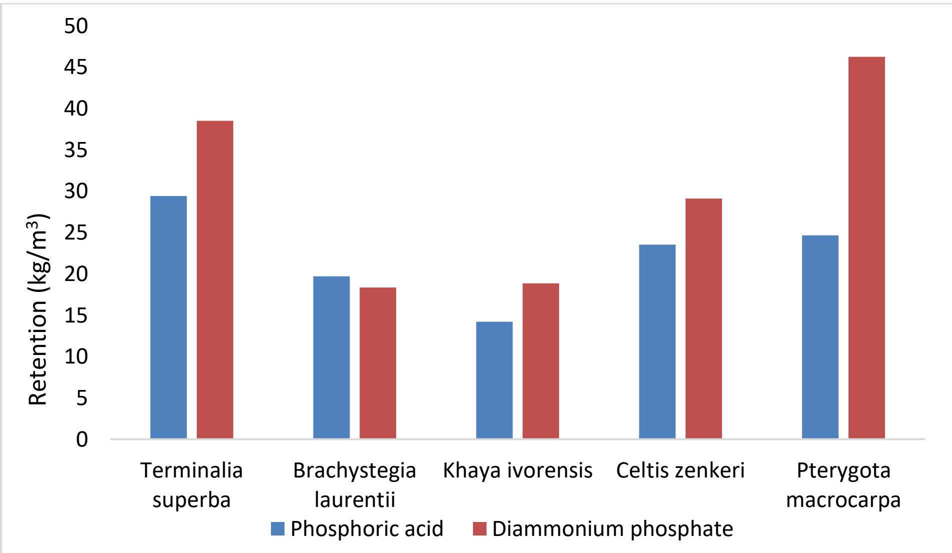


***Fig.*** *Error! No text of specified style in document.**.***
***Retention rate of the five wood species.***

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*Table 2*

***Volumetric swelling of the treated selected wood species***

| Species | Treatment | Soaking Time | Volumetric swelling±SD (%) | | |
|---|---|---|---|---|---|
| *Terminalia superba* | Phosphoric acid | 24 hours | 3.67±1.90 | 6.46±2.85 | 6.85±3.50 |
| | | 48 hours | 6.42±1.78 | | |
| | | 72 hours | 9.29±1.35 | | |
| | Diammonium | 24 hours | 6.43±2.25 | 8.99±3.85 | |
| | | 48 hours | 8.88±3.59 | | |
| | | 72 hours | 11.65±4.11 | | |
| | Control | 24 hours | 2.66±1.36 | 5.10±2.70 | |
| | | 48 hours | 5.30±2.19 | | |
| | | 72 hours | 7.32±2.29 | | |
| *Brachystegia laurentii* | Phosphoric acid | 24 hours | 5.18±1.59 | 7.04±2.14 | 7.06±2.30 |
| | | 48 hours | 6.74±1.43 | | |
| | | 72 hours | 9.19±1.14 | | |
| | Diammonium | 24 hours | 5.47±2.48 | 6.75±2.52 | |
| | | 48 hours | 6.12±2.36 | | |
| | | 72 hours | 8.64±1.85 | | |
| | Control | 24 hours | 5.32±1.89 | 7.39±2.35 | |
| | | 48 hours | 7.26±1.50 | | |
| | | 72 hours | 9.60±1.41 | | |
| *Khaya ivorensis* | Phosphoric acid | 24 hours | 3.64±1.47 | 5.53±2.11 | 7.42±2.82 |
| | | 48 hours | 5.54±1.43 | | |
| | | 72 hours | 7.42±1.55 | | |
| | Diammonium | 24 hours | 6.62±1.65 | 8.15±1.73 | |
| | | 48 hours | 8.23±1.25 | | |
| | | 72 hours | 9.61±0.80 | | |
| | Control | 24 hours | 5.74±1.52 | 8.59±3.43 | |
| | | 48 hours | 8.27±2.06 | | |
| | | 72 hours | 11.76±3.43 | | |
| *Celtis zenkeri* | Phosphoric acid | 24 hours | 5.39±1.97 | 7.25±2.38 | 9.09±4.44 |
| | | 48 hours | 7.41±1.54 | | |
| | | 72 hours | 8.96±2.36 | | |
| | Diammonium | 24 hours | 4.83±2.25 | 6.85±2.55 | |
| | | 48 hours | 7.32±2.03 | | |
| | | 72 hours | 8.40±2.29 | | |
| | Control | 24 hours | 9.40±2.19 | 13.16±4.79 | |
| | | 48 hours | 12.28±1.90 | | |
| | | 72 hours | 17.80±5.14 | | |
| *Pterygota macrocarpa* | Phosphoric acid | 24 hours | 4.01±1.32 | 7.33±2.96 | 8.72±3.55 |
| | | 48 hours | 7.41±1.25 | | |
| | | 72 hours | 10.58±0.68 | | |
| | Diammonium | 24 hours | 6.25±2.62 | 9.50±3.74 | |
| | | 48 hours | 9.74±2.52 | | |
| | | 72 hours | 12.52±3.34 | | |
| | Control | 24 hours | 6.24±2.48 | 9.32±3.69 | |
| | | 48 hours | 9.30±2.68 | | |
| | | 72 hours | 12.42±3.23 | | |

Values are means±SD

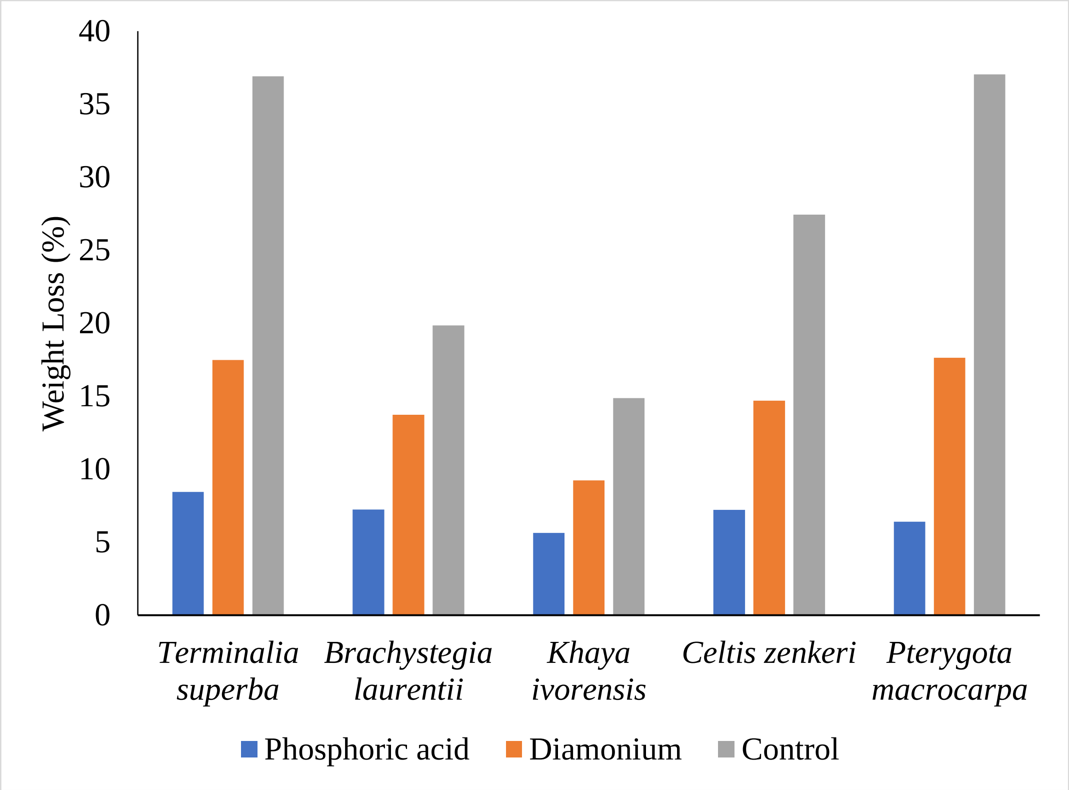


***Fig. 1.***
***Weight loss due combustion of the treated selected wood species.***

*T.superba* control after combustion

*T.superba* after combustion

*B. laurentii* control after combustion

*B. laurentii* after combustion

*K.ivorensis* control after combustion

*K.ivorensis* after combustion

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*C. zenkeri* control after combustion

*C.zenkeri* after combustion

*P.macrocarpa* control after combustion

*P.macrocarpa* after combustion

***Fig. 6.***
***Flame spread observation of selected wood species; untreated and treated with phosphoric acid.***

*T.superba* control after combustion

*T.superba* after combustion

*B.laurentii* control after combustion

*B.laurentii* after combustion

*K.ivorensis* control after combustion

*K.ivorensis* after combustion

*C.zenkeri* control after combustion

*C.zenkeri* after combustion

*P.macrocarpa* control after combustion

*P.macrocarpa* after combustion

***Fig. 7.***
***Flame spread observation of selected wood species; untreated and treated with diammonium phosphate.***

**Discussion**
**Physical Properties of the selected wood species**

The results of this study showed there are correlations between the different physical properties of the wood species studied. Firstly, there is an inverse relationship between moisture content and density. *Pterygota macrocarpa* has the highest percentage moisture content but one of the lowest density values, while *Khaya ivorensis* has the lowest moisture content and the highest density value. This suggests that as the moisture content of the wood increases, its density decreases. This has been attributed to higher density reducing the empty spaces inside the wood which causes decrease in the initial moisture content (Vinha *et al*. 2015). There is a positive correlation between volumetric shrinkage and moisture content. This can be seen in the fact that the wood species with higher moisture content (*Pterygota macrocarpa* and *Terminalia superba*) have higher volumetric shrinkage values. Also, there is a negative correlation between volumetric shrinkage and density. This can be seen in the fact that the wood species with higher density values (*Khaya ivorensis* and *Celtis zenkeri*) have lower volumetric shrinkage values. According to a study by De-Almeida *et al.* (2017) which determined the correlation between dry density and volumetric shrinkage coefficient of three Brazilian tropical wood species, it was discovered that there was no positive correlation between the volumetric shrinkage and density of the wood species. Furthermore, there is a positive correlation between weight loss due to leaching and moisture content. This is evident in the fact that the wood species with higher moisture content (*Pterygota macrocarpa* and *Terminalia superba*) have higher weight loss values due to leaching. However, there is positive correlation between volumetric swelling and moisture content. *Pterygota macrocarpa*, which has the highest percentage moisture content recorded the highest average values for volumetric swelling for all soaking times.

Overall, these relationships suggest that the moisture content of wood plays a significant role in determining its physical properties. Higher moisture content can lead to lower density, higher volumetric shrinkage and swelling, and higher weight loss due to leaching. On the other hand, lower moisture content can lead to higher density, lower volumetric shrinkage and swelling, and lower weight loss due to leaching. However, it is important to note that other factors such as species-specific characteristics and environmental conditions can also influence the physical properties of wood.

**Effect of Fire-Retardant Treatment on the Physical Properties of the Five Selected Wood Species**

Fire-retardant treatments are used to enhance the fire resistance of wood. In this study, the effect of phosphoric acid and diammonium phosphate on the physical properties of five selected wood species was investigated. The results showed that there was a significant difference in the rate of chemical absorption and volumetric swelling obtained for the selected wood species and in the two treatments. Based on the results obtained, it can be seen that both Phosphoric acid and Diammonium solution treatments significantly reduced the rate of chemical absorption of the selected wood species compared to the control. Previous studies have reported similar findings. In a study by Özkan *et al*. (2022), Anatolian black pine was treated with fire retardants of 10, 20, and 30% aqueous solutions composed of di-ammonium phosphate (DAP), borax, boric acid, and glucose to determine the effectiveness of these chemicals in preventing the spread of fire, the post-heat treatment of fire-retardant treated wood reduced water intake and improved dimensional stability. Another study by Jiang and Gao (2015) on the effect of nitrogen-phosphorous based flame-retardant treatment on Chinese fir wood showed that the treatment significantly improved the wood's dimensional stability.

Wood species treated with diammonium phosphate generally had a higher retention rate in all the wood species except for *Brachystegia laurentii* compared to phosphoric acid treatments. Baysal, (2011) reported similar findings when diammonium phosphate and ammonium sulphate fertilizers were impregnated into Calabrian pine at 10, 20, and 30% concentrations prior to combustion test. The result showed that diammonium phosphate had retention of 43.2 $kg/m^3$ at 20% concentration compared to other treatments.

Diammonium solution treatment was more effective in reducing the rate of chemical absorption in wood species compared to Phosphoric acid treatment. Furthermore, the volumetric swelling of the wood species treated with both Phosphoric acid and Diammonium solution were lower than the control group, indicating a reduction in swelling potential. These findings are consistent with previous research works that have shown the effectiveness of Phosphoric acid and Diammonium solution treatments in reducing the rate of chemical absorption and volumetric swelling of wood species (Jiang and Gao 2015). In terms of the specific wood species used in this study, previous research has also reported similar results. For instance, a study by Terzi *et al.* (2011) on the effect of fire-retardant treatment on four wood species, including *T. superba* and *P. macrocarpa*, found that the treatment significantly reduced the wood's water absorption and thickness swelling. However, the wood species treated with Diammonium solution had a slightly higher volumetric swelling than those treated with Phosphoric acid. This indicates that Phosphoric acid treatment is more effective in reducing volumetric swelling of wood species compared to Diammonium solution treatment. This conforms to the study of Izran *et al*. (2009) who conducted a research on the fire propagation and strength performance of kenaf (*Hibiscus cannabinus*) core particle board. It was treated with three different commercialized fire retardants (diammonium phosphate, BP and monoammonium phosphate) using ten percent concentration of fire retardants. It was discovered that diammonium phosphate hygroscopicity increased the water absorption rate, thus increased the thickness swelling of the treated particle boards. This was also the case in the research conducted by Ayrilmis *et al*. (2007).
Overall, the results suggest that both Phosphoric acid and Diammonium solution treatments are effective in reducing the rate of water absorption and volumetric swelling of wood species, with Phosphoric acid treatment being more effective in reducing volumetric, while Diammonium solution treatment is slightly more effective swelling in reducing the rate of chemical absorption.

**Effect of Fire-Retardant Treatment on the Retardant Properties of the Five Selected Wood Species**

The results of the fire-retardant treatment on the weight loss due to combustion of the five selected wood species (Fig. 6, 7) in this study are consistent with previous research works. According to a study by Gaff *et al*. (2019), the weight loss due to combustion of fire-retardant-treated wood was significantly lower than untreated wood. The reduction in weight loss was due to the charring effect of the fire retardant that protected the wood from burning. In terms of the effect of treatment on individual wood species, the results of this study showed that for species treated with phosphoric acid, *P. Macrocarpa* and *K. ivorensis* had the lowest weight loss while for species treated with diammonium phosphate, *K. Ivorensis* and *B. laurenti* had the lowest weight loss due to combustion. This indicates that these wood species have a higher resistance to fire and can be suitable for use in applications where fire resistance is required. This finding is consistent with previous studies by Gašparík *et al*. (2017), which reported that the weight loss due to combustion of different wood species varied, with some species exhibiting higher resistance to fire than others. In a study conducted by Gaff *et al*. (2019), it was reported that the weight loss of thermally modified teak treated with ammonium phosphate decreased by up to 92% compared to the values measured in untreated specimens. Similarly, in a study conducted by Lubloy *et al*. (2021) it was reported that the weight loss of spruce, pine, and oak treated with five different fire retardants was lower compared to control samples. Generally, *K. ivorensis* had the lowest weight loss after combustion for both treatments with phosphoric acid being the lowest. This agrees with the work of Adetayo and Dahunsi (2019) who reported lowest percentage loss for *K. ivorensis* when exposed to fire. Also, the results of research done by Listyanto *et al.* (2020) showed that borax and boric acid effectively improved the fire resistance property (mass losses) of mahogany wood. Lastly, this work affirmed that sample treated with phosphoric acid had the lowest weight loss due to combustion compared with sample treated with diammonium phosphate

## CONCLUSION

According to this study, there exist relationships between the various physical properties of different wood species, and density has a big influence on these characteristics. Also, the results revealed that both phosphoric acid and diammonium phosphate treatments are effective in reducing the rate of dimensional change of wood species. Phosphoric acid treatment was found to be more effective in reducing volumetric swelling, while diammonium phosphate treatment was slightly more effective in reducing the rate of water absorption. The study also found that the fire-retardant treatments improved the fire retardant properties of the wood species, as evidenced by the reduced weight loss due to combustion. *K. ivorensis* and *B. laurenti*, exhibited higher resistance to fire and may be suitable for use in applications where fire resistance is required.

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