Journal of Scientific Research & Reports

26(4): 81-98, 2020; Article no.JSRR.56795
ISSN: 2320-0227

Correlations of Major Flame Characteristics of Some Fire Tolerant Trees in South-East Nigeria by Coefficient of Determination (R^2)

Vincent Nwalieji Okafor[1*], Matthew Chiemezie Obiadi[1]
and Joy Ngozika Obiefuna[1]

[1]Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, P.M.B. 5025, Awka,
Anambra State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author VNO designed and wrote the entire manuscript and sourced most of the data and literature and as well supervised authors MCO and JNO during laboratory work. Author MCO also provided some literature on fire tolerant trees while author JNO in addition assisted in the procurement of research materials and literature on statistical analysis. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2020/v26i430250
Editor(s):
(1) Dr. Ahmed Mohammed Abu-Dief Mohammed, Sohag University, Egypt.
Reviewers:
(1) Ionac Nicoleta, University of Bucharest, Romania.
(2) P. Swarnalatha, CSE, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/56795

Original Research Article

Received 10 March 2020
Accepted 17 May 2020
Published 27 May 2020

ABSTRACT

Background: Bush fire is a common hazard in South East-Nigeria as in other parts of the country during the harmattan. Every year, thousands of hectares of forests as well as suburban lands are severely burnt. These forest fires have been catastrophic, destroying large areas of tropical rain forests and in most cases have claimed many lives and destroyed properties worth millions of naira. However, some of these trees identified by local people and named by taxonomists as *Daniellia oliveri*, *Anacadium occidentale, Vitex doniana, Lonchocarpus griffonianus*, *Gmelina arborea, Nauclea latifolia, Tectona grandis, Mangifera indica, Delonix regia, Newbouldia laevis*, *Azadirachta indica*, *Dialium guineense, Terminalia superba, Manilkara obovata* and *Irvingia gabonensis* have proven to be fire tolerant.

Aim: The aim is to establish correlations among the physical properties (wood density and moisture content) and flame characteristics (ignition time, flame propagation rate, flame duration, afterglow time, ash formation and limiting oxygen index) of these fire tolerant trees.

**Corresponding author: E-mail: vnw.okafor@unizik.edu.ng;*

Study Design: An item structured instrument was developed by the researchers which reflected the six points modified Likert scale of strongly agree, agree, somewhat agree, somewhat disagree, disagree, strongly disagree and used to elicit information from the respondents who were mainly seasoned wood dealers of above 60 years of age. Analysis of Variance (ANOVA) was the major tool of analysis used to establish whether the tree species tolerates fire or not while correlation of the parameters was achieved by the application of R^2.
Place and Duration of Study: Determination of both the physical properties and flame characteristics of the tree species was done at the Research Laboratory of the Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka between June, 2018 and April, 2019.
Methodology: The physical properties of the tree species as well as their flame characteristics were carried out using their standard methods.
Results: The values for these parameters vary among the tree species. Correlation among the parameters indicates a determination coefficient range from 0.000 to 0.637.
Conclusion: There are highly significant correlations between wood density and both ignition time and flame propagation rate as well as wood density and limiting oxygen index. There is also strong correlation between ignition time and both flame propagation rate and limiting oxygen index. Afterglow time depends on limiting oxygen index and vice versa.

Keywords: Correlation; R^2; flame characteristics; fire tolerant trees; South-East Nigeria.

1. INTRODUCTION

Woods, a natural resource, are employed in such diverse areas as in construction of boats, vehicles and in buildings, household furniture of immense variety, bridges as well as for generation of chemicals and pharmaceuticals and as fuel for small scale furnace works [1]. One factor that has limited the application of this resource is combustibility. When ignited most times by accident, it flames and destroys anything it comes in contact with due to its combustibility. The combustibility of woods leading to fire incidents has claimed many lives and destroyed properties worth millions of naira. Markets, business and residential buildings, farmlands and farm products have been lost to fires in Nigeria and beyond since the history of fire [2-7].

Fire or flame, simply put, is a region of hot gases raised to incandescence [8]. This definition implies that the burning material, which in most cases polymers such as cellulose, plastics, rubbers, woods, etc., must be able to supply gases that burn. Factors that control the burning of materials are many [9-11], the most obvious being the chemical composition of the material [12] Others are geometry, type and size of ignition source, draught, age, and conditioning (including initial temperature) of the sample, the atmosphere (moisture regain and relative humidity) as well as temperature [13]. Geometry can be a decisive factor in that it embraces all the qualities such as back and packing, orientation, surface contour and specimen construction [12].

An approach in preventing the combustibility of wood is the use of fire resistance woods in their diverse applications. McPherson and others [14] described fire resistant species as species with morphological characteristics that give it a lower probability of being injured or killed by fire while a fire- sensitive species, has a “relatively high probability of being injured or killed by fire. This implies that the organism does not get injured by things that would seem able to injure it according to Johnson and Van Wagner [15]. Rowe [16] uses a more restrictive definition of resistance; relating it only to plants with above ground parts that survive fire. According to Levitt [17], there are two kinds of resistance namely, tolerance (species that mitigate dangerous, often lethal conditions) and avoidance (ways of preventing cells from heating to lethal temperatures). Most plant cells that survive fire do so through avoidance – because of insulating tissues, for example, or because of an insulated microenvironment.

Other workers [6,18-21] had reported some methods of estimating flammability. Another well established and standardized measure of flammability is the limiting oxygen index. The limiting oxygen index (LOI), also called the critical oxygen index (COI) or oxygen index (OI) is the minimum concentration of oxygen, expressed as a percentage that will support combustion of a polymer [22]. A numerical index, the ‘LOI’, is also defined as a minimum concentration of oxygen in an oxygen-nitrogen mixture, required to just support downward burning of a vertically mounted test specimen [23].

Reports on flammability studies of some fire tolerant trees of the tropical rain forests and as well the effects of density and moisture content of woods on some flame properties and flame retardants on timbers abound [18-20,24]. It is surprising that little or no effort had been made to correlate the physical properties of woods with the major parameters of flammability of fire tolerant trees. This study therefore is focused on the establishment of correlations among the major flame properties of some fire tolerant tree species in South-East, Nigeria and their physical properties by the application of coefficient of determination.

2. MATERIALS AND METHODS

2.1 Materials

An item structured instrument which was developed by the researchers was used to elicit information from the respondents. The fifteen (15) tropical timbers were procured from different rainforests in South-East, Nigeria based on the information obtained from respondents to questionnaires.

The apparatuses used in this work: stopwatch, clamp and retort stand, crucible with lid, top loading mettler balance, muffle furnace, vacuum oven etc. were collected from the research laboratory of the Department of Pure and Industrial Chemistry of Nnamdi Azikiwe University, Awka.

2.2 Study Design and Statistical Method

The study adopted experimental and descriptive survey designs. Ikeagwu [25] noted that studies of this nature use the survey method to look for information on facts, practices and opinions of the respondents on the issues surrounding the subject matter of the investigation. To Obasi [26], the use of survey is always adopted because it provides an important means of gathering information especially when the necessary data cannot be found in statistical records in form of secondary data. In the test of significant difference, One Way Analysis of Variance (ANOVA) is the most suitable tool as it has the capacity to show the existence of difference at 5% level of significance [27]. Two hypotheses, H_0 and H_1 were stated and tested for:

H_0: There is no significant difference among samples of interest.

H_1: There is significant difference among samples of interest.

The result of the p- value (significance value) was used to accept or reject either of the hypotheses.

2.3 Sample Preparation

Forty (40) splints of 0.7cm thick by 0.7 cm broad by 100 cm long of each tree species were made. The splints were kept in a dust free atmosphere for 48 hours at room temperature and relative humidity of 70%.

2.4 Methods

The physical and flammability properties of the tree species were investigated using published protocols [28-32] at room temperature in the research laboratory of the Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka. The results were interpreted by the application of coefficient of determination. R^2 value of one (1) indicates a perfect relationship and R^2 value of zero (0) shows no relationship at all [33].

3. RESULTS AND DISCUSSION

Results from our previous work [34] show that all the trees are fire resistance since the p-values in all the tree species were greater than 0.05 at 95% confidence interval. Hence, H_0 was accepted and H_1rejected, in all the timbers investigated.

The density of the tree species ranged from 0.39 to 0.97gcm^{-1}. The results as shown in Table 1 indicate that *I. gabonenses* has the highest wood density whereas *D. oliveri* has the least wood density. Density of wood varies, depending on the amount of material (cell wall) and voids (cell cavities) present in the certain volume. The density of wood is also influenced by structure of wood. Late wood is made of cells which have thicker walls and smaller cavities in comparison to early wood. This results in high density of latewood as compared with early wood and explains why the density of wood increases with increasing proportion of latewood. Higher amounts of extractives are a course for the higher density of heartwood in comparison to sapwood; removal of extractives results in reduction of density [35].

The effect of density on moisture content, ignition time, flame propagation rate, flame duration, afterglow time, ash formation and limiting oxygen index are shown in Figs. 1- 7. In general, the results show an increase in ignition time and limiting oxygen index with increasing density (Figs. 2 and 7) respectively. Again, as wood density increases, flame propagation rate and ash formation decrease as shown in Figs. 3 and 6 respectively. The observations in Figs. 1, 4 and 5 hardly indicate any correlation between wood density and moisture content, wood density and flame duration, and wood density and afterglow time considering their respective R^2 values. Some specimens, however, have different ignition time, flame spread rate, ash formation and/or limiting oxygen index values at similar densities. The reasons for this could be due to effects of morphological differences such as chemical composition, void volume within the cell walls, early wood: latewood ratios and resin contents. Even in the case of timbers having similar densities, the afterglow times are substantially different. It is likely that apart from the density of the timber, the nature of the unburned material that has gone through thermal episode, in form of char (whether dense or open), the depth to which the surface flame had sunk as it traversed the wood surface, may help to explain the result [36].

Table 1. Physical and flammability properties of the tree species

S/N	Tree species	WD (gcm^{-1})	MC (%)	IT (s)	FPR (cms^{-1})	FD (s)	AGT (s)	AF (%)	LOI (%)
1	*Daniellia oliveri*	0.39	9.91	3.00	0.27	12.00	184.00	1.26	28.78
2	*Anacadium occidentale*	0.40	9.69	4.00	0.26	17.00	215.00	1.33	26.81
3	*Vitex doniana*	0.44	10.73	5.00	0.24	31.00	267.00	2.38	27.14
4	*Lonchocarpus griffonianus*	0.45	10.26	3.00	0.23	27.00	204.00	2.16	26.29
5	*Gmelina arborea*	0.46	9.68	3.00	0.22	34.00	166.00	0.26	27.52
6	*Nauclea latifolia*	0.46	9.96	4.00	0.21	28.00	198.00	0.88	26.06
7	*Tectona grandis*	0.47	8.02	6.00	0.20	39.00	99.00	1.12	29.56
8	*Mangifera indica*	0.59	10.00	6.00	0.16	27.00	70.00	2.14	28.60
9	*Delonix regia*	0.61	10.02	5.00	0.17	56.00	172.00	0.36	26.00
10	*Newbouldia laevis*	0.62	10.70	4.00	0.15	27.00	218.00	1.53	27.03
11	*Azadirachta indica*	0.63	11.56	7.00	0.15	26.00	179.00	0.29	28.32
12	*Dialium guineense*	0.71	9.91	8.00	0.15	33.00	134.00	0.19	28.21
13	*Terminalia superba*	0.75	10.13	3.00	0,18	28.00	170.00	0.56	29.75
14	*Manilkara obovata*	0.94	10.61	10.00	0.15	13.00	197.00	0.19	30.49
15	*Irvingia gabonensis*	0.97	10.44	9.00	0.15	19.00	185.00	0.96	29.93

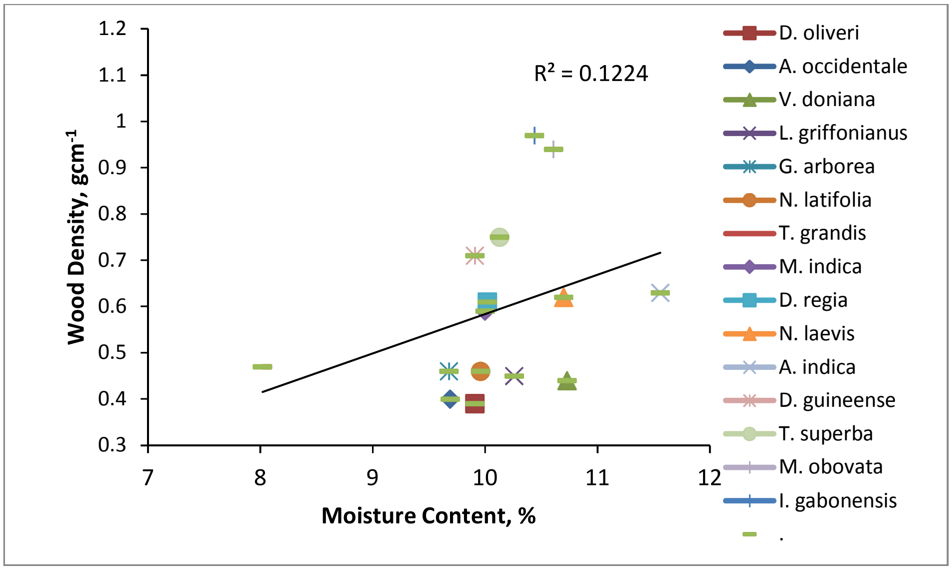

Fig. 1. Wood density versus moisture content

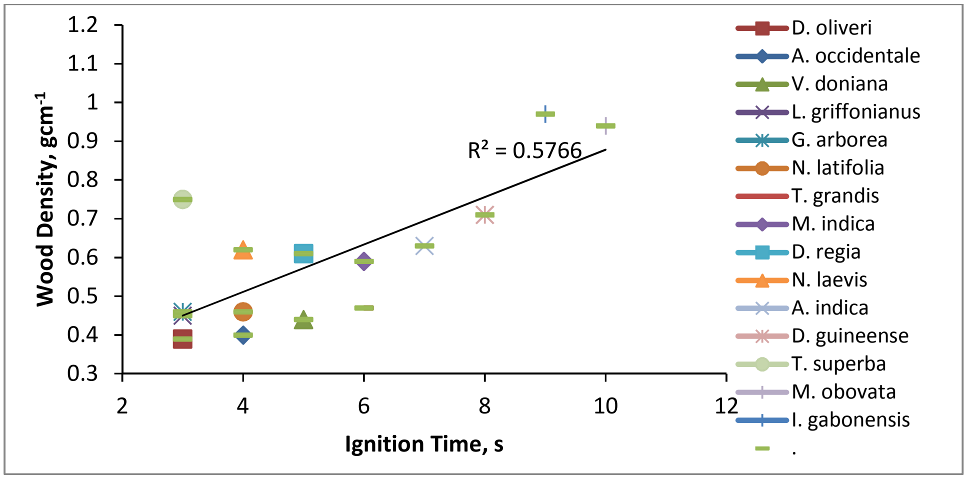

Fig. 2. Wood density versus ignition time

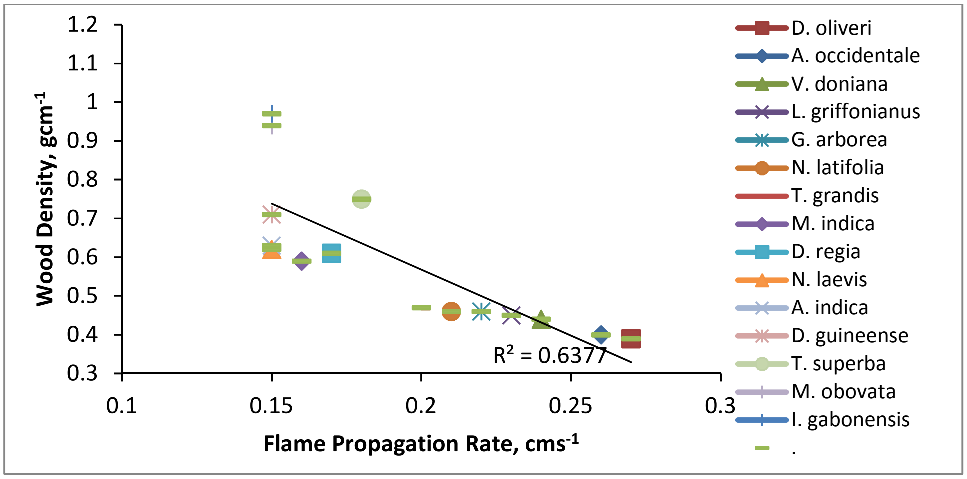

Fig. 3. Wood density versus flame propagation rate

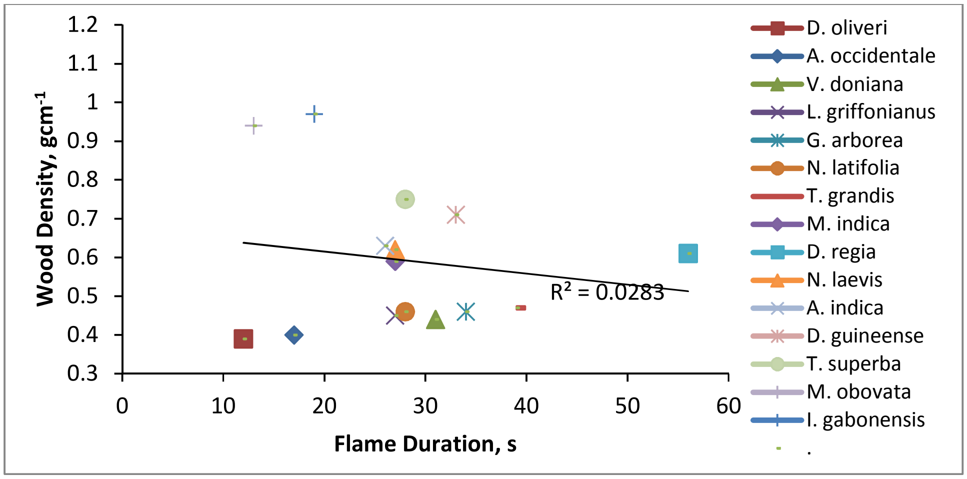

Fig. 4. Wood density versus flame duration

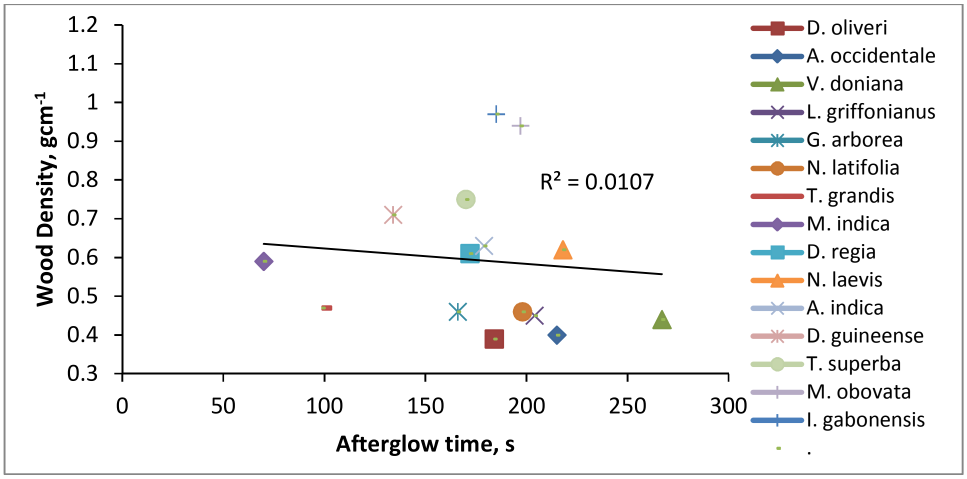

Fig. 5. Wood density versus afterglow time

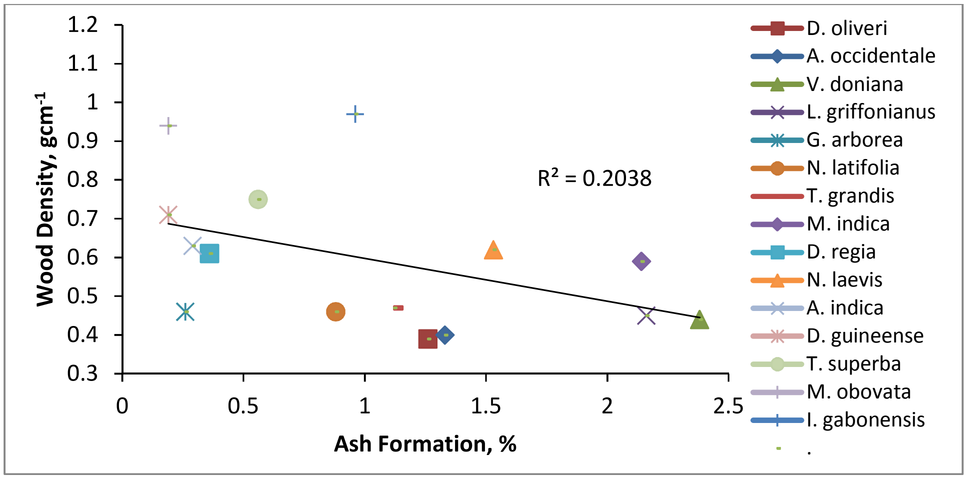

Fig. 6. Wood density versus ash formation

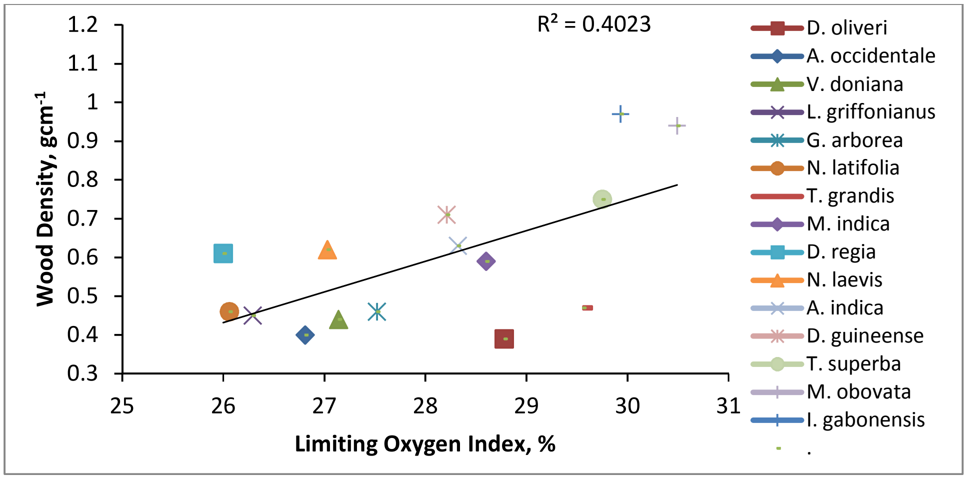

Fig. 7. Wood density versus limiting oxygen index

The moisture content of the timbers ranged between 8.02 and 11.56% as presented in Table 1. Contrary to expectation, Figs. 8-13 hardly suggest any strong correlation between moisture content and other parameters such as ignition time, flame propagation rate, flame duration, afterglow time, ash formation and limiting oxygen index. Moisture content reduces ease of ignition and flame propagation rate [35]. Again, the observation on the correlation between moisture content and limiting oxygen index contradicts that reported by White [32].

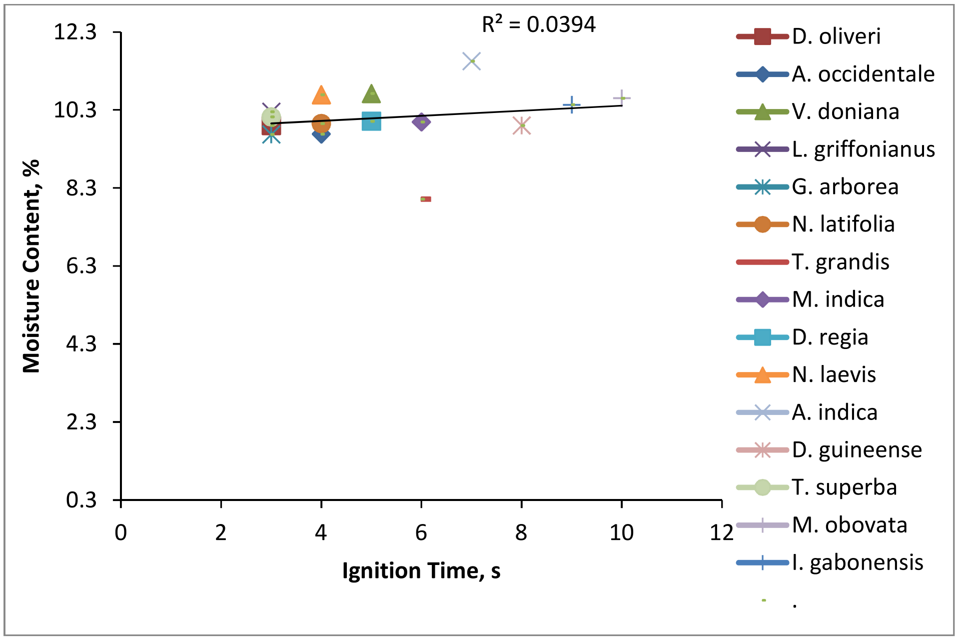

Fig. 8. Moisture content versus Ignition time

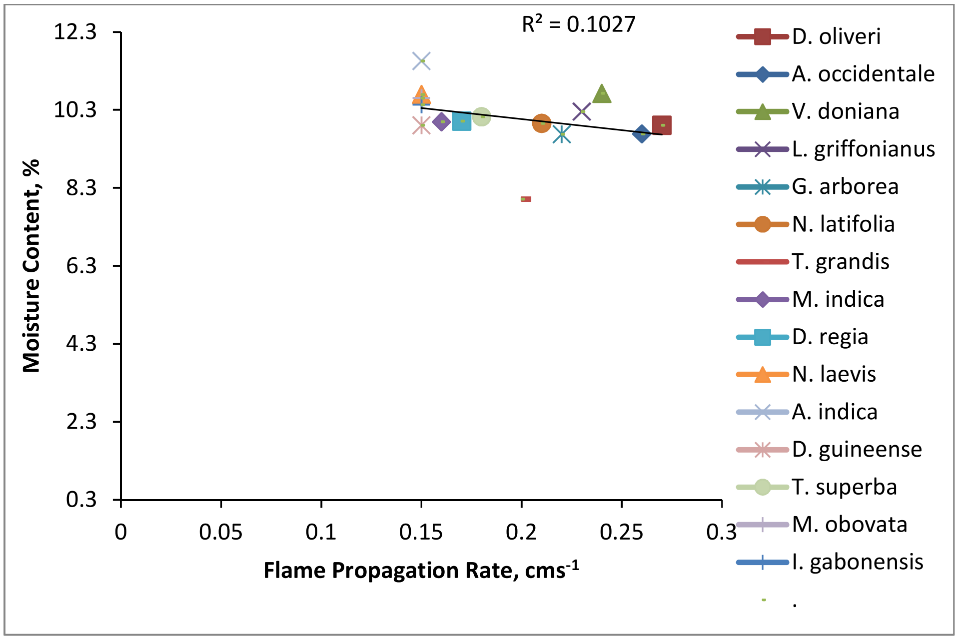

Fig. 9. Moisture content versus flame propagation rate

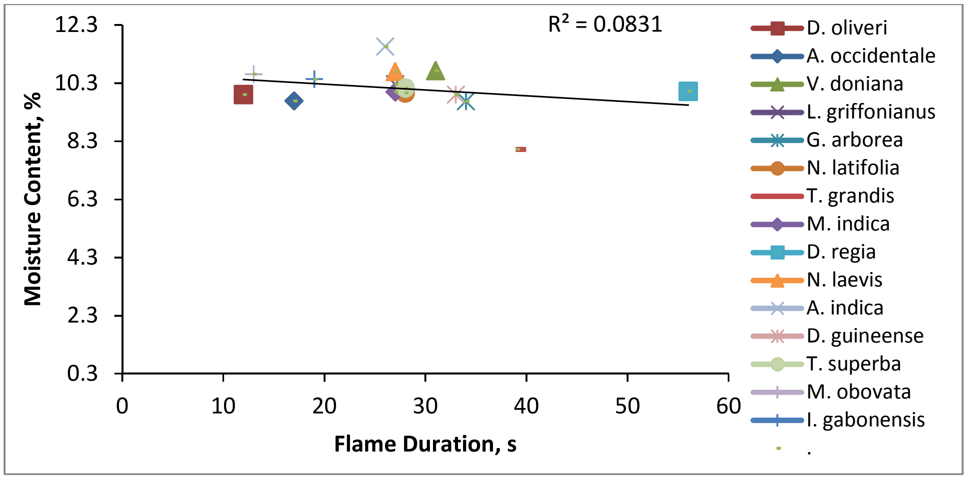

Fig. 10. Moisture content versus flame duration

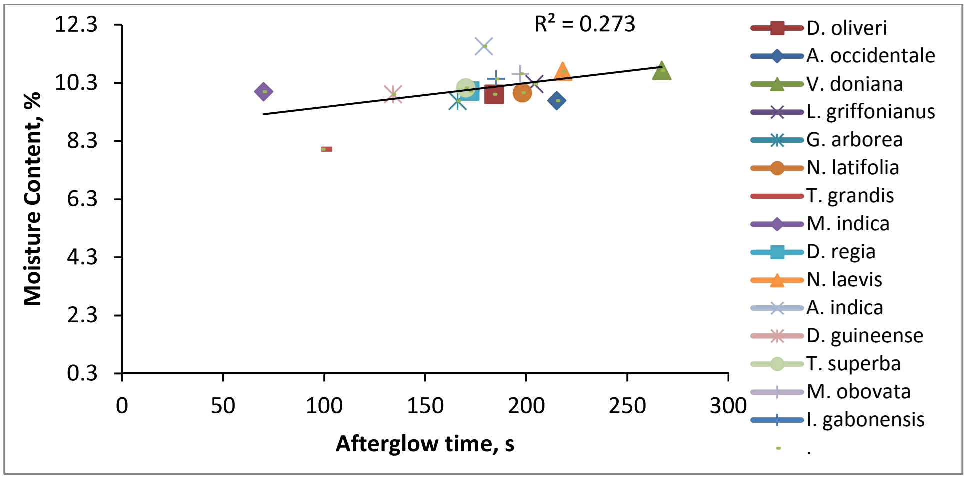

Fig. 11. Moisture content versus afterglow time

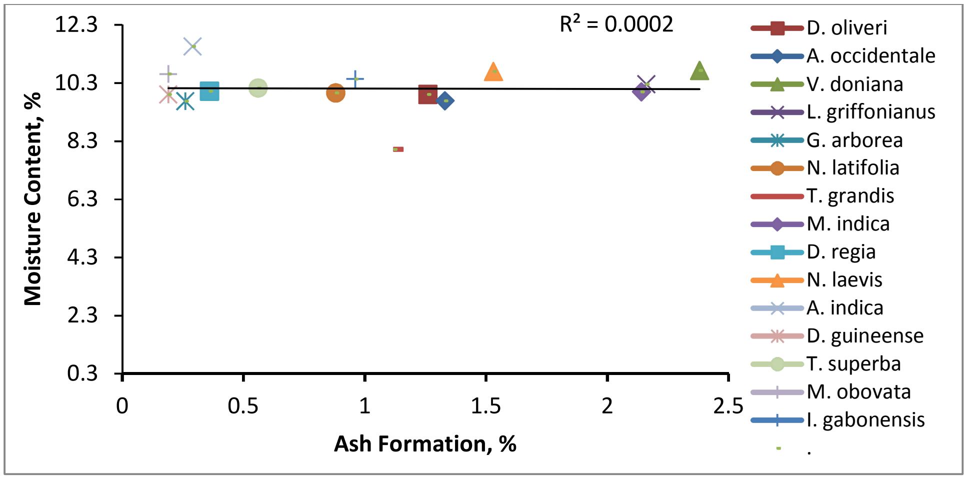

Fig. 12. Moisture content versus ash formation

The observed differences could be as a result of variations in the composition of the substrate ranging from different types of wood to different types of natural plant, fibres/cells, and the effect of these on the phenomena of heat and mass transfer as well as presence of trace amounts of inorganic impurities or contamination [31,34,36].

Ignition time of the woods ranged from 3 to 27 seconds (Table 1). Figs. 14 and 18 indicate that there is a relationship between ignition time and flame propagation rate, and ignition time and limiting oxygen index respectively.

However, Figs. 15, 16 and 17 hardly indicate any definite correlation between ignition time and such other parameters as flame duration, afterglow time and ash formation. These observations are in agreement with those of Eboatu and coworkers [31,36].

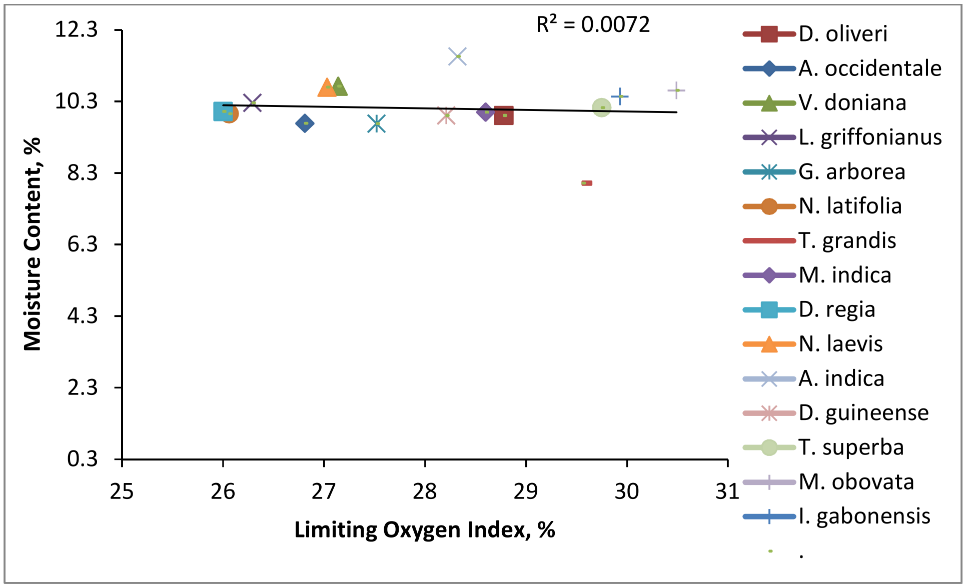

Fig. 13. Moisture content versus limiting oxygen index

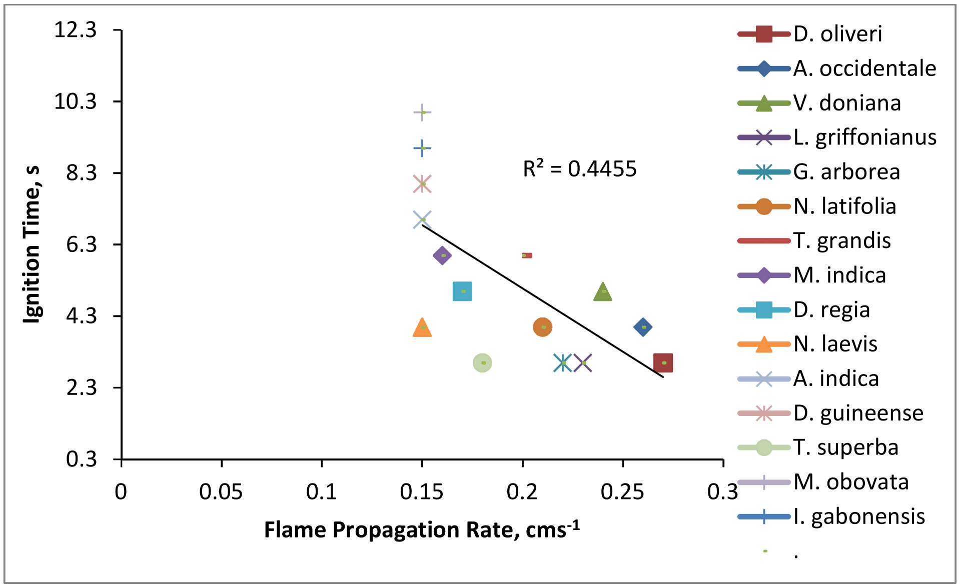

Fig. 14. Ignition time versus flame propagation rate

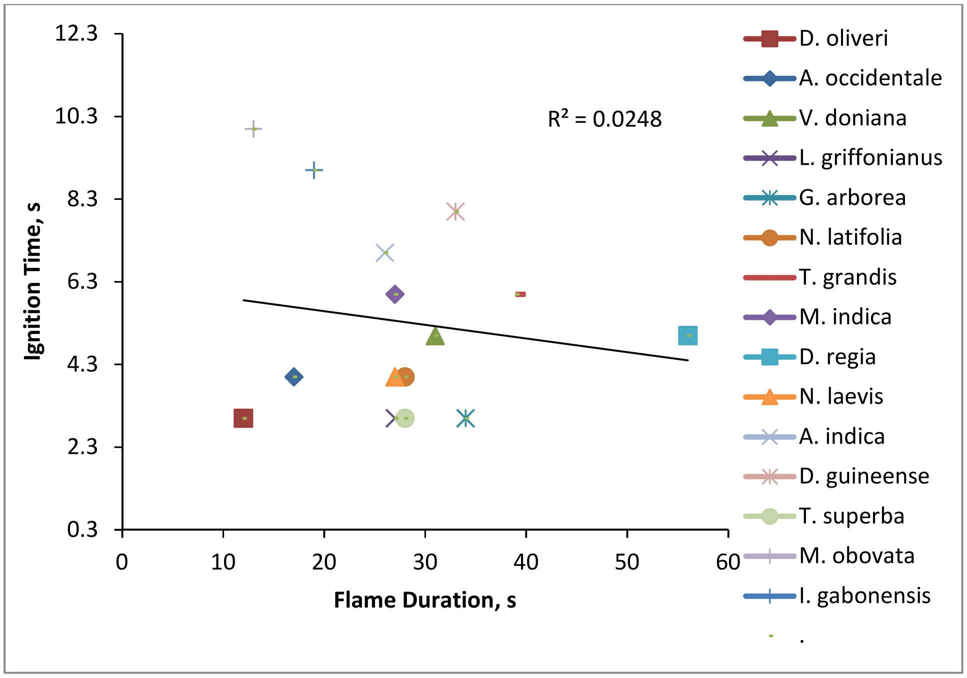

Fig. 15. Ignition time versus flame duration

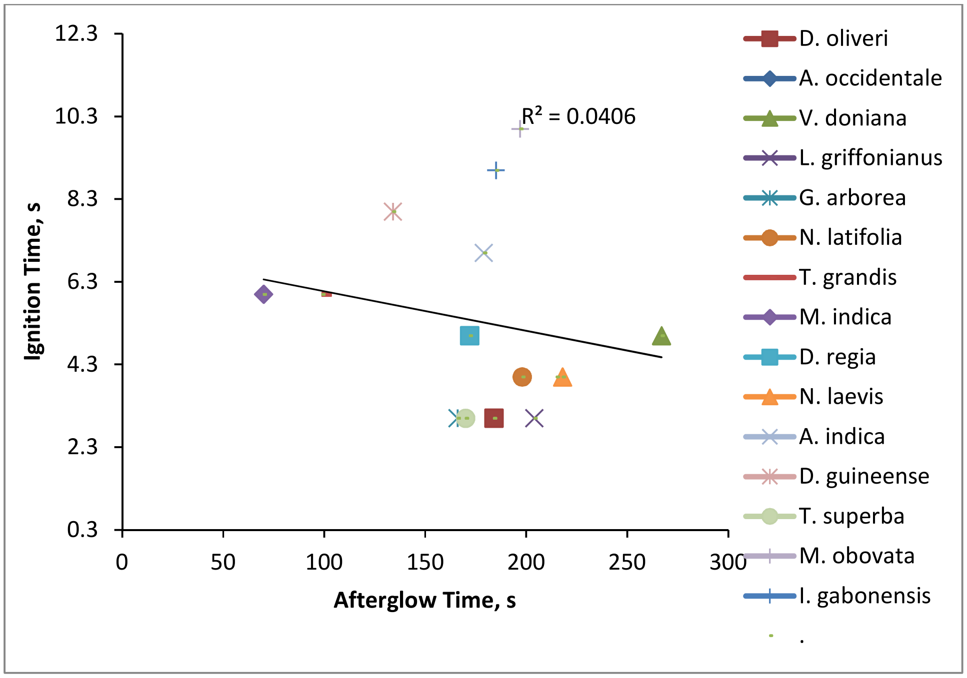

Fig. 16. Ignition time versus afterglow time

The values of flame propagation rate of the timbers as shown in the Table ranged between 0.15 and 0.27 cms^{-1}. The observations in Figs. 19, 20, 21 and 22 hardly suggest any strong correlation between flame propagation rate and flame duration, flame propagation rate and afterglow time, flame propagation rate and ash formation, and flame propagation rate and limiting oxygen index respectively.

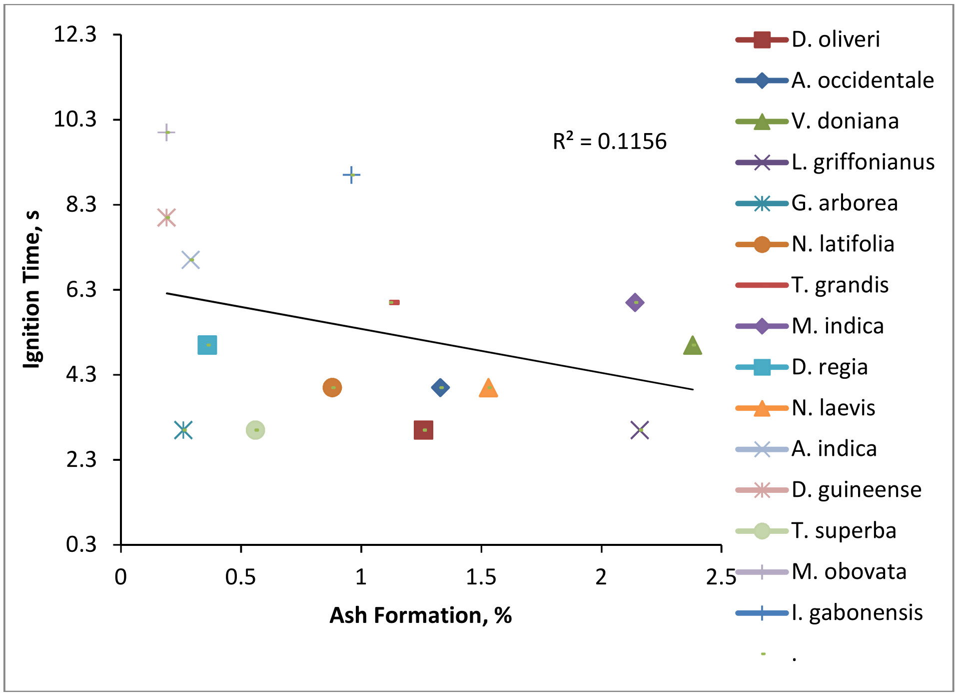

Fig. 17. Ignition time versus ash formation

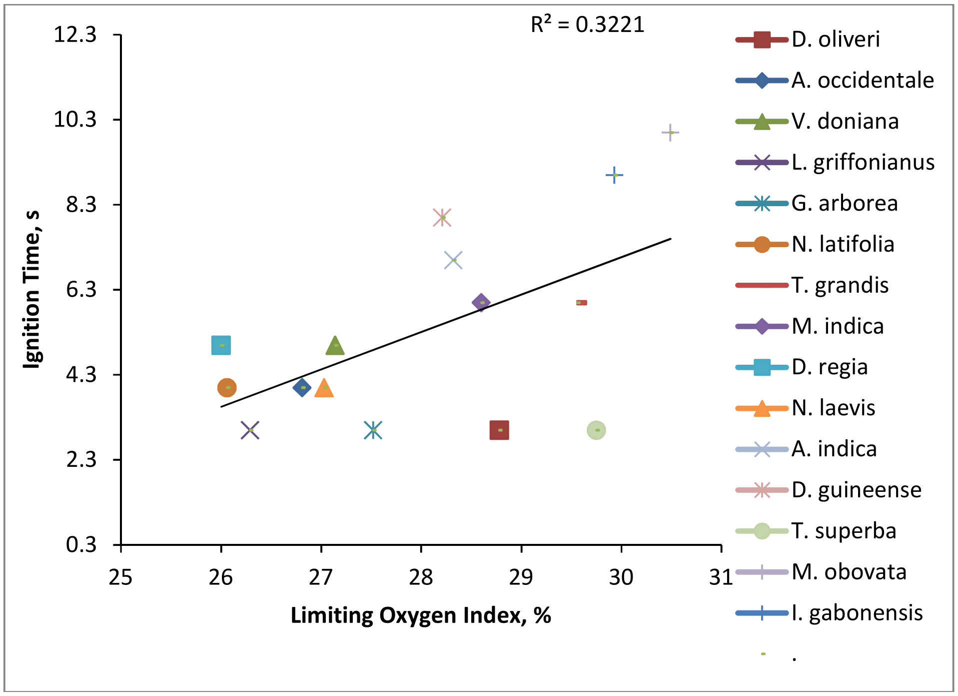

Fig. 18. Ignition time versus limiting oxygen index

Flame duration ranged from 12 to 56 seconds. Figs. 23 and 24 hardly indicate any correlation between flame duration and both afterglow time and ash formation. Flame duration depends on fuel supply to the material, gasification of the fuel supplied and the volume of the mixture of the gaseous product with the oxygen in the presence of heat [36]. Contrary to expectation, Fig. 25 suggests that flame duration has no definite correlation with limiting oxygen index.

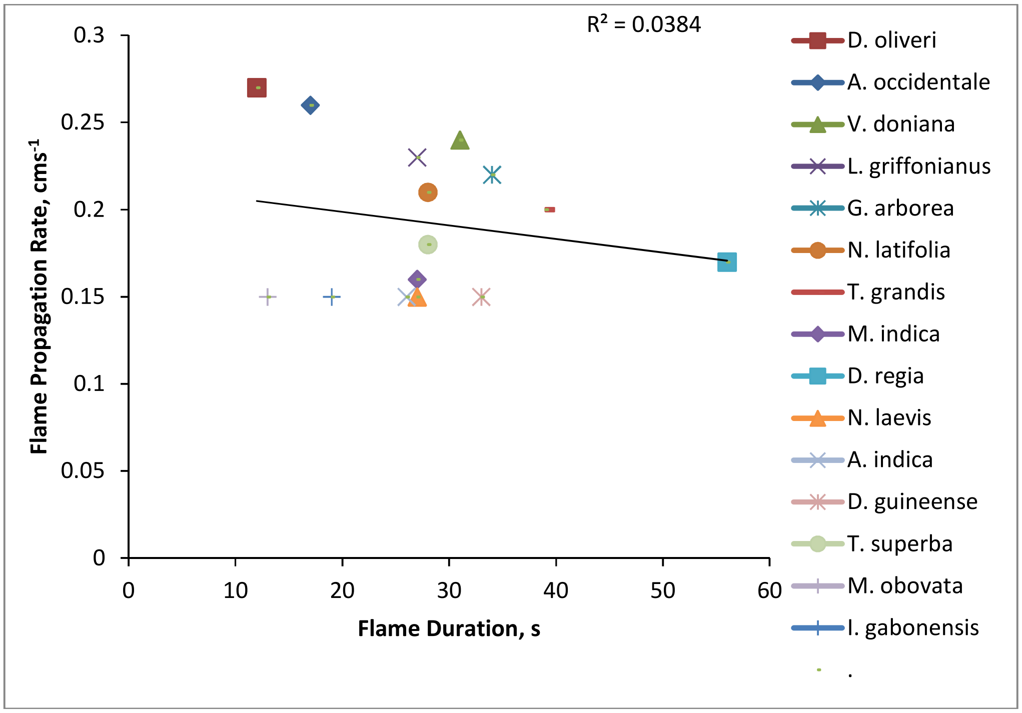

Fig. 19. Flame propagation rate versus flame duration

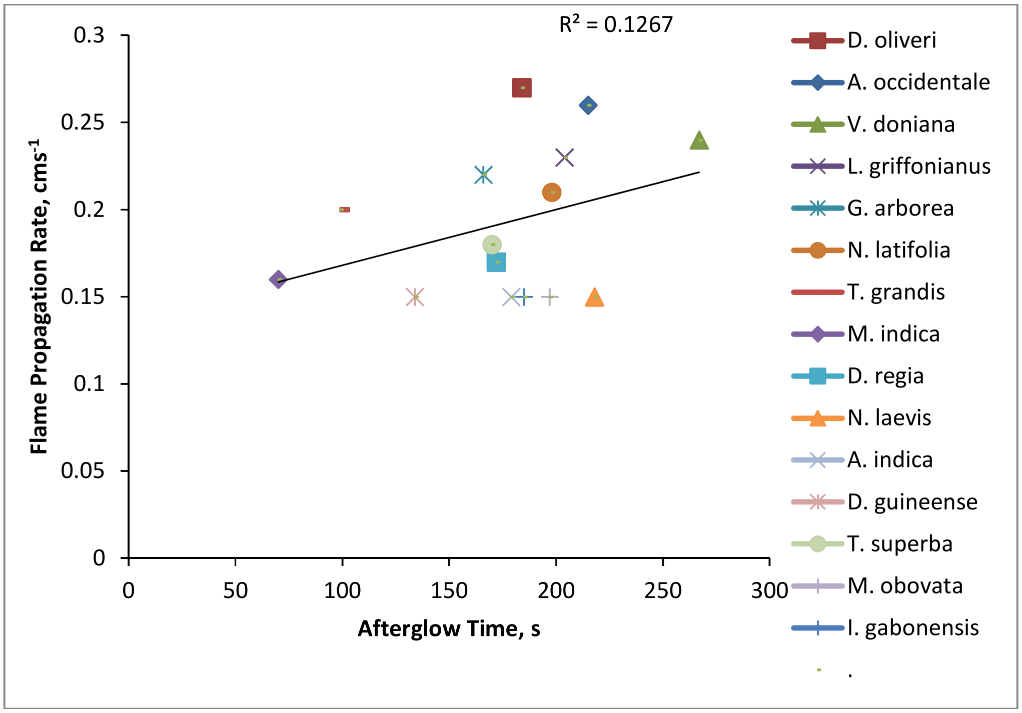

Fig. 20. Flame propagation rate versus afterglow time

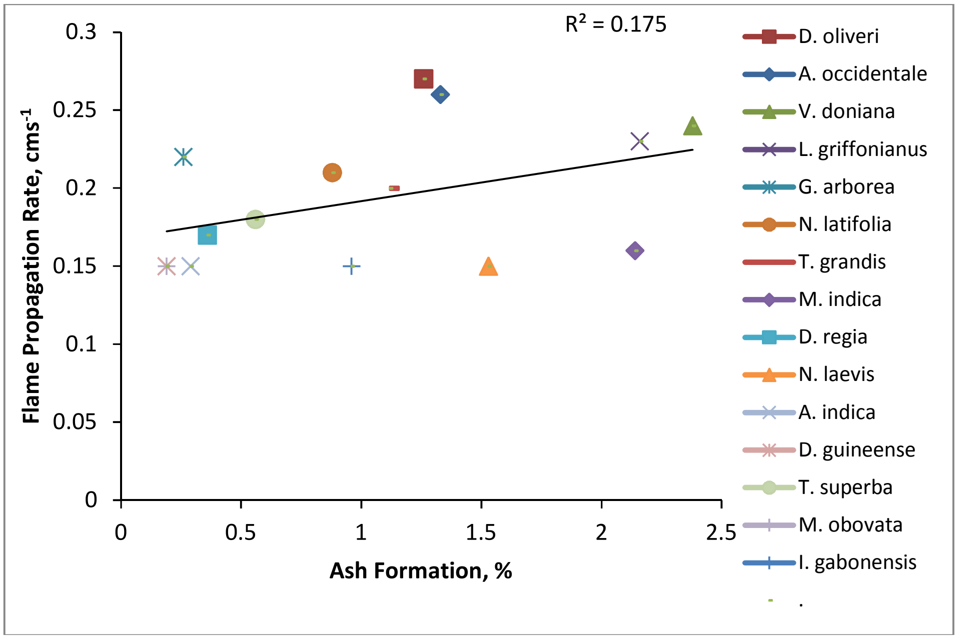

Fig. 21. Flame propagation rate versus ash formation

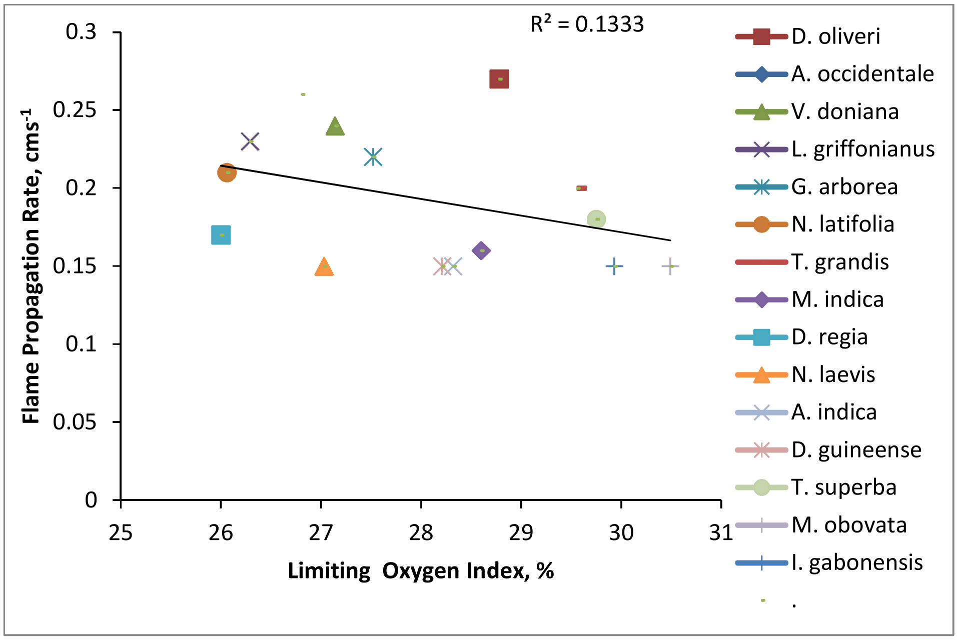

Fig. 22. Flame propagation rate versus limiting oxygen index

The table shows that afterglow time of the woods ranged between 70.00 and 267.00 seconds. Glow is defined as an exothermic surface reaction that radiates heat and light without a flame. It usually occurs in an abundance of oxygen and depends on unburned material as well as on char [37] but the observation shown in Fig. 26 hardly indicates any serious correlation between afterglow time and ash formation. Generally, the higher the afterglow time, the greater the ash yield as might be expected if the former is related to carbon content. This is an indication that afterglow also depends largely on the presence of inorganic salts. Nevertheless, the relationship in Fig. 26 is not linear as expected due to probably the morphological, age and/or habitat differences of the tree species [38] However, Fig. 27 suggests a decreasing afterglow time with increasing limiting oxygen index. The ash values of the woods ranged from 0.19 to 2.38%. Fig. 28 hardly indicates any strong correlation between ash formation and limiting oxygen index as expected. This observation reveals that ash formation is independent of limiting oxygen index and vice versa [39].

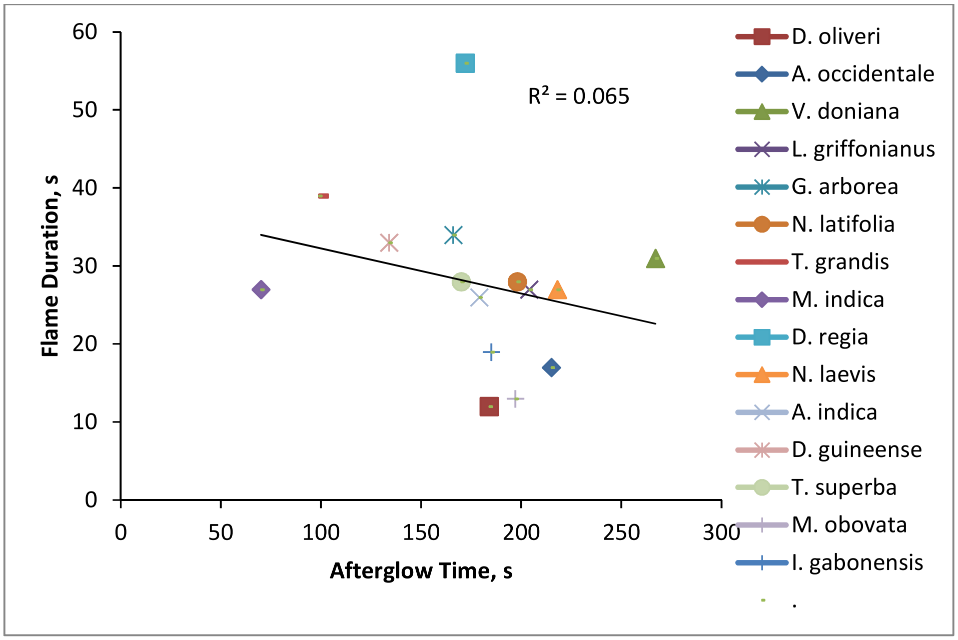

Fig. 23. Flame duration versus afterglow time

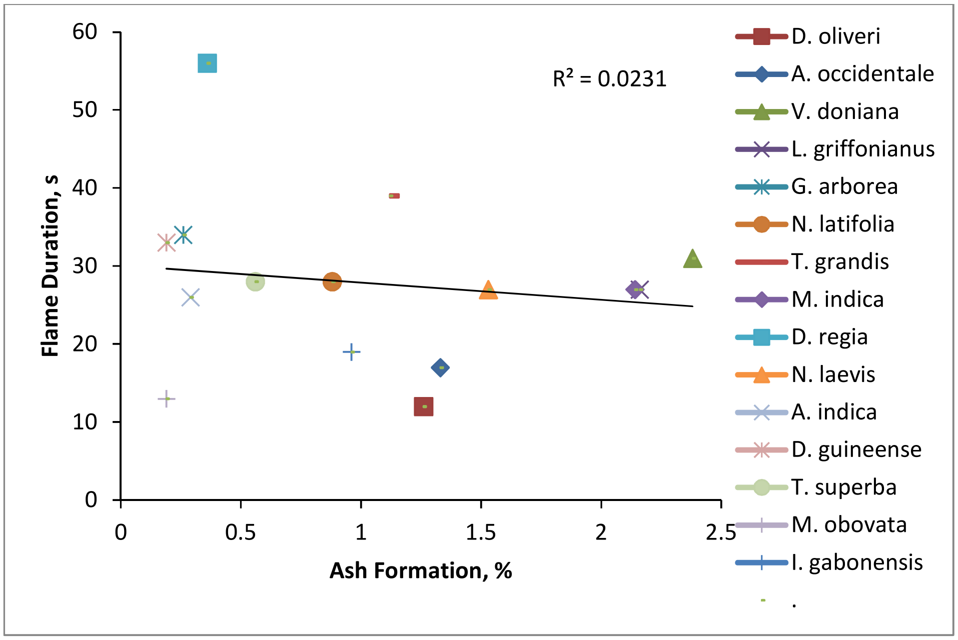

Fig. 24. Flame duration versus ash formation

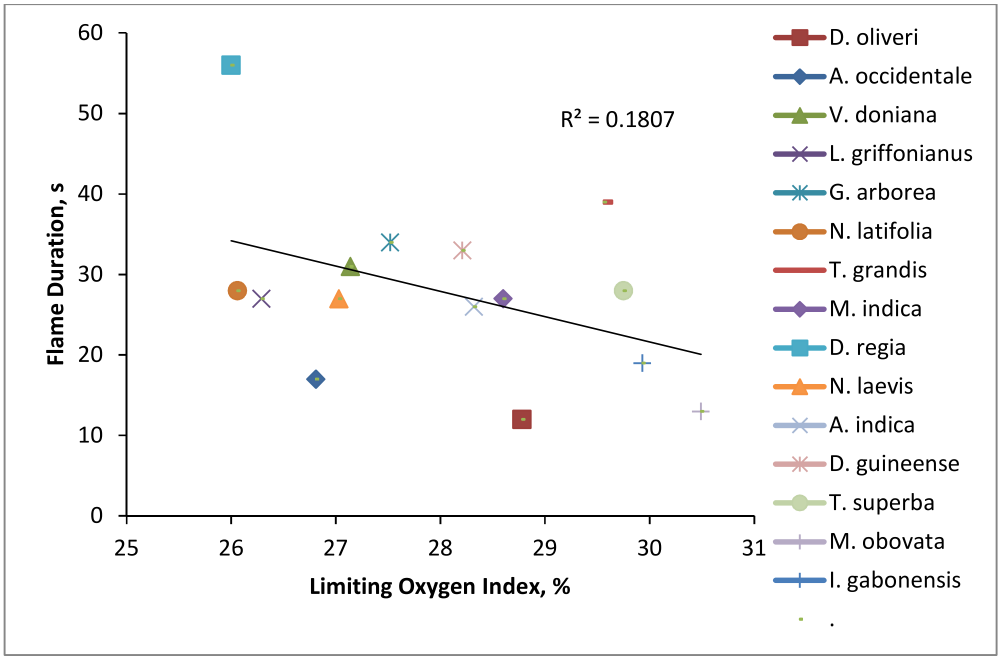

Fig. 25. Flame duration versus limiting oxygen index

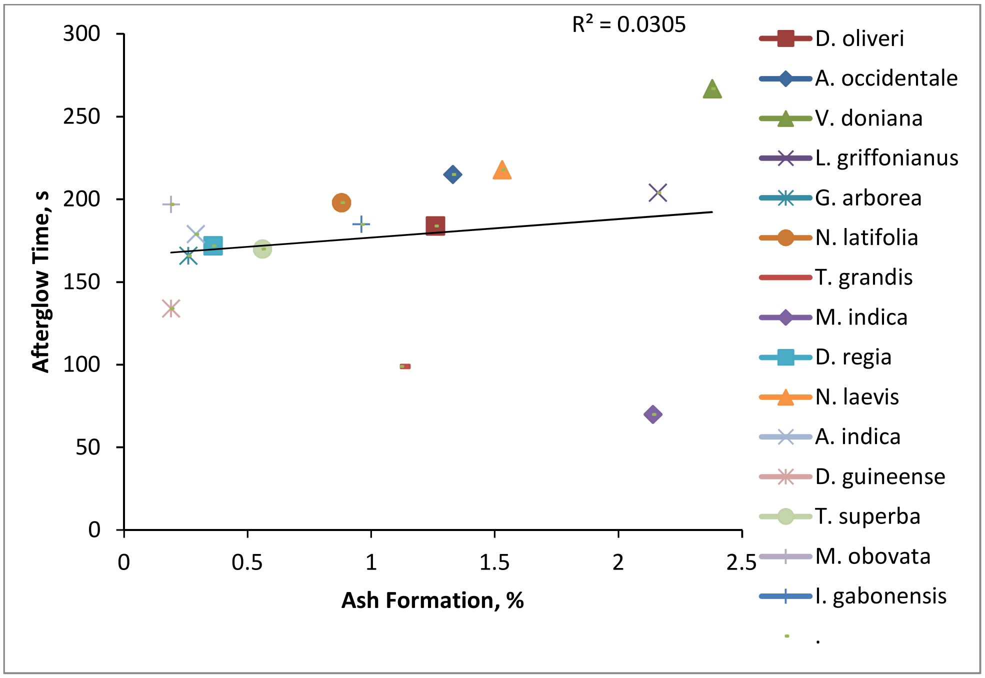

Fig. 26. Afterglow time versus ash formation

These results are difficult to explain but our method of determination of limiting oxygen index cannot be said to be totally accurate since the experimental environment requires only oxygen and nitrogen. It is likely that apart from experimental environment, the nature of the unburned material that has gone through thermal episode, in form of char (whether dense or open), the depth to which the surface flame had sunk as it traversed the wood surface, may help to explain the result [40].

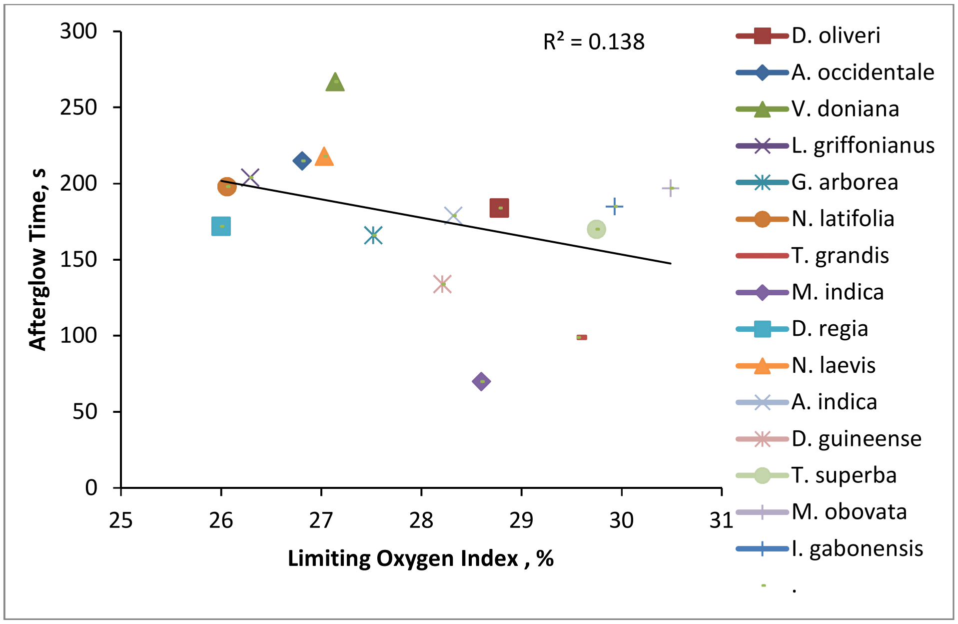

Fig. 27. Afterglow time versus limiting oxygen index

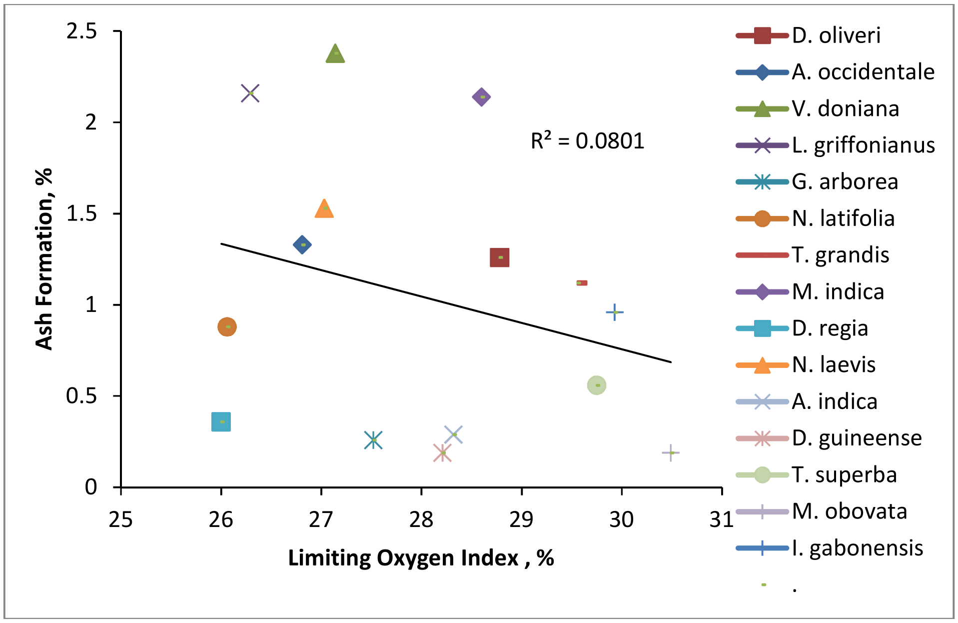

Fig. 28. Ash formation versus limiting oxygen index

4. CONCLUSIONS

For the timbers studied, there are highly significant correlations between wood density and both ignition time and flame propagation rate as well as wood density and limiting oxygen index. There is a strong correlation between ignition time and flame propagation rate, and ignition time and limiting oxygen index. Afterglow time depends on limiting oxygen index and vice versa.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Spurr SH, Barnes BV. Forest-Ecology. 2nd Ed., New York Ronald Press Co. 1973; 570.
2. World First Statistics Report (WFSR). List of fire outbreak in 77 countries. 2001;9: 345-450.
3. Isaac P. Fire outbreak in buildings and non-buildings. Nigeria Security and Civil Defense Corps. 2014;3:124-160.
4. Oscar P. Annual Report on fatal statistics in Lagos State. National Emergency Management Agency (NEMA). 2014;5: 211-230.
5. Olusegun A, Adesokan O. An overview of the number of fires together with an estimation of their societal costs in Lagos State. Ministry of Environment, Health Monitoring Unit. 2014;6:86-98.
6. Olaoye A. Fatal fires and fire death in homes in Lagos State. Lagos State Fire and Safety Services. 2014;2:91-120.
7. Adekunle A, Umanah II, Ibe KE, Imonikosaye MR. Statistical analysis of fire outbreaks in homes and public buildings in Nigeria: A case study of Lagos State. International Journal of Engineering Research and Advanced Technology. 2018;4(8):21-30.
8. Eboatu AN. Fire, flammability and firefighting. Anchor Educational Publishers, Lagos. 1992;1-13.
9. Friquin KL. Material properties and external factors influencing the charring rate of solid wood and glue-laminated timber. Fire Mater. 2011;35(5): 303-327.
10. Inghelbrecht A. Evaluation of the burning behaviour of wood products in the context of structural fire design. MSc., The University of Queensland, Ghent University; 2014.
11. Drysdale D. An introduction to fire dynamics. Wiley, Hoboken; 2011.
12. Bartlett AI, Hadden RM, Bisby LA. A review of factors affecting the burning behavior of wood for application to tall timber construction. Fire Technology. 2019;55:1-49.
13. Grassier N, Scott G. Polymer degradation and stabilization. Cambridge University, England. 1981;257-260.
14. McPherson G, Wade E, Philips CB. Glossary of wildland fire management terms. In: Bethesda, MD: Society of American Foresters. USA. 1990;409.
15. Johnson EA, Van-Wagner CE. The theory and use of two fire history models. Canadian Journal of Forest Research. 1985;15:214-220.
16. Rowe JS. Concepts of fire effects on plant individuals and species. The role of fire in Northern Circumpolar ecosystems. John Wiley & Sons, New York. 1983; 135-154.
17. Levitt J. Responses of plants to environmental stresses: Chilling, freezing and temperature stresses. 2nd Ed., Academic Press, New York. 1980;1:497.
18. Eboatu AN, Amanfo I, Akpabio IO. Effect of flame-retardant treatment on the mechanical properties of some tropical timbers. Journal of Applied Polymer Science. 1992;44:239-242.
19. Eboatu AN, Alhaji SM, Okoye PAC. Studies on fire tolerant timbers of Sudan Savannah. Journal of Thermal Analysis. 1995;5:207-211.
20. Eboatu AN, Ezike E, Igbelina E. The combination effects of known flame retardant compounds of the thermal behaviour of a timber Sample. Journal of Science, Engineering and Technology. 1985;2:267-273.
21. Eboatu AN, Horrocks AR, Kolawole EG. Thermogravimetric studies of the pyrolytic behaviour in air of selected tropical timbers. Fire and Materials. 1996;20: 173-181.
22. McCrum G, Buckley CP, Buckenals CB. Principles of polymer engineering 2nd Ed., Lukeman Press, New York. 2001;366-367.
23. Cavdar AD. Effects of various wood preservatives on limiting oxygen index levels of fire wood. Measurement. 2014; 50(1):279-284.
24. Okoye NH, Eboatu AN, Arinze RU, Ogbonna OA. Effect of density on flame characteristics of some tropical timbers. IOSR J. Appl. Chem. 2014;1:104-111.
25. Ikeagwu KI. Groundwork of research methods and procedures. Institute of Development Studies, University of Nigeria, Enugu Campus; 1971.
26. Obasi N. Research methodology in political science. Academic Publishing Company. Enugu, Nigeria; 1999.
27. Gupta SC. Fundamentals of statistics. Himalaya Publishing House, Delhi, Mumbia; 2011.

28. Momoh M, Eboatu AN, Horrocks AR. Flammability of tropical woods–1-investigations of the burning parameters. Journal of Polymer Degradation and Stability. 1990;48:273-279.
29. ASTM E84-Standard test method for Surface burning characteristics and building material. American Society for Testing Materials. Philadelphia, PA.
30. Traux TR. Making wood fire retardant. Forest Service, U.S. Department of Agriculture, Forest Products Laboratory. 1950;1-8.
31. Eboatu AN, Garba B. Effect of flame retardant on the thermal behaviour of some tropical timbers. J. Appl. Polym. Sci. 1990;39:109-228.
32. White RH. Oxygen index evaluation of fire-retardant treated wood. Wood Science. 1979;12(2):113-121.
33. Zhang D. A coefficient of determination for generalized linear models. The American Statistician. 2017;71(4):310-316.
34. Okafor VN. Flammability studies of some potential fire tolerant trees of South- East, Nigeria. MSc Thesis. Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka; 2010.
35. Horrocks AR. An Introduction to the burning behaviour of cellulosic fibres. Journal of the Society of Dyers and Colourists. 1983;99(7-8):191-197.
36. Eboatu AN, Atline AM. Studies on the thermal characteristics of some tropical woods. Journal of Renewable Energy. 1991;2(1):49-53.
37. Price D, Horrocks AR, Tuner M. Flame retardants for cellulosic materials. Chemistry in Britain. 1987;235.
38. Sidletskiy O, Vedda A, Fasoli M, Neicheva S, Gektin A. Crystal composition and afterglow in mixed silicates: The role of melting temperature. Phys. Rev. Applied. 2015;4:1-37.
39. Kumar A, T'ien JS. Numerical modeling of limiting oxygen apparatus for film type fuels. International Journal of Spray and Combustion Dynamics. 2012;4(4): 299-232.
40. Shen D, Gu S. The mechanism for thermal decomposition of cellulose and its main products. Bioresour Technol. 2009; 100(24):6496-6504.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/56795