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The Use of Wood Composites as Building Materials for Sustainable Development

[1]Adefisan, Olufemi Oluseye, [2] Mosuro, Tolulope & [3]Obakin, Olufunmilola Adetayo

Abstract

The escalating environmental and human impact of indiscriminate wood waste disposal from the wood industry necessitates sustainable solutions. This study explores the utilization of wood cement composites as building materials to address this issue. Recycling wood waste into value-added composites offers the potential to alleviate pressure on diminishing forest resources, mitigate environmental pollution, and foster economic growth. The production of environmentally friendly wood composites for low-cost building components is investigated, emphasizing their applications in housing infrastructure, interior decoration, furniture manufacturing, and industrial needs. However, the challenge lies in the substantial binder requirement, constituting a significant portion of manufacturing costs. To address this, various binders, both organic and inorganic, have been employed, with a focus on reducing the use of formaldehyde due to its hazardous nature. This study particularly explores the incorporation of polystyrene-based resin as an alternative binder, derived from discarded polystyrene packaging materials, aiming to enhance composite properties while reducing toxic emissions. The research examines the strength and sorption properties of wood composites from specific Nigerian wood species, namely Albizia zygia and Cordia millenii, comparing conventional water-based resin and polystyrene as bonding agents. Results indicate distinctive characteristics in composites bonded with polystyrene, suggesting improved interfacial bonding and potential benefits in terms of strength and moisture resistance.

Keywords
Wood composites, Recycling wood waste, Polystyrene-based resin, Sustainable building materials, Environmental impact

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Contact
Olufunmilola Adetayo Obakin
morenifunmi@gmail.com

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1. Introduction

The indiscriminate disposal of vast quantities of wood waste from the wood industry poses severe environmental and human health risks, including air and water pollution, respiratory issues, and climate change (Akhator et al., 2017). Recycling these wood wastes into value-added composites is proposed as a solution to alleviate pressure on Nigeria's depleting forest resources, reduce environmental pollution, and stimulate economic growth (Sambe et al., 2021). Researchers, such as Abdulkareem et al. (2017) and Abdulkareem and Adeniyi (2017), advocate for environmentally friendly wood composites, emphasizing their potential as low-cost building components for various applications.

However, the production of high-quality wood composites requires a substantial amount of binder, constituting approximately 32% of total manufacturing costs (Lam et al., 2021). To address this, different organic and inorganic binders, including hazardous ones like formaldehyde, have been used (Lam et al., 2021). Formaldehyde's adverse health effects, such as skin infections and asthma attacks, have led to the exploration of alternative binders to reduce carcinogenic emissions (Lam et al., 2021). One such alternative is the incorporation of polystyrene-based resin, derived from discarded polystyrene packaging materials, which has shown promise in reducing emissions, lowering moisture uptake, and enhancing mechanical properties in composite production (Osemeahon and Dimas, 2014).

The production of polystyrene-based composites is seen as a sustainable approach to mitigate environmental issues associated with

[1&2]*Department of Wood Products Engineering, Faculty of Technology, University of Ibadan, Nigeria*
[3]*Department of Architecture, University of Ibadan, Nigeria*

improper disposal of wood waste and polystyrene. This approach holds the potential for creating low-cost insulating composites that can be integrated into interior building components to address housing needs in Nigeria, Adefisan, (2018). Despite this, there is a lack of literature on the impact of polystyrene-based resins on the properties of composites made from Nigerian wood species. This study focuses on investigating the strength and sorption properties of wood composites from Albizia zygia and Cordia millenii, comparing the commonly used water-based resin with polystyrene as bonding agents.

2. Methodology

Collection of Raw Materials: Particles derived from Albizia zygia and Cordia millenii woods were sourced from a local mill in Ibadan, Oyo state. Molten polystyrene (PS) was procured locally within the Ibadan metropolis.

Preparation of Wood Particles: The collected wood particles underwent an air-drying process for 14 days, achieving a moisture content of approximately 10% before being used in board formation.

Particle Characterization:

Sieve Analyses: Sieve analyses of the wood particles were performed following the procedures outlined by Olorunnisola et al. (2005). Standard sieves with apertures of 0.04, 0.60, 0.85, 1.20, 2.40, 3.35, and 4.75mm were employed.

Bulk Density Determination: The loose bulk densities of the wood particles were determined in adherence to the specifications outlined in BS 3797 (1990).

Ash Content Determination: The ash content was determined gravimetrically. Wood samples were subjected to a temperature of 600°C for 16 hours in a furnace.

Experimental Replicates: All analyses and experiments were conducted in triplicate to ensure reliability and consistency in the obtained results.

Board Formation: Wood species particles were combined with molten polystyrene slurries in ratios of 2:1 and 3:1, then shaped into a mat using a wooden deckle measuring 30 x 30 x 10 cm^3. The mat underwent cold pressing at 3 MPa for 30 minutes and was conditioned in a room at (25 ± 2°) temperature and 72% relative humidity for 14 days. This procedure was replicated for boards formed with a conventional water-soluble adhesive, serving as a comparative element from the wood industry.

Fourier Transform Infrared Radioscopy (FTIR) of the Polystyrene Glue: The functional groups of the composites were identified using a Fourier transform infrared (FTIR) machine (PerkinElmer FT-IR system spectrum BX), following the methodology outlined by Fabiyi et al. (2010). Dried samples (2 mg) were homogenized with 200 mg of Potassium bromated (KBR) salt. Pelletized discs were formed using a hydraulic press and analyzed in the FTIR machine, with the spectrum derived from an average of 64 scans at a resolution of 4 cm^{-1}.

Tests:

Physical Property and Flexural Test: De-moulded boards were cut into sample sizes adhering to the American Society for Testing and Materials (ASTM) standard D1037-96, and the composites' densities were determined. A 600kN Okhard Universal Testing Machine (UTM) conducted the flexural test at a crosshead speed of 2 mm/min, yielding mechanical properties such as moduli of rupture (MOR) and elasticity (MOE).

Water Absorption (WA) and Thickness Swelling (TS) Tests: Samples of A. zygia and C. millenii composites (five replicates) were initially weighed, soaked in water at room temperature for 61 days, and periodically measured following the procedures adopted by Fabiyi et al. (2010). Water absorption (WA) and thickness swelling (TS) of the wood species were determined based on initial weights and thicknesses.

Statistical Analysis: Data from the flexural and sorption tests underwent analysis of variance (ANOVA) at $P \leq 0.05$. Significant means were differentiated using Duncan's Multiple Range Test.

3. Results and Discussion

Particle Characterization: Sieve Analyses, Bulk Densities, and Ash Contents: The results of the sieve analyses conducted on particles of Albizia zygia (A. zygia) and Cordia millenii (C. millenii) are presented in Tables 1 and 2. Notably, 60% of the porous A. zygia particles were retained on the 0.85mm sieve, while 61% of C. millenii particles were retained on the 0.60mm sieve (Table 2). This outcome suggests that A. zygia possesses relatively larger-sized particles compared to C. millenii.

The bulk densities of A. zygia and C. millenii particles were measured at 0.13 and 0.15 g/cm³, respectively. These values align closely with the 0.15 g/cm³ reported for Cissus populnea but are lower than those recorded for coir (1.15 g/cm³) and sisal fibers (1.45 g/cm³) (Amoo et al., 2016). The obtained low bulk density in this study raises concerns about potential adverse effects on the flexural and sorption properties of the resulting composites. The higher bulk density observed for C. millenii may be attributed to a prevalence of smaller-sized particles.

In terms of ash content, A. zygia and C. millenii particles exhibited respective values of 2.3% and 2.1%. These figures are consistent with the 0.9–3.4% range reported by Adefisan and McDonald (2017) for Mahogany and Teak woods. The relatively higher ash content in A. zygia compared to C. millenii suggests a higher inherent presence of inorganic materials in the former.

Table 1: Sieve Analysis of *A. zygia* Particles

Sieve Aperture (mm)	Retained particle (%)	Passing Particle (%)	Cumulative Particles Retained (%)
4.76	0	100	0
3.35	1	99	1
2.40	26.5	72.5	27.5
1.20	12.5	60	40
0.85	28.5	31.5	68.5
0.60	2.5	29	71
0.04	26	3	97
Pan	3	0	100

Table 2: Sieve Analysis of C. millenii Particles

Sieve Aperture (mm)	Retained Particles (%)	Passing Particles (%)	Cumulative Particles Retained (%)
4.76	0	100	0
3.35	1	99	1
2.40	5.5	93.5	6.5
1.20	11	82.5	17.5
0.85	22	60.5	39.5
0.60	3	57.5	42.5
0.04	39.5	18	82
Pan	18	0	100

Fourier Transform Infrared Radioscopy (FTIR) Analysis of Composite Boards: The outcomes of Fourier Transform Infrared Radioscopy (FTIR) for the wood composites are detailed in Table 3 and illustrated in Figures 1 and 2.

Table 3:Infrared Bands of the A. zygia and C. millenii Composites

S/N	Wave No. (cm^{-1})	Peak Assignment
1	3422-3437	O-H stretching Vibration
2	3028-3067	Aromatic C-H stretching vibration
3	2921-2927	C-H Aliphatic stretching vibration
4	1603-1606	Aromatic C=C stretching vibration
5	1444-1448	C-C bending vibration
6	1030	C-O stretching vibration
7	689-754	Aromatic C-H stretching vibration

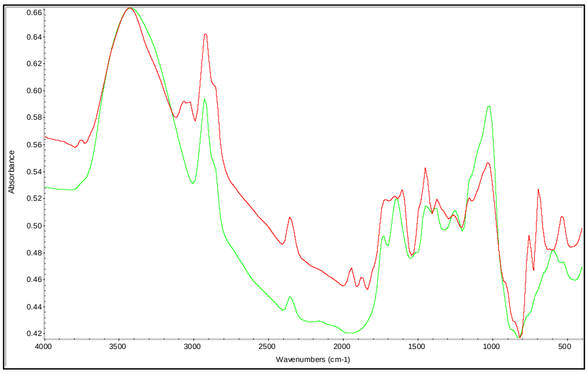

Figure 1: Infrared Spectra of Polystyrene and Water Based Adhesive bonded A. zygia Composites

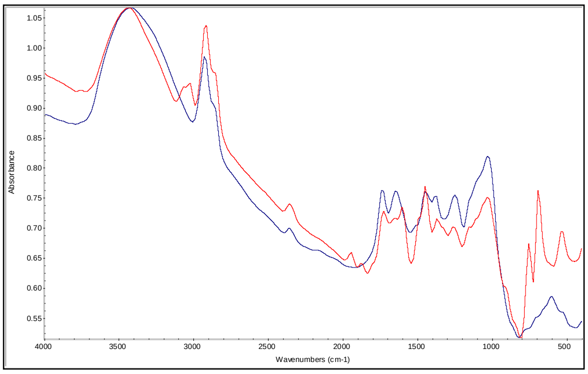

Figure 2: Infrared Spectra of Polystyrene and Water Based Adhesive bonded C. millenii Composites

The infrared spectrum of the polystyrene composites revealed absorption bands at 3431 and 3436 cm^{-1}, corresponding to O-H stretching vibration, indicating the adhesive's capacity to form bonds with other substances. Notably, the aromatic C-H stretching vibration, occurring at 3069.87 cm^{-1} and 3027.53 cm^{-1}, is associated with potential enhancements in strength and abrasion properties. Additionally, the saturated C-H vibration appeared at 2923.27 cm^{-1} and 2921.62 cm^{-1}, while the bands at 1656 and 1653 cm^{-1} corresponded to C=C stretching vibration. Peaks at 1601.91, 1605, and 1448.46 cm^{-1} were assigned to C=C stretching of the phenyl group, and the C-H deformation vibration of the benzene ring hydrogen occurred at 754.4 cm^{-1}, with ring deformation observed at 689.92 cm^{-1} (Osemeahon and Dimas, 2014).

Comparatively, composites bonded with water-soluble adhesive exhibited similar trends with absorption bands at 3425 and 3423 cm^{-1}. A notable distinction between polystyrene composites and those bonded with water-based adhesive lies in the absence of absorption bands at 3000-3100 cm^{-1}, representing aromatic C-H stretching vibration crucial for strength and abrasion properties. The prevalence of aromatic compounds in polystyrene-based composites implies potentially superior interfacial bonding compared to those bonded with water-soluble adhesives. These components are likely contributors to enhanced strength and reduced moisture ingress observed in polystyrene-based composites when compared to their water-based adhesive counterparts.

Physical and Flexural Properties of Wood-Polystyrene Composites: Table 4 presents the densities of the wood composites, showcasing values ranging from 468 to 627.8 kg/m^3 for Albizia zygia (A. zygia) composites and 437.0 to 749 kg/m^3 for Cordia millenii (C. millenii) composites. These densities align favorably with Adefisan's findings (2018). The obtained medium densities indicate that the composites are unsuitable for structural (load-bearing) applications.

Table 4: Physical and Flexural Properties of A. zygia and C. millenii Composites

Mixing Ratio	Density (kg/m^3)	MOR (N/mm^2)	MOE (N/mm^2)
***A. zygia* Composites Bonded with water-based Adhesive**			
2:1	468.7^d	2.5^d	611.1^c
3:1	620.6^b	5.2b^c	1297.5^c
Polystyrene-based *A. zygia* Composites			
2:1	493.9^{cd}	5.2b^c	4878.3^b
3:1	627.8^b	7.4^a	7740.7^a
***C. millenii* Composites bonded with water-based Adhesive**			
2:1	437.0^d	1.9^d	1217.5^c
3:1	623.0^b	5.8^b	1527.0^c
Polystyrene-based *C. millenii* Composites			
2:1	512.3^c	4.2^c	6437.9^a
3:1	749.3^a	5.4^{bc}	7924.4^a

(Means with the same letters and columns are not statistically different. Significant at 5% Level of probability)

Higher mixing ratios and the use of polystyrene as a binder led to increased densities, suggesting enhanced interfacial bonding, potentially due to the prevalence of aromatic compounds in polystyrene. C. millenii composites exhibited higher densities than A. zygia, attributed to smaller-sized particles and higher bulk density. Statistical analysis (Duncan's range test) confirmed significant effects of mixing ratios and glue types ($P < 0.05$) on densities, while wood species did not influence this parameter (Table 5).

Table 5: Duncan's Multiple Test of the Effects of Species, Mixing Ratios and Glue Types on the Physical and Flexural Properties of A. zygia and C. millenii Composites

Variables	Density (kg/m^3)	MOR (N/mm^2)	MOE (N/mm^2)
Species			
A. zygia	548.6^a	5.0^a	3630.9^a
C. millenii	579.8^a	4.2^a	4266.7^a
Mixing Ratio			
2:1	476.7^b	3.3^b	3276.2^b
3:1	651.8^a	6.2^a	4612.4^a
Glue Type			
Water Based	528.5^b	3.6^b	1153.3^b
Polystyrene Based	600.0^a	5.4^a	6735.3^a

(Means with the same letters and columns are not statistically different. Significant at 5% Level of probability)

The Modulus of Ruptures (MORs) for A. zygia and C. millenii composites ranged from 2.5 to 7.4 N/mm^2 and 1.9 to 5.8 N/mm^2, respectively (Table 4). These values fall below the recommended range of 15.1 to 24.1 N/mm^2 by the Forest Product Laboratory (FPL) and the range of 14.5 to 32.0 N/mm^2 reported by Kosonen et al. (2000) and Voulgardis et al. (2003). However, they align with Adefisan's (2018) findings. Modulus of Elasticities (MOEs) ranged from 611.1 to 7740.7 N/mm^2 for A. zygia and 1217.5 to 7924.4 N/mm^2 for C. millenii, comparable with the FPL's recommended range (2800–4100 N/mm^2) and Adefisan's results. The low MORs suggest the composites are unsuitable for structural applications, indicating potential use as insulating components like panels and ceiling boards. The observed low MORs may be attributed to moderate density profiles and low bulk densities of the wood particles.

A. zygia composites exhibited higher MORs but lower MOEs compared to C. millenii, possibly due to differences in wood structural integrity and particle size distribution. A. zygia, belonging to a higher strength group (N_3), yielded composites with higher strength than those from C. millenii (N_6 strength group). Higher densities increased mixing ratios, and the use of polystyrene as a binder correlated with higher MORs and MOEs compared to water-based adhesive-bonded composites. Statistical analyses (Duncan's) confirmed significant influences ($P < 0.05$) of mixing ratios and glue types on MORs and MOEs, with no notable effect from wood species (Table 5).

Water Absorption (WA) and Thickness Swelling (TS) Analysis: The water absorption (WA) and thickness swelling (TS) characteristics of composites fabricated from Albizia zygia (A. zygia) and Cordia millenii (C. millenii) were examined and are presented in Table 6 and Figure 3.

Table 6: Water Absorption and Thickness Swelling of A. zygia and C. millenii Composites

Mixing Ratio	Water Absorption		Thickness Swelling	
	1 Day	**61 Days**	**1 Day**	**61 Days**
***A. zygia* Composites Bonded with water-based Adhesive**				
2:1	80.1^{e}	121.0^{b}	3.0^{d}	7.9^{ab}
3:1	51.8^{g}	91.2^{cd}	3.9^{dc}	7.7^{ab}
Polystyrene-based *A. zygia* Composites				
2:1	56.4^{fg}	85.9^{de}	2.8^{d}	6.3^{abc}
3:1	33.8^{h}	60.5^{fg}	2.0^{d}	4.9^{bdc}
***C. millenii* Composites Bonded with water-based Adhesive**				
2:1	100.4^{c}	134.9^{a}	4.8^{bdc}	9.0^{a}
3:1	26.8^{h}	79.9^{e}	3.2^{d}	7.4^{ab}
Polystyrene-based *C. millenii* Composites				
2:1	32.7^{h}	85.2^{de}	2.9^{d}	7.6^{ab}
3:1	26.1^{h}	56.4^{fg}	2.4^{d}	7.3^{ab}

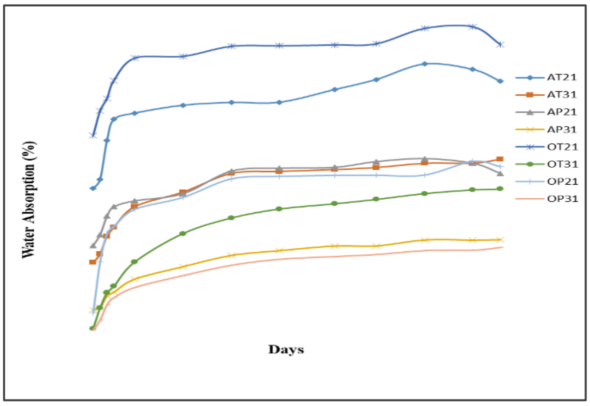

Figure 3: Water Absorption of A. zygia and C. millenii Composites

Table 6 indicates that the fabricated composites exhibit limited dimensional stability, suggesting suitability only for indoor applications. Composites bonded with higher mixing ratios of polystyrene generally displayed lower WA and TS, indicating improved interfacial bonding attributed to the prevalence of aromatic compounds in the polystyrene boards. Figure 3 illustrates the WA reaching a pseudo-equilibrium state, with values ranging from 33.8% to 121.0% for A. zygia and 26.1% to 134.9% for C. millenii composites. The corresponding TS values varied between 2.0% and 7.9% for A. zygia and 2.4% and 9.0% for C. millenii. These results, when compared with Voulgaris et al. (2003) (WA: 11.4% - 93.2% for 2 – 24 hours, TS: 2.1% – 17.0%) and Adefisan (2018) (WA: 2.2% – 140%, TS: 0.5% – 7.1% for 2 -72 hours), demonstrate favorable similarities. Statistical analyses, specifically Duncan's test highlighted significant ($P < 0.05$) influences of mixing ratios, glue type, and wood species on the WA of the composites. Similarly, the TS of the fabricated boards was significantly affected by mixing ratios and glue type, except for the wood species. Notably, composites from C. millenii exhibited significantly lower WA and higher TS, potentially attributable to differences in bulk density, ash content, and particle size distribution

4. Conclusion

The study systematically investigates the utilization of wood composites, focusing on Albizia zygia (A. zygia) and Cordia millenii (C. millenii) particles. Particle characterization reveals distinct size distributions, with A. zygia having larger particles. Concerns arise regarding bulk densities and potential impacts on flexural and sorption properties, especially with A. zygia having lower bulk density. Ash content analysis indicates variations, with A. zygia exhibiting higher ash content. Fourier Transform Infrared Radioscopy (FTIR) analysis of wood composites, particularly those bonded with polystyrene, suggests superior interfacial bonding, contributing to enhanced strength and reduced moisture ingress. Physical and flexural properties show suitability for insulating components rather than structural applications. Water absorption (WA) and thickness swelling (TS) analyses highlight limited dimensional stability, suitable only for indoor applications. Higher polystyrene ratios improve interfacial bonding, leading to lower WA and TS. Statistical analyses confirm significant influences of mixing ratios, glue types, and wood species. The study provides valuable insights into wood cement composites, emphasizing material characterization and binder choice for desired performance. Further research is suggested to explore optimization strategies for specific applications

References

Abdulkareem, S., Raji, S. and Adeniyi, A. (2017). Development of Particleboard from Waste Styrofoam and Sawdust. Nigerian Journal of Technological Development, 14, 18-22. https://doi.org/10.4314/njtd.v14i1.3.

Abdulkareem, S.A. and Adeniyi, A.G. (2017). Production of Particle Boards Using Polystyrene and Bamboo Wastes. Nigerian Journal of Technology, 36, 788-793. https://doi.org/10.4314/njt.v36i3.18.

Adefisan, Olufemi & Mcdonald, Armando. (2017). Evaluation of Wood Plastic Composites Produced from Mahogany and Teak. International Journal of Advanced Engineering Research and Science. 4. 27-32. 10.22161/ijaers.4.12.5.

Akhator, P., Obanor, A. and Ugege, A. (2017) Nigerian Wood Waste: A Potential Resource for Economic Development. *Journal of Applied Sciences and Environmental Management*, 21, 246-251. https://doi.org/10.4314/jasem.v21i2.4.

Amoo K., Adefisan O. O., A. O. Olorunnisola. (2016). Development and Evaluation of Cement-Bonded Composite Tiles Reinforced with Cissus populnea Fibres. International Journal of Composite Materials 2016, 6(4): 133-139. 10.5923/j.cmaterials.20160604.06.

ASTM D1037-99. Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials.

BS 3797:1990. Lightweight aggregates for masonry units and structural concrete.

Elijah Adesanya ADEFISAN & Sani AHMAD. (2018). Assessment of Heat Wave Events in a Changing Climate Over Nigeria. International Journal of Research Science and Management, 5(8), 115–133. Retrieved from http://ijrsm.com/index.php/journal-ijrsm/article/view/352.

James S. Fabiyi, Armando G. McDonald (2010). Effect of wood species on property and weathering performance of wood plastic composites, Composites Part A: Applied Science and Manufacturing, Volume 41, Issue 10, Pages 1434-1440, https://doi.org/10.1016/j.compositesa.2010.06.004.

Lam J, Koustas E, Sutton P, Padula AM, Cabana MD, et al. (2021). Exposure to formaldehyde and asthma outcomes: A systematic review, meta-analysis, and economic assessment. PLOS ONE 16(3): e0248258. https://doi.org/10.1371/journal.pone.0248258.

Olorunnisola, Abel. (2005). Dimensional stability of cement-bonded composite boards made from rattan cane particles. Journal of Bamboo and Rattan. 4. 173-182. 10.1163/1569159054699308.

Osemeahon, S. A., & Dimas, B. J. (2014). Development of urea formaldehyde and polystyrene waste as copolymer binder for emulsion paint formulation. Journal of Toxicology and Environmental Health Sciences, 6(3), 75-88.

Sambe, L.N., Origbo, B. Gbande, S., and Ande P.U. (2021). Assessment of Wood Waste Generation and Utilization In Makurdi Metropolis: Implication For Sustainable Management Of Forest Resources. Journal of Research in Forestry, Wildlife & Environment Vol. 13(1). 188-196.

Shivashankar, Vasundara & Johns, Dexton & Maroli, Ramesh & Sekar, Mahalaxmi & Chandrasekaran, Rathinavel & Karthikeyan, Shanmugavel & Renganathan, Senthil Kumar. (2017). Comparison of the Effect of PRP, PRF and Induced Bleeding in the Revascularization of Teeth with Necrotic Pulp and Open Apex: A Triple Blind Randomized Clinical Trial. Journal of Clinical and Diagnostic Research. 11. ZC34-ZC39. 10.7860/JCDR/2017/22352.10056