



ORIGINAL RESEARCH ARTICLE

PHYSICAL PROPERTIES OF GUINEA CORN STALK FIBRE REINFORCED HIGH-DENSITY POLYETHYLENE (HDPE) COMPOSITE FOR THE PRODUCTION OF PARTICLE BOARD

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ABSTRACT

Majority of developing nations view the construction/manufacturing sector as being crucial to their economy. The industry produces panels and boards for furniture, ceilings, panelling, and other wood-based manufactured projects, relying solely on forest resources. This heavy dependence strains forests, contributing to deforestation and causing prolonged damage to ecosystems. A major interest in finding substitute raw materials for the manufacture of boards and panels through the utilization of agricultural waste products, is becoming the direction to scholars. In this study, guinea corn stalk fibre reinforced high density polyethylene (HDPE) composite was developed and analysed for the production of Particle Board. The composites were produced through the process of compounding and compression moulding operation. The HDPE was varied from 100 - 50 Wt % at interval of 10 Wt % while the filler was reversed from 10 - 50 Wt % at interval of 10 Wt %. Five different composites samples were formulated using 250 μm fibre size using HDPE as binder and a 100 % HDPE as control sample. The physical (density, thickness swelling and water absorption) properties of the developed composite were evaluated. The density (ranges from 943.9 kg/m^3 to 1075.5 kg/m^3), thickness swelling (3.13% to 18.75%), and water absorption (0.28% to 2.01%) of all the composites increased with increasing filler loading with highest values obtained at 50 Wt % material loading. All the values are within the minimum requirement stipulated in the European standard EN 312:2010 for general purpose particle boards except for the density which is above the standard. The incorporation of the fillers into the HDPE matrix generally enhanced the physical properties of the matrix. The Guinea Corn Stalk Fibre (GCSF) composite produced with 60 Wt % matrix and 40 Wt % filler is the most suitable for general purpose particle board production as all the physical properties met the required standard stipulated in the European standard EN 312:2010 for general purpose particle board.

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1.0 Introduction

Particle board is a versatile and economical material composed of wood chips, sawdust, and synthetic resins or other binders. Traditionally, its production depends on wood residues from sawmills and wood-processing industries (Yadav, 2021). However, growing concerns about deforestation, waste management, and environmental sustainability have prompted the search for alternative raw materials. One promising option is agricultural waste, which includes residues from crops like rice husks, wheat straw, sugarcane bagasse, and corn stalks (Odeyemi et al., 2020). These are used to reinforce polymeric materials as reviewed by Aji et al. (2009). For example, Charles et al. (2024) used Balanite shell particles and Palmyra fiber to reinforce epoxy for the production of a low to medium load application hybrid material, Aji et al. (2011) used Kenaf and Pineapple Leave fiber to reinforce High Density Polyethylene (HDPE). Agricultural waste, also known as agro-residue, is a byproduct of farming and agricultural processes. These residues are often burned or left to decompose in the fields, causing environmental pollution and greenhouse gas emissions. Using agricultural waste for particle board production offers several advantages: abundant supply, cost-effectiveness, and

environmental benefits. These residues are produced in large quantities worldwide (Lee *et al.*, 2022). Using this biomass can provide a sustainable and renewable raw material source for particle board production. Agricultural waste is typically low-cost because it is a byproduct of existing agricultural activities mostly left behind as waste by farmers and when used by the industries, it can lower the overall production costs compared to traditional wood-based materials. Moreover, using agricultural waste helps to reduce the pressure on our forests, mitigating deforestation and promoting sustainable land use. It also addresses waste management issues by diverting agro-residues from landfills and reducing open burning, which contributes to air pollution (Lee *et al.*, 2022). The majority of developing nations view the construction/manufacturing industries as being crucial to their economy. These industries produce panels and boards for furniture, ceilings, paneling, and other wood-based manufacturing projects exclusively from forest resources (Amenaghawon *et al.*, 2016).

The Nigerian industry has seen progressive expansion in the last few years and in the early 1990s, the demand for wood and wood-derived panels/boards was expected to reach 2.866 million m³ and 0.121 million m³, respectively. However, it was predicted that in the next 20 years these values will rise to 4.704 million m³ and 0.688 million m³, respectively (Atoyebi *et al.*, 2018). A major interest in finding substitute raw materials for the manufacture of boards and panels has arisen from the desire to lessen reliance on wood and forest resources. Researchers have identified some solutions to this problem; among them is the utilization of agricultural waste products, such as sugarcane bagasse, corncob, bamboo, rice husk, sunflower stalk, cashew shells, banana leaves, etc as an alternative (Atoyebi *et al.*, 2020) Most of these agricultural wastes are left on the farm following the harvest of the intended crops. In most underdeveloped and developing countries such as Nigeria, these wastes have very little reuse potential and they are mostly disposed of inappropriately or openly burnt (Atoyebi *et al.*, 2020).

Utilization of agricultural waste present prospective benefits both environmentally as well as economically. They are affordable, abundantly available, and resource-oriented when handled judiciously and the environmental problems associated with inappropriate disposal are minimized or eliminated (Amenaghawon *et al.*, 2013). Bio-materials have more advantages over their synthetic counterparts: low cost, high toughness, low density, good specific strength properties, good processability, and biodegradability (Seth *et al.*, 2018). This study, therefore, developed particle board from composite of guinea corns stalk fibre and HDPE.

2. Materials and Methods

2.1 Materials

The materials used in this work were:

- i. Guinea corn stalk fibre
- ii. High Density Polyethylene (HDPE) injectable grade

Dried guinea corn stalk and HDPE were employed in this study. The dried guinea corn stalk was obtained from farms within Maiduguri Metropolitan Council, Borno state while the HDPE was obtained from Hafson Chemicals and Scientific Equipment Ltd, Zaria, Kaduna State - Nigeria.

2.2 Equipment

The equipment used in this study are presented in table 1:

Table 1: List of Equipment Used

S/N	Equipment	Model Number	Use/Function
1	Milling machine	Model No 150	Milling the materials into smaller fibres/particles
2	Electrical standard sieve Machine	Model D210	Sieving the materials
3	Digital Weighing Balance	Model	Weighing the materials and samples
4	Two-roll mill machine	Model: 5183	Compounding composite into homogenous mix
5	Compression Moulding Machine	Model: 0557	Compressing composite into mould

2.3 Method

This section describes processes and basis of achieving the aim of this work. Seth *et al.*, (2018) deduced that the smaller the particle size the better the properties of the composite because better compaction is achieved and it lessens porosity which permits effective stress transfer between the matrix and the particles. Similar result was reported by Obasi *et al.*, (2021), Hammajam *et al.*, (2014) and Aji *et al.*, (2011) which influence the decision of using 250 μm sizes for the Guinea corn stalk fibre.

2.3.1 Guinea Corn Stalk Fibre (GCSF) Preparation

The guinea corn stalks were sorted out and the leaves were removed from the stalks to obtain clean and leaves free stalks. The guinea corn stalks were then sun dried and cut into smaller pieces between 10 to 30 cm and was further dried for three hours at 70 °C in oven before introducing into the milling machine to mill into fine material. The fine milled material was sieved using an electrical standard sieving machine for 15 minutes to obtain 250 μm fibre size as presented in plate 1.



Plate 1: Guinea Corn Stalk Fibre (after milling)

2.3.2 Formulation of Composite

The HDPE was varied from 100 - 50 Wt % at interval of 10 Wt % i.e. (100 Wt %, 90 Wt %, 80 Wt %, 70 Wt %, 60 Wt % and 50 Wt %) while the GCSF was varied from 10 – 50 Wt % at interval of 10 Wt % i.e. (10 Wt %, 20 Wt %, 30 Wt %, 40 Wt % and 50 Wt %). Five different types of composite samples were formulated and a 100 % HDPE served as controlled sample. 250 μm fibre size in HDPE binder were used. Table 2 presents the composition of the composite.

Table 2: Formulation of Composites

S/N	Designation	Material	Composition
1	S0		HDPE (100 Wt %)
2	GCSF1	Guinea corn stalk + HDPE	HDPE (90 Wt %) + GCSF (10 Wt %)
3	GCSF2	Guinea corn stalk + HDPE	HDPE (80 Wt %) + GCSF (20 Wt %)
4	GCSF3	Guinea corn stalk + HDPE	HDPE (70 Wt %) + GCSF (30 Wt %)
5	GCSF4	Guinea corn stalk + HDPE	HDPE (60 Wt %) + GCSF (40 Wt %)
6	GCSF5	Guinea corn stalk + HDPE	HDPE (50 Wt %) + GCSF (50 Wt %)

2.3.3 Production of Composite

The composite materials were mixed according to the formulation in Table 2 by first introducing the polymer (HDPE) to the two-roll mill to soften for 5 minutes at a temperature of 170 °C to achieve a band and bank formation after which the prepared Guinea corn stalk particles were introduced gradually and allowed to mix

further for 3 minutes to compound into a homogenous mixture. To produce the composite particle boards for test, the compounded mixtures were compressed into a 120 mm × 100 mm × 3.2 mm mould at 150 °C for five minutes under a 2.5 MPa pressure provided by hydraulic hot press (compression moulding machine).



Plate 2: Composite Samples from Guinea Corn Stalk Composite

2.4 Characterization of the Composites

The composites samples produced were subjected to physical test (density, thickness swelling and water absorption test).

2.4.1 Determination of Composite's Density (D)

The density is the quotient of mass and volume of the piece. It is measured in Kg /m³. The basic method of determining the density of board composite samples is by measuring the mass and volume of the sample used. The density of the boards was estimated from equation 1. The test was carried out in accordance with ASTM D1037.

$$D = \frac{M}{V} \quad (1)$$

where: D = density, kg/m³, M = mass of the test specimen, g and V = volume of the test specimen, m³

2.4.2 Thickness Swelling (TS) and Water Absorption (WA) test

The thickness swelling is the ratio of the difference between the thickness of the piece after the water immersion and before the water immersion, to the thickness before the water immersion, it is expressed in percentage. The Specimens prepared for evaluation of the thickness swelling were measured at the middle with a micrometer and immersed into distilled water at room temperature in parallel for 7 days. The thickness was measured again upon removal from the water and cleaning the surface water at an interval of 24 hours to determine the thickness swelling rate using equation 2. The test was carried out in accordance with ASTM D570.

$$Ts = 100 \times \frac{(T - T_0)}{T_0} \quad (2)$$

where: Ts = the thickness swelling rate (%), T₀= the initial thickness, T = the thickness measure after a given immersion time.

The water absorption is the ratio of the difference between the wet piece mass and the dried piece mass before immersion, divided by the dried piece mass before immersion. It is expressed as the percentage of increment with respect to its weight before immersion. To determine the water absorption rate, each sample

piece was weighed with the aid of digital weighing balance before immersion in distilled water at room temperature for 7 days. The samples were weighed upon removal from the water and drying the surface water at interval of 24hrs of immersion for 7 day to determine the water absorption rate. The percentages were determined using equation 3. The test was carried out in accordance with ASTM D570.

$$WA = 100 \times \frac{W - W_0}{W_0} \tag{3}$$

where: WA(t) = the water absorption (%) at time t, W₀ = the initial weight, and W(t) = the weight of the sample at a given immersion time t.

3. Results and Discussion

3.1 Determination of Density

The results obtained for density of GCSF composites presented in Figure 1 reveal that the composite' density increases with increased filler loading as observed by Neher *et al.* (2020).

The densities of the composites at all filler loadings exceed the range of 450–750 kg/m³ specified by the European Standard EN 312:2010 (PI: general-purpose particle boards for use in dry conditions). This suggests that the composite is unsuitable for general-purpose particle boards. However, the higher density may enhance mechanical properties such as stiffness and strength, making the material more suitable for applications that demand denser boards, including flooring systems, wall panels, partitions, and packaging crates.

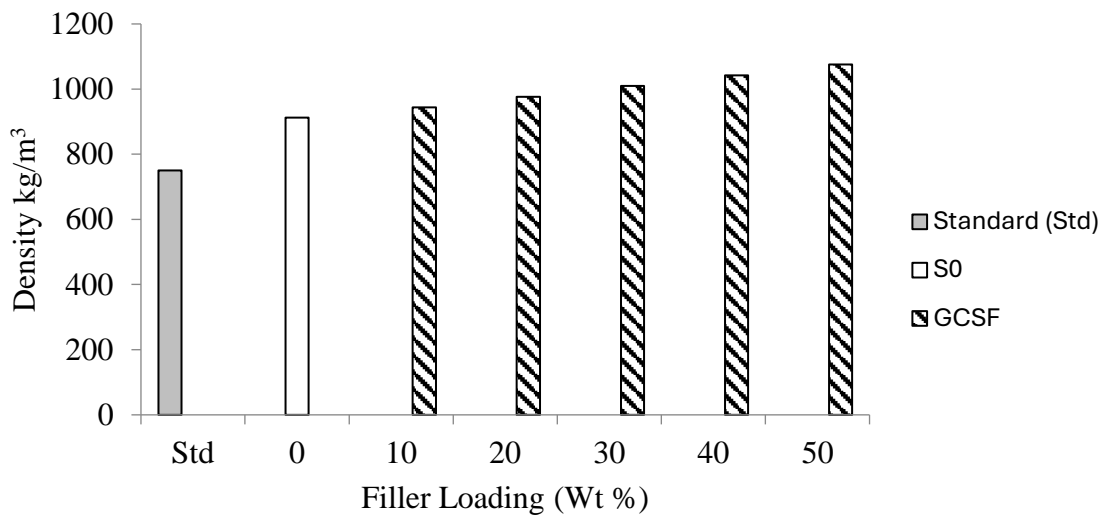


Figure 1: Effect of filler loading on the density of GCSF composites

3.2 Thickness Swelling (TS) and Water Absorption (WA) test

3.2.1 Thickness Swelling (TS)

Figure 2 show that as filler loading increases, the thickness swelling increases. This is because the fillers introduced hydrophilic groups into the polymer matrix, increasing its affinity for water and causing it to absorb more moisture, leading to higher swelling. Kufojiri *et al.*, (2023) also observed that the hydrophilic nature of the filler contributes to increased water absorption in the composites, which could lead to greater thickness swelling as the filler content increases.

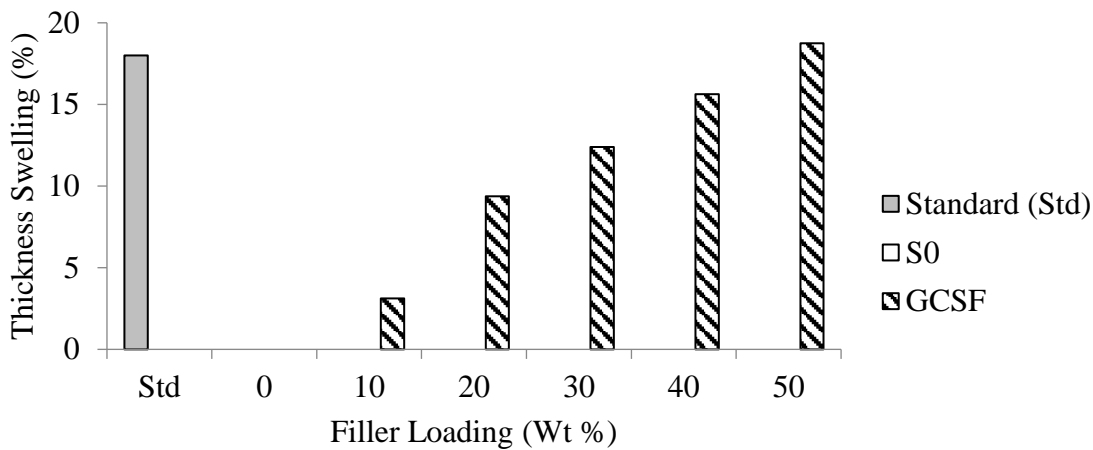


Figure 2: Effect of filler loading on thickness swelling of GCSF composites

The thickness swelling of the composite in all the filler loading are below the 18 % maximum acceptable value stipulated by European standard EN 312:2010 (PI: general purpose particle boards for use in dry condition) except for composite at 50 Wt % filler loading (18.75 %), which is slightly above the acceptable value stipulated. The high thickness swelling of the composite limits its use in applications where thickness swelling resistance is critical. This means that composites made from GCSF have a tendency to swell significantly when exposed to moisture or humidity. As a result, these composites are not suitable for outdoor applications especially where precise dimensions are critical or where the material will be exposed to varying environmental conditions.

3.2.2 Water Absorption (WA) test

The results obtained is presented in figure 3. It demonstrates increase in water absorption with increasing filler loading as observed by (Ferede 2020). This could be attributed to the phenomenon that as the filler loading increases, so does the surface area of the fillers available for water molecules to attach to, leading to increased water absorption.

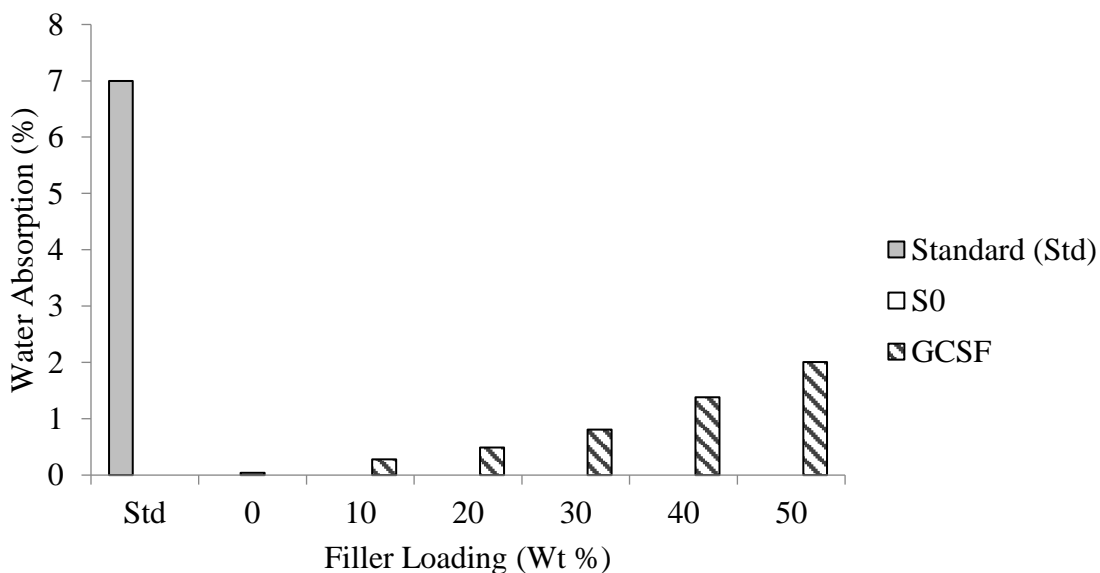


Figure 3: Effect of the filler loading on water absorption of GCSF composite

GCSF are hydrophilic, meaning they have an affinity for water. Their ability to create hydrogen bonds with water molecules is attributed to their hydroxyl groups (OH-) (Neher *et al.*, 2020).

The water absorption of the composite in all filler loading is below the 7 % maximum acceptable value stipulated by European standard EN 312:2010 (PI: general purpose particle boards for use in dry condition).

4. Conclusion

The following conclusions were drawn:

- i. Based on the observed physical properties (density, thickness swelling, and water absorption) of the GCSF composite, the optimum composition (proportion) for the particle board composite is achieved with a 60 Wt % matrix and 40 Wt % filler loading.
- ii. The thickness swelling and water absorption properties of the produced GCSF composite met the minimum requirement of the European standard EN 312:2010 (PI: general purpose particle boards for use in dry conditions). While the obtained density values surpass the acceptable range (750 kg/m³) specified for general-purpose particle boards.
- iii. The formulated composites were characterized in terms of density (ranging from 943.9 kg/m³ to 1075.5 kg/m³, thickness swelling (3.13% to 18.75%), and water absorption (0.28% to 2.01%). The results indicate that incorporating fillers into the HDPE matrix significantly enhanced its physical properties, making it a suitable composite for particle board production.

References

Aji, I.S., Zainudin, E.S., Khalina, A., Sapuan, S.M., and Khairul, M. D. 2011. Studying the effect of fiber size and fiber loading on the mechanical properties of hybridized kenaf/PALF-reinforced HDPE composite. *Journal of Reinforced Plastics and Composites*, 30(6): 546–553. <https://doi.org/10.1177/0731684411399141>

Aji I.S., Sapuan S.M., Zainudin E.S. and Abdan K. 2009. Kenaf fibres as Reinforcement for Polymeric Composites; A review; *International Journal of Mechanical and Materials Engineering*, Vol. 4, No. 3, University of Malaya, Selangor, Malaysia

Aji I.S., Zainudin E.S., Khalina A., Sapuan S.M. and Khairul M.D. (2011). Studying the effect of fiber size and Fiber Loading on the Mechanical Properties of Hybridized Kenaf/PALF Reinforced HDPE Composite; *Journal of Reinforced Plastics and Composites*, Vol. 30, Issue 6, March pp. 546 – 553

Amenaghawon, N.A., Aisien, F.A., and Ogbeide, S.E. 2013. Bioethanol production from pretreated cassava bagasse using combined acid and enzymatic hydrolysis. *University Benin J Sci Technol*, 1(2): 48–53.

Amenaghawon, A., Osayuki-Aguebor, W., and Okieimen, C.O. 2016. Production of particle boards from corn cobs and cassava stalks: Optimisation of mechanical properties using response surface methodology. *Journal of Materials and Environmental Science*, 7, 1236–1244.

Atoyebi, O.D., Awolusi, T.F., and Davies, I.E. 2018. Artificial neural network evaluation of cement-bonded particle board produced from red iron wood (*Lophira alata*) sawdust and palm kernel shell residues. *Case Studies in Construction Materials*, 9, e00185. <https://www.sciencedirect.com/science/article/pii/S2214509518300718>.

Charles D., Aji. I.S. and Mshelia Z.A. 2024. Effect Of Particle and Fiber Loading on Tensile, Flexural and Impact Properties of Hybridized Balanite Shell Particles and Palmyra Fiber Reinforced Epoxy Composite. *Arid Zone Journal of Engineering, Technology and Environment*, 20(4): 891-902

Ferede, E., 2020. Evaluation of Mechanical and Water Absorption Properties of Alkaline-Treated Sawdust-Reinforced Polypropylene Composite. *Journal of Engineering*, 2020(1): 3706176. <https://doi.org/10.1155/2020/3706176>.

Hammajam, A.A., Ismarrubie, Z.N., and Sapuan, S. M. 2014. Effect of fiber loading on the mechanical properties of millet husk filled high density polyethylene composites. *Applied Mechanics and Materials*, 564: 350–354. <https://www.scientific.net/AMM.564.350>.

Kuforiji, C., Durowaye, S., Kassim, K. and Lawal, G., 2023. Influence of sawdust particles reinforcement on physical and mechanical properties of High-Density Polyethylene (HDPE) matrix composites. *Kathmandu University Journal of Science, Engineering and Technology*, 17(1). <https://doi.org/10.3126/kuset.v17i1.62382>.

Lee, S.H., Lum, W.C., Boon, J.G., Kristak, L., Antov, P., Peđzik, M., Rogoziński, T., Taghiyari, H.R., Lubis, M.A.R., Fatriasari, W. and Yadav, S.M., 2022. Particleboard from agricultural biomass and recycled wood waste: A review. *Journal of Materials Research and Technology*, 20: 4630-4658. <https://doi.org/10.1016/j.jmrt.2022.08.166>.

Neher, B., Hos sain, R., Fatima, K., Gafur, M.A., Hossain, Md.A. and Ahmed, F. 2020. Study of the Physical, Mechanical and Thermal Properties of Banana Fiber Reinforced HDPE Composites. *Materials Sciences and Applications*, 11: 245-262. <https://doi.org/10.4236/msa.2020.114017>

Obasi, H.C., Mark, U.C., and Mark, U. 2021. Improving the mechanical properties of polypropylene composites with coconut shell particles. *Composites and Advanced Materials*, 30, 263498332110074. <https://doi.org/10.1177/26349833211007497>.

Odeyemi, S.O., Abdulwahab, R., Adeniyi, A.G. and Atoyebi, O.D., 2020. Physical and mechanical properties of cement-bonded particle board produced from African balsam tree (*Populous Balsamifera*) and periwinkle shell residues. *Results in Engineering*, 6: 100126. <https://doi.org/10.1016/j.rineng.2020.100126>.

Seth, S.A., Aji, I.S., and Tokan, A. 2018. Effects of particle size and loading on tensile and flexural properties of polypropylene reinforced doum palm shell particles composites. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, 14(1): 231–239. <https://core.ac.uk/download/pdf/235050632.pdf>.

Yadav, R. 2021. Development of low formaldehyde emitting particle board by nano particle reinforcement. *Journal of Applied and Natural Science*, 13(4): 1187 - 1197. <https://doi.org/10.31018/jans.v13i4.2959>