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Impact of Reinforcement on Environmentally Green Bio-Composites of HDPE/Mixed Agro-Waste: Via Mechanical, Surface Morphology, Water Absorption, and Biodegradable Properties

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ABSTRACT

Wastes like cow pea husk, rice husk, bread fruit husk, peanut husk, sugarcane bagasse, corn cobs, and the rest, emanating from agricultural produce are naturally very vital materials. They could be used as replacement of wood flour/wood fiber. Because of the inadequate resources in forest and enhanced pollution in the environment, utilization of fillers is very paramount. This research work intends to assess the impact of mixing sugarcane bagasse with corn cob in the proportion of 50:50 as hybrid fillers on the morphological and mechanical features of high-density polyethylene composites. The work also determined their biodegradability and water absorption rate. The resulting mixture were again mixed vigorously with the HDPE resins in varying amount such as 0, 5, 10, 15, and 20%. The composites were fabricated with the aid of a molding technique called injection. Based on the reported data, the mechanical property test showed reduction in percentage elongation and tensile stress at the break. The results showed raise in compressive strength, shear modulus, and hardness of the developed bio-composition. Since the fillers exhibits better dispersive ability in the polymer matrix, the morphological features assessment showed a very good interfacial bond and adhesion between the polymer matrix and the fillers. After burying the composite for a period of 90-days, the results of biodegradation showed a decrease in composite's mass, confirming that the composite is friendlier ecologically. The water absorption results showed that, there was no any noticed enlargement in the mass of the composite when immersed in water, suggesting that, the composite materials can be utilized in a moist condition.

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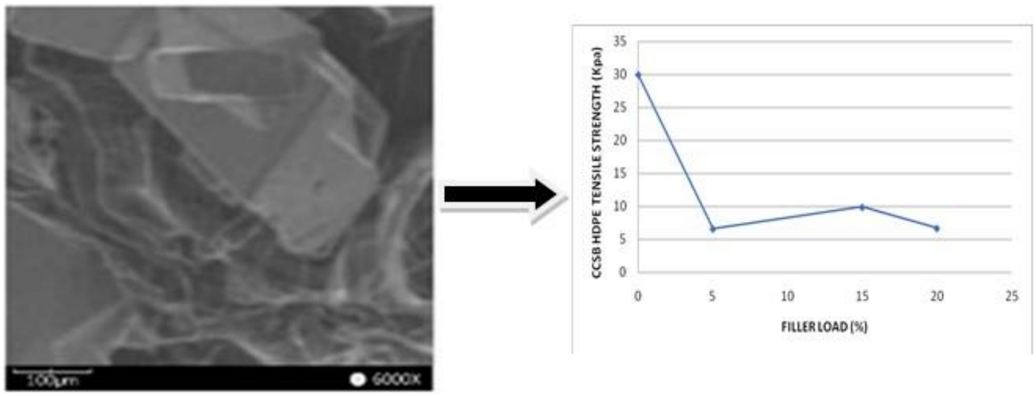
Graphical Abstract



Introduction

More qualitative materials that are gotten from the combination of two or more materials of less quality are termed as composite materials [1-3]. Because of the persistence of plastic wastes in the environment, its health and environmental implications are pervasive. They often pileup landfills and are most times located as micro plastics in the water bodies, causing a serious health implication, particularly in the marine biodiversity. Even though, current researchers are making efforts to create a long-lasting substitute to harmful artificial fibers as a support to polymer composite materials. Fibers like sugarcane bagasse and corn cobs which are naturally found in the environment are mostly suggested for long-term support because of their distinct qualities which suite wider range of applications [4-8].

For physical modification of polymers, natural fibers are utilized to develop composites that have improved qualities such as degradations and strength. There is a substantial implication on the properties of fabricated composite materials as a result of the interactions which exist between the particles of the fillers and the polymer matrix. In the crystalline phases of polymers in some situations, powdered fillers may serve as heterogeneous nucleates, particularly at lower concentration [9-14].

Some factor like properties exhibited by fillers within the composite, interfacial bond, and interaction among the polymer matrix and the fillers, and the utilized type of fillers might alter the polymer composite's properties [15-19].

Composites strength can be improved by effective dispersion of fillers within the microstructure of the fillers. This effective dispersion of the fillers can be accomplished by compounding the composite materials efficiently. Besides, it may be noted that, when the filler's content is added or increased within the composites, there may be reduction in the composite's strength. The susceptibility of fibers that are natural or composite materials support by fillers to the absorption of moisture and the impact to which this has on their mechanical, thermal, and physical features, is among the major challenges for their utilization [20-26].

There was a research conducted by [27], which finalized that, it is most important to modernize the interface's properties to enhance the adhesive force amongst these chemically varying polymer compositions. This is mostly achievable by either modifying or treating the surface of the fiber with chemicals that are most appropriate or by utilization of some agents which enhanced compatibility. Both academics and business are increasingly interested in the use of natural fillers for composite reinforcement.

Another research was equally varied out by [28]. The study assessed the mechanical and physical features of sugarcane bagasse fiber-supported composite of epoxy, treated with chemicals. The fabricated bagasse-supported composites treated with chemicals described a better mechanical and physical feature. The research hence suggested this material for utilization in replacement of normal natural fibers. Similarly [29] developed composites of polypropylene with varying amount in weight of fish bone and egg shell. The results from his research reported that, there was a noticeable raise in the flexural strength, hardness, and tensile strength as the filler load raises, but there was a reduction in the elongation percentage at the break.

This study therefore intends to investigate the durability of the hybrid fillers made with sugarcane bagasse and corn cobs in the development of high-density polyethylene composites.

Experimental

Materials and Methods

High Density Polyethylene (HDPE) (ExxonMobil HMA014) Made in USA was utilized in the course of this work. The agricultural wastes, sugarcane-bagasse and corn-cobs were obtained from Ajegunle in Lagos State of Nigeria. The waste from agricultural produce were washed with water and dried under the sun for the period of 3-days and later crushed and allowed to pass through a locally made sieve. This process was repeated again with grain-mill-machine (M6FFC-270) to a fine particulate powder of sizes 75 microns.

Method of producing composites

To make HDPE composites, virgin crystalline HDPE pellets weighing 0.19 kg, 0.18 kg, 0.17 kg, and 0.16 kg were completely blended in a ratio of 50:50 mix of corn-cobs and fillers of sugarcane-bagasse. The resulting mixture weight was varied between 0.01 kg, 0.02 kg, 0.03 kg, and 0.04 kg, which are respectively equivalent to 5%, 10%, 15%, and 20% filler-loading. A mold, circular in shape located in the injection-molding machine with TU150 200-gram hopper was filled with the homogeneous polymer and filler mixture. The composite materials were manufactured to a dimension which is standard for mechanical property investigation [30-35].

Method of analyzing composites

Composites produced were subjected to mechanical, morphological, water absorption, and degradation analyses. Mechanical analysis was carried out using a Hounsfield Monsanto Tensiometer 8889. Tests conducted included percentage elongation at break, tensile strength, Brinell hardness, and shear modulus a compressive strength. Mechanical analysis was carried out based on the standards stipulated by ASTM (American Society for Testing and Materials) standards [35-42].

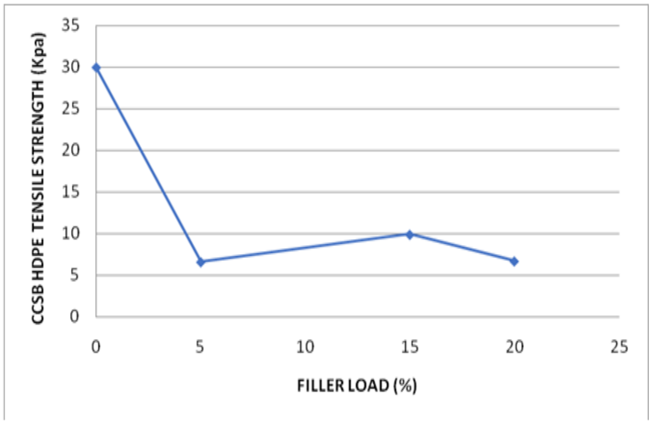


Figure 1. Impact of filler-load on HDPE composite

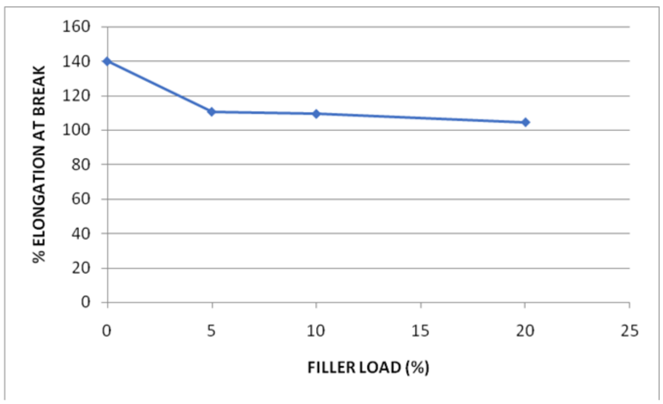


Figure 2. Impact of filler-loading on the elongation percentage at break of the HDPE composites

Results and Discussion

Tensile strength

This refers to the ability of a material to resist elongating loads. In another manner, the maximum pressure a material is able withstand before it gets breaks when expanded or pressed [43]. Figure 1 depicts the influence of filler loading on the composite's tensile strength.

78% drop in the composite's tensile stress was noticed with a 5 wt% filler-loading. This drop which agrees with the findings of [44,45] is connected to the poor adherence of the filler to the polymer matrix. It could also be due to filler dispersion in the polymer matrix being uneven, resulting in greater number of interactions in filler to filler compared to the predicted interactions in filler to matrix.

Elongation percentage at break

Composite material's ductility being the ratio of the raise in length to original length determined after the material test rupture, also known as fracture strain was measured here [46]. The impact of filler content on the elongation percentage at break of composites can be seen in Figure 2.

Figure 2 depicts a general drop in elongation percentage at break of composites, and this is an indication that the composite hardened with increased filler load. [47] reported that this drop is commensurate to reduced resilience of the composite implying that transmission of pressure from filler of the polymer to the matrix is not supported by the filler.

Hardness

The composites' hardness refers to their ability to resist indentation, deformation, and penetration [48]. The alteration of the filler concentration on composite's Hardness is depicted by Figure 3. According to Figure 3, there is a raise in hardness of the material composite with raise in filler loading. Filler's strengthening impact put into the matrix of the polymer might be the factor responsible for increment of the hardness. In most cases, fillers are utilized to enhance the strength and stiffness of polymer materials. This is because of the filler's composition. The tougher and stiffer the material grows as the percentage of fillers introduced increases.

Compressive strength

The strain (residual) which was left in test sample after being subjected to pressure for a time period and left to settle after the deformation load has been removed is known as compressive strength [49]. The result of the compressive strength of the fabricated material composite is depicted by Figure 4.

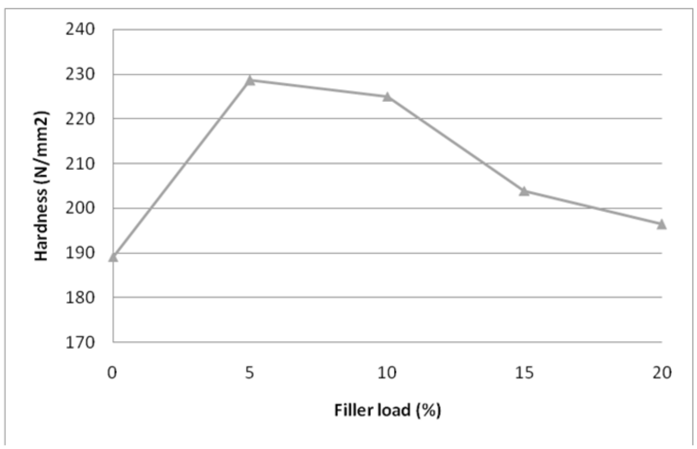


Figure 3. Effect of filler concentration on hardness of HDPE composite

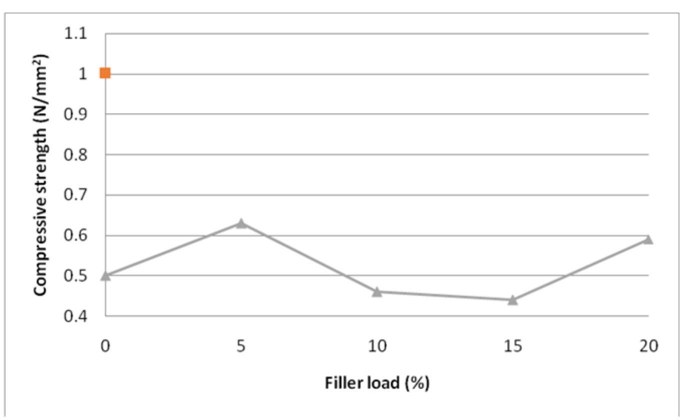


Figure 4. Variation of compressive strength of HDPE with filler loading

Between 0% to 5% filler loading, a raise in compression strength was observed as in Figure 4. Further loading of filler from 5% up to 15% resulted in fall of the compressive strength of the fabricated materials. There was raise again in the compressive strength of the materials as the filler-loading advances from 15% to 20%. This is an indication that the material would easily return to its initial form if a weight is removed from it, which could be attributed to the improved mechanical qualities of the fillers. The reduction in the compressive strength which results from the increment of 10 wt% and 15 wt% filler content is related to the degree of compatibility between the fillers and the polymer matrix. This improved compression set may be attributed to combined reinforcement of the quality of fillers that improves the mechanical features of the composite's materials. The report of this work agrees with the report of [50, 51].

Shear modulus

Stiffness modulus of a substance commonly known as shear modulus is evaluated via the measurement of solid deformation by the application of parallel force to the solid surface, whereas another force opposite to the surface act on the solid. A substance which has its shear modulus as zero and deformed when force is applied on it is referred to as fluid [52]. Figure 5 illustrates the variation of shear modulus of the HDPE filler loading. Figure 5 depicts the overall improvement in the composite's shear modulus as the filler loading increases. This rise indicates that the fillers improved the composites' hardness and stiffness, requiring a greater force to ensure composite's deformation in force direction.

Morphological study

One of the major facilities utilized in checking the surface morphological properties of a material as well as its microstructure is SEM (Scanning Electron Microscopy) [53]. SEM could equally be utilized in studying how compatible and dispersive a polymer matrix and filler is. The discrepancies in the mechanical features of composites may be linked to the SEM-micrographs. The following results were acquired during the investigation of the composites' morphology. The micrographs of CCSB-HDPE 0 wt%, 5 wt%, 10 wt%, and 15 wt% are demonstrated by Figure 6a-d, respectively.

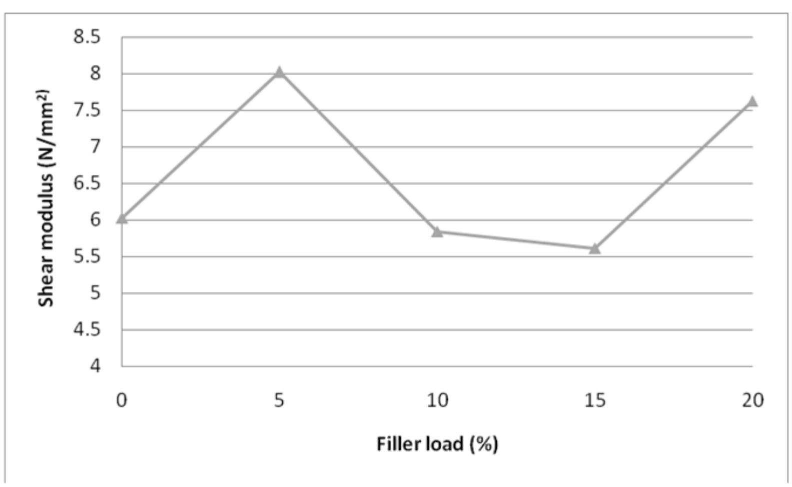


Figure 5. Variation of shear modulus of HDPE with filler load

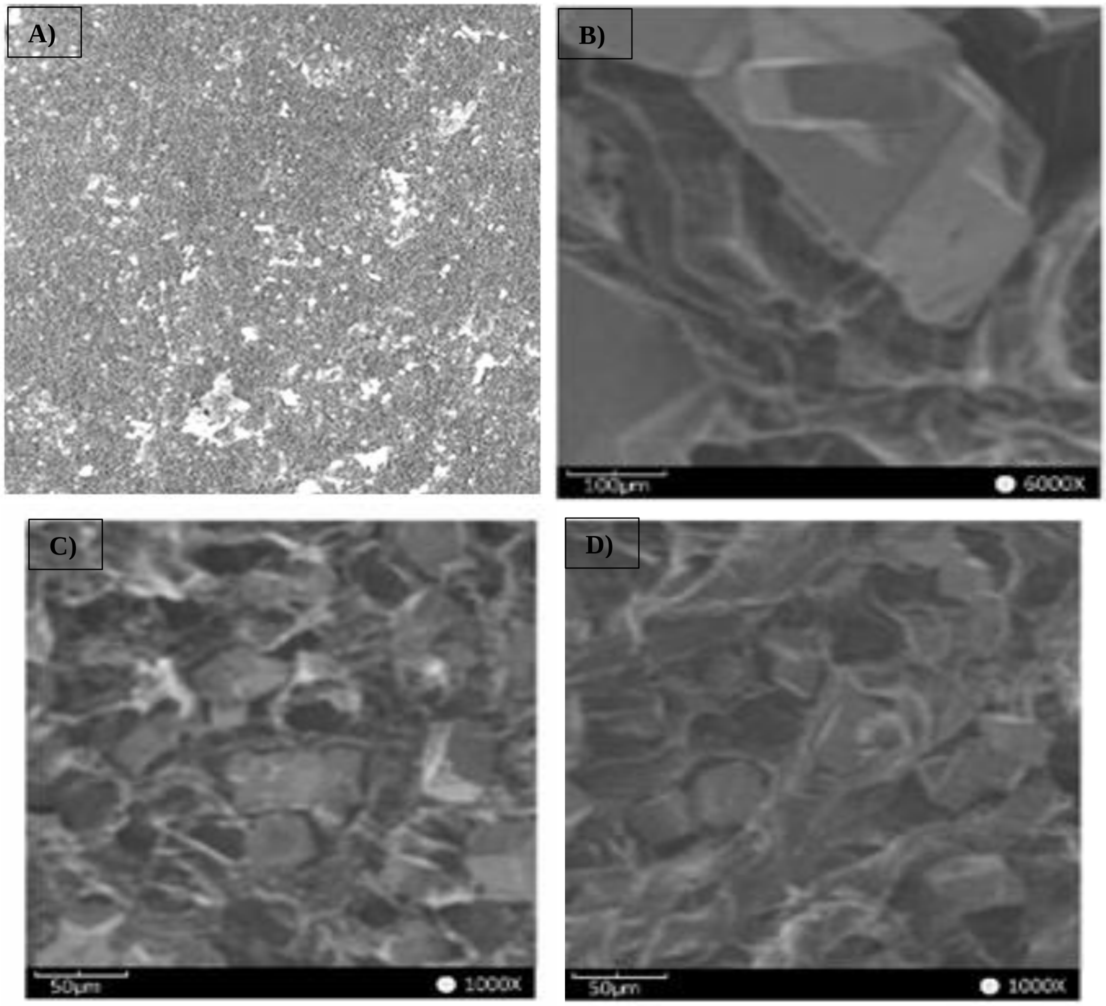


Figure 6. SEM of HDPE composites

Figure 6 shows that the dispersive ability of filler raises as the filler concentration is added. The filler particles were correctly attached to the matrix of the polymer and appeared to be firmly immersed in it. The efficiency of this mixing was connected to the superior interfacial contact among the matrix of the polymer and hybrid fillers. The capability of the composites is improved as a result of uniform dispersive ability of the fillers in the polymer matrix. The result of this study demonstrates that the filler and the matrix of the polymer has good adherence. Therefore, the interfacial layer strength has improved.

Test for absorption of water

The techniques utilized in assessing the composite's absorption of water according to ASTM D-570-98 were discussed in this test. The composites were cut into 50x50 mm squares and dried before being submerged for three days in water. The amount of moisture a composite absorbed is calculated using the daily change in weight of the material. The change ratio in mass of the composite to its initial mass is used to compute the percentage moisture absorption capability [54]. The water absorption test of the composites revealed that after complete immersion in water, the composites' final weight remained unchanged. This could be because to the hydro-phobic properties of the matrix of the polymer and lignin, a component of a filler. Furthermore, the filler's lower quantity in relation to the matrix of the polymer, as well as the extent of homogeneity in dispersion of filler, might be a factor, indicating that the fabricated material composites could be utilized in a moist place, like tanks used as storages of water or bathroom interiors.

Test for degradation

This test was conducted to investigate how fast it took a composite material in an environment to decay [55]. A soil burial degradation technique was employed to achieve this test. Soil obtained from an automobile or mechanic workshops were utilized to bury the composite materials of HDPE for deterioration, where the drop-in mass of the composite materials was noticed and record, and in turn, used to measure the composite degradation. After cutting the composite materials into pieces of 50 by 50 squared millimeter in dimension, they were then weighted and then buried into the obtained soil to a depth of 0.15 m for three months. The composite materials undergone weighting procedure for 90 days in step of 30 days to confirm if the weight drops from day one to day thirty, from day thirty to day sixty, and from day sixty to day ninety.

The least filled composite and the most filled composite were investigated for this study (respectively for 5 wt percent and 20 wt percent). Figure 7 demonstrates the result of the test for degradation after a 90-day burial period. Figure 7 shows that in the entire period of the test for 90 days, the weight of 0 percent LDPE did not change, as expected. There was a lost in weight which was noted in the 5 wt percent composites after 30 days of testing, and in general, there was a weight decrease noted when the duration of the burial progressed. The figure also shows that increasing the filler content caused the composites to degrade faster.

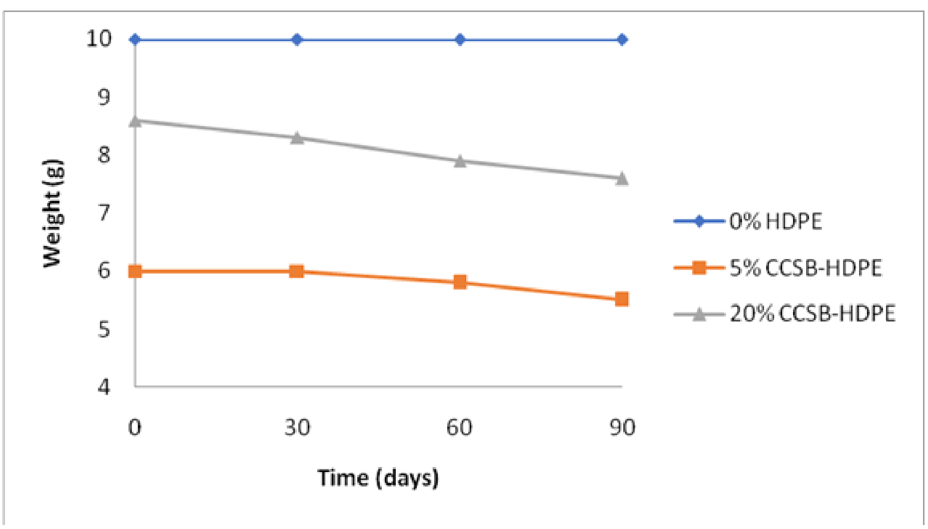


Figure 7. Degradation test result of HDPE composites

Conclusion

To manufacture polymer composites, sugarcane bagasse and corn cobs were blended successfully to obtain hybrid filler into a HDPE (high-density polyethylene) matrix of polymer. The shear modulus of the composite, the hardness of the bio-composition and the composite's compressive strength were all improved using this mixed filler. While the elongation percentage at the break and tensile strength was seemed to be reduced. This conclusion is consistent with previous research and indicates that the action of lingo-cellulosic fillers on the HDPE composites. The interaction between the filler and the matrix of the polymer resulted in a great influence on the composite's mechanical features, sizes of the filler composite's particles, and filler distribution in the matrix of the polymer. At the testing phase, the composite materials were observed to have resisted water absorption, which makes it suitable for utilization as pipes for drainages, storages for water, and similar kinds of applications. It was similarly observed that the developed composites degraded, as shown by their weight loss during the test time of three months. Therefore, employing high concentration of filler in the composites matrix would significantly increase their degradability. Because of waste from agro, like sugarcane bagasse and corn cob and are more cost-effective and practical, it is advised to use them as fillers in the production of plastics as a result of the findings. When disposed, the resulting plastics would simply decompose.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the article and agreed to be responsible for all the aspects of this work.

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