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(Research Article)

Comparative study of the carbon footprint of an eco-material ribbed slab and a reinforced concrete ribbed slab

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Abstract

Environmental sustainability is a major concern in the construction industry due to its high greenhouse gas emissions and energy consumption. To mitigate its environmental impact, alternative solutions that reduce the carbon footprint of buildings while ensuring adequate structural performance are necessary. This study assesses the carbon footprint of an eco-material ribbed slab, consisting of a compression table made of laterite concrete reinforced with rattan, rice husk concrete hollow blocks, and longitudinal laterite concrete ribs reinforced with palmyra wood and transversely with rattan liana. The carbon footprint of this slab was compared to that of a traditional reinforced concrete ribbed slab with sand-cement hollow blocks. The life cycle assessment (LCA) was conducted in compliance with the Emission Factor Guide 5 from the French Environment and Energy Management Agency (ADEME), as well as ISO 14040, 14044, and EN 15978 standards. The results show that the reinforced concrete slab emits 1.93 times more CO_2 than the eco-material slab, amounting to 3.629 tons of CO_2 equivalent for the traditional slab compared to 1.881 tons of CO_2 equivalent for the eco-material slab.

Keywords: Life Cycle Assessment (LCA); Carbon footprint; laterite concrete; Plant-based reinforcement; Bio-based materials; Sustainable building

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1. Introduction

As industrialization and urbanization rapidly progress, environmental issues are becoming a major concern, whether it concerns access to natural resources or pollution resulting from human activities [1]. The construction sector is among the world's largest emitters of greenhouse gases (GHGs) and energy consumers. In August 2021, the Intergovernmental Panel on Climate Change (IPCC) warned of the urgency to reduce these emissions quickly to keep the temperature rise below 1.5 °C, a goal that is becoming increasingly difficult to achieve. The construction sector is responsible for 35% of the final energy consumed and almost 40% of carbon dioxide (CO_2) emissions [2].

In this context, it is vital to find solutions that reduce the carbon footprint of buildings while ensuring adequate structural performance. The construction of green buildings, which are low in energy consumption and produce fewer GHGs throughout their lifecycle, has become a priority. Attention is increasingly turning towards natural or bio-based materials, such as plant fibers, laterite, clay, and wood. Agossou et al. [3] investigated the implementation of rattan as transverse reinforcement in ribs and as reinforcement for the compression slab in lateritic gravel concrete, in developing a hollow ribbed floor. To assess the environmental relevance of these materials, a life cycle assessment (LCA)

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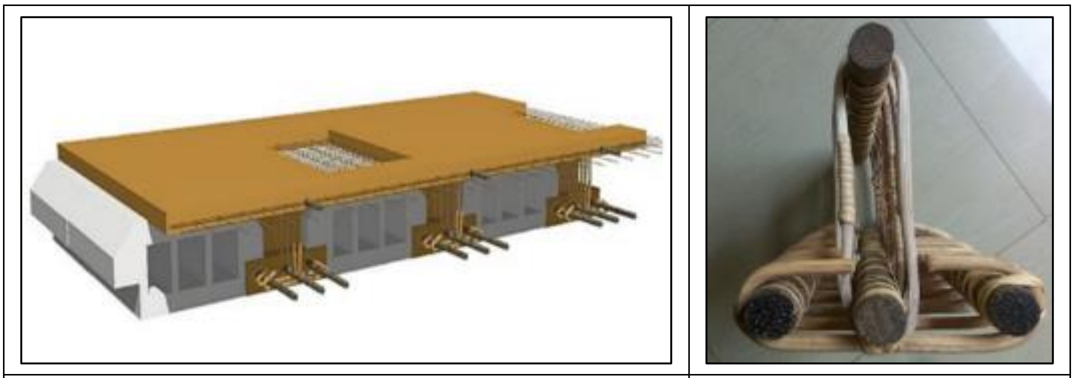
is essential. Although several studies have addressed the Life Cycle Assessment (LCA) of buildings, few have focused on the life cycle of bio-based materials [4–7]. In this context, this study examines the LCA of an eco-material floor, requiring an evaluation of the actual amount of CO2 emitted by this type of floor. The goal is to compare a traditional reinforced concrete ribbed floor with this ecological alternative, in order to identify the most environmentally friendly solution.

2. Materials and methods

2.1. Materials

In this comparative study, two types of ribbed floors were analyzed:

- **Eco-material floor:** This innovative floor, illustrated in Figure 1, includes a compression slab made of laterite concrete, exclusively reinforced with rattan. The hollow blocks are made of lightweight rice husk concrete, and the ribs are composed of laterite concrete, longitudinally reinforced with palmyra wood and transversely with rattan liana.
- **Traditional reinforced concrete floor**: This ribbed floor, also studied for comparison, consists of a reinforced concrete compression slab, sand-cement concrete hollow blocks, and reinforced concrete ribs.



a) Floor

b) Plant-based reinforcement

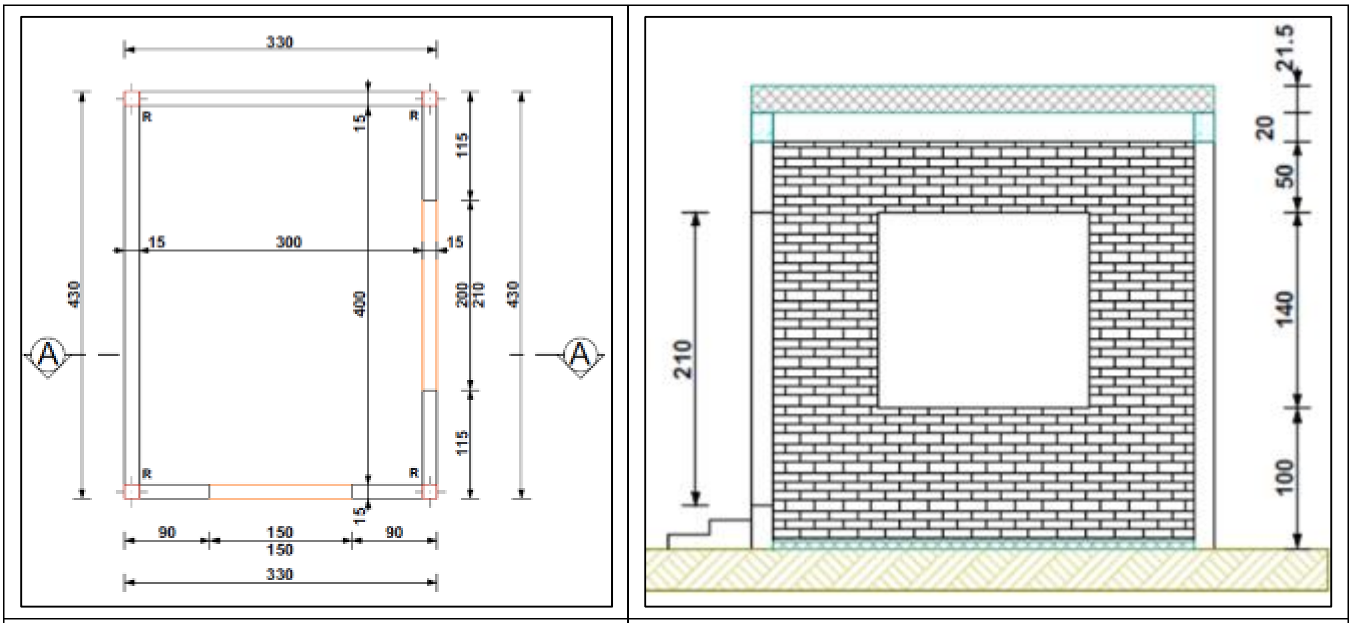
Figure 1 Eco-material ribbed floor [3]

2.2. Introduction to Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a standardized method used to assess the environmental impacts associated with a product or service from raw material extraction to end-of-life (from cradle to grave) [2,8]. This analysis includes several stages such as manufacturing, distribution, use, and disposal. The aim is to evaluate the consumption of natural resources, greenhouse gas emissions, and other forms of environmental pollution. The ISO 14040 and ISO 14044 standards [8,9] define the guidelines for this method, which is conducted in four distinct phases.

2.3. Scope and assumptions of the study

To assess the behavior of the eco-material floor, a reference building, illustrated in Figure 2, is chosen. This building, an office with four facades and an accessible floor, serves as the study object. Two scenarios are compared: one in which the ribbed floor is made of eco-materials, and the other where the floor is made of traditional reinforced concrete. This comparison determines the environmental impact and effectiveness of each type of floor under similar usage conditions.



a) Plan view

b) Section AA

Figure 2 Building studied for the case study [3]

Certain assumptions were made to focus the analysis on specific aspects:

- The cultivation of rice and its transport to the milling factories are not considered. Only the transport of rice husk to the hollow core slab prefabrication factories was included.
- For palmyra and rattan, only transport and machining are considered.
- Energy consumption during the use of the floors is not included, as the floor is studied in isolation.
- Carbon ratios for the transport of materials were taken from the ADEME Emission Factor Guide version 5 [10].

2.3.1. Functional unit

The functional unit of this study is defined as the ground floor office space with an accessible floor area of 14.19 m^2 in the city of Calavi, Benin, considering a lifespan of 50 years. [11]. The system under study includes two case studies and energy consumption but excludes all elements of interior design as well as the cultivation of rice and palmyra and rattan.

2.3.2. System boundaries

Among other things, the system boundaries define the life cycle stages considered in the study. The Life Cycle Assessment (LCA) of the building includes the extraction of resources, the manufacturing of construction materials (hollow blocks, rattan and palmyra reinforcements), construction, energy consumption and maintenance, end of life, as well as all necessary transportation throughout the life cycle (Figure 3).

In the life cycle, the hollow blocks, whether made from rice husk-cement composite or sand-cement, are products whose complexity is equivalent to that of the floor construction itself, thus warranting a complete life cycle assessment. The manufacturing process of the rice husk hollow blocks, as shown in Figure 4, starts with step A1, which is the sourcing of raw materials. This phase involves the collection of rice husks. Step A2 involves the transport of the husks from the milling factory to the pre-fabrication sites. Finally, step A3 focuses on the primary transformation or pre-fabrication of the hollow blocks.

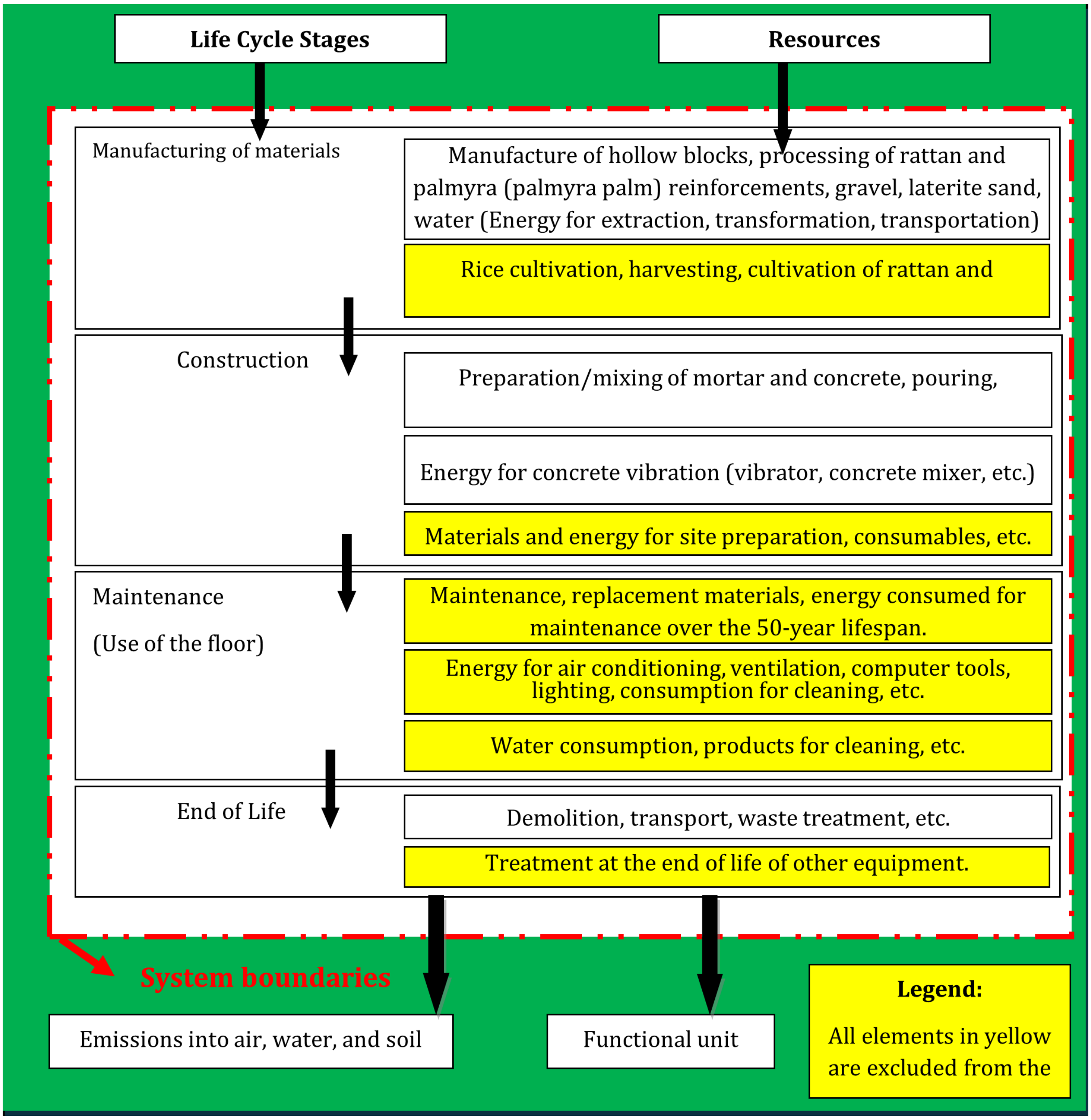


Figure 3 Diagram of the boundaries considered for the case study

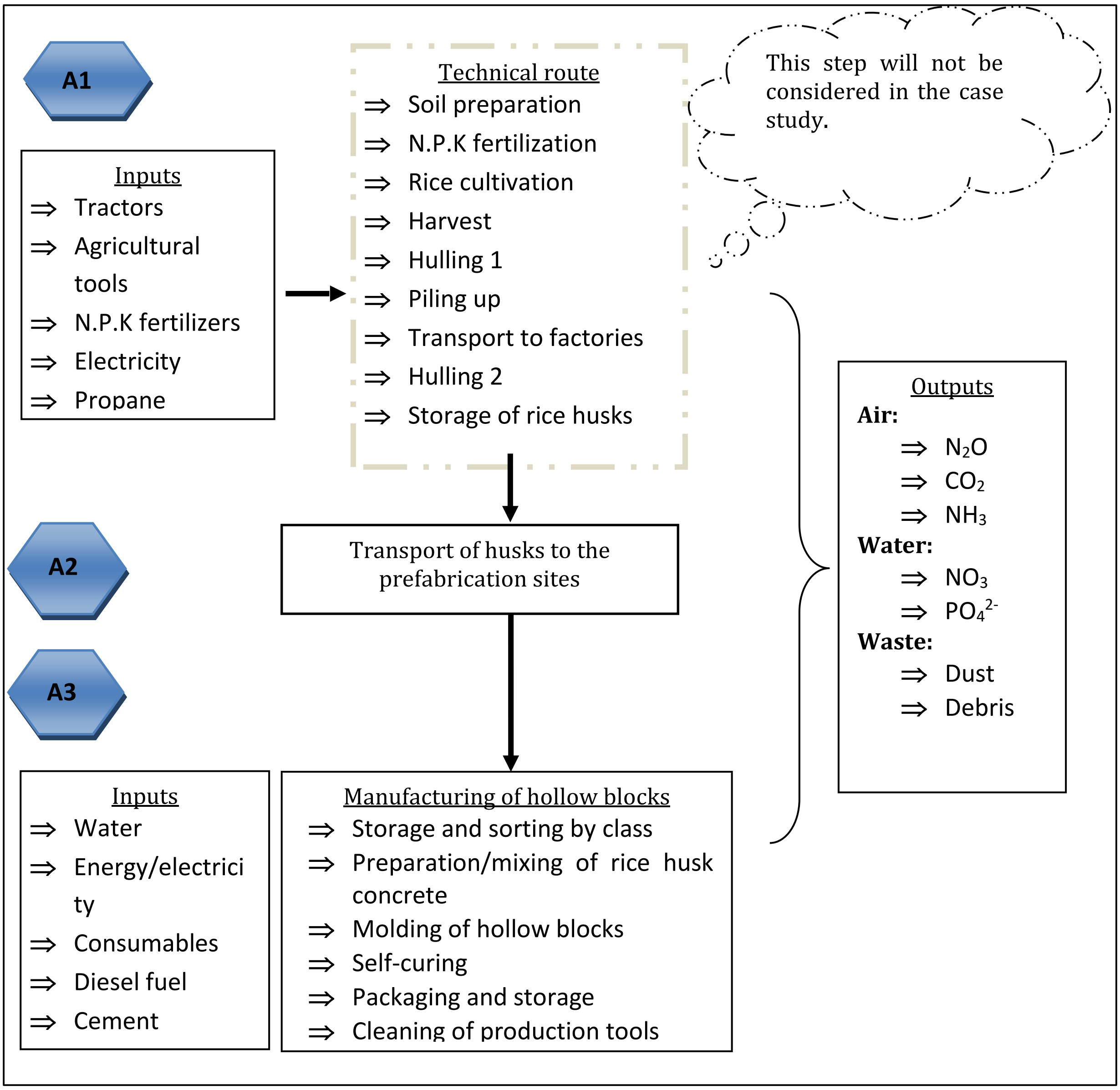


Figure 4 Life cycle of hollow blocks

2.4. Environmental Impact calculation

Environmental impacts were calculated according to the carbon emission equation (1) [10].

$$Q_i = q_i . m_i . f_x \dots\dots\dots\dots (1)$$

Where Q_i represents the total impact in kilograms of equivalent carbon (kg eq CO2); q_i denotes the elementary impact in kilograms of equivalent carbon per unit; m_i is the quantity of material in kilograms or cubic meters; f_x is the emission factor according to the guide.

Materials such as rice husk, rattan, and palmyra, lacking specific data in the ADEME guide, were assimilated to similar materials to use relevant impact factors. The vegetable products being manually harvested, their extraction is less mechanized, thus reducing the carbon footprint. Additionally, the effect of photosynthesis of plant-based materials was taken into account in the final evaluation.

3. Results and Discussions

The carbon footprint results for the two types of floors are presented in Figure 5.

The eco-material floor generated 1.881 tons of CO_2 equivalent. The main emissions come from the rice husk concrete, laterite concrete, and the transport of wood (palmyra and rattan). The ribs made of laterite concrete and wood represent a significant source of emissions. The traditional reinforced concrete ribbed floor generated 3.629 tons of CO_2 equivalents. The concrete and steel used in the ribs and compression slab are the main contributors. Although other components, such as mortar, also have a significant impact, the emissions generated by these elements are less.

The results indicate that the traditional reinforced concrete floor emits 1.93 times more CO_2 than the eco-material floor. This difference is partly due to the use of local materials such as wood, rice husks, and lianas, which absorb biogenic CO_2 during their growth. This captured carbon is not released into the atmosphere once these materials are integrated into the floor structure.

In both types of floors, the ribs remain the main source of CO_2 emissions, regardless of the materials used. However, the eco-material floor remains a more environmentally friendly solution. Further research on the economic and energy aspects will refine this comparison. The use of software and more comprehensive databases would also help to estimate impacts by emission category, which was not possible in this study based solely on the ADEME guide. Although materials such as laterite, palmyra wood, rattan, and rice husks are locally available, questions remain about their recyclability. Laterite appears to be recyclable, but rice husk, palmyra wood, and rattan require further exploration to determine their reuse potential.

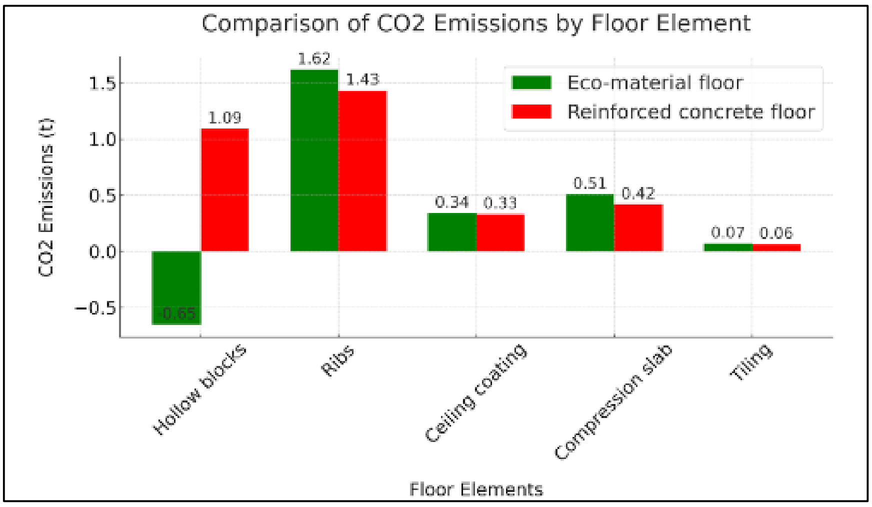


Figure 5 Comparison of CO_2 emissions by floor element

4. Conclusion

This study compared the CO_2 emissions of two types of floors: an eco-material floor and a traditional reinforced concrete floor, thus exploring their impact on environmental sustainability in the construction sector. The results show that the eco-material floor emits less CO_2, with a significant reduction compared to the reinforced concrete floor. This reduction is primarily attributed to the use of local materials such as palmyra wood, rattan, and rice husks, which absorb biogenic CO_2 during their growth.

The impact of these findings suggests that integrating bio-based materials into construction can reduce the carbon footprint of buildings. However, the study also highlighted challenges, particularly regarding the recycling and long-term management of these materials. While laterite appears to be recyclable, other materials such as palmyra wood and rattan require further research to fully assess their recycling potential.

For future work, it would be relevant to consider the economic and energy impact of using these materials in larger construction projects. The use of advanced software and more comprehensive databases could provide a more accurate assessment of the environmental impacts of various construction materials, considering all aspects of their life cycle.

These results encourage the continuation of innovation and the adoption of environmentally friendly construction practices, while emphasizing the need for a detailed assessment of the economic, environmental, and durability aspects to optimize the use of materials in the construction sector.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there are no conflicts of interest that could inappropriately influence, or be perceived to influence, the work reported in this manuscript.

Author Contributions

- *Conceptualization and study design*: E. C. Adjovi, E. Chabi, T. A. Amadji
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- *Manuscript drafting*: E. Chabi, D. D. Deguenon
- *Critical manuscript review for intellectual content:* E. Chabi, T. A. Amadji, D. D. Deguenon, E. C. Adjovi
- *Final manuscript approval:* E. Chabi, T. A. Amadji, D. D. Deguenon, E. C. Adjovi

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