

Manipulating the Acoustic Characteristics of Kenaf as a Sound Absorber by Modifying the Thickness and Air Gap

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Abstract

The primary aim of this study is to profile kenaf fibre's acoustic characteristics from the National Kenaf and Tobacco Board (NKTB) and to evaluate its effectiveness as a sound absorption material. The non-woven kenaf fibre, produced from kenaf plant fibres, is processed into a non-woven fabric. This material comprises 65% kenaf fibre and 35% Bico (Polyester), which acts as a binder. The manufacturing process uses a Thermo-bonding machine, where Bico (Polyester) melts to bond the kenaf fibres. The study assesses acoustic properties, including sound absorption and noise reduction coefficients. Results indicate that increasing the sample thickness and incorporating an air gap improve both the sound absorption coefficient and noise reduction value, with the 50 mm sample showing notable performance in the middle-frequency range (500 Hz–1000 Hz). A comparative analysis between kenaf fibre and an industrial synthetic foam absorber reveals that kenaf fibre performs comparably to synthetic materials. This research highlights kenaf fibre's potential as an effective alternative to sound absorbers. It underscores the advantages of using kenaf fibre due to its biodegradability, environmental safety, and cost-effectiveness, aligning with natural, sustainable materials.

1. Introduction

Kenaf, a natural fibre derived from *Hibiscus cannabinus*, is known to improve the properties of polymer matrix composites (PMC) and has thus been recognised as an essential fibre source for composites and various industrial applications [1]. Most contemporary research focuses on sustainable material development, particularly emphasising using natural fibres as reinforcements in polymeric composites. Natural fibres provide many benefits as reinforcing materials, covering cost-effectiveness, non-abrasive quality, low energy consumption, and lightweight properties [2]. Additionally, pineapple leaves and oil palm fruit bunches as by-products from the agriculture sector can be utilised to reinforce polymeric composites. Due to their fast growth rates, species such as kenaf are widely cultivated in Malaysia for fibre extraction. Kenaf fibre is readily available in the market and has the potential for increased production to meet growing market demands [3]. Contributing to its excellent strength-to-weight ratio and stiffness, kenaf fibre has been extensively used as reinforcement material in the automotive, aerospace, and marine industries [4].

To date, kenaf bast fibres are extensively used in food packaging, composites, textiles, and filters, among other products. The high growth rate and short rotation cycle of this crop make it outstanding as a fast, sustainable food source. The crop is harvestable as early as 4–6 months when the height of the plant reaches 4–5.6 metres (equivalent to 14–19 feet), as illustrated in Fig. 1. Kenaf's adaptability to diverse weather and soil conditions further enhances its values [4]. Belonging to the Malvaceae family, both cotton and kenaf share similar characteristics. The plant stem's fibre composition includes 65 per cent of the inner core fibre, while the outer

bast fibre accounts for the remaining 35 per cent. Certain components and fibres from this plant have been used to develop medicinal and dietary products, as well as being raw materials in the manufacture of musical instruments and fabrics [5]. With its potential to replace tobacco cultivation, kenaf is poised to become the next major industrial crop in Malaysia [6]. Recognised in over 20 countries for its significant industrial applications, kenaf continues to gain global recognition [4]. Previous research has suggested that kenaf fibres could be a viable alternative for acoustic absorption [7]. Nonetheless, a thorough assessment of its performance across different parameters is still missing and requires additional research.



Fig. 1 Natural fibrous of kenaf [8]

Noise control is essential for addressing noise-related issues, with sound absorbers being viable. While synthetic materials are commonly used for sound absorption, their non-biodegradable nature poses significant environmental risks, contributing to landfill problems and increased carbon dioxide emissions [9]. Consequently, looking for biodegradable alternatives to synthetic sound absorbers is crucial.

The thickness of the material essentially affects the sound absorption. Studies have shown that the absorption of low-frequency sounds is directly associated with the thickness of porous materials. For instance, previous research indicated that the sound absorption coefficient of natural fibre improves with increased thickness at lower frequencies [7]. In this study, a constant bulk density of 93.5 kg/m^3 was maintained while investigating how different material thicknesses affect performance [7]. Sound absorption coefficients for various specimens were measured in a reverberation chamber. However, at higher frequencies, the effect of fibre thickness on sound absorption is minimal [10]. For frequencies above 1 kHz, specimens thicker than 40 mm exhibit absorption coefficients ranging from 0.80 to 1 [7]. The maximum absorption of the absorber corresponds to a quarter wavelength, as noted by [11]. As sample thickness increases, the sound absorption coefficient rises across all frequency bands [12].

2. Structure

The primary material utilised in this study is kenaf, which was chosen for its potential as both a sound absorber and a vibration transmitter. Kenaf fibre, native to Malaysia, ensures the material's availability and accessibility. For this research, the National Kenaf and Tobacco Board (NKTB) provided a by-product of Kenaf fibre. Non-woven Thermo-bonding products were manufactured using Thermo-bonding machines and various mechanisation processes to create the necessary experiment samples.

2.1 Materials

Kenaf (65%) and Bico (35%) are the two main components of non-woven Kenaf products. Among them, Bico (Polyester) is a low-melting synthetic fibre that melts during the thermo-bonding process, effectively fusing the kenaf fibres together. The density and thickness of these non-woven thermo-bonded products can be adjusted according to specific requirements, with higher densities leading to increased weight per square meter for the same volume of kenaf material. The materials prepared, as shown in Fig. 2, were used to create the samples following the appropriate procedures. The initial step involved cutting the samples to the required dimensions for testing. For sound absorption coefficient tests, the non-woven kenaf fibre was trimmed to a diameter of 100 mm and a thickness of 28 mm.

2.2 Impedance Tube

All kenaf fibre samples were assessed using the SCS9020B Impedance Tube, a technique designed to measure multiple acoustic properties, such as the sound absorption coefficient. This testing setup comprises an interconnecting apparatus of two microphones, an impedance measurement tube, a dual channel signal analyser and a power amplifier connected to a computer. The tests have adhered to ASTM E1050-08, the standard for

measuring the sound absorption coefficient. The connection of the impedance tube system to a VA-LAB IMP software computer facilitates sound absorption measurements and data analysis using BSWA SW series hardware. Fig. 3 and Fig. 4 illustrate the impedance tube.

This testing method was applied to various fibrous materials, including mineral fibre, cellulose board, and fibreglass, as well as foam products, textiles, and screens. The apparatus can accommodate materials with diameters ranging from 100 mm to 28 mm and up to 250 mm thicknesses. This study used two impedance tubes (double tubes), following standard procedures to evaluate conditions across low and high-frequency ranges (Table 1). The device's microphones were positioned in their default configuration. The test's limitations were dictated by the tube's diameter and the distance between the microphones.



Fig. 2 Non-woven kenaf fibre by-product provided by the National Kenaf and Tobacco Board (NKTB)

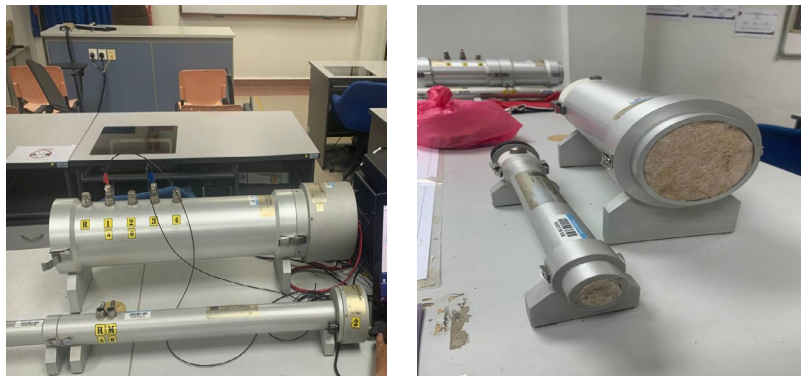


Fig. 3 Impedance tube

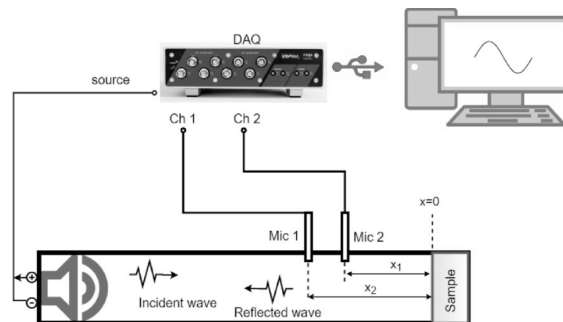


Fig. 4 Schematic diagram for impedance tube

Table 1 Impedance tube diameter tube and measurement (Hz)

The diameter of the Impedance Tube (mm)	Measurement (Hz)
100	50 - 1200
28	500 - 6000

3. Results and Discussion

All experimental data were analysed to address the research objectives. Each sample underwent two distinct analyses, resulting in four data sets that needed to be examined to describe the tested samples comprehensively. The following sections assessed all presented samples. In this study, the analysis is divided into two main parts: (1) Sound Absorption Coefficient (and) Noise Reduction Coefficient (NRC). The raw experimental datasets were converted into graphical visualisation and tables illustrating the testing parameters. Additionally, these data were converted into relevant coefficients. Three different samples were prepared to evaluate the acoustic properties of kenaf fibre, and its performance was benchmarked against an industrial sound absorber made from a foam composite, as well as compared to that of a composite incorporating natural fibres.

3.1 Thickness Determination

Prior to advancing to the next phase, the non-woven kenaf board was weighed to determine the density of the kenaf fibre provided by NTKB. The weight of the kenaf board was 0.455 kg, which was used in conjunction with the board's volume to determine its density. The dimensions of the Kenaf board are 0.425 m x 0.425 m x 0.0256 m, resulting in a calculated density of 98.40 kg/m³. The physical properties of samples with different thicknesses are depicted in Table 2.

Table 2 Physical characteristics of each sample

Index	Sample Thickness (mm)	Sample Mass (g)	Bulk density, $\rho = m/V$ (kg/m ³)
Sound absorption coefficient	25	24	113.529
	50	48	113.529
	75	72	113.529

3.2 Sound Absorption Coefficient Test

In the initial part of the analysis, the focus was on examining the impact of varying thicknesses while maintaining a consistent mass of kenaf fibre in each sample. The tests were conducted without any air gap to understand how thickness influences the sound absorption coefficient. The results are illustrated in Fig. 4. The highest sound absorption coefficient recorded was 0.97 at 2000 Hz at a 25 mm thickness. At a thickness of 50 mm, the peak sound absorption coefficient was 0.97 at 1250 Hz. In contrast, with a thickness of 75 mm, the highest coefficient value was slightly reduced to 0.96, occurring at 800 Hz and 4000 Hz. There was a noticeable difference in the graph for the middle-frequency range between the 50 mm and 75 mm thicknesses. In contrast, both thicknesses exhibited no significant differences in the high-frequency range.

Previous research has extensively examined how thickness influences sound absorption performance. Typically, thicker samples exhibit a higher sound absorption coefficient in the mid-frequency range compared to the high-frequency range. The density of the material is often linked to thickness to improve absorption efficiency [14]. This study reinforces that increasing thickness enhances the sound absorption coefficient in the mid-frequency range. Experiments with cork sheets revealed that thicker samples achieved better sound absorption in the low to mid-frequency range [15].

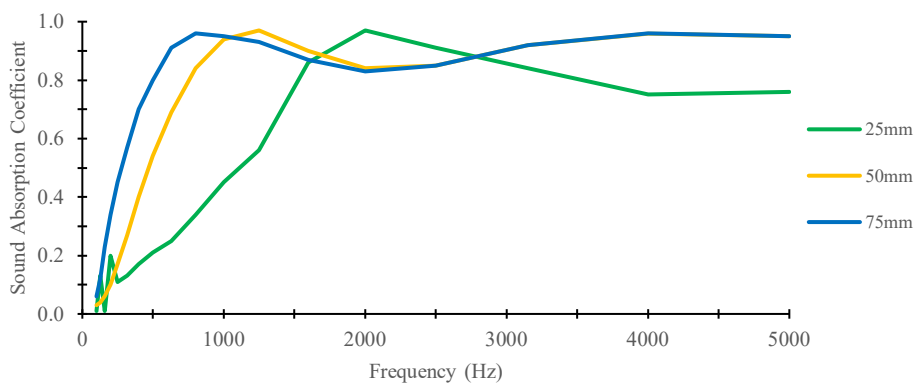


Fig. 4 The effects of thickness on the sound absorption coefficient

This section investigates how an air gap affects the sound absorption coefficient of sound absorbers. The main goal is to evaluate and compare the sound absorption effectiveness of samples with air gaps versus those without. A consistent sample thickness of 25 mm was used throughout the study to ensure accurate comparisons. A 10 mm distance was maintained between the sample and the tube wall for the air gap experiment, resulting in a total sample thickness of 35 mm when including the 10 mm air gap. The results of this experiment are shown in Fig. 9. As illustrated in the curve in Fig. 5, the sound absorption coefficient peaked at 0.93 for the 25 mm sample with a 10 mm air gap. Between 1500 Hz to 2000 Hz frequency range, the sound absorption coefficient is slightly higher with the presence of an air gap. A significant difference is observed at higher frequencies (3150 Hz), where samples with an air gap exhibit a higher sound absorption coefficient (0.87) compared to those without an air gap (0.76). Additionally, as the experiment progressed, the sound absorption coefficient for samples with an air gap continued to increase towards the end of the frequency spectrum.

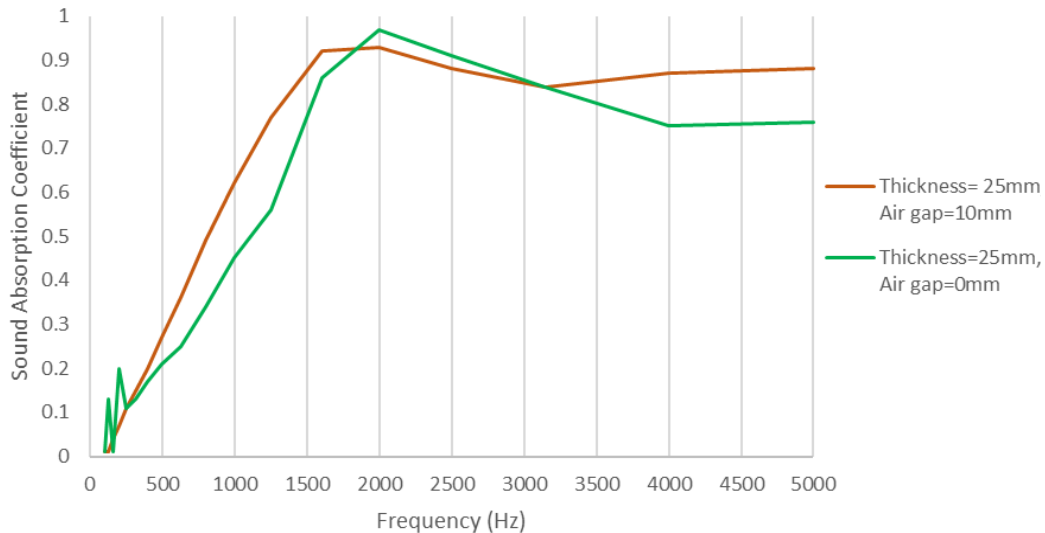


Fig. 5 Sound absorption coefficient of a 25 mm sample with a 10 mm air gap compared to a 25 mm sample without an air gap

Examining the graph in Fig. 6 reveals that both curves exhibit a similar gradual upward trend, though they show slight variations in their sound absorption coefficient values. Both curves reach a peak of 0.97 at a thickness of 50 mm without an air gap within the frequency range of 1000 to 1200 Hz. A significant difference is observed at the mid-range frequency of 1600 Hz, where 50 mm thick samples without an air gap show a more gradual increase in sound absorption coefficient compared to 25 mm thick samples with a 25 mm air gap. It is interesting that the sound absorption coefficient for both types of samples remain similar up to 5000 Hz. Within the low-to-mid frequency range (100 Hz – 630 Hz; Fig. 7), both samples maintained a consistent sound absorption coefficient of 0.91. For the 50 mm sample with a 25 mm air gap, the coefficient increased gradually from 630 Hz to 1000 Hz and fluctuated between 1250 Hz and 5000 Hz, peaking at 800 Hz with a value of 0.98. Meanwhile, the 75 mm thick sample without an air gap reached a peak coefficient of 0.96. When it reached 5000 Hz, both samples exhibited an absorption coefficient of 0.95. This distinction between the 50 mm sample with a 25 mm air gap and the 75 mm sample without an air gap highlights their differences despite both graphs showing a generally similar trend with minor variations.

A significant difference in sound absorption coefficient performance exists when an air gap is present compared to when it is absent between the sample and the tube plunger wall [16]. Research indicates that samples with an air gap, such as luffa kapok, generally performed better at middle-range frequencies than those without an air gap. An air gap allows sound waves to dissipate into the surrounding air after hitting the plunger wall, reducing wave intensity and enhancing the sound absorption coefficient [16]. In contrast, without an air gap, sound waves are fully reflected.

A study by [15] on cork sheets found that an air gap between a flexible panel and a rigid wall can absorb part of incident sound energy. The extent of this effect depends on the total length of the air gap. An air gap shifts the absorption characteristics to lower-to-middle range frequency ranges. Positioning a panel at a certain distance from a wall in a controlled setup can effectively improve sound absorption [15]. This shift occurs because the material's higher impedance causes acoustic resonance to move towards the low-to-middle frequency range, thereby enhancing absorption [17].

In conclusion, incorporating an air gap between fibrous materials offers a cost-effective and resource-efficient method for improving sound absorption. A thinner sound absorber made from Kenaf fibre from the NKTB shows

better sound absorption with an air gap. Conversely, a thicker sound absorber might provide a higher sound absorption coefficient value [18]. However, this air gap proves to be particularly effective for middle-frequencies. Sound absorption shows a slightly unstable trend at higher frequencies before increasing again. This study highlights that acoustic performance can be optimised with reduced material usage, making thicker sound absorbers less necessary.

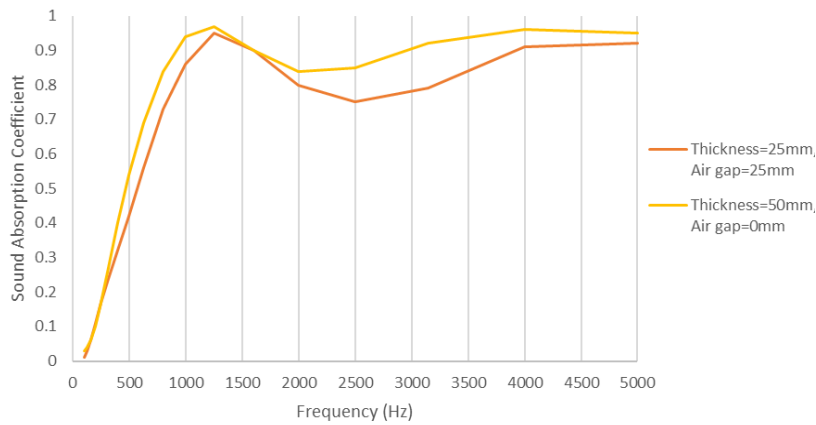


Fig. 6 Sound absorption coefficient of 25 mm sample with 25 mm air gap and 50 mm sample with no air gap

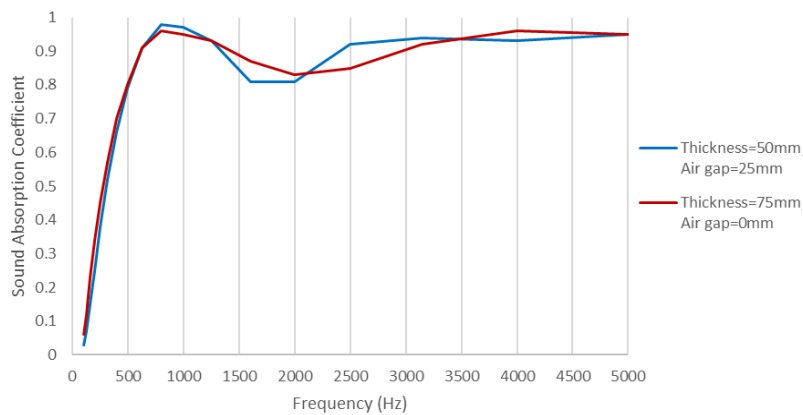


Fig. 7 Sound absorption coefficient of a 50mm sample with a 25mm air gap compared to a 75mm sample without an air gap

3.3 Noise Reduction Coefficient Test

The Noise Reduction Coefficient (NRC) measures the mean sound-absorbing performance of an acoustic material. This analysis calculated the average NRC value using the sound absorption coefficient data from the experiment. This was done by averaging the sound absorption coefficients at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The NRC value for each sample was determined by summing these coefficients and dividing by four. As shown in Table 3, the sample with a thickness of 75 mm achieved the highest NRC, while the 25 mm thick sample had the lowest. This observation is consistent with the previous research, which found that thicker samples generally exhibit higher NRCs than thinner ones [14]. Additionally, another study [16] confirmed that increasing material thickness, as seen with additional layers of kapok mat, results in a higher NRC.

Table 3 Noise reduction coefficients for 25mm, 50mm and 75 mm samples

Sample	Frequency (Hz)				NRC
	500	1000	2000	4000	
25mm	0.2100	0.4500	0.9700	0.7500	0.5950
50mm	0.5400	0.9400	0.8400	0.9600	0.8200
75mm	0.8000	0.9500	0.8300	0.9600	0.8850

The 75 mm thick sample consistently delivered strong performance across all four tested frequencies, resulting in the highest NRC. In contrast, other samples generally perform better at high-frequency ranges but showed lower effectiveness at the middle-range frequencies, which led to lower NRC values for these samples. The data indicate that the NRC improves with increased sample thickness, with notable differences between the 25 mm and 50 mm samples. The NRC difference between the 50 and 75-mm samples is relatively small.

Fibrous materials are recommended as effective sound absorbers because they can efficiently absorb sound energy [19]. This is consistent with the findings about natural coir fibre, where greater thickness results in higher NRC value [17]. For comparative purposes, the 50 mm thick sample's acoustic performance was assessed against another material using data from the manufacturer's datasheet.

The data suggested that NKTB kenaf fibre excels at middle frequencies, while synthetic foam composites had a better performance within the range of higher frequencies (Table 4). This observation aligns with research by [20], which found that glass wool absorbers were most effective at high frequencies, whereas oil palm empty fruit bunch fibre excelled at middle-range frequencies. Consistent with [7], the performance of NKTB kenaf fibre is comparable to that of reference kenaf fibres. However, the NRC calculations reveal that NKTB kenaf fibre outperforms the synthetic foam composite absorber.

Table 4 Comparison of sound absorption and noise reduction coefficients

Sample Frequency	Frequency (Hz)				NRC
	500	1000	2000	4000	
Kenaf fibre from NKTB	0.5400	0.9400	0.8400	0.9600	0.8200
Kenaf fibre [7]	0.5800	0.7800	0.9400	0.9600	0.8150
Foam composite [21]	0.3400	0.5600	0.900	1.00	0.7000
Sugarcane bagasse [22]	0.8200	0.7500	0.8700	0.7300	0.7925
Oil Palm Empty Fruit Bunch [23]	0.5300	0.4800	0.2100	0.2300	0.3600

Overall, NKTB kenaf fibre exhibits a high NRC, demonstrating its effectiveness as a sound absorber. Increasing the thickness of the sample was crucial for optimising performance, with the 75 mm thick sample achieving the highest NRC value of 0.885 in this study. This result suggests that further increasing the thickness could enhance the sound absorption coefficient even more [18]. The study confirms that kenaf fibre is a viable material for sound absorption, performing on par with synthetic absorbers widely used in industry. The NRC is a crucial metric for evaluating sound-absorbing materials.

4. Conclusion

A comparative analysis was conducted between NKTB kenaf fibre sound absorber samples and an industrial synthetic foam composite absorber. The results demonstrated that the kenaf fibre absorber outperformed the synthetic foam, especially in the middle to high-frequency ranges. However, at mid-range frequencies (approximately 500 Hz), sugarcane bagasse fibre demonstrated superior performance compared to NKTB kenaf fibre. When evaluating the NRC, NKTB kenaf fibre slightly exceeded the performance of the reference kenaf fibre [7] by 0.005. Overall, the NKTB kenaf fibre consistently showed improved sound absorption coefficients across different thicknesses and with air gaps, indicating successful experimental outcomes. Besides its renewability, the NKTB kenaf fibre is biodegradable and environmentally friendly, unlike synthetic alternatives, and presents fewer health risks. As a by-product, it offers a cost-effective option for industries using natural fibres. Therefore, at the industrial level, NKTB kenaf fibre is a promising and practical choice for sound absorber production.

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Conflict of Interest

The authors state that there are no conflicts of interest related to the publication of this paper.

Author Contribution

The author assumes full responsibility for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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