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Using Walnut Shell Waste as an Eco-Friendly Aggregate for Concrete

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Abstract: Agricultural production currently generates large quantities of walnut shell waste. Therefore, the issue of efficient disposal of this waste is highly relevant. The aim of this study was to investigate the potential of walnut shells as an environmentally friendly coarse aggregate in concrete production. In the experimental study, concretes were produced with varying walnut shell contents (WS), replacing a portion of the coarse mineral aggregate, ranging from 0% to 50% by volume in 10% increments. Concrete tests were conducted 28 days after production. Density, compressive strength, and water absorption were studied. The composite structure was also assessed using SEM methods, and structural quality factors were calculated. The results showed that concrete density decreased by 15.5% at 50% WS content. It was recorded that with an increase in the volume fraction of WS, compressive strength decreased by 45%, and water absorption increased by 53.4%, respectively. The optimal content WS accounts for 10% by volume. The WS-containing concretes developed in this study are environmentally friendly building materials with a reduced environmental impact and can be effectively used in green construction.

Keywords: Walnut shell (WS), Concrete, Compressive strength

Introduction

Concrete and cement composites are among the most important materials for the construction industry; however, their use is associated with a number of environmental and resource-intensive challenges. In particular, cement production is characterized by significant carbon dioxide (CO_2) emissions, accounting for approximately 8% of global greenhouse gas emissions. Therefore, replacing traditional inert aggregates with alternative materials has become a pressing issue (Murali, 2025; Klyuev et al., 2025). Nutshells, due to their high porosity and water absorption capacity, represent a promising lightweight aggregate. However, their use is associated with a number of issues, including water consumption and physical and mechanical properties. The following paper examines the use of nutshells in cement composites, including various shell types, pre-treatment methods, and optimal dosages for achieving the required characteristics of composite materials (Akulova et al., 2016; Hilal et al., 2021).

The incorporation of nutshells into composite materials such as wood concrete and concrete alters their physical and mechanical properties, but this comes with certain compromises in strength and durability. Specifically, walnut shell-based wood concrete has a density range of 640 to 670 kg/m³, with the optimal density being around 650 kg/m³. Compressive strength after 90 days reaches 3.68–3.90 MPa, but water absorption is 43%, and resistance to subzero temperatures is 35 cycles. When using B30 concrete with the addition of nutshells, density decreases from 2344 to 2148 kg/m³ at a 30% replacement rate. The compressive strength also changes: at 5% substitution it is 45.5 MPa, and at 30% – 34.8 MPa. For the coconut shell-based composite, the compressive strength decreases to 38.0 MPa at 5% substitution and to 26.2 MPa at a replacement level of 30%, while water

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absorption increases from 6.0% to 13.0% (Akulova et al., 2016; Alsalami, 2017; Beskopylny et al., 2023; Nadir & Sujatha, 2018; Stel'makh et al., 2023). In self-compacting concrete, the use of walnut shells leads to a sharp decrease in density from 2162 kg/m³ to 1449 kg/m³ with 40% sand replacement. Compressive strength characteristics also demonstrate a nonlinear relationship: small additions (5%) of walnut shells improve strength properties, but at higher concentrations (30%), the interphase transition zone becomes heterogeneous and defective, which leads to a decrease in overall strength (Puzatova et al., 2024). A similar relationship is observed for concrete using coconut shells, where maximum strength is achieved with 5% replacement, after which a significant decrease in strength is observed with an increase in the proportion of filler (Beskopylny et al., 2023; Hanumanthappa et al., 2026; Stel'makh et al., 2023). In permeable concrete, the fine fraction of walnut shells, replacing part of the sand, helps to increase the efficiency of heavy metal immobilization (Karol et al., 2025).

The addition of walnut shells to ultra-high-performance concrete (UHPC) reduces the autogenous shrinkage of the UHPC matrix and improves hydration (Ren et al., 2025). The use of walnut shells as a replacement for coarse aggregate and steel slag as a replacement for fine aggregate is a rational formulation solution and allows for the production of environmentally friendly concrete with the required performance characteristics (Venkatesan et al., 2021, Boukhelkhal et al., 2023). Walnut shells are an artificially created by-product of recycling and can be used in cement composite technologies as a natural renewable filler, which is also confirmed by numerous other studies (D'Eusanio et al., 2023; Khalife et al., 2024; Mhaya et al., 2022; Shafigh et al., 2026). This work is aimed at developing the concept of sustainable development in the construction industry using environmentally friendly building materials.

The possibility of using walnut shell waste as a partial replacement for mineral filler in concrete production will be considered. The scientific novelty of this study lies in the development of new compositions of environmentally friendly lightweight concrete containing walnut shells and the discovery of new relationships between the properties and structure of the composites and the proven formulation parameters. Therefore, the primary objective of the study is to explore the potential of walnut shells as an environmentally friendly coarse aggregate in concrete production and to evaluate the feasibility of using these composites in the construction of various industrial and civil infrastructure facilities.

Materials and Methods

Materials

(a) (b)

Figure 1. Walnut shell: (a) walnut shell halves; (b) crushed shell

Before use in concrete, walnut shells were pre-cleaned and subjected to mechanical processing, which was carried out by crushing them in a laboratory jaw crusher to grains with a fraction size of 5-20 mm.

5. Plasticizer PK1 (P) (Polyplast , Moscow, Russia). Properties: density – 1.11 g/cm^3.

The following raw materials were used to produce experimental concrete samples:

1. Portland cement CEM I 42.5 H (PC) (CEMROS, Stary Oskol, Russia). Properties: specific surface area – 350 m2/kg; setting time – 3-10 hr-min; setting time – 4-40 hr-min; normal consistency – 30%; compressive strength at the age of 28 days – 54.3 MPa; flexural strength at the age of 28 days – 7.3 MPa;

2. Crushed sandstone produced by (CrS) "Aninsky Mining and Processing Plant" (Anikin village, Russia). Properties: fraction size 5-20 mm; bulk density – 1479 kg/m3; true density – 2661 kg/m3 ; crushability – 10.1% by weight; content of lamellar (flaky) and needle-shaped grains – 7.5% by weight;
3. Quartz sand (QS) (Subsoil, Samarskoye village, Russia). Properties : bulk density – 1347 kg/m3; the content of dust and clay particles – 0.06%; modulus size – 1.83;
4. Walnut shells (WS) (collected in the Krasnodar region, Russia). Properties: bulk density – 448 kg/m3; Water absorption – 17.6%; content of lamellar (flaky) and needle-shaped grains – 45.6% by weight. The appearance of a walnut shell is shown in Figure 1.

Methods

The production of experimental concrete samples with different WS contents, replacing part of the coarse mineral filler, was carried out in accordance with the recipe presented in Table 1. The coarse mineral filler was replaced by WS by volume from 0% to 50% in 10% increments.

Table 1. Compositions of concrete mixtures with different WS content

Mixture type	PC (kg /m$^{3)}$	QS (kg/m$^{3)}$	CrS (kg/m^3)	W (L)	WS (kg /m^3)	P (kg/m^3)
0WS	385	712	1093	210	0	3.85
10WS	385	712	984	210	33	3.85
20WS	385	712	874	210	66	3.85
30WS	385	712	765	210	100	3.85
40WS	385	712	656	210	133	3.85
50WS	385	712	547	210	166	3.85

The experimental concrete samples with WS were prepared as follows. Initially, all raw materials were dosed according to the recipe. The prepared raw materials were then poured into a concrete mixer in the sequence PC and QS and mixed dry. Next, coarse aggregates CrS and WS were added with mixing water and a dissolved plasticizer and mixed until a homogeneous consistency was achieved. The finished concrete mixture was poured into metal cube molds measuring 100 x 100 x 100 mm. The molds containing the concrete mixture were compacted on a vibrating platform for 60 seconds. The finished samples were removed from the molds after 24 hours and cured in a curing chamber for 27 days. At 28 days of age, the control and WS concretes were subjected to laboratory tests for density, compressive strength, and water absorption. All laboratory tests were conducted in accordance with standardized methodologies:

1. Density (ρ, kg /m^3). The density of concrete was determined on samples dried to constant mass and calculated using formula 1 with an accuracy of 1 kg /m^3:

$$\rho = \frac{m}{V} \cdot 1000 \tag{1}$$

where m is the mass of the sample (g);

V – sample volume (cm^3).

The density of a series of samples was determined as the arithmetic mean of the test results of three samples.

2. Compressive strength of concrete (R, MPa). Cube specimens were installed in a testing machine and loaded until failure at a constant rate of (0.6 ± 0.2) MPa /s. Compressive strength was calculated using formula 2 with an accuracy of 0.1 MPa:

$$R = \alpha \frac{F}{A} \tag{2}$$

where F is the breaking load (H);

A – area of the working cross-section of the sample (mm^2);

α is a coefficient that takes into account the dimensions of the samples (for samples with a side of 100 mm α = 0.95). The compressive strength of a series of samples was calculated as the arithmetic mean of three samples, the two with the highest strength.

3. Water absorption of concrete (W, %). Experimental concrete samples were placed in a container filled with water at a temperature of (20±2) °C and saturated until the results of two consecutive weighings differed by no more than 0.1%. Water absorption was calculated using formula 3 with an accuracy of 0.1%:

$$W = \frac{m_{\text{B}} - m_c}{m_c} \cdot 100 \quad (3)$$

where m_{B} is the mass of the dried sample, g;

m_c – mass of dry sample, g.

The water absorption of a series of samples was calculated as the arithmetic mean of three samples.

Results and Discussion

The results of determining the properties of concrete with different WS contents are presented in Figures 2-4.

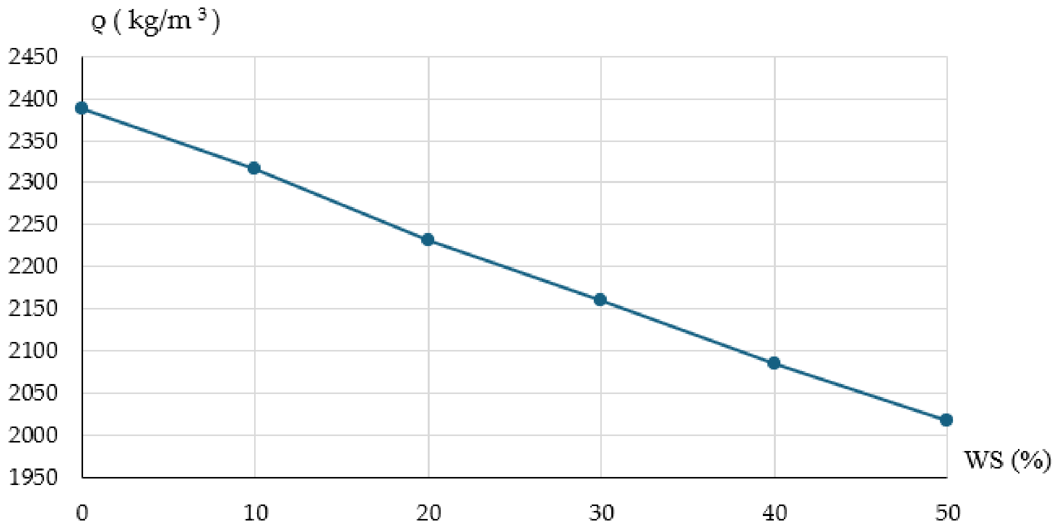


Figure 2. Concrete density versus WS content

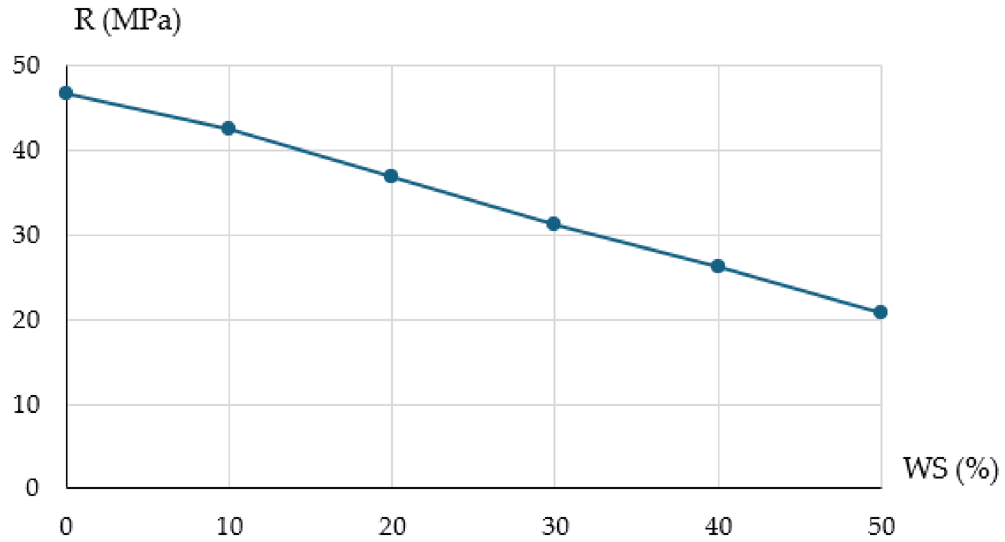


Figure 3. Dependence of compressive strength of concrete on WS content

According to the data presented in Figure 2, concrete density decreases as the WS content increases, replacing part of the coarse mineral aggregate. The control composition has the highest density of 2387 kg /m³. The lowest density of 2016 kg/m³ was recorded for the 50WS composition, which is 15.5% lower than the control composition. The reduction in the density of the composite is aZchieved by including WS, which has a low density (Edan et al., 2024; Ren et al., 2025).

The dependence of the change in compressive strength of concrete with WS is linear and decreases with increasing content volume fraction of WS. The control composition has the highest compressive strength of 46.7 MPa. Compositions of the 10WS, 20WS, 30WS, 40WS and 50WS types have the following compressive strength values: 42.5 MPa , 36.8 MPa , 32.3 MPa , 28.2 MPa and 25.7 MPa , respectively. For composition 50 WS the reduction in compressive strength was 45%. WS has significantly lower strength compared to CrS and leads to a decrease in the strength properties of the composite (Hanumanthappa et al., 2026; Shafigh et al., 2026).

Water absorption of concrete containing WS tends to increase with increasing WS volume fraction in the concrete. For example, the water absorption of the 50WS composition was 8.9%, 53.4% higher than the control value. Walnut shells are wood-based materials that actively absorb moisture. In the concrete composite structure, WS is saturated with water, increasing water absorption (Cheng et al., 2017).

Based on the results of assessing the density, compressive strength, and water absorption of concrete with varying WS content, it was found that the inclusion of WS reduces its density. However, this decrease in density is accompanied by a decrease in compressive strength and an increase in water absorption. The change in concrete properties (Δ) in % depending on the amount of WS is presented in Table 2.

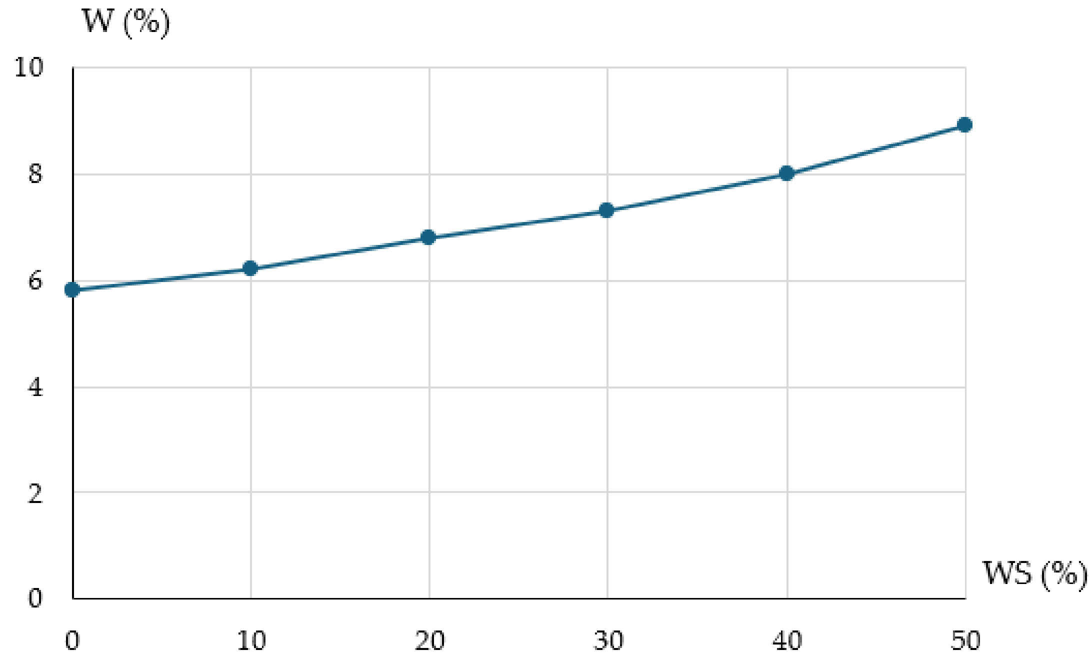


Figure 4. Dependence of concrete water absorption on WS content

Table 2. Concrete characteristics (Δ) in % depending on the amount of WS

Properties	WS content (%) 0	10	20	30	40	50
Δρ (%)	0	-3.0	-6.5	-9.6	-12.7	-15.5
Δ R (%)	0	-9.0	-21.2	-30.8	-39.6	-45.0
Δ W (%)	0	+ 6.9	+ 17.2	+ 25.9	+ 37.9	+ 53.4

Further, Figure 5 presents the results of calculating the structural quality factors for concrete with different WS contents. The structural quality factor FC is calculated using formula 4:

$$CCQ = \frac{R}{\rho_{FC}} \tag{4}$$

R – compressive strength (MPa)

ρ – density (g/cm^3).

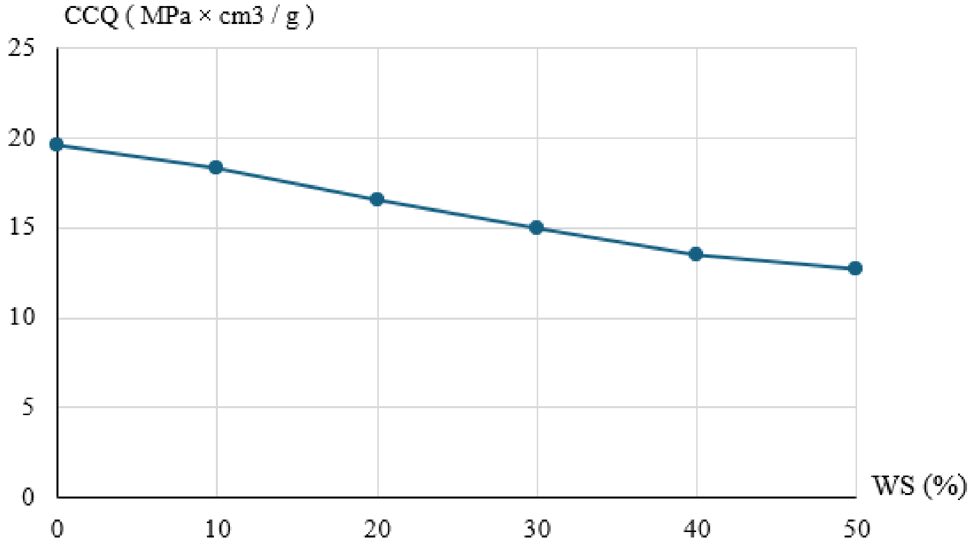
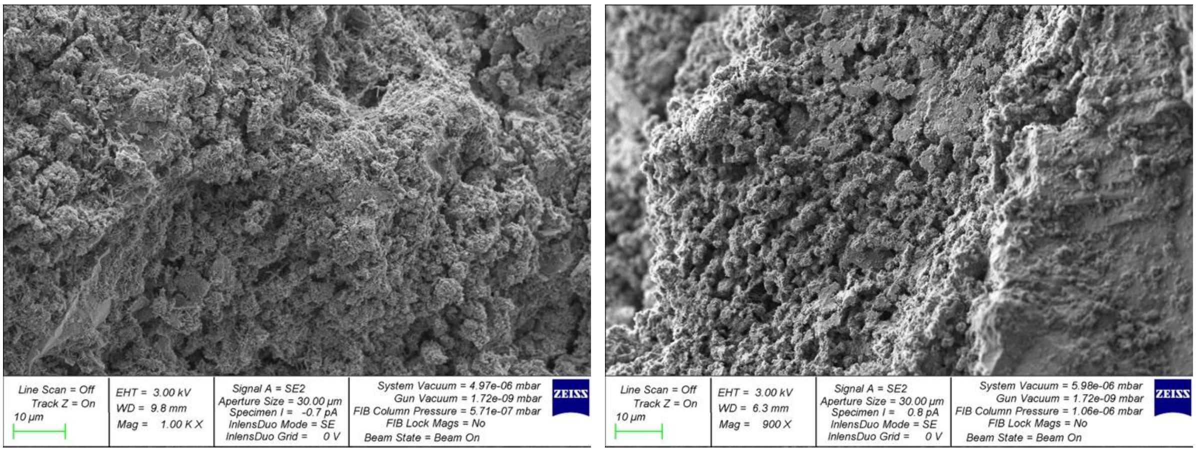


Figure 5. Results of determining the CCQ of concrete with WS

As can be seen from Figure 5 , the CCQ values of concrete with 10%, 20%, 30%, 40% and 50% WS content were 19.6 MPa×cm^3/g , 18.4 MPa × cm^3/g ; 16.5 MPa×cm^3/g; 14.5 MPa×cm^3/g; 12.6 MPa×cm^3/g and 10.3 MPa×cm^3/g. A comparative microstructural analysis of the cement matrices of the control concrete and the WS-containing concrete was performed. The results of the SEM analysis are presented in Figure 6.



(a) (b)

Figure 6. SEM analysis of concrete structure: (a) control concrete composition; (b) concrete composition with WS

The structure of the control composite (Figure 6a) is more organized and ordered compared to the structure of the composite containing WS (Figure 6b). The microstructure image of the control composite shows a more uniform distribution of calcium silicate hydrous (CSH) accumulation zones. The high density of CSH zones directly indicates the higher strength properties of the 0WS type composition (He et al., 2020).

The results obtained during the study are important for the sustainable development of the construction industry. It has been proven that crushed walnut shells can be used as lightweight aggregate in concrete technology. The optimal percentage of walnut shells replacing coarse mineral aggregate without significantly reducing strength properties is 10%. Further, as the volume content increases, With WS, the strength reductions become more significant, and at 50% WS, the compressive strength decreased by 45% compared to the control composition. Perhaps the main limitation of this study is the lack of understanding of durability properties, such as resistance to negative temperature effects and various aggressive chemical influences. This study demonstrates the feasibility and potential of using walnut shells in concrete products with varying cross-sectional characteristics (variotropic) manufactured using centrifugal molding (centrifugation or vibrocentrifugation). Walnut shell particles, which are lighter than traditional aggregate, will concentrate closer to the inner diameter of the ring-shaped product and influence the final properties of concrete, products, and structures made from it (Shcherban' et al., 2025).

Future research will focus on determining the properties of variotropic concretes and the durability of concretes containing walnut shells, as well as proposing new formulations and technological solutions aimed at increasing the resistance of these composites to aggressive environmental influences (Khalife et al., 2024; Li et al., 2023).

Conclusions

This study developed lightweight, eco-friendly concretes using walnut shells. Experimental composite samples were evaluated for density, compressive strength, and water absorption. Microstructural properties of the composites were analyzed, and structural quality factors were calculated. The density of concrete decreases with increasing volume fraction of WS replacing coarse mineral aggregate. Minimum density 2016 kg/m^{3}has a composition with 50% WS content. The compressive strength of concrete decreases with increasing volume fraction of WS and ranges from 46.7 MPa for the control composition to 25.7 MPa for the composition with 50% WS content. The inclusion of WS also increases the water absorption of the composites, which ranged from 5.8% for the control composition with 0% WS content to 8.9% for the composition with 50% WS content. Thus, concrete produced with partial replacement of coarse aggregate with WS maintains the basic physical and mechanical properties at the required level and can be effectively used in sustainable green construction.

Recommendations

The results show that the use of walnut shells as a partial substitute for coarse aggregate may be a promising direction for the production of lightweight concrete composites. The most rational is the WS content at a level of about 10% by volume, which ensures an acceptable level of strength while reducing the density of the material. Such compositions can be recommended for use in structures where weight reduction and improved thermal insulation properties are important, for example, in enclosing and curtain elements of buildings. In the future, it is advisable to conduct additional studies on the durability, water absorption and microstructure of concrete with WS, as well as to evaluate its behavior under prolonged operating loads.

Scientific Ethics Declaration

* The authors declare that the scientific, ethical, and legal responsibility for this article published in the EPSTEM journal belongs entirely to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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