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Study of the Ecological Interest of a Rice Husk Ash Mortar

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ABSTRACT: To comply with the requirements of sustainable development, several organizations are studying the possibility of using renewable and ecological materials. This work aims to determine in what context it is ecological to replace cement with rice husk ash partially. To do this, on the one hand, we determined the CO_2 mass emitted during the production of cement from the limestone decarbonation equation. On the other hand, we determined the CO_2 mass emitted during the production of RHA (rice husk ash) using the complete rice husk combustion equation and Steven's realistic decomposition model. We then compared the quantity of CO_2 emitted during the production of cement to that emitted during the combustion of the rice husk. Finally, we partially replaced cement with ground RHA to evaluate the effect of this substitution on the porosity and compressive strength of mortars. According to the findings of this study, cement production emits 0.94 kg of CO2 per kilogram of clinker, compared to 1.72 kg for RHA production, per kilogram of clinker and per kilogram of RHA, respectively. Also, these results show that using RHA leads to an improvement of the porosity up to 10.14%, and 15.59% for the improvement of the compressive strength. It is, therefore not more ecological to produce rice husk ash and replace it with cement. However, using rice husk ashes from energy production furnaces has a double advantage. The first concerns the environmental aspect, and the second concerns the improvement of mortars' durability and compressive strength.

Keywords: Strategic Management, Element, Evaluation and Control.

INTRODUCTION

It is well established that agricultural crop residues are not managed efficiently (Ghosal and Moulik, 2015; Amin and Abdelsalam, 2019; Khoso et al., 2022; Ganta et al., 2022). For this reason, work over the past two decades has shown ways of using these residues to recover them. Among these works, several explain the usability of rice husk ash in construction. From all this work, we realize that: The calcination of the rice husk gives ash whose rate is about 20% of the rice husk mass (Anshar and al. al., 2015; Ghosal and Moulik, 2015; Washington et al., 2018). Furthermore, rice husk ash, when produced in a temperature range between 550°C and 900°C (Thiedeitz et al., 2020; Ganta et al., 2022; Zaffar et al., 2022), offers an exciting proportion of silica which makes it useful as a cement additive (Zaid et al., 2021; Sanou et al., 2019). Silica reacts with cement to transform hydrated lime into silicates (Bheel et al., 2019; Pamphile et al., 2020) which improves the performance of the cementitious matrix. When rice husk ash is used in proportions of less than 20%, it increases the compressive strengths of the cementitious material (Krishna et al., 2016; Washington et al., 2018; Jongpradist et al., 2018; Saand et al., 2019; Bheel et al., 2019; Amin and Abdelsalam, 2019; Isberto et al., 2019). Due to its porosity, rice husk ash makes cementitious materials lighter than the reference material (Olutoge and Adesina, 2019). From these listed points, we realize that rice husk ash can reduce cement production by up to 20%. It is, therefore, a good alternative, given that cement production releases a large amount of CO_2 and consumes a large amount of energy during the cement production phase. The cement industry is also the world's second largest producer of CO2, with around 5 to 8% (Thiedeitz et al., 2020; Ganta et al., 2022) of global carbon dioxide production. If the above works allow us to know the amount of carbon dioxide emitted during the production of cement, if they show us that it would be technically interesting to substitute cement with rice husk ash, few or no work has shown the quantity of CO2 emitted during the production of rice husk ash. This work aims to determine in which context it is ecological to partially replace cement with rice husk ash.

MATERIAL AND METHODS

Rice Husk

The rice husks used come from the commune of Matéri in Benin.

Figure 1: Rice Husk

Rice husk ashes

To identify the calcination temperature necessary to obtain a constant ash content, we carried out the calcination at different temperatures: 400°C, 450°C, 500°C, 550°C, 600°C, 650°C, 700°C, 750°C, 800°C, 850°C. This calcination was done in two phases. A first of one-hour thinking in which the temperature rises in the oven to the target value. The second phase is where the temperature in the oven is maintained at the target value for one hour. The ash rate as a function of the calcination temperature is shown in Figure 5. From 600°C, the rice husk ash obtained is white and the proportion of rice husk ash hardly varies for temperatures above 600°C. For this reason, we used the ash obtained at 600°C to make cementitious mortars.
Once the ash has been obtained, it’s ground before its substitution to part of cement.

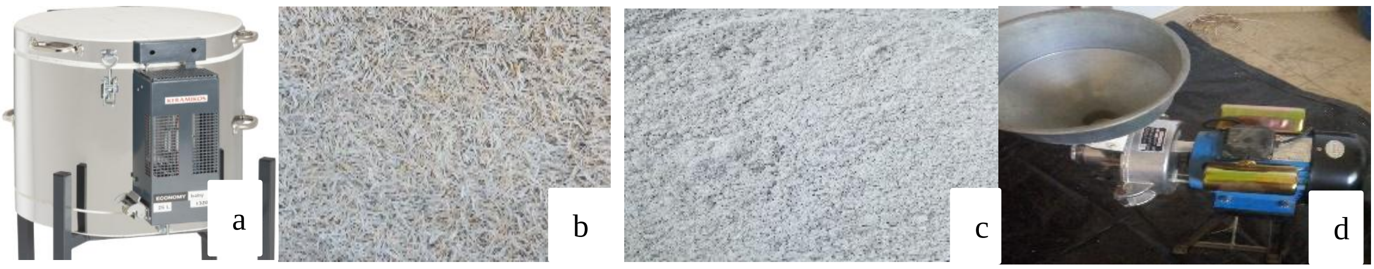

Figure 2: kiln (a), unground RHA (b), ground RHA (c), grinder (d)

Preparation of reference specimens

The reference mortar was made in accordance with the requirements of standard NF EN 196. We have produced a mixture whose proportion of constituents is as follows:
The mass fraction of sand is three times that of cement. The W/C ratio used is 0.6 due to the differences between the sand used and that standardized.

Formulation of rice husk ash mortar

We replaced part of the cement with rice husk ash in these formulations. Therefore, we substituted cement with rice husk ash at rates of 2.5%, 5%, 7.5%, 10%, and 12.5% in mass fraction.

Making rice husk ash mortars

The preparation of the rice husk ash-based mortars is conducted in the same way as for the case of the reference mortar; the difference here is the substitution of part of cement by the rice husk ash. Here, the rice husk ash is poured into the bowl simultaneously with the cement. In addition, 5cm*5cm*5cm cubic specimens were made to determine the impact of grinding rice husk ash on the mechanical characteristics of the composites.

Storage of rice husk ash mortars

Once the specimens have been made, they are kept in water until the day of crushing

Figure 3: Specimen curing condition

Determination of physical characteristics

We determined the spread of fresh mortar using a flow table in accordance with the NF EN 1015-3 standard and its density in accordance with the NF EN 1015-6 standard. In addition, we determined the density, the absorption coefficient, and the apparent porosity of hardened mortar in accordance with the ASTM C948-81 standard.

Impact of cement and rice husk ash manufacturing on the environment and energy consumption

Determination of the amount of energy needed to produce cement

To get an idea of the amount of energy consumed during cement production, we have recourse to the literature.

Determination of the amount of CO_2 released during this production.

To estimate the amount of carbon dioxide emitted during the transformation of raw material into clinker, we used the limestone decarbonation equation.

The limestone decarbonation results in the equation (eq1):

$$C_aCO_3 \rightarrow C_aO + CO_2 \qquad (eq1).$$

The decarbonation of limestone releases a mass of carbon dioxide given by the equation (eq2):

$$m_{CO_2} = \frac{m_{C_aCO_3} \times M_{CO_2}}{M_{C_aCO_3}} \qquad (eq2).$$

Being $m_{C_aCO_3}$ the mass of limestone, $M_{C_aCO_3}$ and M_{CO_2} respectively the molecular molar masses of limestone and carbon dioxide. The mass of carbon dioxide released during cement production is obtained by adding the mass resulting from decarbonation 0.39 Kg corresponding to the mass linked to the combustion of fuels (Gartner, 2004). It should be noted that one ton of clinker requires approximately 1.6 tons of raw material and that approximately 78% of the raw material is composed of C_aCO_3 (Prax, 1979). To ensure that the estimation method is correct, we compared the estimated quantity of carbon dioxide to that obtained in the literature (Habert et al., 2010; Omatola and Onojah, 2012; Telschow et al., 2012).

Amount of CO_2 emitted during the calcination of the rice husk

To estimate the amount of CO_2 emitted during the production of rice husk ash, we proceeded as follows: determine the composition of the rice husk, use the proportions from the real decomposition method (Steven et al., 2022) to estimate the mass of CO_2, use the elemental composition of the rice husk to estimate the mass of CO_2 through the carbon to the carbon dioxide conversion equation.

Determination of the elemental composition of rice husk

X-Ray Diffraction carried out the elemental analysis of our rice husk. Using proportions from the real decomposition method (Steven et al., 2022). This decomposition method assumes that the product obtained is composed of gas, liquid and carbon (solid) at the volatilisation stage. These are N_2, CO, CO_2, H_2O, and remaining O_2 (Anshar et al., 2015; Steven et al., 2022). Unlike the simple decomposition method, which assumes that the product from volatilization is composed of C, H, O, N (Bindar, 2013).

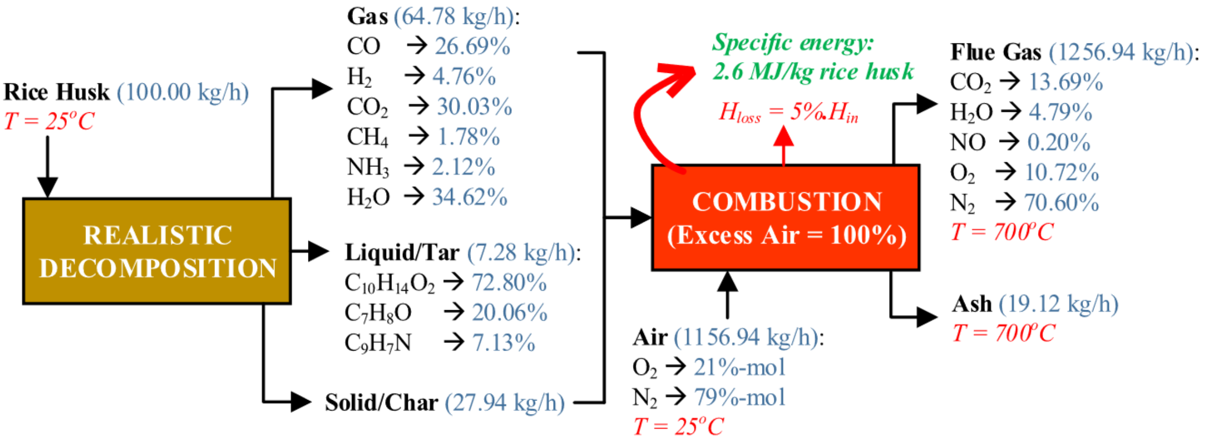

Figure 4: Proportion of products from burning rice husks (Steven et al., 2022)

For a given mass of calcined rice husk, it is possible to find the mass of flue gas and carbon dioxide mass by using the proportion of CO_2 in this gas.

Using Elemental Composition of Rice Husk to Estimate CO_2 Mass.

The elemental composition of the rice husk gives us the mass proportion of carbon in the rice husk. So, for a given mass of rice husk, we can determine the associated mass of carbon. As every large molecule of carbon dioxide contains a carbon atom, carbon dioxide emission involves the consumption of carbon atoms. We assume that there is enough air during combustion to convert all the carbon in the elemental composition of the rice husk into CO_2 through the equation:

$C + O_2 \longrightarrow CO_2$ (eq3)

To calculate the mass of carbon dioxide, we used the equation $(eq4)$:

$$m_{CO_2} = \frac{m_C * M_{CO_2}}{M_C} \qquad (eq4).$$

Being m_C the mass of carbon M_{CO_2} and M_C , respectively the molecular molar mass of carbon dioxide and carbon.

The equation $(eq5)$ allowed to determine the mass of carbon from the mass of rice husk:

$$m_C = \%C \times m \qquad (eq5).$$

$\%C$ being the percentage of carbon in raw rice husk and m the mass of rice husk

RESULTS AND DISCUSSION

Table 1 shows the elemental composition of rice husk. This composition is very close to that used by (Steven and al., 2022) for the thermodynamic modeling of rice husk combustion. This model could therefore be appropriate to give reliable results in the present study. Figure 5 shows the evolution of the mass of ash resulting from the combustion of the rice husk. We note that this mass drops very quickly with low temperatures and eventually stabilizes from 600°C around 20% of the initial mass. Anshar et al.(2015), Ghosal and Moulik (2015), and Washington et al.(2018) found this value in the literature. This stabilization is linked to the total departure of carbon only to leave white ash. We realize that the composition of our rice husk and the rate of our ash are very close to those resulting from the work of (Steven et al., 2022) for the thermodynamic modeling of rice husk combustion. This justifies the ability of his model to give an estimate of CO2 from the combustion of our rice husk.

Table 1 :The elemental composition of rice husk

Elements	C	H	O	N
Proportions (%)	46.21	7.70	44.39	1.70

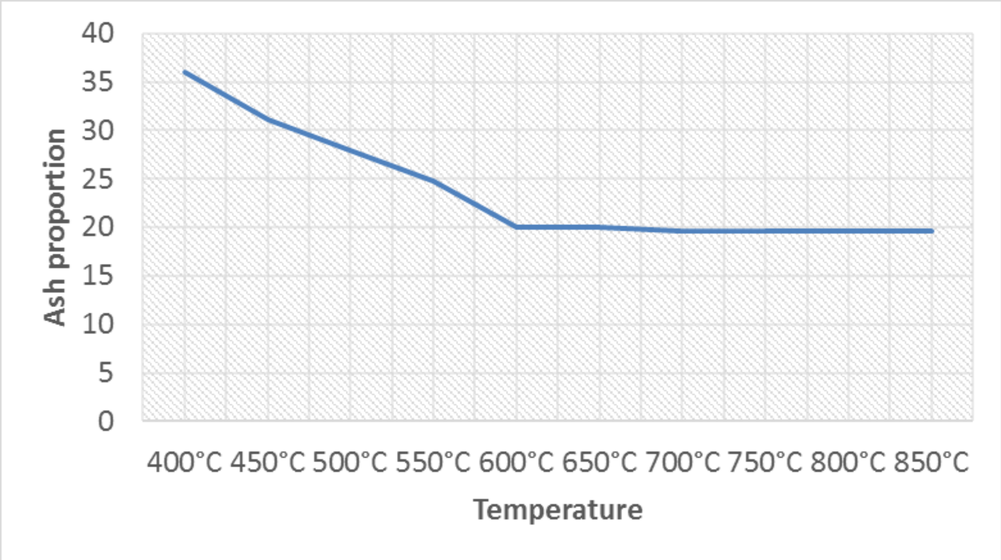

Figure 5: Evolution of the rice husk ash mass as a function of calcination temperature

Table 2: Mass of the products resulting from the complete combustion of the rice husk according to Steven's method

Combustion Product	CO_2	H_2O	NO	O_2	N_2
Quantity per Kg of rice husk	1.72	0.60	0.03	1.35	8.87

Amount of carbon dioxide from cement manufacturing

Table 3 gives us the mass of carbon dioxide released during the production of cement. We notice that the mass of carbon dioxide that we obtained using the equation $(eq2)$ is very close to the values obtained by other authors (Habert et al., 2010; Omatola and Onojah, 2012; Telschow et al., 2012).

Table 3: Mass of carbon dioxide released to produce one kilogram of cement

Quantity of CO_2 emitted during		Estimation value	Telschow	Habert	Omatola
Decarbonation	CO_2	0.55	0.54-0.6	0.53	-
Cement manufacturing		0.94	0.9-1	0.92	1-1.25

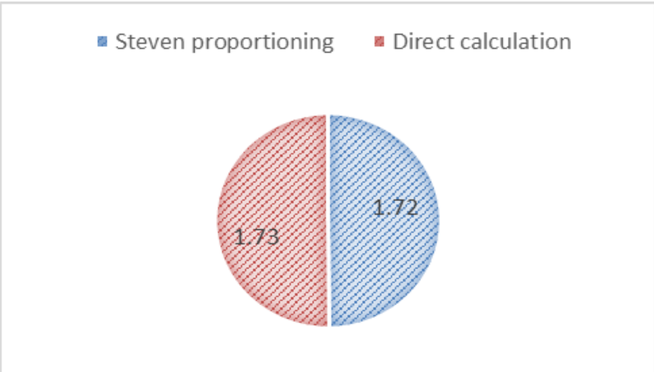

Figure 6: Mass of CO_2 released during the complete combustion of 1Kg of rice husk

Figure shows us the mass of CO_2 obtained during the complete combustion of one kilogram of rice husk using the proportions of Steven's model and using the equation for the conversion of carbon into carbon dioxide $(eq4)$. This figure shows us that the value obtained by using equations$(eq3)$ and $(eq4)$ is very close to that obtained by the realistic decomposition method of (Steven et al., 2022). Figure shows us the amount of CO_2 emitted during rice husk ash and clinker production. This figure shows us that rice husk ash releases a little more carbon dioxide during its production than cement. If we only consider this aspect of the amount of CO_2 emitted, we will be tempted to say that the use of rice husk ash has no interest. However, cement production requires more than 1.75MJ/Kg (Telschow et al., 2012; Taylor, 1997), while rice husk has a high calorific value (Arranz et al., 2021) with a value of up to 15.27MJ/Kg (Steven et al., 2021; Singh et al., 2022; Steven et al., 2022). It can therefore be used in part to produce energy, without forgetting its renewable aspect, and serve as silica-rich material (Okoya, 2013) that can be recovered in construction (Saand et al., 2019; Khoso et al., 2022). In addition, the amount of CO_2 released by the combustion of the rice husk is still captured (Van der Kooi et al., 2016) by new rice plants during their growth (Thompson et al., 2017). Thereby CO_2 produced by calcining the rice husk enters the life cycle of the rice husk material.

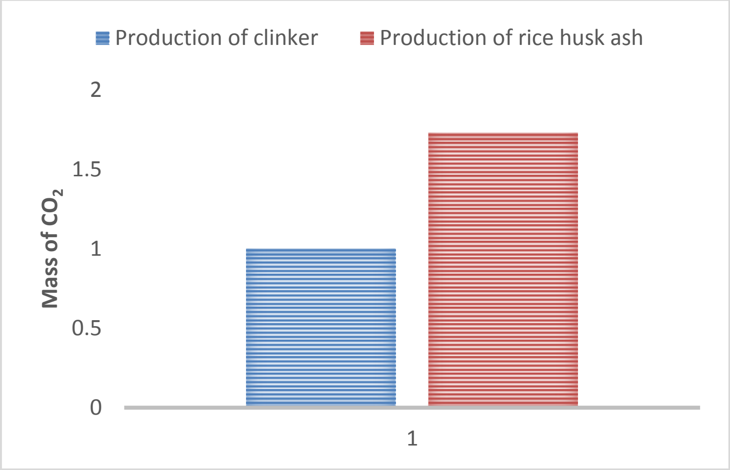

Figure 7: Mass of carbon dioxide released as function of the material calcinated

Interest in using ground rice husk ash in filling mortar pores.

Figure 8 shows us the evolution of the improvement of the porosity of the cementitious mortar as a function of rice husk ash mass fraction in replacement to cement. We notice that a positive coefficient represents the porosity of the mortar up to 7.5% of cement substitution. This means that at these rates, we have a decrease in porosity. This is interesting because it could improve the durability of the mortar (Bheel et al., 2019; Zaid et al., 2021). However, the porosity is represented by a negative coefficient for 10% and 12.5% rates. This means that the porosity of these mortars is greater than that of the reference material. Note that the pore introduction coefficient at 10% is still very low, which is acceptable.

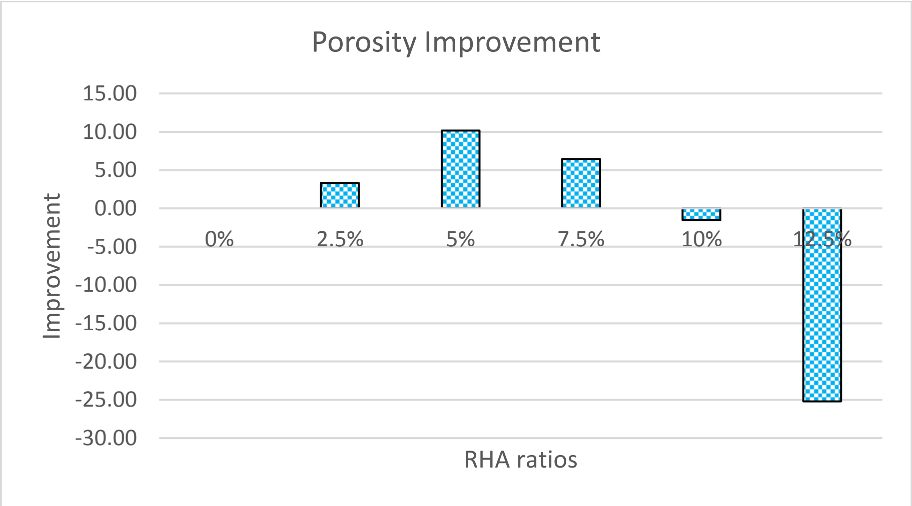

Figure 8: Evolution of porosity improvement as a function of rice husk ash mass fraction

The interest in using crushed rice husk ash on compressive strength

Figure 9 shows us the compressive strength evolution according to the cement replacement rate by rice husk ash. We notice a positive and increasing coefficient up to the rate of 10%. This means that the compressive strength is improved up to 15.59% with 10% cement replacement by rice husk ash (Krishna et al., 2016; Isberto et al., 2019). This is related to the fact that silica present in rice husk ash reacts with portlandite to form new silicates, reducing the material's pores (Dao et al. 2018). On the other hand, with a rate of 12.5% of cement replacement by rice husk ash, we observe a drop in the compressive strength of the mortar compared to the reference; this results in a negative coefficient. This drop in resistance is explained by the fact that at 12.5%, the cement is no longer sufficient to transform all the rice husk ash into silicates. This leaves areas of weakness in the material.

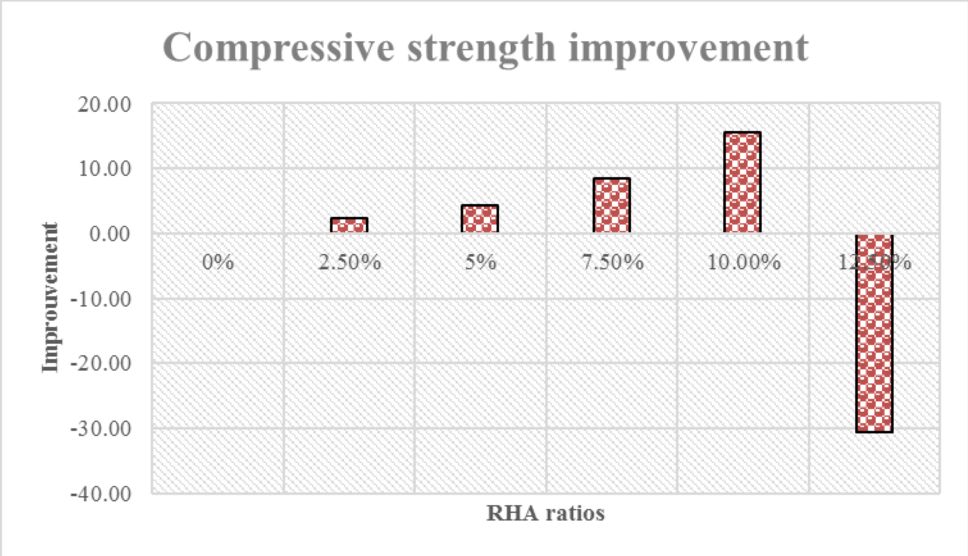

Figure 9: evolution of compressive strength improvement as a function of rice husk ash mass fraction

CONCLUSION

This work aims to determine in which context it is ecological to partially replace cement with rice husk ash in a cementitious matrix composite. The results of this study allow us to say that:

- Calcination of rice husk produces more carbon dioxide than cement manufacture
- Given the calorific value of the rice husk, if it is used as fuel in a temperature-controlled oven, it will be very interesting in terms of renewable raw material
- Rice husk ash reduces porosity in the mortar
- Rice husk ash improves compressive strength for replacement rates of less than 12.5%
- Rice husk ash is recommended as a partial substitute for cement if it is a residue from a power generation kiln.

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Ethical Clearance Number
No available.

Competing Interests
No potential conflict of interest.

Funding Information
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Authors Contributions
All the authors contributed equally to this work.

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