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Research Paper

Resin Matrix Composition on the Performance of Brake Pads Made from Durian Seeds: From Computational Bibliometric Literature Analysis to Experiment

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Abstract

The purpose of this study was to analyze the effect of a resin composition on the performance of brake pads with durian seeds (BDs) as the base material. Experiments were done by attaching saw-milled BD particles to a polymer matrix. Various resin compositions were used for preparing the brake pad, which was then tested (press test, puncture test, and friction test). Physical properties (i.e., particle size, surface roughness, morphology, and density), as well as mechanical properties (ie: hardness, wear rate, and friction coefficient properties), were investigated. Based on observations, the best mechanical properties were found in the highest resin mixture, reaching a compressive strength value of 2.4 MPa. The impact of the homogeneity of the brake pad filler particles is the main reason. The high resin composition causes more cross-links to be formed. This research demonstrates the prospective environmentally friendly and inexpensive brake pads used to replace current products that use hazardous materials.

Keywords: Brake pad; Durian seeds; Bibliometric; Agricultural waste

1. Introduction

One of the most important parts of a vehicle is the brake pad. The function of the brakes is to control, slow down, and stop the speed of a vehicle. Brakes work by converting kinetic energy into heat. The change of kinetic energy into heat is done by rubbing the disc with the pads when the two components are in contact [1]. Based on the manufacturing process, brake pads are particulate composites consisting of binders and reinforcing materials. The reinforcing material consists of particles that are evenly dispersed in a matrix, whose function is as a binder, to obtain a compact structure [2]. Apart from reinforcing materials and binding materials, the important elements contained in brake pads are fillers and friction materials [3]. The binder consists of various resins including phenolic, epoxy, polyester, silicone, and rubber. Resin serves to bind various constituent substances in friction. At a stable temperature, the binder can form a matrix [4]. Friction materials have an important role in the properties of brake pads such as increasing flexural resistance, reducing porosity/noise, and increasing strength [5]. For the last 8 years, asbestos has dominated as the friction material. However, now the use of asbestos as a friction material has been banned because it is dangerous and carcinogenic [6]. Carcinogenic is a substance that can cause the growth of cancer cells [7].

In recent years, the development of environmentally friendly brake pads using biomass as non-asbestos organic material (NAO) has become the main focus of researchers [3], [8]. The use of biomass in brake pads includes rice husks [3], sawdust [9], palm shells [10], periwinkle shells [11], cocoa beans [12], corn husks [6], and shells [13]. Here, different from other studies, we used durian seeds as particles in the manufacture of brake pads using various resin/hardener compositions. The selection of durian seeds (BDs) as a composite filler is because they are one of the agricultural wastes that are abundant and largely available, creating problems for the environment. Although they can be grown, most people dispose of them directly. BDs are focused as filler in composite materials because they contain high cellulose and lignin content. The durian variant used is a durian originating from Medan (with the Latin name of *Durio zibethinus Murr*).

Based on previous research (**Table 1**) on the effect of particle size on the mechanical properties of materials [14]. BDs are used as a friction material in resin-based brake pads. While other methods require high temperatures and pressures in the manufacture of brake pads [3], this study was carried out the manufacture of resin-based brake pads at room temperature without additional heat and pressure. The involvement of polymerization of epoxy resins at room temperature in the manufacture of brake pads aims to bind durian seed particles in the construction of brake pads. The most common composite component used as a binder or matrix in brake pad compositions is resin. The resin can accommodate all materials so that the brake pads can withstand heat and mechanical loads. To affect the friction of the shoe composite brake, phenolic resin is used. The coefficient of brake pads will increase with the amount of phenolic resin [5] and when the amount of phenolic resin is low, the coefficient will decrease. Phenolic resin is influenced by temperature characteristics which will have an impact on the composite where the modulus of the phenolic resin storage area will decrease [7], [9]. In addition, a bibliometric study with the keywords "Resin-Based Brake Pad" was conducted in this study to assist and as a reference for researchers in conducting and deciding on research topics, especially those related to resin-based brake pads.

Table 1. Previous research on brake pads

Type of agricultural waste	Authors	Results	Ref
Rice Husk	Nandiyanto, A. B. D., Hofifah, S. N., Girsang, G. C. S., Putri, S. R., Budiman, B. A., Triawan, F., and Al-Obaidi, A. S. M.	Particle size that affects the surface, inter packing distance, and matrix softening matrix of rice husk and resin particles.	[3]
Sawdust	Anbu, G., Manirethinam, N., Nitish, K. P., Pavithran, K., Priyadharsan, A., and Sabarigiri, S.	The impact produced by the addition of Sawdust is on the level of wear and degradability of the brake pads.	[9]
Palm Shells	Afolabi, M., Abubakre, O. K., Lawal, S. A., and Raji, A.	The size of the palm shells affects the density, impact strength, hardness value, water resistance, and oil resistance.	[10]
Periwinkle Shells	Yawas, D. S., Aku, S. Y., and Amaren, S. G.	High wear rates and high friction coefficients are strongly associated with a decrease in the particle size of Periwinkle Shells.	[11]
Cocoa Beans	Olabisi, A. I., Adam, A. N., and Okechukwu, O. M.	The decrease in the number of cocoa beans was correlated with hardness, compressive strength, high breaking strength, and impact strength.	[12]
Corn Husks	Ademoh, N. A., and Olabisi, A. I.	Corn husks produce the acquisition of brake pads with better compression strength, lower porosity, higher hardness, and lower rates of brake pad wear.	[6]
Snail shell	Abutu, J., Lawal, S. A., Ndaliman, M. B., Lafia-Araga, R. A., Adedipe, O., and Choudhury, I. A.	The increase in the snail shell particle size contributes to high oil absorption, high water absorption, wear rate, compressive strength, and low density.	[13]

In addition to research on brake pads, research on bibliometrics has been carried out by many researchers. However, bibliometric research with the keyword "Resin-Based Brake Pad" is still rare. Previous studies on bibliometrics include: Digital learning [15], computer science [16], vocational school [17], high school [18], covid-19 research [19], scientific publications [20], chemical engineering [21], materials research [22], special Needs Education [23], publication of techno-economic education [24], engine performance [25], dataset portrays decreasing number of scientific publications [26], application in robotic hand systems [27], research effectiveness in a subject area among top-class universities [28], educational research [29], bioenergy management [30], magnetite nanoparticle [31], nanocrystalline cellulose production [32], nano metal-organic frameworks [33], titanium dioxide nanoparticles [34], nanocrystalline cellulose [18], carbon nanotubes [35], nano-sized agricultural waste brake pads [36].

The brake pads in this study were made using durian seed particles with a certain size and composition of different resin variants (made from Bisphenol A-Epichlorohydrin and Cycloaliphatic Amine). Puncture strength and compressive tests were carried out to analyze the mechanical properties of the brake pads. Friction tests are then carried out to provide the heat resistance, mass loss, wear rate, and friction coefficient of the prepared brake pads. In previous studies, it has been known that particle size affects the mechanical properties and friction properties of brake pads [3]. This study was conducted to strengthen this statement and to show the potential of durian seeds as a friction material in brake pads and the effect of the amount of resin on the strength level of brake pads.

2. Method

Figure 1 shows the flowchart of the experimental procedure.

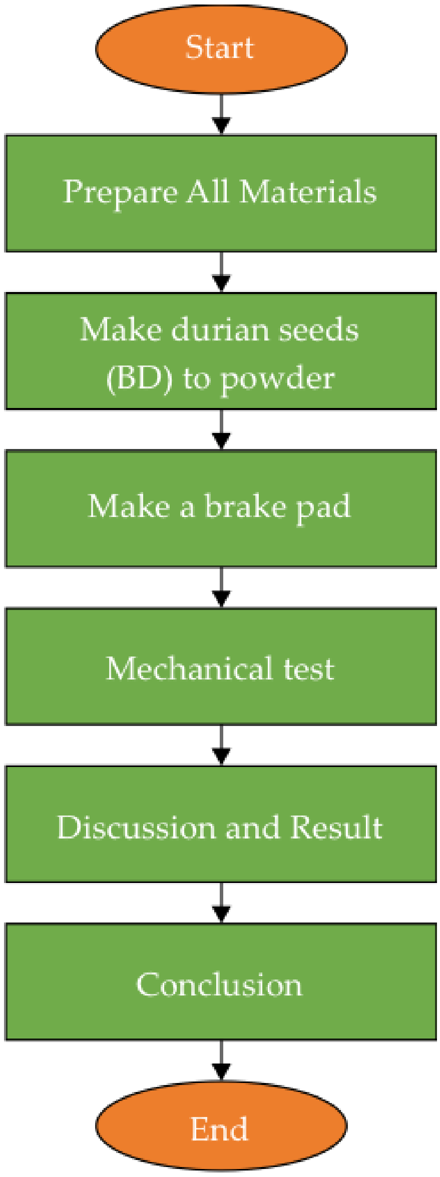


Figure 1. Flowchart of the research procedure.

2.1. Materials

Brake pads are made using two main ingredients, namely resin (a mixture of Bisphenol A-Epichlorohydrin and Cycloaliphatic Amine) and BDs (a Medan durian; with a Latin name of *Durio zibethinus Murr*; purchased from the local market in Bandung, Indonesia).

2.2. Brake Pad Production

Figure 2 shows a flowchart of the process of making brake pads of resin-based brake pads with BDs particles. Based on **Figure 2**, the first step that must be done before making brake pads is to prepare BD. BD was prepared to be powder. First, the BDs were dried in an oven at 200°C to create carbon. Too high temperature can create a mass loss. Carbon converts to carbon monoxide and carbon dioxide when the temperature is higher than 200 °C [37], [38]. After that, carbon particles from BDs were grounded using a saw-milling tool to obtain BD particles of various sizes (200-1000 μm) using sieve mesh apparatus following ASTM D1921 [3]. Detailed information on the use of a saw-milling process is shown in our previous report [39].

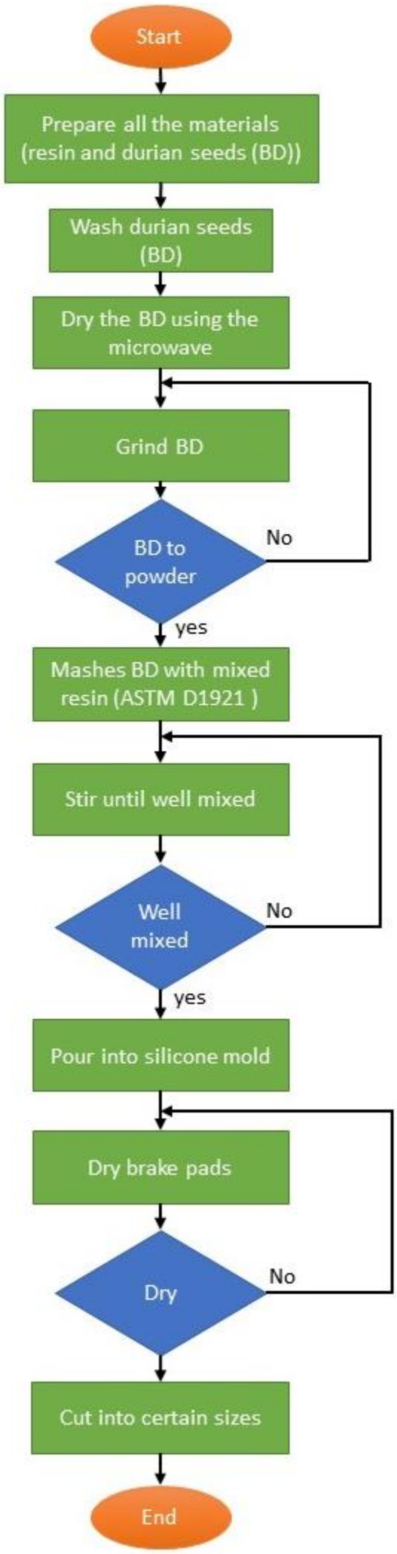


Figure 2. Flowchart for the experimental procedure for the production of the brake pad

After preparing the BD, the next step is to make brake pads. To make the four brake pad samples, BD which had been mashed and turned into powder was added with a mixture of resin (Bisphenol A-epichlorohydrin (BAE)) and hardener (Cycloalphatic Amine (CA)). Here, the composition of BD was kept constant. Meanwhile, the composition of the resin and hardener was varied with the mixture of resin and hardener being 1:1 for each sample. Table 2 shows the mass composition of the raw material in detail. Then, the mixture was stirred until evenly distributed and then poured into a silicone mold (dimensions 1 x 1 cm) and dried in a room (at room temperature and pressure) for 1 week (7 days). During the drying process, avoid exposure to sunlight. Table 2 summarizes the mass composition of the materials used in the manufacture of brake pads.

2.3. *Physical Characterization*

A digital microscope was used to investigate the particle size and morphology of the raw material (calcium carbonate from chicken bone waste). Fourier transform infrared was used for chemical characterization to analyze elemental structure products (FTIR, FTIR-6600, Jasco Corp.; Japan). A detailed explanation for the FTIR analysis is reported in the literature [40].

2.4. *Mechanical Properties Test*

The mechanical properties of brake pads were determined by performing compressive strength tests and puncture strength tests. The stand (Model I ALX-J, China, ASTM D-2240) is equipped with a digital force meter (Model HP-500, Serial, No. H5001909262, ASTM D-4713) which is used as a compression test device. Constant displacement rate of 2.6 mm/min. The compressive force simultaneously produces a curve that describes the texture of the profile. The compressive strength is obtained from the maximum point of the compressive stress-strain curve. As a model, brake pad samples with dimension 1 x 1 cm was used.

Table 2. Composition of raw materials (mass) in the manufacture of brake pads.

Raw Materials	Mass (g)			
	DA	DB	DC	DD
BD (Durian Seed)	10.0	10.0	10.0	10.0
BAE (Bisphenol A-epichlorohydrin)	4.0	3.0	2.8	2.0
CA (Cycloalphatic Amine)	4.0	3.0	2.8	2.0

Assessment of hardness during the testing process using the maximum force (in units of Newtons (N)). The instrument used to perform the puncture strength test is the Shore Durometer (Shore A Hardness, in size, China). During the test, a probe is used to puncture the brake pads. Brake pads' hardness is measured on a scale of 0 – 100. Each sample was tested (puncture test and compressive test) 5 times [3], which is to ensure the precision.

2.5. *Specific Gravity*

The specific gravity of the test object is calculated by dividing the unit weight of the brake pad material by the unit weight of water. The formula for specific gravity is shown in Eq. 1 [41].

$$Density\ (\frac{g}{cm^3}) = \frac{M}{V} \quad (1)$$

where M is the mass (g) and V is the volume (cm^3).

2.6. *Friction Test*

Before the test is carried out, the resin layer on the surface of the brake pads is removed by polishing. The friction test was carried out by sanding the brake pads using sandpaper (80 grit; Dae Sung CC-80 Cw) with a mass load of 9 kg for 5 minutes and a sanding speed of 25 cm/s. The mass of the brake pad would be recorded every 1 minute. Eq. 2 is used to calculate the wear rate of the brake pads (*M*) [3].

$$M = \frac{M_a - M_b}{t \times A} \quad (2)$$

where *Ma* is the initial weight of the brake pad (g), *Mb* is the final weight of the brake pad (g), *t* is the testing time (s), and *A* is the area of friction cross section (mm^2).

The coefficient of friction (μ) is the ratio of the frictional force (*f*; Newton) to the applied force (*N*; Newton), which is expressed in the form of Eq. 3 below [42].

$$\mu = f / N \quad (3)$$

3. Results and Discussion

3.1. *Analysis on Brake Pads Study Using Bibliometric Analysis*

The development of research on the keywords that the researchers used, namely "Resin-Based Brake Pad" based on the range of years that the researchers chose (2017-2018) can be seen in **Figure 3**. The article data taken are articles that have been published and indexed by Google scholar. Then, we put data into "publish or perish" and mapped using VOSviewer. Based on **Figure 3**, in 2017, only 1 article discusses research on resin-based brake pads. In the following year, research developments regarding the keyword resin-based brake pad began to appear and each year the number increased. In 2018, there were 199 articles, increasing to 239 articles in 2019, then increasing to 259 articles in 2020. The decrease in the number of articles published regarding resin-based brake pads occurred in 2021. However, the decrease was only 1 article, which in 2020, there were 259 articles, down by 1 article to 258 articles in 2021.

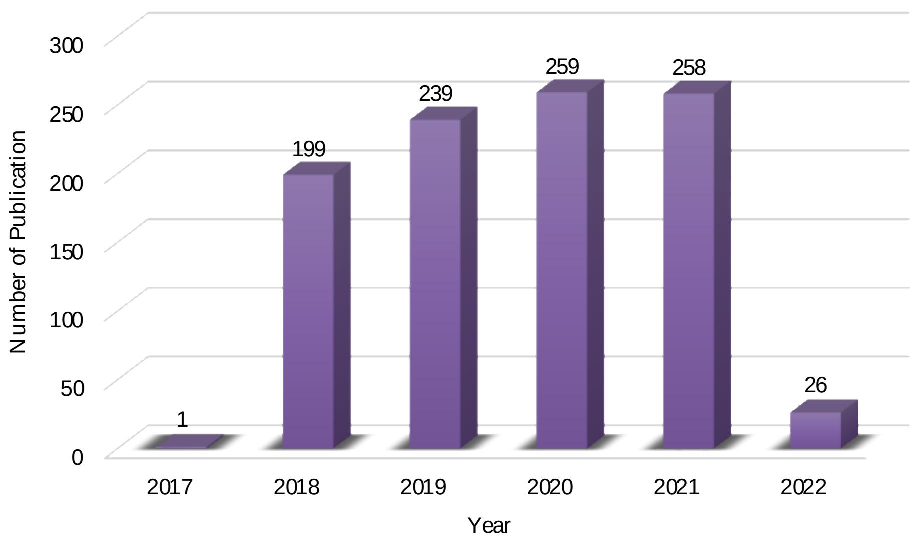


Figure 3. Development of article publications related to resin-based brake pads.

In 2022, although it was only the beginning of the year, the number of articles that had been published regarding resin-based brake pads was quite a lot, namely 26 articles. In addition, the detailed step-by-step bibliometric analysis is shown in our previous report [14].

Based on the results of these developments, it can be concluded that research related to resin-based brake pads was first popular in 2018 until now. The difference from the articles that have been published is mostly in the additional materials used.

Based on the results of the mapping using the VOSviewer application with the keyword "Resin-Based Brake Pad", there are 9 clusters with different colors and types of terms from one another. The color of each cluster we can edit or change according to our wishes. The circle shape of the cluster can be changed with the form of frames. The clusters obtained are circular, where the size of the circle is determined by the frequency with which the term is used for research. The larger the circle size, the more often the term is used in research.

Figure 4 shows clusters of each researched topic area in the form of network visualization with the keyword "Resin-Based Brake Pad".

3.2. *Physical Appearance of Brake Pads*

FTIR analysis was used to determine the functional group contained in raw BDs, and the analysis was compared to the literature [40]. Based on **Figure 5** brake pad specimens labeled DA, DB, DC, and DD have a similar spectrum to each other because the brake pads in each specimen have the same mixture of fillers, namely BD. The absorbance in the 3500-3200 cm^{-1} region indicates the O-H frequency of OH groups in cellulose as well as intra and intermolecular hydrogen bonds, possibly polymer compounds, alcohols, phenols, and carboxylic acids. The sharp absorbances at 2927 and 2854 cm^{-1} can be ascribed to the C-H frequency stretching and the relative peak centered at 1434 cm^{-1} coincides with the C-H bending. Thus, the sharp peak at 1742 cm^{-1} corresponds to the vibration strain of the ester group. Listed at 1634 cm^{-1}, there was a relatively wide peak resulting from stretching of the C=C bonds in aromatic compounds, and the absorbance at 1000 cm^{-1} was due to the C-O-R or C-O-H groups in the ester and alcohol groups. The absorption peak of about 1447 cm^{-1} corresponds to the C-O carboxy band. Epoxy groups are shown in the range of 1610-1604 cm^{-1} [41].

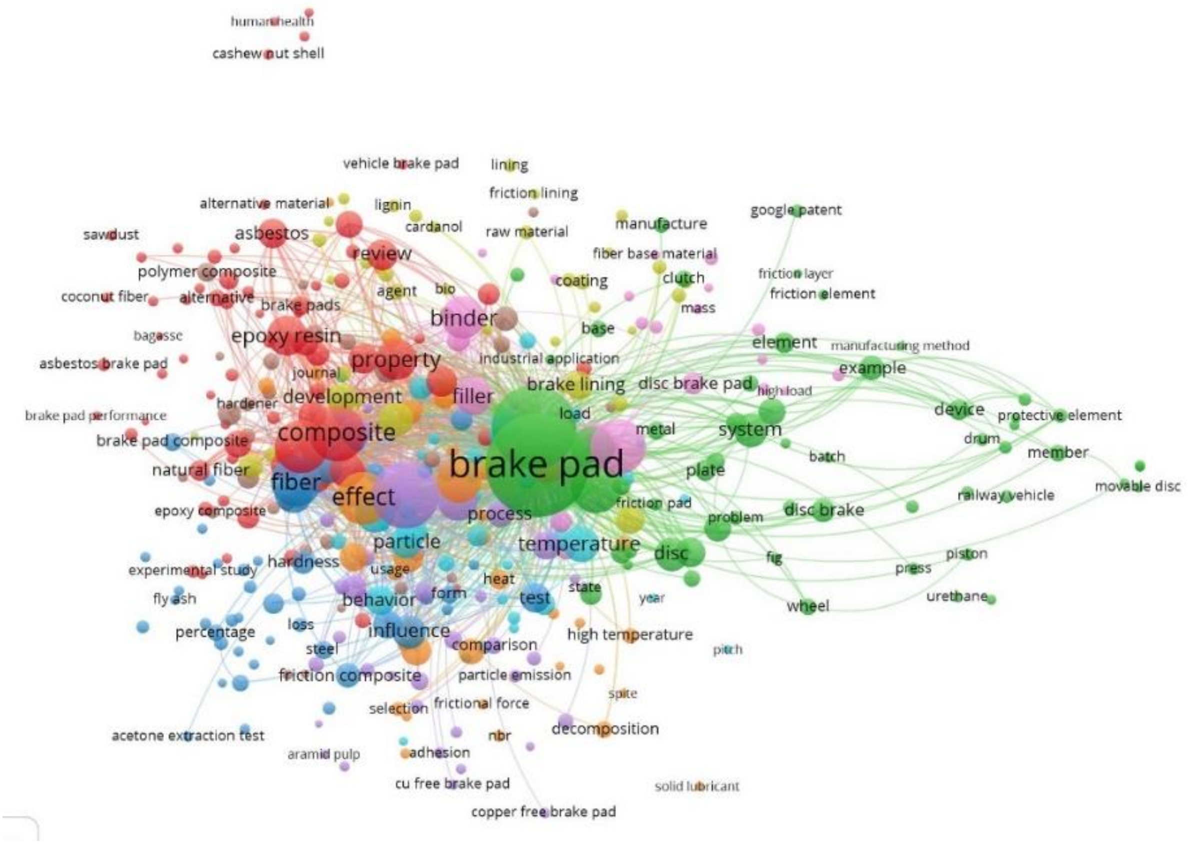


Figure 4. Network Visualization of Resin-Based Brake Pad Keyword

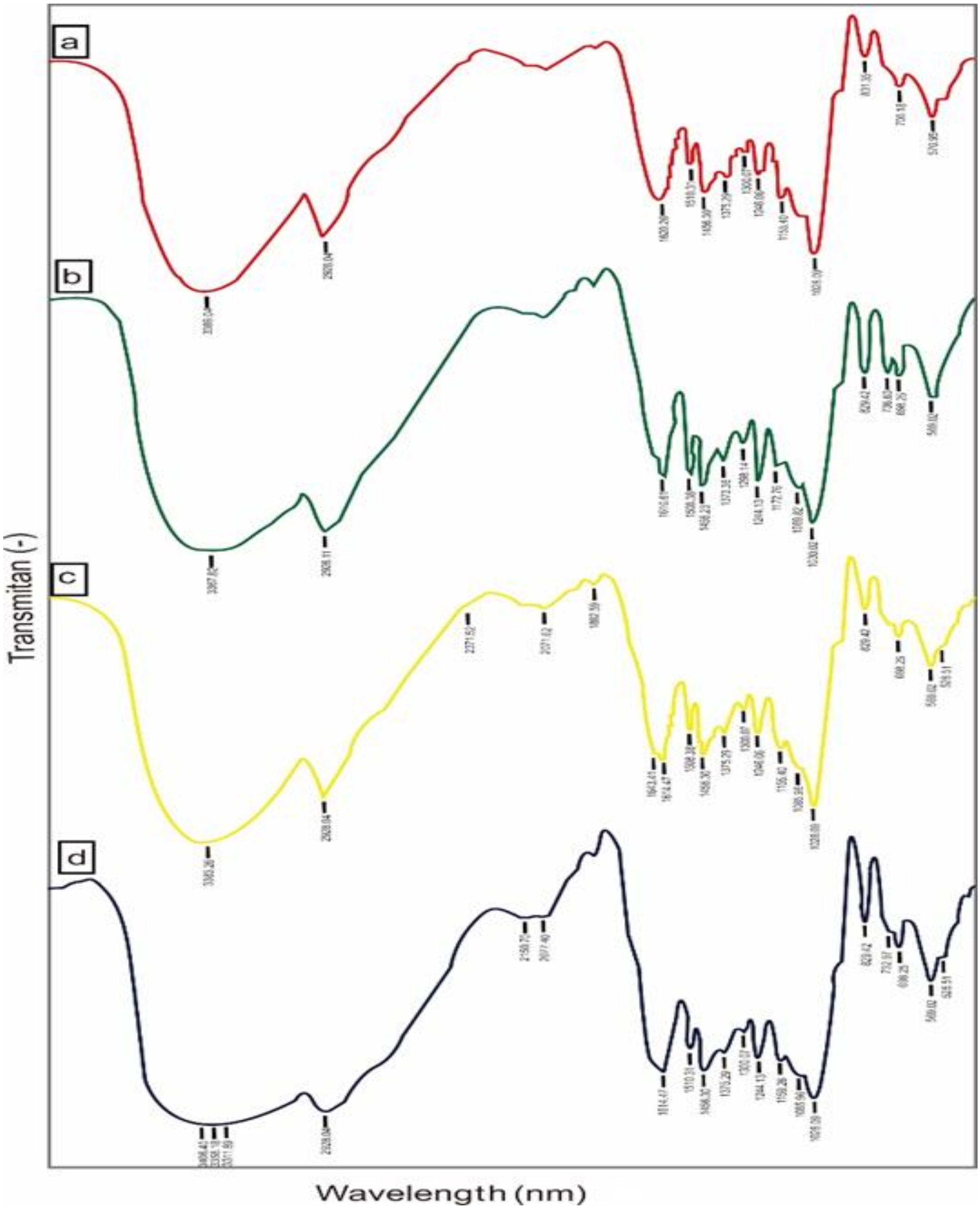


Figure 5. FTIR spectrum of artificial brake pads from (a) DA; (b) DB; (c) DC; and (d) DD

Figure 6(a) shows a microscopic image of durian seed particles. Durian seed particles show an inhomogeneous particle size. The particle size of durian seeds was analyzed using Feret analysis as shown in **Figure 6(b)**. The results of the Feret analysis showed that the particle size of durian seeds was in the range of 100-500 μm with an average size of 285 μm.

The physical appearance of the brake pads can be seen in **Figure 7**. The brake pads that we make are made of resin which has a different composition of variants in each sample, which is reinforced with durian seed particles.

Based on the research that we have done previously, namely the research on brake pads made of resin plus rice husks [3], the pores of the

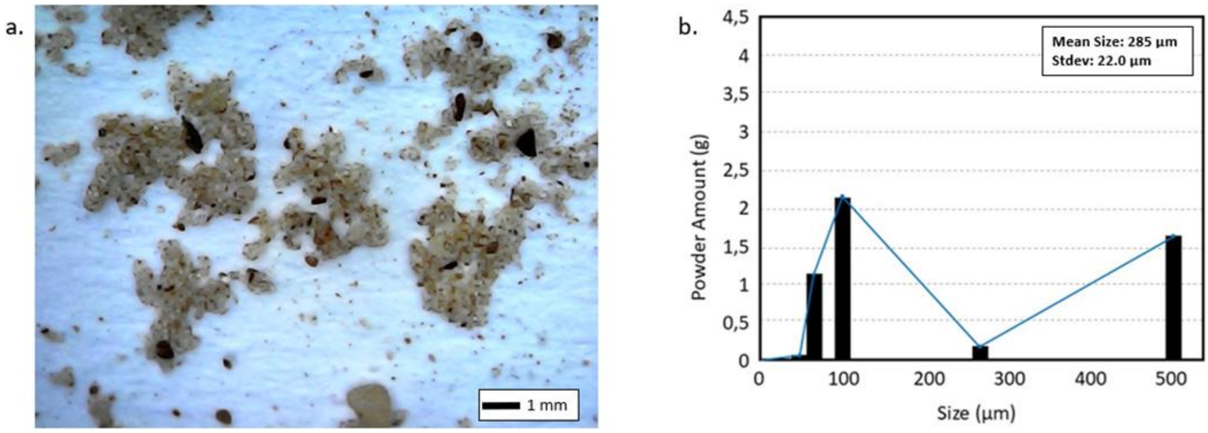


Figure 6. Photographic images and particle size distribution of BD particles.

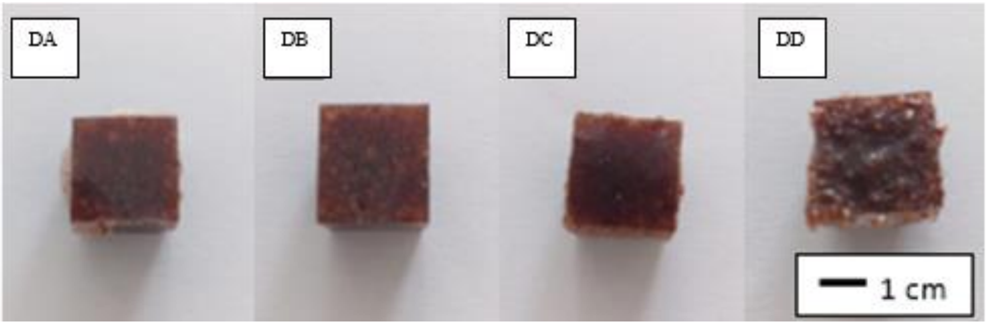
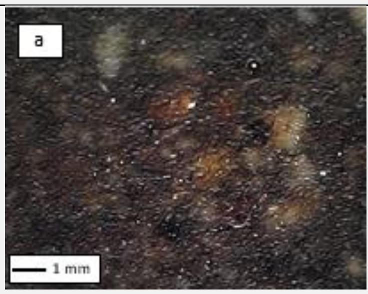
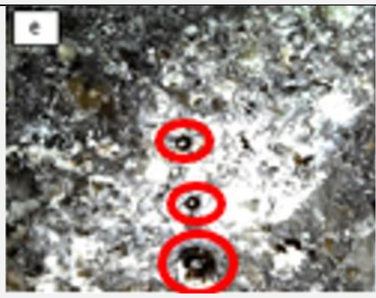
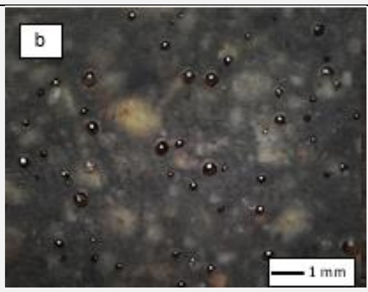
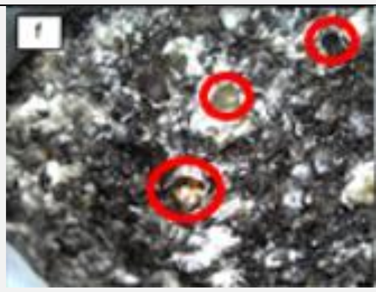
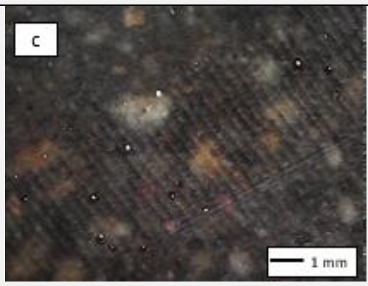
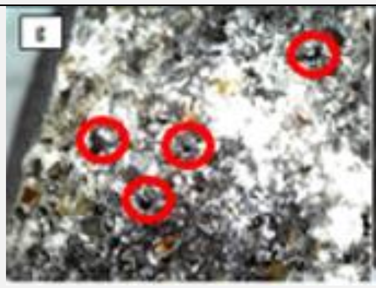
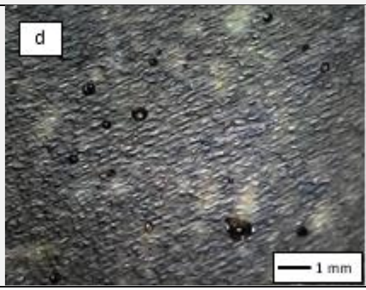
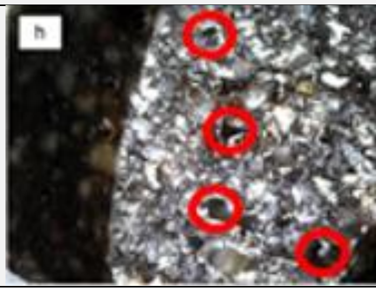


Figure 7. Sample images of DA, DB, DC, and DD brake pads arranged in sequence.

brake pads would affect the performance of the brake pads. In this study, this statement is strengthened. Based on the results of the study and **Table 3**, when viewed from the physical form of brake pads that have a high hardness level (DA sample (see in result in point 3.3 about mechanical properties)) have fewer pores. This is related to the performance of the brake pad because the brake pad with a high level of hardness that has fewer pores would have a better performance than the brake pad, which has a low level of hardness. Pore testing would be better if it is carried out using a radiographic test. Thus, it could observe the inside pore structure of the sample. However, due to limitations in accessing the analysis, we are still unable to use radiography in pore testing. We will carry out more testing in our future research. Paneled figures e, f, g, and h contained in **Table 3** show the differences in pore homogeneity and grain size that will affect the strength. Further explanation can be found in our previous study [3].

Figure 8 depicts the variation of composite density with the increasing resin composition. It can be seen that the density of the brake pad samples increases with the appearance of the resin. The decrease in the resin composition causes the brake pad sample to have a low density but must be accompanied by a thorough distribution of BD particles. Brake pad samples with high resin mixtures should have higher density and strength but we found that in lower BD samples this could be due to low-density composites having more voids, porosities, and spaces within the composite's components. However, we need to do further research to confirm this result, and it will be done in our future research [42]. The DA samples had the highest density, which was due to the closer packing of the BD particles, which created more homogeneity across the whole-body composite phase. Data regarding density will be more valid if studied using SEM and EDX will be more valid [42] than using FTIR and digital microscopes. However, due to limitations in accessing the analysis, we are still unable to use SEM and EDX in pore testing. We will carry out more testing in our future research. The density of conventional car brake pads is 1.89 g/cm^3 [43], while the sample density ranges from 1.15 to 1.25 g/cm^3, indicating that the density of the sample is very good compared to conventional brake pads. Moreover, this predictive value is consistent with the exact density of commercial brake pads, which ranges

Table 3. Microscopic observation of brake pad samples. (a and e) DA samples; (b and f) sample DB; (c and g) DC samples; and (d and h) sample DD. The red circle indicates the presence of pores.

Sample	Outer Surface	Inner Surface
DA		
DB		
DC		
DD		

from 1.01 to 2.06 g/cm^3, as reported by Ikpambese et al. [44]. Due to its lower density compared to other materials, the use of BD as a filler can result in the production of lighter composites.

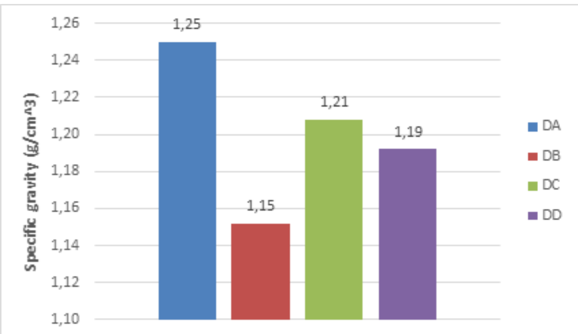


Figure 8. Variation of sample density with the variation of the resin composition

3.3. *Mechanical Properties*

Figure 9a and 9b show the results of the compression test that has been carried out. Based on **Figure 9a and 9b**, the greater the compressive resistance of the material is indicated by the higher compressive stress obtained from the compressive test. **Figure 9a** shows the highest peak for the DA specimen. **Figure 9b** shows the detailed values for each specimen DA, DB, DC, and DD is 2.43, 1.79, 2.39, and 2.04 MPa, respectively. Thus, based on the compression test, the hardest brake pad specimen is DA. To confirm the results of the compression test, a puncture test was performed. The data on the results of the prick test can be seen in **Table 4**.

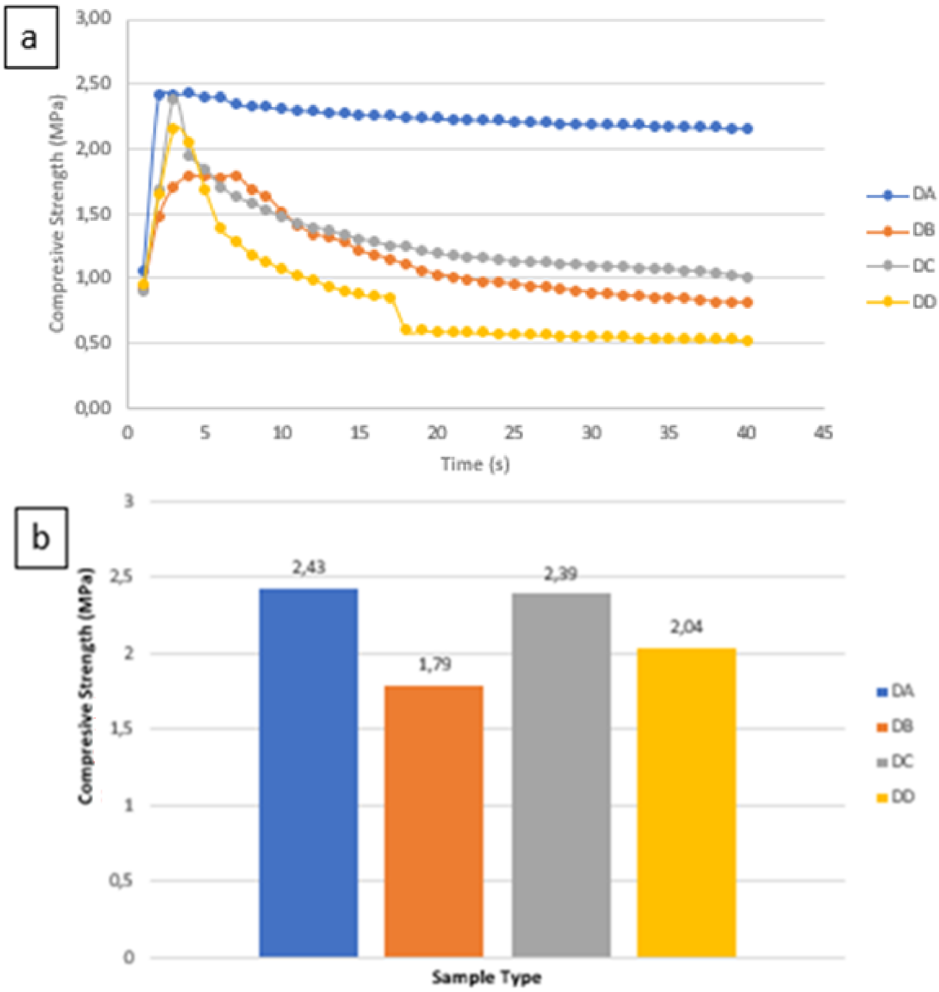


Figure 9. Variation of sample density with the variation The results of the compression test are as follows: (a) compressive stress-strain curve and (b) compressive strength

Table 4. The results of the puncture strength test of the brake pad specimen

Sample	Durometer Shore Brake Pad Hardness Scale
DA	88.6
DB	92.0
DC	89.2
DD	90.6
Commercial	88.5

Based on **Table 4**, higher values are obtained when the compressive test value is small or the hardness value is small. So, the smaller the compression test value, the greater the puncture test value, and vice versa, the greater the compression test value, the smaller the puncture test value. If we connect the results of the puncture test and the pressure test, the results of the puncture test are following the results of the compression test (**Figure 9a and 9b**) that the brake pad test object with the best hardness is the DA specimen. DA was chosen to be the strongest brake pad sample compared to the other three samples, namely DB, DC, and DD because DA has relatively few pores. Indeed, this is in line with the compression test and puncture test that showed DA to have better results. However, when compared to commercial brake pads, the hardness of the DA sample is still less hardness value of commercial brake pads, whereas the commercial brake pad puncture test value shows a relatively small result (with a value of 88.5), meaning that it has a high hardness value [3].

It has been previously mentioned in the research conducted by Nandiyanto et al. [3] that brake pads with more pores make the performance of the brake pads less good and brake pads with fewer pores make the performance better too, this is following the results of the research we have done now.

Figure 10 shows the change in mass of the prepared brake pads during a friction test. During friction testing, the brake pads are forced to make direct contact with the sandpaper (as in the drum/brake disc model), the contact is made to convert kinetic energy into heat energy. During the friction test process, this also generates debris. The increase in mass loss is caused by a decrease in the characteristics of the brake pad hardness caused by a decrease in the BD particle ratio and the amount of resin mixture.

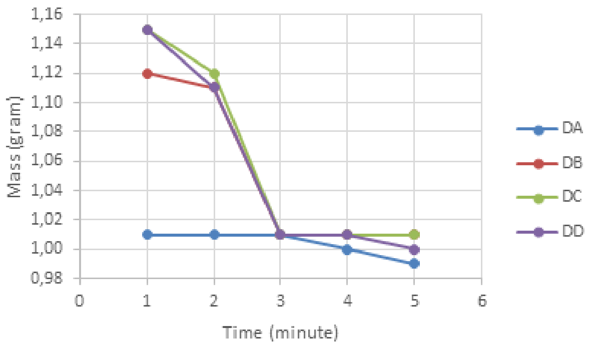


Figure 10. Changes in the mass of fabricated brake pads during a friction test

Table 5 shows the mass loss rate, wear rate, and overload reduction in detail. Lower mass rates are associated with lower wear rates and higher effect losses. Rema bearings with a resin composition of 4:4 have a lower mass rate and a higher coefficient of friction (see Table 5). The coefficient of friction is calculated using equation 4 which has been normalized. To be clear, the brake pads prevent samples DA, DB, DC, and DD are 1.52, 1.38, 1.52, and 1.46 respectively. While the friction coefficient of commercial brake pads is 0.99. This value is obtained after normalizing by dividing the friction coefficient of commercial brake pads and samples of brake pads of DA, DB, DC, and DD. The DA specimen is the best specimen among DB, DC, DD, and commercial specimens. We tested the specimen at room temperature. Each material has a different heat resistance and brake pads must also be able to work at high temperatures. However, in this study, we did not examine the heat resistance of each sample. We will carry out this research in our future research. Based on the test, all samples have better characteristics than commercial brake pads. In this study, brake pads have the characteristics of having higher hardness and lower mass-loss rate. However, at the beginning of the study, the brake pad samples still need to be investigated further in our future research.

The level of hardness in the DA sample is influenced by the amount of resin composition used. The resin composition affects the hardness of the brake pad because the more resin there is, the more crosslinking will be formed which causes a high level of hardness, this is supported by the statement of Irawan et al. [45]. Irwan et al. [45] stated that the compression strength, hardness, and density of the resulting sample all increased as the amount of resin mixture increased. In addition, the hardness of the brake lining occurs because the microstructure is denser, and the relationship is stronger.

4. Conclusion

Overall, the results of the analysis in this study indicate that the increased amount of resin composition gives good mechanical results in the fabrication of brake pads with durian seeds as reinforcement. DA brake pads with a higher amount of resin composition had better mechanical properties than the other 3 samples, namely, DB, DC, and DD. This is based on the results of hardness tests, compression tests, and friction tests that have been carried out. The greater the amount of resin composition in the brake pad causes the mixture of resin particles with strong materials to become more homogeneous and harder. This is because a higher

Table 5. Mass loss rate, wear rate, and friction coefficient of specimen with different composition.

Sample	Initial Mass (g)	Final Mass (g)	Mass loss rate (%)	t (s)	A (mm²)	Wear Rate (g/s.mm²)	Friction Coefficient After Normalization
DA	1.16	0.99	0.03	300	100	0.57	1.52
DB	1.19	1.01	0.18	300	100	0.60	1.38
DC	1.18	1.01	0.17	300	100	0.57	1.52
DD	1.17	1.00	0.17	300	100	0.57	1.46
Commercial	1.88	1.26	0.63	300	100	2.07	0.99

amount of resin increases cross-linking and the microstructure becomes denser and stronger. However, the amount of resin does not determine the hardness of the brake pad if the resin mixture is not homogeneous. However, if the DA sample is compared with a commercial brake pad, the puncture test has a higher value, meaning it has a lower hardness than the commercial brake pad. Expected this study to provide benefits for further studies of resin-based brake pads with reinforcement from durian seeds.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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