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Implementation of fuzzy logic using the Tsukamoto method in forecasting the amount of bolu cake production

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Abstract

Rumah produksi berkah bolu merupakan salah satu UMKM yang memproduksi kue bolu di Kota Pekanbaru. Pemilik usaha tersebut kesulitan dalam menentukan jumlah produksi kue karena hanya berdasarkan pada jumlah permintaan yang ada. Berdasarkan permasalahan tersebut, maka dipilihlah metode fuzzy Tsukamoto karena menggunakan penalaran monoton dalam setiap aturannya. Terdapat 4 tahapan yang dipakai dalam perhitungan metode Tsukamoto yaitu fuzzifikasi, inferensi, komposisi/Agregasi dan defuzzyfikasi. Hasil MAPE yang diperoleh dengan metode fuzzy Tsakomoto adalah 6,91% dan tingkat keakuratan sebesar 93,01%, yang memiliki arti bahwa metode fuzzy Tsukamoto sangat baik dalam memprediksi jumlah produksi, sehingga dapat digunakan sebagai sistem untuk mendukung keputusan dalam penentuan jumlah produksi kue bolu di rumah produksi Berkah Bolu.

The Berkah Bolu Production House is one of the Small and Medium Enterprise (SMEs) that produces bolu cakes in Pekanbaru City. The business owner has difficulty in determining the amount of cake production because it is only based on the number of existing requests. Based on these problems, the Tsukamoto fuzzy method was chosen because it uses monotonous reasoning in each rule. There are four stages used in the calculation of the Tsukamoto method, namely fuzzification, inference, composition or aggregation and defuzzification. The MAPE result obtained by the fuzzy Tsukomoto method is 6.91%, and the accuracy level is 93.01%, which means that the fuzzy Tsukamoto method is very good at predicting the amount of production, so it can be used as a decision support system in determining the amount of bolu cake production in the Berkah Bolu Production House.

Keywords: Fuzzy Logic, Forecasting, Tsukamoto Method, Bolu Cake, Production

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INTRODUCTION

Pekanbaru, as the centre and largest city in Riau Province, is known for its promising tourism attraction, strategic geographical location, and complete infrastructure, making it a major destination for tourists. Pekanbaru's cuisine is a major attraction for tourists as it reflects the uniqueness of urban tourism despite not having a large natural tourism potential. Therefore, efforts are being made to develop culinary tourism to attract visitors to tourist destinations around Pekanbaru City. Currently, most of the economic activities in Pekanbaru City are still dominated by Small and Medium Enterprises (SMEs) (Chaniago et al., 2023)

Today, the snack business is one of the fastest-growing SMEs. It is a home-scale business that offers good opportunities for now and the future (Dewi & Berlianti, 2018). Bolu cake is one of the snacks that is very popular with the public, and there are many SMEs that produce bolu cake in Pekanbaru.

Berkah Bolu Production House is one of the SMEs that produces Bolu cakes in Pekanbaru City. This production house is a home industry without structured sales management like SMEs in general; this makes the author interested in understanding the strategies and mechanisms used by the Berkah Bolu production house in managing sales activities, including the ability to determine the number of bolu cakes to be produced. From the beginning of producing bolu cakes until now, Berkah Bolu Production House has always used a simple method in the manufacturing process to meet consumer needs, namely by referring to the number of requests to determine the number of bolu cakes to be produced in the following month.

From the beginning of producing bolu cakes until now, Berkah Bolu Production House has always used a simple method in the manufacturing process to meet consumer needs, namely by referring to the number of requests to determine the number of bolu cakes to be produced in the following month (Beu & Husna, 2019). Berkah Bolu production house faces challenges with unstable monthly demand fluctuations, making it difficult for them to determine the right amount of bolu cake production. To be able to overcome these obstacles, a prediction process is needed to estimate the amount of bolu cake production needed to meet existing demand.

There are various methods that can be used to manage the prediction process in determining the amount of bolu cake production. Fuzzy logic is one method that can be

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utilized (Tundo, 2020). The advantage of fuzzy logic lies in its intuitive ability and has been widely applied by various groups. This method is suitable for making predictions because it is able to produce dynamic output values (Muhajirah et al., 2019; Wu & Xu, 2021). Fuzzy has advantages over other methods, such as time series regression, because it does not require much historical data to predict (Biringallo et al., 2022).

Fuzzy logic is a logic that has reasoning capabilities, such as human reasoning systems, so that it can handle the uncertainty found in the data (Prima et al., 2020). This fuzzy logic was implemented and introduced by Lotfi Asker Zadeh in 1965 in fuzzy set theory (Khairudin et al., 2020; Tundo & Mahardika, 2023). Fuzzy logic It is an extension of boolean logic based on degrees of truth that lie between 0 and 1 or true/false. Fuzzy logic is based on the themes of degree, inaccuracy, linguistics, and observation. Fuzzy expert systems analyze knowledge from vague and ambiguous data using a linguistic approach (Thakkar et al., 2021).

In reality, human decision-making includes various possibilities between true or false, such as definitely true, probably true, probably false, definitely false and others. Since classical logic cannot handle ambiguous information expressed in natural language, fuzzy logic is proposed to model such imprecise reasoning modes. Most research in decision making has emphasized the use of fuzzy logic (Wu & Xu, 2021).

Fuzzy logic has methods that are often used, including the Tsukamoto, Sugeno and Mamdani methods (Muhajirah et al., 2019). The method that can be used for forecasting here is the Tsukamoto fuzzy method. The author chose the Tsukamoto fuzzy method because it uses a computational process that is very simple and easy to understand; this is in line with the opinion of Setyono and Aeni (2018). This reasoning has also been supported by several previous studies. Tundo et al. (2020), the forecast results of the Tsukamoto method are relatively closer to the actual data than the Sugeno method; the accuracy of the Tsukamoto method is 83%. Saepullah (2015) obtained research results that show that the Tsukamoto fuzzy method inference system is better than the Mamdani and Sugeno methods in saving electricity usage. Napitupulu et al. (2020), Tsukamoto and Mamdani methods are better than the Sugeno method in predicting the selling price of export goods. Tundo and Sela (2018) state that the forecast of the Tsukamoto method is closer to the actual data than the Sugeno method in determining the amount of woven fabric to be produced. The prediction results with the

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Tsukamoto method are also better than the Mamdani method in determining the amount of robusta coffee production (Wibowo & Mukammila, 2022).

The Tsukamoto method is a reasoning method that uses fuzzy logic with monotonous membership functions. In this method, all consequences of IF-THEN rules are represented by fuzzy sets with monotone membership functions. As a result, the inference output of each rule is presented strictly using alpha predicates (fire strength). The final output is obtained through the use of a weighted average (Riansyah et al., 2021). The final result refers to the amount of Bolu cake production. The Tsukamoto fuzzy method has the following form.

$$IF\ (X\ IS\ P)\ and\ (Y\ IS\ Q)\ THEN\ (Z\ IS\ R)$$

P, Q, and R are Fuzzy sets.

The Tsukamoto method has been applied to forecast the amount of palm kernel oil that will be produced. The results of the study concluded that the Tsukamoto method inference system is very accurate and can be a reference for companies when making decisions (Kartika et al., 2019). Tsukamoto method can be effective in determining hotel rental rates that are influenced by the number of visitors, room types and holidays (Nugroho et al., 2019). The Tsukamoto fuzzy method is also used to predict the amount of tofu production, whereas, in the study, the error rate using the Tsukamoto fuzzy method calculation was 1.09% (Basriati & Safitri, 2021). Tsukamoto's method can also estimate the amount of fish medicine production correctly (Resti & Resti, 2019).

Referring to this background, the purpose of this research is to see how Tsukamoto fuzzy method is used in forecasting the amount of production, then author compare the results of Tsukamoto method forecasting with actual data related to the amount of bolu cake production at the Berkah bolu cake production house, Pekanbaru.

METHODS

The type of research used is descriptive research, which begins with observation to obtain information and problems, then conducts literature studies to analyze and find solutions to problems; the research subject is the amount of bolu cake production. Tsukamoto's fuzzy method is used in this research. Puspitasari et al. (2019), in the inference process, the Tsukamoto method involves a series of processes as follows:

1. Fuzzification is a step where crisp inputs are mapped into fuzzy sets, and the result

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is fuzzy inputs represented in the form of fuzzy rules.

2. Fuzzy rules are formulated to express the relationship between input and output variables. Using "IF-THEN" statements, using the "AND" operator between input variables. The statement after "IF" is named antecedent, while the statement after "THEN" is named consequent.
3. Composition or aggregation is the process performed to convert Fuzzy inputs into Fuzzy outputs, by following predefined rules, and the result is known as α-predicate.
4. Defuzzification is a step in converting the fuzzy output into a crisp value. The weighted average method is a commonly used defuzzification method, as seen in the equation below.

$$Z = \frac{\sum_{i=1}^{n} a_i z_i}{\sum_{i=1}^{n} a_i} \quad (1)$$

With Z as the output variable, α_i being the α-predict value, and zi as the output variable value.

In this study, bolu cake production data was used from January 2023 to November 2023 at Berkah Bolu production house, Pekanbaru City.

Forecasting Accuracy Rate

To determine the accuracy of the calculation of the Tsukamoto fuzzy method, the author use MAPE (Mean Absolute Percentage Error). Mean Absolute Percentage Error (MAPE) is a method that measures the accuracy or correctness of a forecast (Latipah et al., 2019). MAPE indicates the level of forecasting error in absolute percentages compared to the actual data. The smaller the MAPE value, the greater the accuracy of a forecast (Ngurah Diksa, 2021). The accuracy calculation with MAPE can be seen in the following equation.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{P_t - P'_t}{P_t}\right| \times 100\% \quad (2)$$

With P_t is the value of the actual data at time t, P'_t is the predicted value at time t and n is the amount of data (Surur et al., 2023). MAPE has a range of values that can be used as a reference to determine the level of accuracy of forecasting the amount of bolu cake production, the range of values can be seen in table 1.

Table 1. MAPE accuracy rate

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MAPE (%)	Forecasting Accuracy Level
< 10	Highly accurate forecasting
10-20	Accurate Forecasting
20-50	Less accurate forecast
>50	Inaccurate Forecast

Source (Ngurah Diksa, 2021)

RESULT AND DISCUSSION

As for the number of Bolu requests arranged from January to November 2023, the data has three variables, namely production, demand and inventory, as can be seen in Table 2.

Table 2. Bolu cake production data

Month	Production	Demand	Inventory
January	1400	1350	50
February	1290	1300	60
March	1190	1220	80
April	1630	1680	100
May	1140	1175	85
June	1380	1450	120
July	1605	1630	175
August	1345	1420	125
September	1250	1350	150
October	1275	1315	90
November	1020	1100	130

From Table 2, it is obtained that the largest demand is 1680 pans per month, the smallest demand is 1100 pans per month, the largest inventory is 175 pans per month, the smallest inventory is 50 pans per month, the Bolu berkah production house can produce the most 1630 pans per month and the least 1020 pans per month. Using October data in 2023. It is known that the number of bolu cake requests is 1315 pans, and the number of cake supplies is 90 pans. The following is a calculation with the Tsukamoto fuzzy method:

1. Fuzzification

Fuzzification is a process carried out to determine fuzzy variables, fuzzy sets, fuzzy curves and membership degree values.

a. Demand variable consisting of 2 fuzzy sets, namely: DOWN demand and UP demand.
b. Inventory variable consisting of 2 fuzzy sets, namely DOWN inventory and UP

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inventory.

c. Production variable consisting of 2 fuzzy sets, namely INCREASED production and REDUCED production.

The following are the function curves and membership degree values of the demand, inventory and production variables.

a. Function curves and membership degree values for Demand Variable

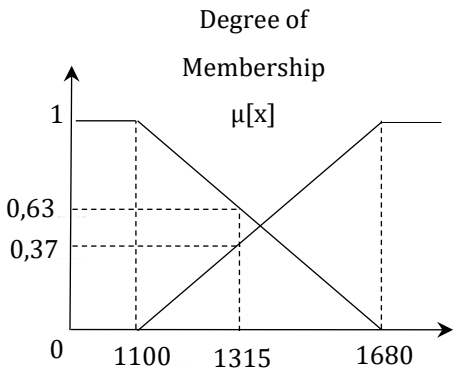

Figure 1. Degree of membership function of the demand variable

Based on Figure 1, the degree membership function of the demand variable can be seen in equations (3) and (4).

$$\mu\ down(x) = \begin{cases} 1;\ x \leq 1100 \\ \frac{1680-x}{1680-1100}; 1100 \leq x \leq 1680 \\ 0;\ x \geq 1680 \end{cases} \quad (3)$$

$$\mu\ up(x) = \begin{cases} 0;\ x \leq 1100 \\ \frac{x-1100}{1680-1100}; 1100 \leq x \leq 1680 \\ 1;\ x \geq 1680 \end{cases} \quad (4)$$

b. Function curves and membership degree values for Inventory Variable

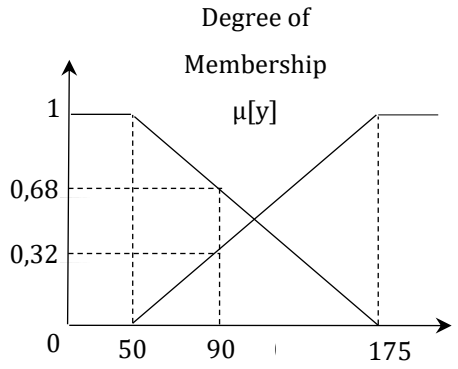

Figure 2. Degree of membership function of the inventory variable

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Based on Figure 2, the degree membership function of the inventory variable can be seen in equations (5) and (6).

$$\mu\, down(y) = \begin{cases} 1; & y \leq 50 \\ \frac{175-y}{175-50}; & 50 \leq y \leq 175 \\ 0; & y \geq 175 \end{cases} \quad (5)$$

$$\mu\, up(y) = \begin{cases} 0; & y \leq 50 \\ \frac{y-50}{175-50}; & 50 \leq y \leq 175 \\ 1; & y \geq 175 \end{cases} \quad (6)$$

c. Function curves and membership degree values for Production variable

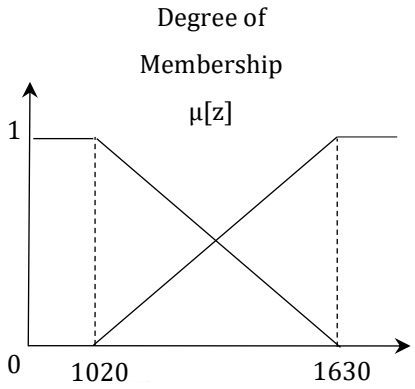

Figure 3. Degree of membership function of the production variable

Based on Figure 3, the degree membership function of the production variable can be seen in equations (7) and (8).

$$\mu\, reduced(z) = \begin{cases} 1; & z \leq 1020 \\ \frac{1630-z}{1630-1020}; & 1020 \leq z \leq 1630 \\ 0; & z \geq 1630 \end{cases} \quad (7)$$

$$\mu\, increased\ (z) = \begin{cases} 0; & z \leq 1020 \\ \frac{z-1020}{1630-1020}; & 1020 \leq z \leq 1630 \\ 1; & z \geq 1630 \end{cases} \quad (8)$$

2. Rule Evaluation
   a. [R1] IF Demand UP And Inventory UP, THEN Bolu Cake Production INCREASED
   b. [R2] IF Demand UP And INVENTORY DOWN, THEN Bolu Production INCREASED
   c. [R3] IF demand DOWN and inventory UP, THEN Bolu cake production REDUCED
   d. [R4] IF demand DOWN and inventory DOWN, THEN Bolu cake production REDUCED

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3. Composition/Aggregation

The rules that can be used to find the α-predicate and z values using the AND operation equation are as follows:

a. [R1] IF Demand UP And Inventory UP, THEN Bolu Cake Production INCREASED

α-*predicate1* = ($\mu_{UP} \cap \mu_{UP}$)
= (μ_{UP} [1315], $\cap$ μ_{UP} [90])
= (0,37; 0,32) = 0,32

Pay attention; the production of the Bolu cake has increased. Then z_1 can be found with the following formula:

$\frac{z_1 - 1020}{1630 - 1020}$ = 0,32 <=> $\frac{z_1 - 1020}{610}$ = 0,32 <=> z_1 = 1215,20

b. [R2] IF Demand UP And INVENTORY DOWN, THEN Bolu Production INCREASED

α-*predicate2* = ($\mu_{UP} \cap \mu_{DOWN}$)
= (μ_{UP} [1315], $\cap$ μ_{DOWN} [90])
= (0,37; 0,68) = 0,37

Pay attention; the production of the Bolu cake has increased. Then z_2 can be found with the following formula:

$\frac{z_2 - 1020}{1630 - 1020}$ = 0,37 <=> $\frac{z_2 - 1020}{610}$ = 0,37 <=> z_2 = 1246,12

c. [R3] IF demand DOWN and inventory UP, THEN Bolu cake production REDUCED

α-*predicate3* = ($\mu_{DOWN} \cap \mu_{UP}$)
= (μ_{DOWN} [1315], $\cap$ μ_{UP} [90])
= (0,63; 0,32) = 0,32

Pay attention; the Bolu cake production set has been REDUCED. Then z_3 can be found with the following formula:

$\frac{1630 - z_3}{1630 - 1020}$ = 0,32 <=> $\frac{1630 - z_3}{610}$ = 0,32 <=> z_3 = 1434,80

d. [R4] IF demand DOWN and inventory DOWN, THEN Bolu cake production REDUCED

α-*predicate4* = ($\mu_{DOWN} \cap \mu_{DOWN}$)
= (μ_{DOWN} [1315], $\cap$ μ_{DOWN} [90])
= (0,63; 0,68) = 0,63

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Pay attention; the Bolu cake production set has been REDUCED. Then z_4 can be found with the following formula:

$$\frac{1630-z_4}{1630-1020} = 0{,}63 <=> \frac{1630-z_4}{610} = 0{,}63 <=> z_4 = 1246{,}12$$

4. Defuzzification

By applying the weighted average rule, the affirmation or defuzzification value is obtained as follows.

$$z^* = \frac{\alpha_{predicate1} * z_1 + \alpha_{predicate2} * z_2 + \alpha_{predicate3} * z_3 + \alpha_{predicate4} * z_4}{\alpha_{predicate1} + \alpha_{predicate2} + \alpha_{predicate3} + \alpha_{predicate4}} \quad (9)$$

$$= \frac{0{,}32(1215{,}20) + 0{,}37(1246{,}12) + 0{,}32(1434{,}80) + 0{,}63(1246{,}12)}{0{,}32 + 0{,}37 + 0{,}32 + 0{,}63}$$

$$= \frac{2094}{1{,}64} = 1.276{,}90$$

So it is concluded that the number of cakes that must be produced is 1,276.90 ≈ and 1,277 pans so that demand can be met.

For the next month, by using the same method to get the results of the amount of production, the results of the prediction of the amount of production are obtained as in the following table:

Table 3. Forecast results with the Tsukamoto method

Month	Actual data	Forecast data
January	1400	1283
February	1290	1243
March	1190	1214
April	1630	1337
May	1130	1232
June	1380	1355
July	1605	1577
August	1345	1343
September	1250	1295
October	1275	1277
November	1020	1301

The next step is to measure the accuracy of forecasting using MAPE (Mean Absolute Percentage Error), forecasting accuracy can be found by 100% minus MAPE. MAPE (Mean Absolute Percentage Error) calculation is done by subtracting the actual data from the forecast data written in absolute value, then dividing by the actual value per each period, and then summing up each result. This can be seen in Table 4.

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Table 4. Finding the MAPE value

Month (t)	Actual data (Pt)	Forecast data (P't)	Pt-P't	(Pt-P't)/Pt
January	1400	1283	117	0,0836
February	1290	1243	47	0,0364
March	1190	1214	24	0,0202
April	1630	1337	293	0,1798
May	1130	1232	102	0,0903
June	1380	1355	25	0,0181
July	1605	1577	28	0,0174
August	1345	1343	2	0,0015
September	1250	1295	45	0,0360
October	1275	1277	2	0,0016
November	1020	1301	281	0,2755

By using equation (2), the MAPE result is 6.91%. Furthermore, the forecasting accuracy that has been done can be seen as the following:

$$100\% - MAPE \qquad (10)$$

$$100\% - 6{,}91\% = 93{,}09\%$$

The following is a graph of MAPE test results:

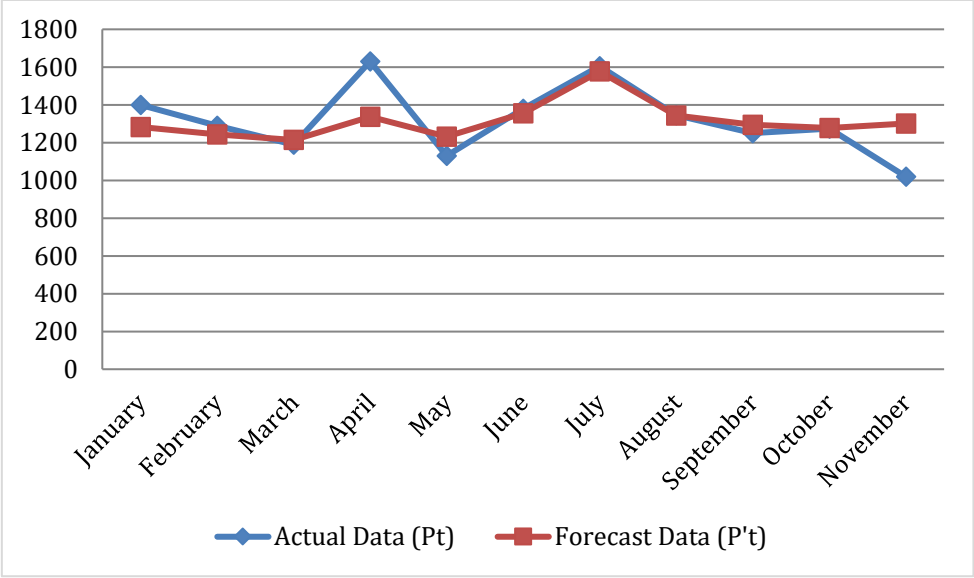

Figure 4. Forecasting chart

The accuracy of forecasting with the Tsukamoto fuzzy method is 93.09%. Referring to Table 1, the MAPE value, which is less than 10%, indicates that the accuracy of forecasting using the Tsukamoto fuzzy method regarding the amount of

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bolu cake production is said to be very good; this is supported by Basriati & Safitri (2021) in their research, namely forecasting the amount of tofu production with the Tsukamoto method is very good with a MAPE of 1.09%, Wahyuni (2022), Tsukamoto method forecasting is very good in diagnosing pneumonia because it produces MAPE 3.15%, as well as Pradini et al. (2022), tsukamoto method has a very good level of accuracy in predicting rice seed production with MAPE 0.0%.

CONCLUSION

From this study, it is concluded that the Tsukamoto fuzzy method can help in determining the amount of production according to the amount of demand and the amount of inventory. In October 2023, the difference between the prediction or forecast data and the actual data is very small, namely 2, while in April 2023, the difference between the prediction or forecast data is quite large, namely 283. The level of forecasting accuracy is 93.09%, or the MAPE value is less than 10%. This means that the Tsukamoto fuzzy method is a very good method for forecasting the number of bolu cakes that will be produced by the Berkah Bolu production house.

Although the MAPE value is quite small, the Tsukamoto fuzzy method is only a method that can be used as a support in deciding how much bolu cake production. The author suggests that further research can use other methods such as weighted moving average or other types of fuzzy methods with more data.

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CONFLICTS OF INTEREST

We declare no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies, have been completed by the authors.

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AUTHOR CONTRIBUTIONS

Jabal Yasir Nasution: Conceptualization, writing - original draft, editing, and visualization. **Granita:** Writing - review and editing, formal analysis, methodology, and validation.

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