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Research article

Sharks and rays at Pelabuhan Perikanan Samudera (PPS) Lampulo, Banda Aceh, Indonesia: Morphometric characteristics and differentiators based on multivariate analysis

Nur Hikmah [1], Hayatun Nufus [1, *], Syahrial Syahrial [2], Riri Ezraneti [2], Rika Astuti [3]

[1] Department of Marine Science, Faculty of Fisheries and Marine Sciences, Teuku Umar University, West Aceh, Indonesia
[2] Department of Marine Science, Faculty of Agriculture, Universitas Malikussaleh. Reuleut Main Campus, 24355 North Aceh, Indonesia
[3] Department of Aquatic Resources, Faculty of Fisheries and Marine Sciences, Teuku Umar University, West Aceh, Indonesia

Abstract

Tropical marine environments are abundant and diverse; therefore, shark and ray research at fishing port PPS Lampulo, Banda Aceh City was carried out focusing on morphometric characteristics and differences based on multivariate analysis in July 2020 to identify sharks and rays that landed at fishing port PPS Lampulo, Banda Aceh City and determine their primary characteristics. The shark and ray samples used were from the Indian Ocean and the Malacca Strait and measured total length (TL), fork length (FL), and standard length (SL) for sharks and disc width (DW), TL, and disc length (DL) for rays. Principal component analysis (PCA) and discriminant analysis (DA) were performed on the morphometric data. The PCA analysis revealed that sharks and rays caught in Pelabuhan Perikanan Samudera (PPS) Lampulo, Banda Aceh City, can be divided into two distinct groups. The first group of sharks consists of species with large FL and SL morphometrics, namely *P. kamoharai*, *C. plumbeus, P. glauca*, and *A. superciliosus*. The second group of sharks consists of species with large TL morphometrics, specifically *A. pelagicus* and *C. plumbeus*. For the ray group, the first group comprises species with large TL and DW morphometrics, represented by *A. ocellatus*. The second group of rays consists of species with large DL morphometrics, namely *P. sephen* and *H. jenkinsii*. The results of DA revealed distinct differences in the size of sharks caught in the Indian Ocean and the Strait of Malacca, specifically in PPS Lampulo, Banda Aceh City. However, no significant differences in size were observed for the rays, regardless of whether their size was measured using DW, TL, or DL.

Keywords: Shark, rays, fishing port, morphological measurement, multivariate

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***Corresponding author**: Hayatun Nufus. Email: hayatunnufus@utu.ac.id

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Introduction

Sharks and rays are Elasmobranchii fish that belong to the Chondrichthyes class (Dulvy et al., 2014; Simpfendorfer & Dulvy, 2017; Amaral et al., 2018; Stein et al., 2018; Seidel et al., 2020). The skeleton of juvenile and adult sharks and rays comprises unmineralized cartilage (Seidel et al., 2020), distinguishing them from most other vertebrate animals (Hall, 2005). Shark and ray populations are currently facing a severe threat due to overfishing. Numerous studies (Dulvy et al., 2014; Simpfendorfer & Dulvy, 2017; Walls & Dulvy, 2020) have shown that tens of millions of sharks are caught and traded internationally each year, with the highest levels of fishing occurring in 2003 (Clarke et al., 2006; Dulvy et al., 2014; Davidson et al., 2016). This excessive fishing has led to a decline in their populations (Graham et al., 2001; Dulvy et al., 2014; Dulvy et al., 2016), and nearly a quarter of their species are now at risk of extinction (Clarke et al., 2006; Dulvy et al., 2014; Davidson et al., 2016). These findings are supported by the fact that sharks and rays have very slow growth, low fecundity, and only reach sexual maturity at an advanced age (Musick, 1999; Cortes, 2002).

Morphometrics, as defined by Rohlf (1990), is a fundamental aspect of biology that involves the measurement and analysis of organisms. It encompasses quantitative description methods, statistical analysis of variation, and the examination of shape changes resulting from organism growth (Rohlf & Marcus, 1993; Marcus et al., 1996). In addition, Sprent (1972) asserted that morphometrics involves analysing the relative size of body parts in organisms to identify morphological variations between individuals. The goal of morphometrics is to quantify the size, shape, and the relationship between size and shape (allometry) in organisms (Dujardin, 2011). Therefore, morphometrics plays a crucial role in determining the shape of a biological organism based on its size (Bookstein, 1982).

In addition to the points mentioned above, multivariate analysis is a valuable technique for addressing problems by creating a set of smaller variables and categorizing samples based on similar or dissimilar characteristics (Junior et al., 2019). Furthermore, multivariate analysis is capable of handling large volumes of data (Lins et al., 2018) and effectively filtering out noise from extensive datasets (Bierman et al., 2011; Yan et al., 2012), making it highly useful for simplifying the interpretation of results obtained from intricate systems (Indelicato et al., 2018). According to da Silva et al. (2016) and Lychuk et al. (2017), multivariate analysis is often used to analyze environmental data. This kind of analysis can group and optimize commonalities across environmental units, as mentioned by Cruz-Cardenas et al. (2017) and Syahrial et al. (2019a,b,c). Furthermore, multivariate analysis can serve as a valuable tool for scaling study samples (Junior et al., 2019).

Sharks and rays play a crucial role in marine food webs, as indicated by various studies (Stevens et al., 2000; Myers et al., 2007; Ferretti et al., 2010). Morphological analysis and condition factors of marine biota are important parameters to assess population stocks and fisheries biology (Imam et al., 2010; Ariyanto et al., 2018). Extensive research has been conducted on sharks and rays, including studies in Indonesia (MacKeracher et al., 2019; Bouyoucos et al., 2019; Walls & Dulvy, 2020; Hart, 2020; Hart et al., 2020; Mull et al., 2020; Tyabji et al., 2020; Pacoureau et al., 2021) and specifically in Aceh Province (Aditya & Al-Fatih, 2017; Efendi et al., 2018; Pumpun et al., 2018; Kusnanto et al., 2018; Hernawati et al., 2018; Hidayat et al., 2018; Ekasari et al., 2018; Jaliadi et al., 2017; Muttaqien et al., 2019a). However, there is a scarcity of research worldwide, including in Indonesia, that has extensively analyzed the features and morphometric disparities of sharks and rays using multivariate analysis. Therefore, such a study is imperative. The objective of this study is to determine the distinguishing characteristics of sharks and rays caught at the Lampulo Ocean Fisheries Port (PPS) in Banda Aceh City, Aceh Province, and to identify the key criteria that define them.

Methods

The research was carried out in July 2020 at PPS Lampulo, located in Banda Aceh City, Aceh Province (Figure 1). The shark and ray specimens used in the study were obtained from captures made with bottom longline fishing gear and handlines in the Indian Ocean and the Malacca Strait. A total of 170 shark samples were used, consisting of 135 females and 35 males. Additionally, 48 ray samples were examined, with 44 females and 4 males included. Morphometric meas-

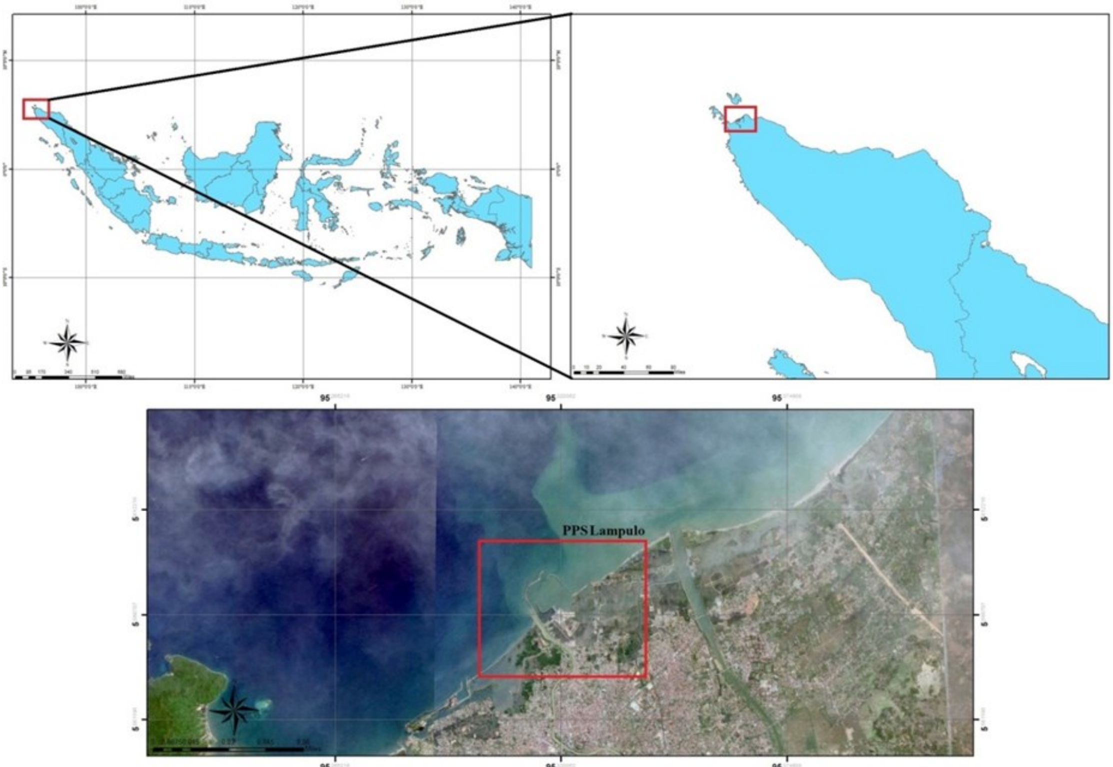

Figure 1. Fishing port of Pelabuhan Perikanan Samudera (PPS) Lampulo, Banda Aceh, Indonesia

urements of sharks and rays were conducted in each sample using the measurement technique described by Muttaqin et al. (2019b). For shark samples, the measurements included total length (TL), fork length (FL), and standard length (SL). Meanwhile, for ray samples, the measurements included disc width (DW), total length (TL), and disc length (DL).The obtained morphometric data of sharks and rays landed at PPS Lampulo, Banda Aceh City, Aceh Province were analyzed using Principal Component Analysis (PCA) with PAST 3 software (Hammer et al., 2001; Satheeshkumar & Khan, 2012; Radiarta et al., 2013; Kumar et al., 2018) to determine their morphometric characteristics. Furthermore, discriminant analysis (DA) with SPSS version 24 software was used to analyze the main characteristics of shark and ray morphometrics landing at PPS Lampulo, Banda Aceh City, Aceh Province (Syahrial, 2016).

The density of snails in Langsa mangrove forest was assessed using multivariate Principal Component Analysis (PCA) statistics in the PAST 3 program (Hammer et al., 2001) and SPSS v24. Additionally, the relationship between snails and the condition of the mangrove ecosystem was determined based on similarities in composition. The snails were examined using multivariate cluster statistics based on the Bray - Curtis similarity index in the Primer v7 program, both within observation stations and across different species.

Results

Morphometric characteristics

Principal Component Analysis (PCA) was performed on the morphometrics of sharks and rays in PPS Lampulo, Banda Aceh City, Aceh Province. The results indicated that the combined diversity explained by the first and second main components was 99.94% for sharks and 95.45% for rays (Table 1). Furthermore, the PCA revealed that the morphometrics of the sharks caught at PPS Lampulo, Banda Aceh City, Aceh Province, were divided into two distinct groups. The first group, consisting of SP13, SP6, SP12, and SP2, exhibited the largest FL and SL morphometrics. On the other hand, the second group, comprising SP1 and SP6, showed the largest TL morphometrics (Figure 2). Meanwhile, PCA analysis revealed the development of two distinct groups among the rays. The first group, represented by SP1, exhibited the largest TL and DW morphometrics. On the other hand, the second group, represented by SP9 and SP4, had the highest DL morphometrics (Figure 3).

Morphometric differentiation

The findings of the discriminant analysis for sharks indicated that all evaluated morphometrics were identified as the primary differentiating characteristics between sharks taken in the Indian Ocean and the Strait of Malacca, with a significant value (p-level) less than 0.05 (Table 2). However, according to the standard coefficient value, the TL morphometrics exhibited a higher value of 1,000 compared to the other morphometrics. Similarly, the correlation value for shark TL morphometrics exceeded 1,000 and exceeded the FL and SL measurements. This indicates that TL morphometrics serve as a very suitable differentiation feature between sharks captured in the Indian Ocean and the Strait of Malacca. However, the results of the discriminant analysis for the rays indicated that the DW, TL, and DL morphometrics had a significance value greater than 0.05. Therefore, these three morphometrics cannot be considered as the primary distinguishing factors to determine between rays caught in the Indian Ocean and the Strait of Malacca.

Table 1. Principal component analysis (PCA) of the morphometric variables of sharks and rays landing at PPS Lampulo, Banda Aceh, Indonesia.

	Sharks		
Eigenvalues	F1	F2	F3
Value	2.93583	0.06242	0.00175
% of variability	97.86	02.08	00.06
Cumulative %	97.86	99.94	100.00
Vectors	F1	F2	F3
TL	0.57123	0.82066	0.01467
FL	0.58057	-0.39135	-0.71399
SL	0.58021	-0.41637	0.70000
	Rays		
Eigenvalues	F1	F2	F3
Value	2.65724	0.20610	0.13667
% of variability	88.58	06.87	04.55
Cumulative %	88.58	95.45	100.00
Vectors	F1	F2	F3
DW	0.58506	-0.08839	-0.80616
TL	0.57504	-0.65573	0.48923
DL	0.57186	0.74980	0.33282

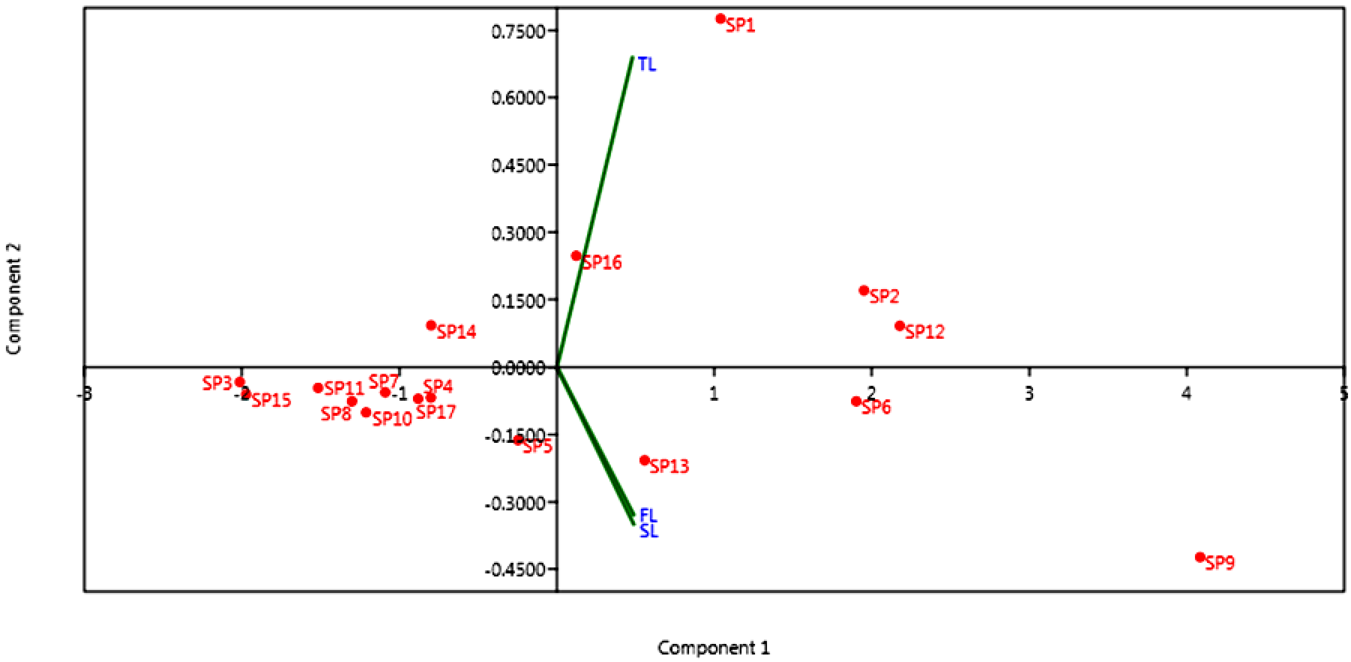

Figure 2. Characteristics of the sharks that landed at PPS Lampulo, Banda Aceh, Aceh Province, according to their morphometrics. SP1 = *Alopias pelagicus*; SP2 = *Alopias superciliosus*; SP3 = *Atelomycterus marmoratus*; SP4 = *Carcharhinus falciformis*; SP5 = *Carcharhinus melanopterus*; SP6 = *Carcharhinus plumbeus*; SP7 = *Carcharhinus sorrah*; SP8 = *Chiloscyllium punctatum*; SP9 = *Galeocerdo cuvier*; SP10 = *Hemigaleus microstoma*; SP11 = *Loxodon macrorhinus*; SP12 = *Prionace glauca*; SP13 = *Pseudocarcharias kamoharai*; SP14 = *Sphyrna lewini*; SP15 = *Squalus hemipinnis*; SP16 = *Stegostoma fasciatum*; SP17 = *Triaenodon obesus*.

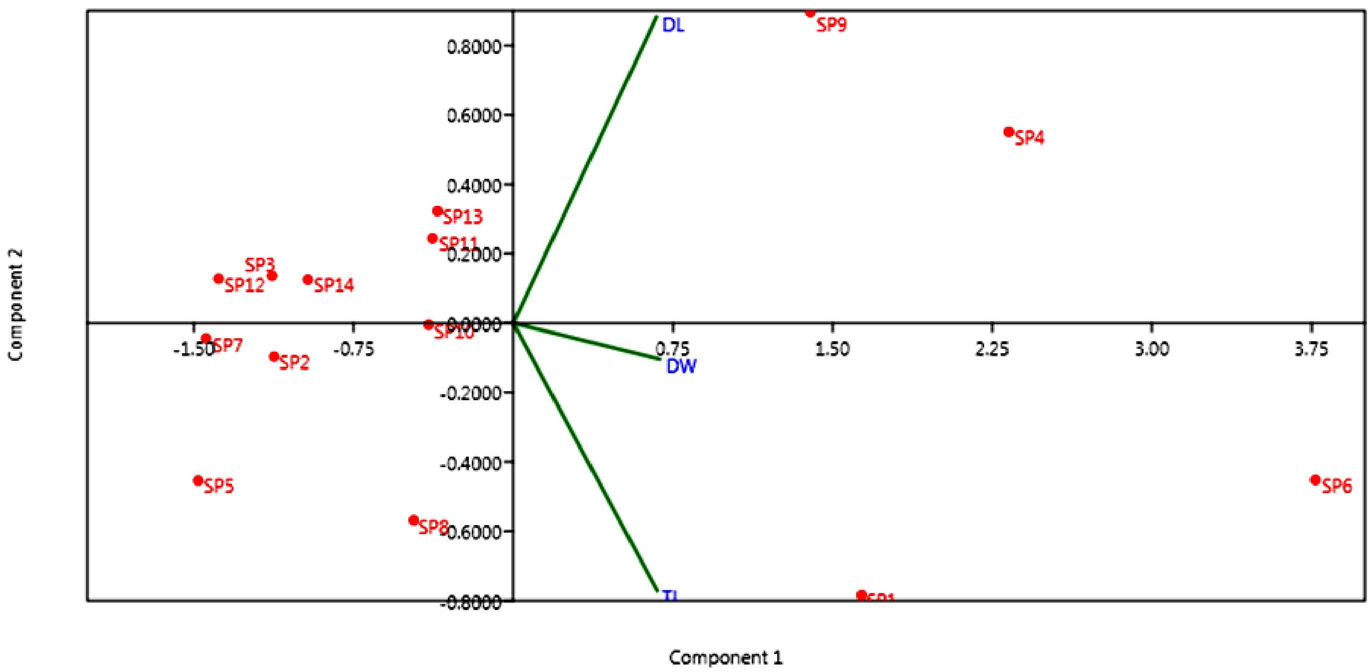

Figure 3. Characteristics of the rays that landed at PPS Lampulo, Banda Aceh, Aceh Province, according to their morphometrics. SP1 = *Aetobatus ocellatus*; SP2 = *Dasyatis akajei*; SP3 = *Gymnura japonica*; SP4 = *Himantura jenkinsii*; SP5 = *Maculabatis gerrardi*; SP6 = *Mobula kuhlii*; SP7 = *Neotrygon kuhlii*; SP8 = *Pastinachus gracilicaudus*; SP9 = *Pastinachus sephen*; SP10 = *Pastinachus solocirostris*; SP11 = *Rhinoptera jayakari*; SP12 = *Taeniura lymma*; SP13 = *Taeniura meyeni*; SP14 = *Urogymnus asperrimus*.

Discussion

The development of a biological organism can be assessed by its body measurement. The reason for this is that size is a critical determinant of growth. The morphometrics of the sharks and rays that landed at PPS Lampulo, Banda Aceh City, were elucidated by the results of the principal component analysis (PCA). The principal component 1 of the sharks

Table 2. Discriminant analysis of the morphometric variables of sharks and rays landing at PPS Lampulo, Banda Aceh, Indonesia.

Variable	*Wilks' lambda*	*F-value*	*p-level*	Standard coefficient	Matrix structure
Sharks					
TL	0.941	10.379	0.002	1.000	1.000
FL	0.958	07.266	0.008	0.000	0.879
SL	0.961	06.850	0.010	0.000	0.869
Rays					
DW	0.999	0.059	0.809	0.000	0.000
TL	0.999	0.060	0.808	0.000	0.000
DL	0.997	0.114	0.738	0.000	0.000

was approximately 97.86%, while the principal component 2 of the sharks was approximately 02.08%. The principal component 1 of the rays was 88.58%, and the principal component 2 of the rays was 06.87% (Table 1). Ma (2014) posits that principal component 1 is a representation of the principal axis, which characterizes the maximum variability of the data, and principal component 2 is a representation of the minimum axis, which characterizes the remaining variability that is not accounted for by principal component 1. Consequently, the use of principal component 1 is crucial in data interpretation and, in some cases, principal component 1 alone is sufficient (Ma, 2011; Ma et al., 2011, 2014).

Each of the shark and ray morphometrics recorded has significant effects on the newly established variables (Table 1), resulting in the formation of two distinct groups (Figures 2 and Table 3). Each group is distinguished by specific species and morphometric sizes. Romanov et al. (2008) found that the size of the FL shark *P. kamoharai* ranges from 39 to 185 cm, and its standard length frequency (SL) is approximately 77.50% of TL (Kizhakudan & Rajapackiam, 2013). Dharmadi et al. (2012) and Widodo & Mahulette (2012) reported that the size of the TL of *A. pelagicus* sharks ranges from 150 to 310 cm. Specifically, the size of the TL for young A. *pelagicus* sharks falls within the range of 150 - 170 cm, while the size of the TL for adult *A. pelagicus* sharks falls within the range of 291 - 310 cm (Dharmadi et al., 2012). The average total length (TL) of *A. ocellatus* rays is around 880 cm, according to Last and Stevens (2009). The maximum body width (DW) is around 330 cm, but the often-seen DW size is approximately 160 cm, as reported by Compagno & Last (1999) and Last et al. (2010).

Morphometric measures play a crucial role in distinguishing different genera of an organism, both within a genus and within a family (Yakubu et al., 2010). The analysis of TL, FL, and SL morphometrics using discriminants strongly supports the observation that sharks caught in the waters of the Indian Ocean are larger than those caught in the Straits of Malacca. This significant difference in size can be used as a key characteristic to distinguish between sharks from these two regions. However, the analysis of DW, TL, and DL morphometrics using discriminant analysis does not provide a reliable means of distinguishing between the sizes of rays from the Indian Ocean and the Straits of Malacca, since the average morphometrics are not significantly different or nearly identical.

Conclusions

Sharks and rays that land in PPS Lampulo, Banda Aceh City, Aceh Province, may be divided into two distinct groups according to their species and morphometric size. Furthermore, the main distinguishing features between sharks captured in the Indian Ocean and the Strait of Malacca are mainly based on total length (TL) measurements. On the other hand, rays do not exhibit distinguishing characteristics based on measurements of disc width (DW), total length (TL), or disc length (DL).

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Authorship contribution

Nur Hikmah: Conceptualization, methodology, investigation, resources, sample processing and analysis, data curation, formal analysis, visualization, writing - original draft preparation, writing - review and editing. **Hayatun Nufus**: Methodology, writing - review and editing, supervision. **Syahrial Syahrial:** Conceptualization, methodology, formal analysis, writing - original draft preparation, writing - review and editing, supervision. **Riri Ezraneti:** Writing - review and editing. **Rika Astuti:** Writing - review and editing. All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Data availability

Datasets generated during and/or analysed throughout the present study are available from the corresponding author upon reasonable request.

Conflict of interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

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