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Improved feature extraction method and K-means clustering for soil fertility identification based on soil image

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ABSTRACT

This research is conducting analysis of digital land images using digital image processing techniques. The main purpose of the research is to classify soil fertility based on two-dimensional RGB colored digital soil images. The research is done by extracting features and shapes from the soil image. The research uses methods of segmentation, extraction, and identification against digital soil images. This research is carried out in three stages. The first phase of this research is image pre-processing which begins with the conversion of RGB color image to Grayscale then color conversion to binary which subsequently performs noise reduction with the method Three-layer median filter. The second stage is a process that is divided into the first two stages, namely the process of segmentation by grouping RGB color images into L*a*b which is continued by clustering using the K-means clustering method. The second is the extraction of characteristics of the soil image which is characteristic of shape and texture. The final stage is the identification of soil images that are clustered into two types: fertile soils and unfertile soil. The study achieved an accuracy of 85% which could accurately identify 20 images while inaccurately classifying 5 images out of a total of 25 input images.

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1. INTRODUCTION

Soil fertility is very important for the world of agriculture. Soil fertility determines the success of agricultural products. The more fertile the soil, the better it will be used for agricultural land, especially food crops such as rice, onions, and corn. Currently, farmers only rely on experience and hereditary abilities in determining soil fertility, it is still very rare to use technology, especially digital image processing technology. The development of technology is very rapid now, especially in the field of computers and more specifically in the field of digital image processing. This study conducted soil fertility detection based on digital soil images that were detected by developing a feature extraction method.

Modern technology is developing quickly to keep up with the ever evolving times [1]. Human existence has been greatly hastened and made simpler by these advancements, particularly in the area of computers [2]. Computers have been a great help to humans in a variety of ways since their invention [3]. Tasks are now simpler, quicker, and more accessible when using computers, and there's the added advantage of having other people watch you in real time. Additionally, computers improve results in a number of procedures and increase labor effectiveness [4], [5]. The swift advancement of computer technology has a significant influence on various facets of human existence. Artificial intelligence (AI) is one field of computer technology that is developing quite quickly [6]. Within computer technology, AI is a fast expanding field [7], [8]. This area of computer science enables machines, or computers, to carry out jobs in a manner akin to that of humans [9]–[11]. Artificial intelligence techniques are used in the development of intelligent systems, and machine learning techniques such as neural networks and deep learning are used to produce systems that can recognize patterns, learn from data, and make predictions [12], [13]. AI is used in many fields, such as data analysis, image processing, chatbots, virtual assistants, facial recognition, and driverless vehicles [14], [15].

One nation in the world with a sizable amount of land used for agriculture is Indonesia. Although there are currently 70 million hectares of agricultural land in Indonesia, only 45 million hectares of that land are actually usable for agricultural production, according to statistics from the country's Central Bureau of Statistics (BPS). Due to the conversion of these fields into non-agricultural property, the extent of paddy fields tends to diminish annually, totaling between 50,000 and 70,000 hectares. Paddy fields are only expanding over a comparatively small area each year-between 20,000 and 40,000 thousand hectares [16], [17]. The quality of the soil on an agricultural plot determines its fertility [18]–[20]. The land gets more productive as its fertility increases. Numerous varieties of food crops are grown in Indonesia. Image processing is a thorough process that involves in-depth visual analysis and perception. The image that has been processed becomes a digital image that is stored in a computer's 0 and 1 data format [21]–[23]. Input data is used in this process, and images are also produced as output data. Nonetheless, when compared to the original image, the processed image has a superior quality [24]–[26]. Digital image processing is more broadly defined as computer-assisted two-dimensional picture processing. Image processing is used by researchers to evaluate image data for a variety of studies.

Land is one of the most precious natural resources on the planet. Fertile soil plays an important role in supporting life, especially in the context of agriculture and natural ecosystems. Fertile soils have characteristic characteristics that distinguish them, such as high nutrient content, good soil structure, optimal moisture levels, and a balanced pH. The presence of active soil microbes is also an indicator of soil fertility. The benefits of fertile soil are very varied. First of all, fertile soil improves agricultural yields, ensures that crops grow fertile and produce quality produce. Moreover, fertil soil also promotes biodiversity by providing a good habitat for various soil organisms. For the farmer, knowing that the land is fertile has a huge advantage. They can optimize resource use, reduce the use of fertilizers and pesticides, and increase harvest yields. In addition, awareness of the importance of preserving and improving soil fertility also contributes to agricultural sustainability and environmental conservation. By keeping the soil fertile, we can ensure the availability of sustainable natural resources and enhance life on this earth.

In a recent study by Almeida-Nauñay *et al.*, [27] soil background removal was optimized to enhance UAV imagery-based wheat trait prediction. By employing a confidence score, remote sensing was utilized to assess grain output and quality across the growth cycle, aiding in achieving efficient and sustainable wheat cultivation. The study proposes optimal thresholds between 0.1 and 0.3 based on the wheat attribute being evaluated and the vegetation index (VI). During the stem elongation growth stage (GS32), the TVO (Threshold-Value Optimization) method demonstrated enhanced yield and nitrogen (N) output estimation. However, the TVO approach resulted in minimal improvements in estimating anthesis protein content (GS65). These findings suggest that the TVO approach can help mitigate the soil effect, highlighting the significance of soil background reflectance in UAV imaging. Soil background reflection introduces uncertainty in predicting grain yield and quality based on VIs, underscoring the importance of accurate soil background removal for reliable UAV-based wheat trait assessment.

In a study titled "Estimating soil properties from smartphone imagery in Ethiopia," M.J. Aitkenhead *et al.* [28] worked. The aim of this study was to investigate the viability of estimating soil parameters in the field using a smartphone-based system, thereby doing away with the necessity of conventional laboratory analysis and sampling. Using an ODK (Open Data Kit) interface created especially for the study, photos and related site characteristics were taken. In order to relate image data to soil parameters, two types of models were studied: partial least squares (PLS) and backpropagation neural networks (NN). When colour and spatial covariate information were combined, as opposed to when colour or spatial covariates were used alone, estimation accuracy for chemical characteristics improved consistently for both NN and PLS models. Similar trends were seen in the physical characteristics, although the findings were less certain and the assessment of physical properties performed less well when validated using statistical models.

This study aims to employ two-dimensional RGB-colored JPG digital soil images to discern and classify soil fertility. It encompasses two distinct extraction methods: form extraction and texture extraction. Form extraction focuses on deriving matric and eccentricity values, while texture extraction aims to determine correlation, energy, and homogeneity of soil image values. The primary objective of this identification process is to assist farmers in assessing the fertility status of their land before cultivation. By doing so, farmers can ensure successful crop growth and enhance both yield and productivity. Furthermore, by introducing novel strategies aimed at yielding more precise and reliable outcomes, this study endeavors to enhance current soil identification methodologies. The findings of this research are expected to significantly benefit farmers in making informed decisions regarding land selection for crop cultivation. By providing valuable insights into soil fertility, this study can potentially revolutionize agricultural practices, leading to increased agricultural output and sustainability. Additionally, the proposed strategies could contribute to advancements in soil management practices, thereby promoting long-term soil health and productivity.

2. METHOD

The main objective of this research is to improve the feature extraction and K-means clustering method to identify soil fertility based on 2-dimensional color soil images. To achieve this goal, several stages of research must be carried out. The research stages in this study are depicted in the research framework in Figure 1.

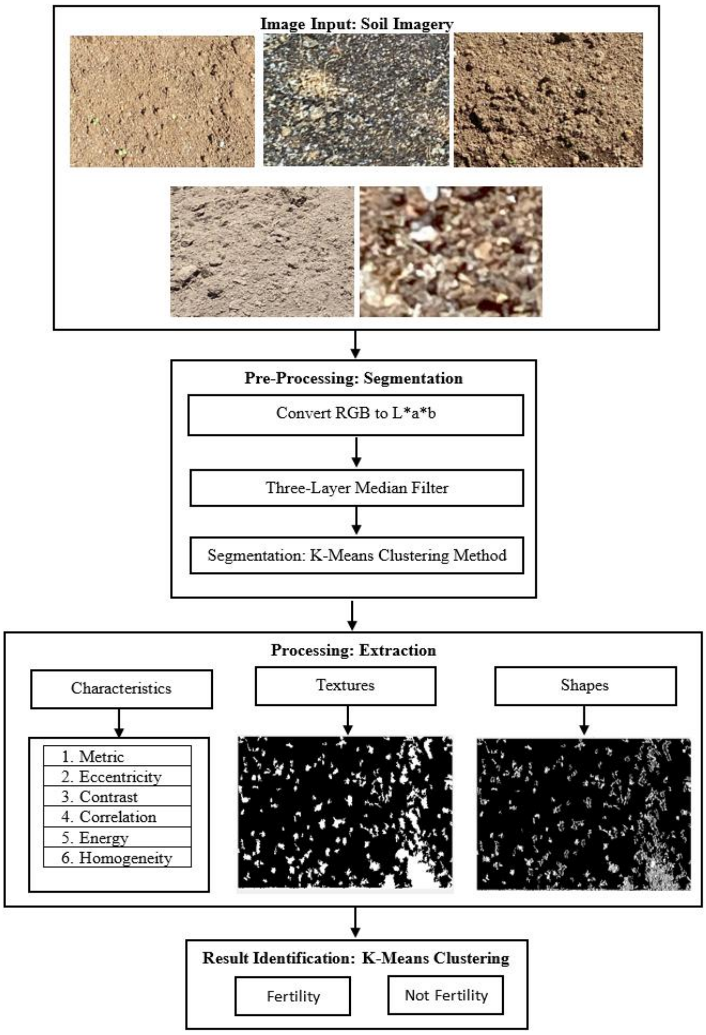


Figure 1. Research framework

There are four categories of study stages in Figure 1 of the aforesaid research framework. The system must first receive an RGB-colored digital image of the ground as input. This is known as the image input step. The next phase is pre-processing, which consists of three processes. RGB-colored soil photos must first be converted to Lab-colored images, the K-means method must then be used to cluster the Lab-colored images and the three layers media filter is to reduce noise from images. The process stage comes next, when the image is extracted using the pre-processing outcomes as a guide. There are three different extraction methods used: characterization, texture, and shapes.

2.1. Image input: soil imagery

The input image data consists of soil photography stored in digital files with the *.jpg extension. These RGB test images are standardized to a pixel size of 658×476 to ensure dimensional consistency during analysis. The test dataset comprises twenty-five soil photos, with five images selected as examples for this research. These images serve as representative samples, offering insights into soil characteristics and facilitating comprehensive analysis of soil fertility levels in the study area.

2.2. Pre-processing: segmentation

The second step in this research involves pre-processing, comprising three key procedures. Firstly, RGB to L*a*b conversion enhances color space for better analysis. Next, segmentation via K-means clustering identifies distinct regions of interest. Finally, a three-layer median filter reduces noise while preserving image details. Each process plays a vital role in refining image data. RGB to L*a*b conversion optimizes color representation, K-means segmentation identifies relevant areas, and the median filter enhances image clarity. This step is crucial for preparing images for subsequent analysis, ensuring accurate and reliable results.

2.2.1. Convert RGB to L*a*b

The next step is to convert the RGB-colored soil image into L*a*b colour after it has been successfully entered into the system [29], [30]. In colour science, photography, and graphic design, colour spaces or colour models are described using the L*a*b colour system. Three elements combine to form colour according to the L*a*b colour system: brightness (L*), red-green tones (a*), and yellow-blue tones (b*). The purpose of this conversion is to make the segmentation process-which comes next-easier. Segmentation is used in this study to try and isolate each colour constituent, with a focus on red-green tones in particular.

2.2.2. Three-layer median filter

One type of image processing method used to lower noise in digital photos is the three layers median filter. It is an expansion of the conventional median filter, which substitutes the median value of each pixel for the value of the pixel next to it. While it takes into account more than one layer or channel in the image, the three layers median filter functions similarly to the conventional median filter. Many digital photos, particularly color or multi-channel images (like RGB images), contain values for each pixel that indicate color or intensity in various channels (such red, green, and blue).

2.2.3. Segmentation: K-means clustering method

Segmentation, sometimes referred to as clustering, comes next after the RGB to Lab colour conversion of an image is finished. The K-means approach is used in this study to cluster data. To make further analysis easier, the primary goal of clustering is to group items that have been recognised in a picture with the image's background. The K-means method's steps are listed below [31], [32].

- Initialization: the first step is to figure out how many clusters you want, 'k.' Choose k sites at random to be the starting centroids. These centroids may be selected by a predetermined initialization procedure or at random [33].
- Step two (distance calculation): determine the separation between every data point and every centroid by using a certain distance metric, such as the Manhattan distance or the Euclidean distance. Next, place every data point in the cluster that has the closest centroid.
- Third phase (centroid update): determine the mean of every data point in every cluster. As the new centroid for that particular cluster, set the average value.
- Fourth step (repeat steps 2 and 3): repeat steps 2 and 3 until convergence is reached, which occurs when the data point distribution to clusters remains constant or when the change in centroids becomes very minimal.
- Fifth step (output): the K-means algorithm's final result will be the clusters that are produced after convergence. Based on how close a data point is to the closest centroid, each data point will be allocated to a cluster.

2.4. Processing: extraction

Following successful completion of the K-means clustering phase, image extraction is initiated. This process entails isolating vital components from the studied image, encompassing color, features, and shape. Three distinct extraction techniques are employed: shape, textural, and feature extraction. Each method is meticulously explained to elucidate their roles in this investigation. Shape extraction identifies geometric properties, textural extraction discerns surface characteristics, and feature extraction quantifies image attributes. These techniques collectively contribute to comprehensive image analysis, facilitating deeper insights into the underlying properties and patterns present within the images under scrutiny. The basic purpose of digital image feature extraction is to reduce complicated image representations into simpler and more intelligible forms. In this study, six types of feature extraction are applied to soil photographs, namely metric, eccentricity, contrast, correlation, energy, and homogeneity. To calculate the value of features extraction we use the (1)-(6).

$$Metric = \frac{Area}{Convex\ Area} \tag{1}$$

$$Eccentricity = \sqrt{1 - \frac{b^2}{a^2})} \tag{2}$$

$$Contrast = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P(i,j)(i-j)^2 \tag{3}$$

$$Correlation = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (\frac{(i-\mu i)(j-\mu j)}{\sigma i\ \sigma j}) \tag{4}$$

$$Energy = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} P(i,j)^2 \tag{5}$$

$$Homogeinety = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \frac{P(i,j)}{1+|i-j|} \tag{6}$$

Where: area is the number of pixels in an object, Convex area is the number of pixels in the convex hull of an object, a is the semi-major (long) axis, b is the semi-minor (short) axis, $P(i,j)$ is the value in the co-occurrence matrix at position (i,j), N is the number of intensity levels in the image, μi and μj is the average intensity value for row i and coloumn j, σi, and σj is the standard deviation of the intensity for row i and coloumn j, below is Algorithm 1 that we use to extract characteristics, textures and shapes.

Algorithm 1. extraction based on characteristics, texture and shapes

```
Input: digital image (input_image)
Output: characteristics, textures, shapes
Initialization:
   Initialize image as input_image
   Initialize characteristics as empty list
   Initialize textures as empty list
   Initialize shapes as empty list
   characteristics.append(color_histogram)
   characteristics.append(edge_features)
   textures.append(GLCM_features)
   textures.append(LBP_features)
   shapes.append(contours)
   shapes.append(hough_lines)
shapes.append(hough_circles)
```

2.5. Result identification: K-means clustering

This research aims to discern soil fertility levels through image analysis. Utilizing the K-means clustering method, soil images are categorized into two groups: fertile and non-fertile soils. This classification system provides insights into soil quality, aiding in agricultural and environmental assessments. By accurately identifying fertile and infertile soil regions, this study contributes to informed decision-making processes regarding land use, crop selection, and soil management practices. The results offer valuable information for enhancing agricultural productivity, sustainability, and environmental conservation efforts.

3. RESULTS AND DISCUSSION

This research culminates in identifying soil fertility levels within land images. Through successive stages of analysis, the desired outcomes are achieved. The comprehensive process entails meticulous examination and interpretation of image data to discern soil characteristics accurately. By determining whether soil is fertile or infertile, this study provides valuable insights for agricultural and environmental purposes. The culmination of efforts underscores the significance of rigorous research methodologies in elucidating critical information vital for land management, agricultural productivity, and environmental sustainability.

3.1. Image input: soil imagery

The test set comprises twenty-five soil photos, all sourced from land in Solok Regency, West Sumatra province, dedicated to food crop cultivation. To illustrate the soil samples, five photos are presented as sample images. Table 1 provides an example of a soil picture from the study. These images represent the diverse soil conditions encountered in the agricultural landscape of the region, serving as essential data for the research's soil fertility analysis.

Table 1. Soil imagery input

Soil imagery input				
				
Soil imagery 1	Soil imagery 2	Soil imagery 3	Soil imagery 4	Soil imagery 5

It is evident from the five sample input photos of the above soil image that each of the five soil photographs is unique. Photographs of smooth soil with few rocks, photographs of slightly coarse soil with slightly more rocks than fine soil, and images of coarse soil with more rocks than fine soil are all available. The plants that are appropriate for planting also differ due to these various situations. Thus, conducting this research is essential. Pre-processing will involve an analysis of the five soil photographs.

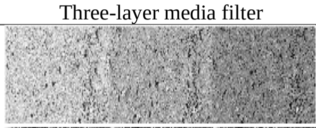
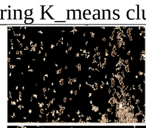
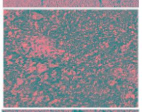
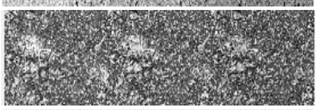
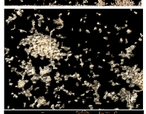
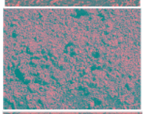
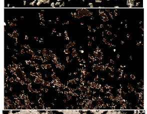
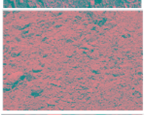
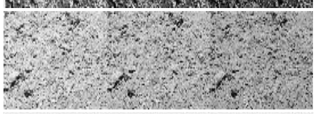
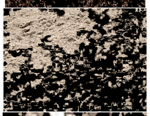
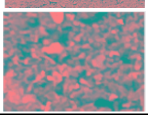
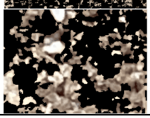
3.2. Pre-processing

a) Convert RGB to L*a*b: in this study, the initial pre-processing step is changing RGB soil pictures to L*a*b colors. The ability to correctly separate the soil image's color into Red and Green indicates that this pre-processing was completed. The RGB source image and the transformed L*a*b image are shown in Table 2. It is evident from the image in Table 2 that an RGB color input image may be correctly transformed to a L*a*b color image. The image's red-green hues are the colors that are separated in this investigation.

b) Clustering using the K-means method. Clustering between the identified objects in the ground image and the image background is the second pre-processing step. K-means clustering is used in this pre-processing segmentation. The RGB soil images that have been transformed to L*a*b can be correctly sorted into rocky items and fine soils following the pre-processing segmentation used in this study. The RGB input image, the converted image to L*a*b color, and the K-means method-generated clustering are shown in Table 2.

c) Three-layer median filter. Three-layer clustering is the process of reducing noise from the image that has clustering from the preceding step. Three layers of clustering give three recommendation images that have been reduced to the next processing step. The result is one of the best noise reductions from the three recommended images. The three-layer median filter can be shown in Table 2.

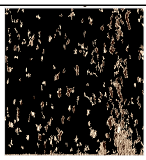
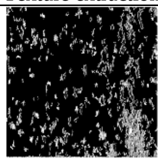
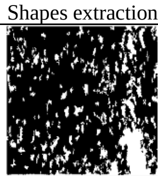
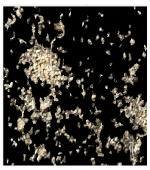
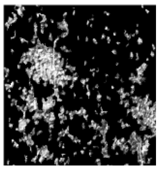
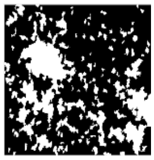
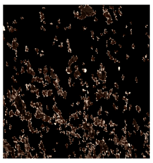
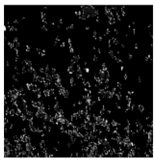
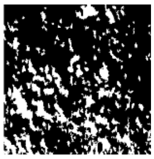
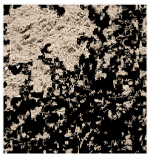
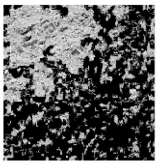
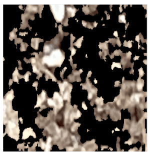
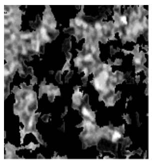
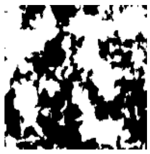
Table 2. Pre-processing result

No	Soil imagery input	Convert RGB to L*a*b	Three-layer media filter	Clustering K_means clustering
1				
2				
3				
4				
5				

3.3. Processing

The process step comes next. The image extraction procedure was completed in stages for this study. Three different methods of image extraction are carried out: shape, texture, and feature extraction. One can do these three extraction methods proficiently. The features, texture, and form extracted from soil image data are shown in Table 3.

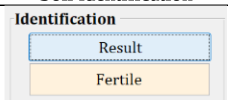
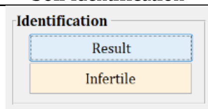
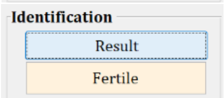
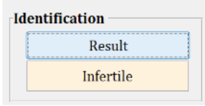
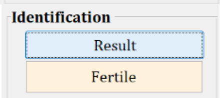
Table 3. Processing result

No	Pre-processing result	Processing result: Characteristics extraction		Texture extraction	Shapes extraction
1		Characteristics	Score		
		Metric	0.13282		
		Eccentricity	0.91559		
		Contrast	1.8827		
		Correlation	0.76985		
		Energy	0.61727		
		Homogeneity	0.89825		
2		Characteristics	Score		
		Metric	0.30161		
		Eccentricity	0.70535		
		Contrast	0.76771		
		Correlation	0.90483		
		Energy	0.49077		
		Homogeneity	0.89756		
3		Characteristics	Score		
		Metric	0.69225		
		Eccentricity	0.85188		
		Contrast	0.93108		
		Correlation	0.66689		
		Energy	0.71399		
		Homogeneity	0.92084		
4		Characteristics	Score		
		Metric	0.27864		
		Eccentricity	0.969		
		Contrast	2.1779		
		Correlation	0.83686		
		Energy	0.24675		
		Homogeneity	0.8087		
5		Characteristics	0.088939		
		Metric	0.84682		
		Eccentricity	0.43069		
		Contrast	0.94436		
		Correlation	0.27184		
		Energy	0.93912		
		Homogeneity	0.088939		

3.4. Result

The results of this research indicate whether the soil is fertile or not based on the analysis conducted. The classification process helps determine the soil's fertility status with a certain level of accuracy. Table 4 presents the detailed outcomes of the evaluation, including key parameters used in the assessment. These findings provide valuable insights for agricultural planning and soil management.

Table 4. Result: identification

No	Soil imagery input	Soil identification	No	Soil imagery input	Soil identification
1			4		
2			5		
3					

4. CONCLUSION

The primary objective of this study is to ascertain the fertility of soil. Through an analysis of the results and subsequent discussions, we aim to draw conclusions regarding the achievement of our goals. A novel identification approach has been developed to improve the precision, correctness, and accuracy of identifying objects within soil images. Through experimentation with a dataset comprising 25 input photographs, our identification method has achieved an accuracy rate of 80%. This means that out of the 25 images, our technique correctly identifies the objects in 20 images, while incorrectly identifying objects in 5 images. This success demonstrates the efficacy of our approach in accurately discerning soil properties. Furthermore, the versatility of our method allows for its application to other photographs, facilitating the identification of different objects within the soil. This suggests potential for broader use in soil analysis and characterization beyond the scope of this study. As such, our findings not only contribute to understanding soil fertility but also offer a promising tool for future research and practical applications in agricultural and environmental sciences.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Agung Ramadhanu	✓	✓	✓			✓				✓			✓	
Halifia Hendri		✓		✓		✓		✓	✓			✓		
Sofika Enggari	✓		✓	✓			✓				✓		✓	✓
Silfia Andini					✓	✓				✓				✓
Retno Devita			✓				✓	✓		✓		✓		
Eva Rianti		✓					✓		✓					✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AR], upon reasonable request.

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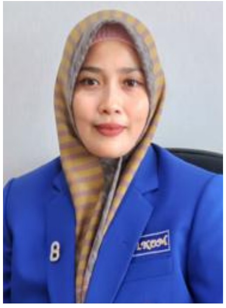

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