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APPLICATION OF DIGITAL IMAGE PROCESSING METHOD FOR ROASTED COFFEE BEAN QUALITY IDENTIFICATION: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

In coffee processing, there are several important stages, one of which is roasting. The roasting process is an important determinant of coffee quality. Determination of coffee quality can be done using digital image processing methods to produce parameters and quality classifications precisely, make images of better quality so that photos and moving images can be easily understood. This analysis uses a Systematic Literature Review (SLR) for the identification, evaluation, and interpretation of all available research results on the topics discussed. The purpose of this study was to identify and analyze the main quality parameters and the best digital image processing methods used in classifying the quality of roasted coffee beans. From the results of the analysis of 31 journals, it is known that the parameters for evaluating the quality of roasted coffee are color parameters, texture parameters, and shape parameters. The color parameters consist of Red Green Blue (RGB), Grayscale, Hue Saturation Intensity (HSI), and L*a*b* features. The texture parameters consist of energy, entropy, homogeneity, and contrast. As for the feature shape parameters, they are area, circumference, diameter, and percentage of roundness. Results of the analysis show that the main parameter that plays an important role in assessing the quality of roasting coffee is the color parameter. This can be seen from the function of the color parameter in quality identification based on the image of the roasted coffee beans. The quality parameters used are image capture, image resolution, training data, testing data, iterations, and accuracy values. In addition, the resulting image processing methods used for quality classification include Backpropagation (BP), Learning Vector Quantization (LVQ), and K-Nearest Neighbor (KNN). Based on results of the analysis, the best method for classifying the quality of roasting results is Backpropagation, and it is known that the accuracy value of this method has a high range of values.

Key words: Backpropagation, K-Nearest Neighbour, Learning Vector Quantization, Coffee Bean Roasting, Image Processing

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INTRODUCTION

Coffee is one of the most abundant plantation products in Indonesia. Indonesia has 26 types of coffee that have been certified as Geographical Indications and the total production reaches 722,500 tons per year based on the 2018 Directorate General of Plantations. Arabica and Robusta coffee are the most common types of coffee plants found. Coffee is included in tropical plants that can grow well between temperatures of 18 - 30°C depending on the growth phase [1]. The global demand for coffee consumption, which reaches 3 billion cups every day, makes coffee a popular drink in the world [2,3]. Coffee goes through several processes before consumption, one of which is the roasting process. Roasting is a process where heat is applied to the raw coffee bean (green bean) which is characterized by physical and chemical changes depending on the time and temperature used. The process involves heat transfer to reduce dry weight and activate the chemical compounds that give aroma to coffee through the Maillard chemical reaction [2,4].

The roasting process is important because it influences a simple determination of the quality of coffee beans, which are then processed and consumed by the community [5]. The characteristics of coffee beans depend on the level of roasting used, which is generally divided into light roast, medium roast, and dark roast [6]. Coffee with various stages of roasting in sequence starting from drying, yellowing, first crack, roast development, and second crack from left to right can be seen in Figure 1. However, coffee that has been roasted often produces an unpleasant coffee taste. Several defects that can occur during the roasting process include baked, quakers, overdeveloped, and underdeveloped [7]. In the sustainable performance assessment, the product quality indicator is one of the economic aspects that is considered very important in the sustainability of the coffee industry because it affects consumer satisfaction [8]. One of the strategies that can be implemented to increase customer satisfaction is to improve the quality of the coffee beans used, so that later it will produce the best quality products. However, in determining the quality of the coffee beans simply through visual observation, there are many errors because the human eye will experience fatigue due to continuous work and other factors such as light intensity. Therefore, a system is needed to minimize errors. The application of digital image processing method is needed to accurately classify and maintain the quality of roasted coffee beans [6,9].

Digital image processing is an initial step in identifying the quality of coffee beans. Digital image processing methods aim to improve image quality for easy interpretation through photos and moving images. The fundamental step in digital

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image processing can be seen in Figure 2. The advantages of this image processing are that it is relatively short, fast, and can identify the physical product objectively [9].

Figure 1: Coffee at different stages of roasting [10]

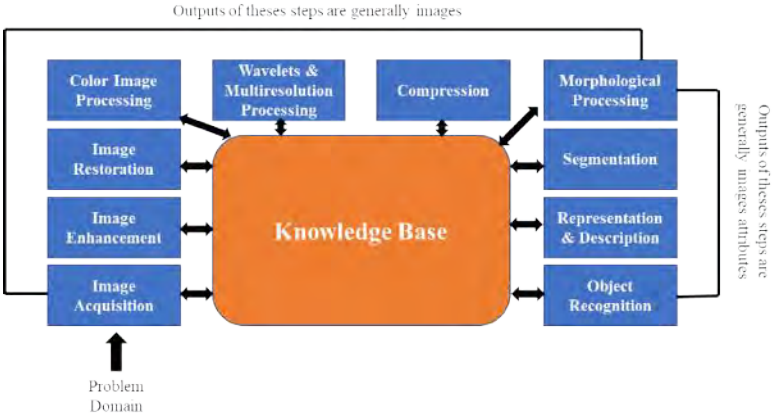

Figure 2: The fundamental steps in digital image processing [11]

This research was conducted using a Systematic Literature Review (SLR), which is a literature study to identify, evaluate, and interpret all relevant research results and focus on a particular topic. The purpose of using the SLR method is to obtain more accurate results in identifying the best digital image processing methods and has the potential to be developed in performing accurate image processing of roasted coffee quality.

The purpose of this study was to identify and analyze the main parameters and the best digital image processing methods used in classifying the quality of roasted coffee beans. This is so that it can help and provide suggestions for improvement to the manager of the coffee bean roasting process in producing good quality coffee beans under predetermined requirements. It is useful for the public when purchasing coffee by knowing the quality of the coffee, without having to carry out a complicated analysis that is expensive.

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MATERIALS AND METHODS

Methods

This research was conducted by comprehensively reviewing the literature on the process of roasting coffee beans and identifying coffee quality with digital image processing. The literature used was published between 2014 and 2023. Library sources through journals related to coffee roasting and digital image processing, using online databases such as Research Gate, Science Direct, ProQuest, and Springer. Searching for articles from online databases uses the Boolean technique, which is a way to combine the words you are looking for with several connectors to produce the desired information. Boolean techniques used are “AND” together with “OR” codes.

Analysis Techniques

This review analysis technique uses Systematic Literature Reviews. The purpose of the Systematic Literature Reviews method is to help researchers better understand the background of the research topic and understand the results obtained to be used as a reference for new research. The procedure for carrying out analytical techniques using Systematic Literature Reviews identifies the research question, searches data, and includes duplication and screening, quality assessment, data extraction, synthesis of results, and conclusion [12].

RESULTS AND DISCUSSION

Search Process

The results of a literature search using the SLR method and results based on database sources and the number of journals can be seen in Figure 3.

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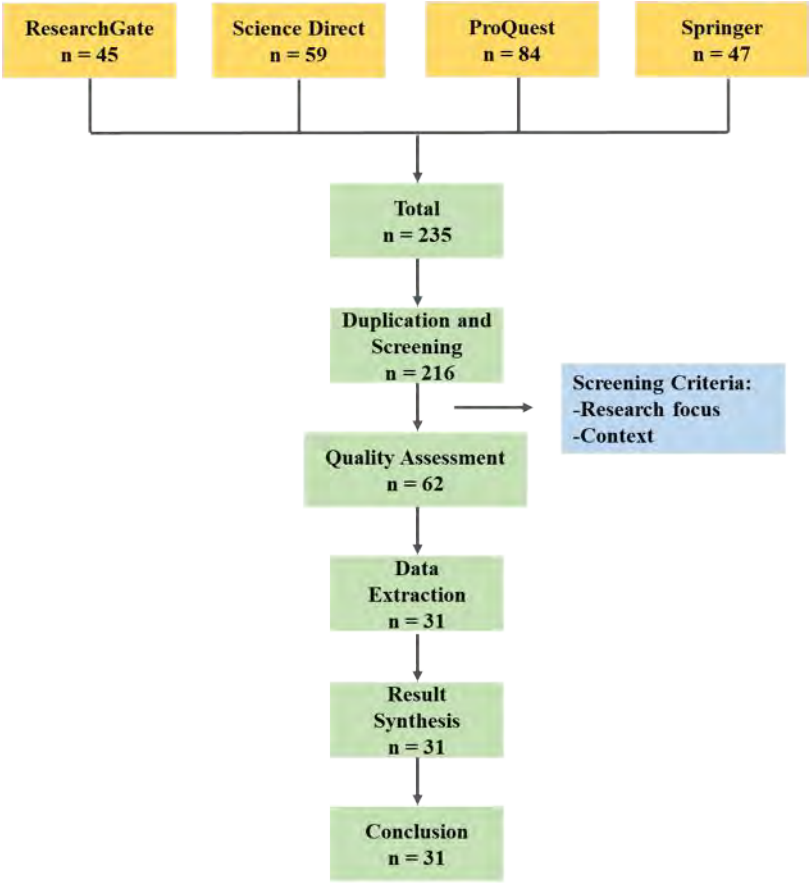

Figure 3: Stages of Systematic Literature Reviews Search Results

Literature Results Based on Duplication and Screening

The results of duplication and screening from database sources can be seen in Table 1. The duplication stage is carried out to find out the same journal based on the title of the journal. If there are similarities in titles from several databases, then only one will be selected, and the others will be removed. The results of the duplication stage of the four databases produced 19 duplicate journals. The screening stage with requirements according to the criteria includes literature published between 2014 and 2023, fully accessible literature, and literature in the form of research articles.

Literature Results Based on Quality Assessment

The assessment was carried out based on predetermined inclusion and exclusion criteria. The inclusion criteria in this study were reputable international journals related to the quality parameters of roasting coffee beans, as well as digital image processing methods, which can be seen in Table 2.

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Literature Results Based on Data Extraction

The final stage was to determine the exact amount of literature to be selected. This data extraction process was carried out by filtering the literature from the results of quality assessment starting from the abstract, objectives, methods, and results. Selected literature results based on data extraction can be seen in Table 3.

The results of the exact number of literatures used were less than the results of the previous stages because there are still journals that use digital image processing methods only up to the feature extraction stage, namely shape and color features, and not to the quality classification stage. Therefore, this is not following the research objectives because the expected results were to know the best quality classification of digital image processing methods. Selected literature results based on data extraction were as many as 31.

Results Synthesis

Results of literature classification of quality assessment of coffee bean roasting and digital image processing methods

Data collection techniques are carried out to obtain new concepts through in-depth understanding, commonly referred to as qualitative techniques [13]. This SLR discusses digital image processing methods used to determine the quality of roasted coffee beans. The grouping of the use of quality assessment parameters and digital image methods can be seen in Table 4.

Based on Table 4, it can be seen that the color parameter is the most used parameter, which is equal to 28, and the K-Nearest Neighbor method is the most used method, which is equal to 18. Then, an analysis will be carried out based on similarities in the use of quality, parameters and classification methods, which aims to determine the best parameters and image processing classification methods in assessing the quality of coffee bean roasting. Coffee bean roasting results from the journal will be divided into two content analyses, namely parameter analysis of the quality of coffee bean roasting results and the quality of digital image processing.

Quality Analysis of Roasted Coffee Beans

In order to be able to evaluate the quality of roasted coffee beans, conducting a content analysis based on the similarity in the use of parameters in assessing the quality of the journals obtained is necessary. Each parameter has different features, each feature will be grouped to determine its important role in assessing

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Volume 24 No. 1
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quality parameters, making it easier to carry out analysis. The grouping of parameters for assessing the quality of coffee bean roasting results can be seen in Table 5. The Frequency of quality parameters and digital image processing methods can be seen in Figures 4 and 5.

Based on the results obtained, the most used features are RGB and grayscale, this is because these two features have a more important role than other features. The role of these two color features is to improve the image of the roasted coffee beans captured by the camera. Image improvement is the initial stage in digital image processing methods, if this initial stage has experienced an error, it will affect the next stage and the final results obtained. To avoid errors at this early stage, it is necessary to improve the image by using the RGB and grayscale color features.

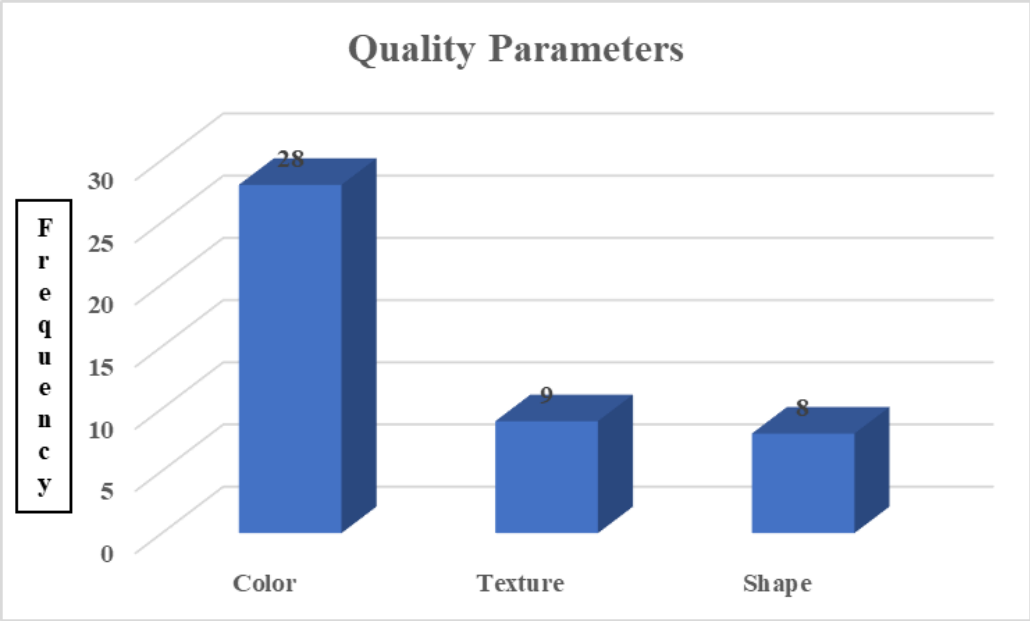

Figure 4: Frequency of quality parameters

Parameters in the form of color, texture, and shape are closely related to the assessment of the quality of roasted coffee beans. These three parameters are included in the stages of digital image processing, namely the feature extraction stage. Feature extraction is a stage for obtaining information from objects through images or images to be examined, objects will be displayed in more detail so that it is easy to distinguish from one object to another [14].

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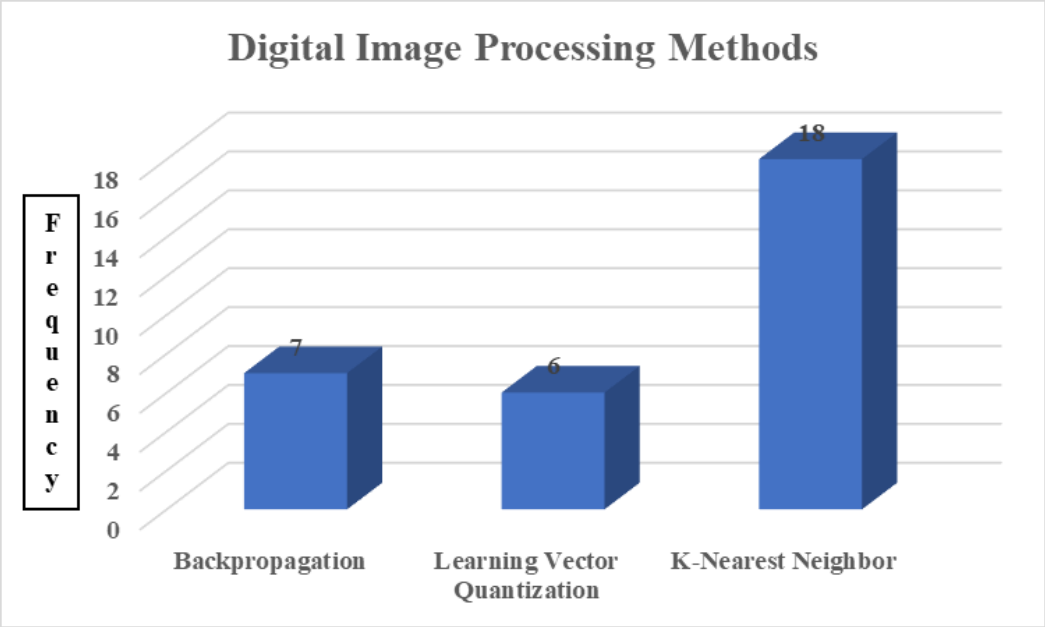

Figure 5: Frequency of digital image processing methods

The results of this feature extraction were later used as input data for further processing, namely the classification stage. The three result parameters from several journals were analyzed in depth, which are presented in the following explanation:

a) Color Parameters

Based on the results of using the four features in this color parameter, it can be concluded that the best combination in using features to evaluate the quality of roasted coffee beans is RGB, grayscale, and HSI features. The determination of this combination is based on the function or role of each feature in the quality assessment process. The use of this RGB feature is for the initial stage in digital image processing, by displaying the color composition of the roasted coffee beans, the HSI feature improves the image of the coffee beans by adjusting the appropriate light so that it can present the input data in the form of coffee beans, while the grayscale feature functions to separate the coffee bean image data so that the images to be used and those to be discarded are be separated. Combining the functions of these three features produces better image data to be used as input in the next process to get maximum results. Frequency of color parameter assessment can be seen in Figure 6.

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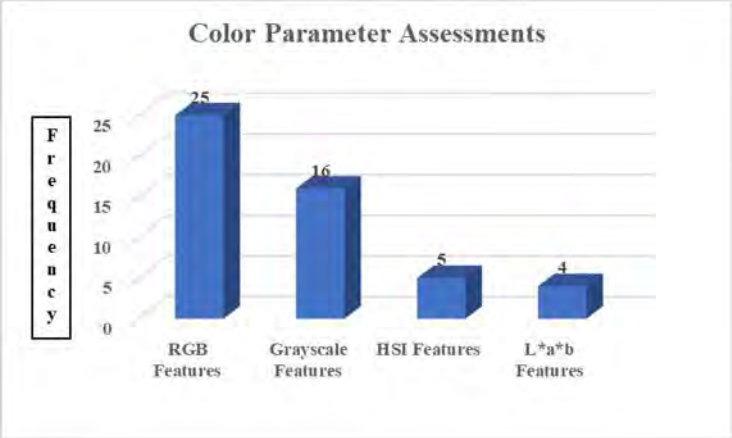

Figure 6: Frequency of color parameter assessments

b) Texture Parameters

Based on the journal used, the use of texture parameters for assessing the quality of roasting coffee beans generally has the same stages, that is, after calculating each energy, entropy, homogeneity, and contrast feature, the average calculation is be carried out for each feature used. The results of the average value are used as input data for the classification process. Frequency of texture parameter assessment can be seen in Figure 7.

c) Shape Parameters

The form parameter in assessing the quality of coffee roasting has a function to detect the properties of the object. The assessment is carried out by differentiating the coffee beans of each type, namely robusta beans and arabica beans, then distinguishing good and defective coffee beans. The feature types contained in the shape parameter include area, circumference, diameter, and roundness percentage. The feature area is measured by counting the number of pixels with a value of one, while the feature circumference is measured by counting the number of pixels located on the border of the coffee bean. The feature diameter is the diameter with the same area as the coffee object used, and the percentage of roundness to measure the circumference of the bean object coffee. Percentage of shape parameter assessment can be seen in Figure 8.

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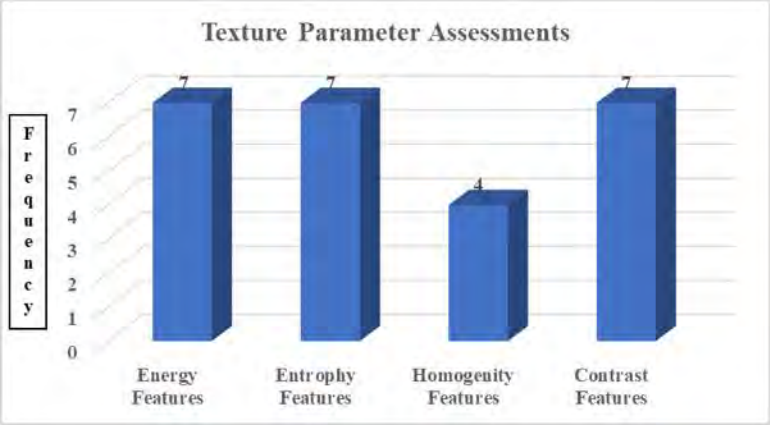

Figure 7: Frequency of texture parameter assessments

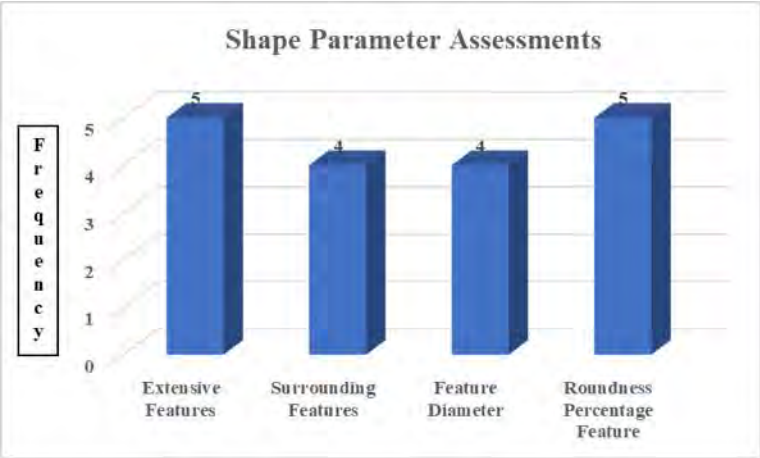

Figure 8: Frequency of shape parameter assessments

Analysis of the Use of Digital Image Processing Methods

Analysis in determining the best image processing method for classifying the quality of coffee bean roasting is carried out using the percentage value of the accuracy of each method. The basis for determining this accuracy value is because the accuracy value can describe how well the method used classifies the quality of roasted coffee beans. If the results indicate high percentage accuracy, then the method used is better and vice versa.

Method analysis begins with grouping journals based on the method used. The results of grouping journals using the Backpropagation method are shown in Table 6. The results of searching journals using the Learning Vector Quantization method are shown in Table 7. The results of searching journals using the K-Nearest Neighbor method are shown in Table 8.

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SCHOLARLY, PEER REVIEWED
Volume 24 No. 1
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Based on the results in Table 6, the average accuracy value resulting from the process using the Backpropagation method has a value range between 94.7% and 100%; this shows that it is in the range of high accuracy values. The results of the accuracy value are influenced by several factors including the use of the number of images, the size of the image resolution, the distribution of training data and testing data, and the use of iterations [15]. Results of the journal using the Backpropagation method use a large number (more than 100) of images. Taking a large number of images will be better able to present the results of quality classification. Another factor that affects the accuracy value is the use of image resolution, and high image resolution will produce a high accuracy value. From the results of the distribution of training data and data testing, it can be seen that the use of larger training data will result in a higher accuracy value. This happens because the results of large data training will produce a better model. Next is the use of iteration or repetition, the purpose of this repetition is to get the best model with a low error rate, and journals that use iterations have a higher accuracy value than journals that do not use iterations.

The percentage of average accuracy values generated using the Learning Vector Quantization method has a value range between 88% and 99.8%. It can be said that the value range is quite low. Based on the result shown in Table 7, it is known that there are 2 studies that use image capture with coffee bean samples below 100, image capture with a range of 100 to 200 samples is found in 3 studies, and only 1 study conducts image capture with many samples above 200.

Determining the number of these images will affect the quality classification results, therefore the images cannot be too few and not too many [16]. The use of a small image resolution is not able to represent the quality of the roasted coffee beans, while in the use of resolution, there are still journals that use a low resolution, namely 64 x 64 pixels. The use of a low resolution will produce an unfavorable image, so it cannot be used as input data in testing [17]. All distribution of training data and testing data in the Learning Vector Quantization method uses training data that is larger than testing data, so the resulting accuracy value is good. Whereas for the use of iteration or repetition in the quality classification process, the highest iteration is 180 times, but there are still journals that do not use iteration.

The results of the analysis of digital image processing methods using the K-Nearest Neighbor method show that one journal has an accuracy value of 69.02% while another has an accuracy value of 70%. Other journals have an accuracy of 80% to 100%. The best method can be seen from the percentage of accuracy

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values, so the higher the accuracy value, the better the method used. The results of this accuracy value are influenced by several things, including the number of images taken, in this journal the amount used is sufficient to be able to present the results because of the 150 images. However, in the captured image, the use of resolution is not determined as this can affect the quality of the image used for input data, and low image quality will give less than optimal results [18]. The division of training data and data testing is in accordance with the literature that good results will be obtained with a training process that is larger than the testing process [19]. The use of iteration in the image classification process is not used in this journal.

Based on the results of an analysis of the three digital image processing methods for the classification of the quality of coffee bean roasting results, the best method is found in the use of the Backpropagation method, this can be seen from the percentage accuracy value, which is higher than the other methods. Results of the accuracy value using the Backpropagation method are high because they are influenced by several things, one of which is because the process for classifying quality using this method aims to minimize the error rate. If the results obtained still have a high error rate, a repetition process will be carried out, namely by returning to the initial stage to obtain the results of a low error rate. If the error rate is low, then the final result obtained is more optimal, and this is an advantage of the Backpropagation method.

For the Learning Vector Quantization method, the process is more complicated, because it is necessary to determine the number of classes for the classification process based on similarities. During this process, errors often occur because there are still input data that do not have similarities but are included in the class members, so the classification process that is carried out does not get perfect results and affects the percentage of moderate to low accuracy values.

Whereas in the K-Nearest Neighbor method, in the process stage, it is necessary to determine the number of nearest neighbors, but the size of the neighbors is not determined. If the data is too large, the process will cause a large error rate, but if the data is too small it cannot be used to interpret the results, which causes errors in the classification process and producing a small percentage of accuracy values.

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

The results of this SLR used 31 journals which are related to methods in digital image processing to identify the quality of coffee bean roasting. The parameters

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Volume 24 No. 1
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ISSN 1684 5374

used in assessing the quality of roasted coffee are divided into three, namely, color parameters, texture parameters, and shape parameters. Based on the results of the analysis of the three parameters for evaluating the quality of coffee roasting, the main parameter that plays an important role in assessing the quality of coffee roasting is the color parameter. In addition, according to the research objective to determine the image processing method used, the results of the analysis obtained three techniques, namely Backpropagation, Learning Vector Quantization, and K-Nearest Neighbor. The best method for classifying the quality of roasting results is Backpropagation, this is known from the results of the accuracy value in this method, which has a high range of values.

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SCHOLARLY, PEER REVIEWED
Volume 24 No. 1
January 2024
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ISSN 1684 5374

Table 1: Duplication and Screening Results from Database Sources

Database Source	Results
ResearchGate	45
ScienceDirect	55
ProQuest	77
Springer	39
Total	216

Table 2: Inclusion and Exclusion of Quality Assessment

Journal Type	Database Source
International	ResearchGate
International	ScienceDirect
International	ProQuest
International	Springer
Total	65

Table 3: Selected Literature Results Based on Data Extraction

Database Source	Results
ResearchGate	13
ScienceDirect	5
ProQuest	10
Springer	3
Total	31

ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 1
January 2024
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ISSN 1684 5374

Table 4: Grouping the Use of Quality Assessment Parameters and Digital Image Processing Methods of Roasted Coffee Beans

Author	Quality Parameter			Digital Image Processing		
	X	Y	Z	1	2	3
Waliyansyah; Hasbullah[17]		√			√	
Pratama *et al.* [20]	√					√
Amanina; Saraswati[21]	√					√
Vilcamiza *et al.* [22]	√	√				√
Benes *et al.* [23]			√			√
Heryanto; Nugraha[24]			√		√	
Sarino *et al.* [15]	√			√		
Gunadi *et al.* [25]	√		√		√	
Nasution; Rumansa; Harahap [26]	√			√		
Arboleda; Fajardo; Medina [27]	√			√		
Garcia;Candelo-Becerra;E. Hoyos [28]	√					√
Hendrawan; Widayaningtyas; Sucipto [29]	√	√			√	
Nasution; Andayani [30]	√	√		√		
Adiwijaya *et al.* [31]	√					√
Pradana; Iranto; Karnila [32]	√	√				√
Murthy *et al.* [33]	√			√		
Gope; Fukai [34]	√		√			√
Araujo *et al.* [35]	√					√
Leme *et al.* [18]	√			√		
Belay; Tegegne [36]	√	√				√
Nansen *et al.* [37]	√			√		
Lee *et al.* [38]	√				√	
Septiarini *et al.* [39]	√		√			√
Chen; Chiu; Zou [40]	√					√
Santos *et al.* [41]	√		√		√	
Hsia; Lee; Lai [42]	√		√			√
Pratama; Kusrini; Muhammad [16]	√					√
Maghfirah; Nasution [43]	√	√	√			√
Arboleda; Fajardo; Medina [44]	√	√				√
Akbar; Awaitawati; Sthevanie [45]	√	√				√
Ligar [19]	√					√
Total	28	9	8	7	6	18

Description:
X=Color Parameters
Y=Texture Parameters
Z=Shape Parameters
1=Backpropagation Method
2=Learning Vector Quantization Method
3=K-Nearest Neighbor Method

ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 24 No. 1
January 2024
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ISSN 1684 5374

Table 5: Grouping Parameters for Quality Assessment of Coffee Bean Roasting Results

Author	Color				Texture				Shape			
	A	B	C	D	E	F	G	H	I	J	K	L
Waliyansyah; Hasbullah [17]					√			√				
Pratama *et al.* [20]	√											
Amanina; Saraswati [21]	√											
Vilcamiza *et al.* [22]	√					√						
Benes *et al.* [23]									√	√		
Heryanto; Nugraha [24]										√		
Sarino *et al.* [15]	√											
Gunadi *et al.* [25]	√	√										√
Nasution; Rumansa; Harahap [26]	√	√										
Arboleda;Fajardo; Medina [27]	√											
Garcia;Candelo-Becerra;E. Hoyos [28]	√	√										
Hendrawan; Widayaningtyas; Sucipto [29]	√	√	√	√	√	√	√	√				
Nasution;Andayani [30]	√	√			√	√		√				
Adiwijaya *et al.* [31]	√	√										
Pradana;Iranto;Karnila [32]	√	√			√	√		√				
Murthy *et al.* [33]	√	√										
Gope;Fukai [34]		√							√			
Araujo *et al.* [35]	√	√	√									
Leme *et al.* [18]		√		√								
Belay;Tegegne [36]	√								√			
Nansen *et al.* [37]	√											
Lee *et al.* [38]	√											
Septiarini *et al.* [39]	√	√									√	√
Chen;Chiu;Zou [40]	√		√									
Santos *et al.* [41]	√								√	√	√	√
Hsia;Lee;Lai [42]	√										√	√
Pratama;Kusrini;Muhammad [16]	√	√										
Maghfirah;Nasution [43]	√	√	√	√	√	√	√	√	√	√	√	√
Arboleda; Fajardo;Medina [44]		√			√	√	√	√				
Akbar;Rachmawati;Sthevanie [45]	√				√	√	√	√				
Ligar [19]	√	√	√	√								
Total	21	16	5	4	7	7	4	7	5	4	4	5

Description: A=RGB Features; B=Grayscale Features, C=HSI Features, D=L*a*b* Features, E=Energy Features; F=Entrophy Feature; G=Homogeneity Features; H=Contrast feature; I=Extensive Features; J=Surrounding Features; K=Feature Diameter; L=Roundness Percentage Feature

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SCHOLARLY, PEER REVIEWED
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Table 6: Grouping Journals with the Backpropagation Method

Author	Results					
	1	2	3	4	5	6
Sarino *et al.* [15]	180	312 x 416	80	20	1000	97.22%
Nasution;Rumansa;Harahap [26]	3120	490 x 316 pixel	160	100	-	-
Arboleda;Fajardo;Medina [27]	100	150 x 150 pixels	30	20	-	-
Nasution;Andayani [30]	180	5152 x 3864 MP	50	35	-	100%
Murthy *et al.* [33]	180	20.1 MP	120	60	-	94.7%
Leme *et al.* [18]	300	-	80	20	500	95%
Nansen *et al.* [37]	180	-	67	33	100	98%

Description: 1=Image Capture; 2=Image Resolution; 3=Data Training; 4=Data Testing; 5=Iteration; 6=Accuracy Value

Table 7: Grouping Journals with the Learning Vector Quantization Method

Author	Results					
	1	2	3	4	5	6
Waliyansyah;Hasbullah [17]	58	3.5 MP	70	-	-	94%
Heryanto;Nugraha [24]	128	12 MP	360	270	50	93.3%
Gunadi *et al.* [25]	107	225 pixel	8	3	-	96.3%
Hendrawan;Widayaningtyas;Sucipto [29]	160	16 MP	66	33	-	97%
Lee *et al.* [38]	50	128 x 128	144	36	180	99.8%
Santos *et al.* [41]	635	200 dpi	445	95	-	>88%

Description: 1=Image Capture; 2=Image Resolution; 3=Data Training; 4=Data Testing; 5=Iteration; 6=Accuracy Value

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Table 8: Grouping Journals with the K-Nearest Neighbor Method

Author	Results					
	1	2	3	4	5	6
Pratama *et al.* [20]	117	8 MP	10	100	-	80%
Amanina;Saraswati [21]	500	48 MP	150	150	-	80%
Vilcamiza *et al.* [22]	60	1920 x 1080 pixel	300	1000	-	91.33%
Benes *et al.* [23]	-	16 MP	36	24	-	100%
Adiwijaya *et al.* [31]	301	2 MP	72	18	-	83%
Pradana;Iranto;Karnila [32]	240	200 x 200	480	20	-	85%
Gope;Fukai [34]	13.77	64 x 64 pixel	1520	190	-	98.19%
Araujo *et al.* [35]	32	300 dpi	14	10	-	99.2%
Belay;Tegegne [36]	150	-	80	20	-	70%
Septiarini *et al.* [39]	150	3024 x 4032 pixel	150	150	-	100%
Garcia;Candelo-Becerra;E. Hoyos [28]	1200	216 x 409 pixel	528	80	-	98.6%
Hsia;Lee;Lai [42]	4626	400 x 400 pixel	18504	-	-	96.84%
Pratama;Kusrini;Muhammad [16]	300	512 x 512 pixel	270	30	-	93.33%
Leme *et al.* [18]	-	1920 x 1080 pixel	500	200	-	91.2%
Maghfirah;Nasution [43]	40	800 x 600 pixel	-	2000	-	69.02%
Akbar;Rachmawati;Sthevanie [45]	6500	256 x 256 pixel	603	243	-	97%
Ligar [19]	180	20.1 MP	120	60	-	100

Description: 1=Image Capture; 2=Image Resolution; 3=Data Training; 4=Data Testing; 5=Iteration; 6=Accuracy Value

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