DEVELOPMENT OF MATHEMATICAL MODEL FOR ESTIMATING THE RICE MILLING DEGREE BASED ON FLUORESCENCE IMAGE
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PENGEMBANGAN MODEL MATEMATIKA UNTUK MENDUGA DERAJAT SOSOH BERAS BERDASARKAN CITRA FLUORESENSI

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DOI: https://doi.org/10.35633/inmateh-73-34

***Keywords:** quality, rice, milling degree, development model*

ABSTRACT
This research aims to develop a mathematical model for estimating the milling degree of milled rice based on fluorescent imaging. The materials used were the Ciherang, IR64 and Mekongga varieties which are widely grown and consumed by Indonesian people. The experiment was conducted by varying the polishing time starting from 0 seconds to 34 seconds with 1 second intervals. Six grains of polished rice were taken to record their images using a camera with 365 nm UV fluorescent ring light. The data collected in this research were milling degree obtained by gravimetric method, milling degree obtained using a milling meter and color values of fluorescent images of milled rice by image processing. The results showed that prediction of milling degree using the RGB color model has the coefficient of determination between 0.8001 – 0.8652, which is considered as potential to be used as a model for estimating the degree of milled rice based on fluorescence images. The RGB color model shows that the image red signal has the highest coefficient of determination compared to green and blue signals. For all of the three varieties in this study, the Ciherang variety has a predictive model equation for the image red signal y = 3.9027x - 429.61, the IR64 variety has a predictive model equation for the image red signal y = 3.7344x - 415.01, and the Mekongga variety has a predictive model equation for the image red signal y = 3.5627x - 388.86.

ABSTRAK
Penelitian ini bertujuan untuk mengembangkan model matematika untuk menduga derajat sosoh beras giling berdasarkan pencitraan fluoresen. Bahan yang digunakan adalah varietas Ciherang, IR64 dan Mekongga yang banyak ditanam dan dikonsumsi oleh masyarakat Indonesia. Percobaan dilakukan dengan memvariasikan waktu pemolesan mulai dari 0 detik hingga 34 detik dengan interval 1 detik. Enam butir beras yang telah disosoh diambil untuk direkam gambarnya dengan menggunakan kamera dengan lampu cincin fluoresen UV 365 nm. Data yang dikumpulkan dalam penelitian ini adalah derajat sosoh yang diperoleh dengan metode gravimetri, derajat sosoh yang diperoleh dengan menggunakan alat ukur milling meter dan nilai warna citra fluoresen beras giling dengan pengolahan citra. Hasil penelitian menunjukkan bahwa prediksi derajat sosoh menggunakan model warna RGB memiliki nilai koefisien determinasi antara 0.8001 - 0.8652, sehingga model ini berpotensi untuk digunakan sebagai model penduga derajat sosoh beras giling berdasarkan citra fluoresensi. Model warna RGB menunjukkan bahwa sinyal warna merah pada citra memiliki nilai koefisien determinasi yang paling tinggi dibandingkan dengan sinyal warna hijau dan biru. Untuk ketiga varietas dalam penelitian ini, varietas Ciherang memiliki persamaan model prediksi untuk sinyal merah citra y = 3.9027x - 429.61, varietas IR64 memiliki persamaan model prediksi untuk sinyal merah citra y = 3.7344x - 415.01, dan varietas Mekongga memiliki persamaan model prediksi untuk sinyal merah citra y = 3.5627x - 388.86.

INTRODUCTION
Rice is a strategic food consumed by most of the world's population. Rice is a grain whose outer husk has been removed by shucking. Rice consumption per capita in 2023 experienced a slight increase compared to 2022, from 256.2 grams/cap/day (93.5 kg/cap/year) to 257.0 grams/cap/day (93.8 kg/cap/year) (*National Food Agency, 2024*). Rice sold in the market is generally milled rice. The degree of milling is the detachment of the aleurone and sub-aleurone layers in rice grains (*Patria et al., 2021*). The degree of milling greatly affects the physical characteristics and nutritional content of rice (*Hasnelly et al., 2020*). Milling will increase the shelf life of rice (*Febriandi et al., 2017*).

Rice quality is a result of combination of grain physical and chemical characteristics. The physical characteristics of rice are degree of milling, whiteness, translucency, grain length, foreign matter, head rice, and chalkiness, while the chemical characteristics are amylose content, gelatinase temperature, and gel consistency (*Bhattacharya, 2011*). Indonesia has rice quality requirements defined in Indonesian National Standards (SNI) 6128:2020, published by the National Standardization Agency (NSA), in which there are six parameters for general quality requirements and eight parameters for special requirements for the quality of milled rice. One of the general requirement parameters to determine the quality of milled rice is the degree of milling (National Standardization Agency*, 2020*).

The rice quality estimation in the market is conducted by looking at the color of rice, smelling the aroma of rice and feeling the texture of rice. This method has weaknesses, namely perceptions that are not the same between one person and another and the fatigue factor of the person. Meanwhile, the determination of the degree of milling based on SNI is qualitatively based on the coloring method (*methylene blue*). In addition to expensive equipment, the use of certain chemicals can also increase evaluation costs. Other unfavorable aspects are the long time required and the waste generated from the process. Based on this, the current determination of general quality requirements for rice in Indonesia still needs improvement and enhancement of its measurement methods. The method that will be developed to identify the general quality requirements of rice is the use of optical-based technology.

The development of non-destructive technology based on optical characteristics has now been widely applied in various fields, including agriculture. Near Infrared (NIR) is one of the non-destructive technologies that can determine the quality of a product with the ability to analyze up to a depth of 5 mm from a product, this technology is different from image processing which only sees the outer appearance. NIR technology involves chemical activities that occur to a depth of 5 mm when the product is subjected to photon energy emitted from the energy source. *Mardison, (2010*), used NIR technology to determine the chemical content of Jatropha non-destructively, and *Angkat, (2012*), used NIR technology to determine the nitrogen content in soil non-destructively.

Image processing technology as one optical-based data set has been used to determine the quality of agricultural products visually and the application of this technology has reached the stage of real-time process on agricultural machineries. The uses of camera as sensor and image processing to analyze the image is known as machine vision as done by *Ahmad et al., (2010*), in developing an orange sorting machine with real-time image processing capability.

Image processing is the process of observing and analyzing an object without having direct contact with the object being observed. The process and analysis involve visual perception with input data obtained in the form of images of the objects being observed. Image processing techniques include image sharpening, highlighting certain features of an image, image correction of out-of-focus or blurry images (*Ahmad, 2005*). Normal color image shows an object just like our eyes see the object directly, contains a set of data as a representative of the object but the data can be extracted and processed by computer to facilitate quantitative analysis. The available data in the normal color image represent what can be seen by eyes only because normal camera works at the same range of wavelength with human eyes. However, more data can be obtained from image if the object is excited with light that covers wider wavelength such as ultraviolet (UV) in combination with visible wavelength to produce fluorescence image. Fluorescence is light emitted by an atom or molecule after absorbing high-energy light. The principle that occurs is that the electrons in the molecule are first excited by absorbing light from a beam, then the electrons move from the ground electronic state to one of various vibrational states in the excited electronic state. After that the molecule will quickly lose the remaining vibrational energy through collisions and fall back to one of the various vibrational levels in the ground electronic state while emitting light in the form of fluorescence (*Lakowicz, 2006*).

Fluorescent imaging systems consist of camera with several additional components such as excitation light source, light transmitting and collecting optical components, and emission filters. Light sources that are often used are LEDs, halogen lamps, and diode lasers. A digital camera has sensors which are divided into two types, namely CCD sensors and CMOS sensors. Fluorescence imaging is closely related to the excitation wavelength because it involves the process of fluorescence. Fluorescence occurs when light is induced into the test material or sample. This material consists of atoms or molecules that have certain energy levels. When light hits a substance, the photon energy is used to excite the atoms or molecules to a higher energy level (*Albani, 2007*).

Research on rice using fluorescence imaging through UV light excitation has been carried out for example to determine the freshness of the rice with the results of the fluorescent intensity being strongly correlated with the freshness of the milled rice at 0.819 (*Hachiya et al., 2009*). Other research was to determine the origin of rice using hyperspectral fluorescence image analysis with the results showing that hyperspectral fluorescence imaging technology can be used to discriminate the rice with different origin with high levels of 98.89% (*Kim et al., 2020*). The fluorescence imaging can be used also to measure the degree of graininess of rice based on UV spectrum characteristics and the results showing that the most influential measurement parameters in estimating the degree of graininess are the duration of deposition, the shape of the sample, and the concentration of the n-hexane solvent for Ciherang variety (*Mardison, 2019*). Detecting the distribution of rice bran residue on the surface of rice was also conducted using fluorescence imaging with the SLC prediction error result being 2.44% (*Chen and Kuo, 2014*), and determination of multiple rice quality parameters simultaneously using image analysis method with the result of the regression coefficient (R) were 0.9916, 0.9691, 0.9938, 0.9929, 0.9649, and 0.9377 for length, width, length-to-width ratio, head rice, percentage of chalky rice, and lime content *(Fang et al., 2014*).

Based on the mentioned problem, it is necessary to design an alternative method to analyze the quality of milled rice which is cheap, fast and does not damage the rice and is environmentally friendly. One technology that has the potential to be applied is fluorescent imaging. This research aims to develop a model for predicting the degree of milled rice based on fluorescent images.

MATERIALS AND METHODS

Samples Collection

The samples used were three varieties of rice (Ciherang, IR64 and Mekongga varieties). A total of 315 samples of rice weighing 100 grams per sample were prepared. The three varieties were selected in this research because they are widely grown and consumed by Indonesian people.

Equipment

The equipment for processing whole grain into rice, namely the Zaccaria brand PAZ-1 DTA rice mill, is used to remove husk and produce whole rice kernel and directly polish the rice kernel until white rice was obtained. The TRG05B type SATAKE brand rice grader is used to separate head, broken and rice groats. Rice milling meter type New MM1D made by SATAKE, Japan is used to measure polishing parameters which are expressed in whiteness (%), transparency (%) and milling degree values and analytical scales. Equipment for image processing, namely a 48 MP 4K Monocular Microscope Camera which is connected to a Digital Video Microscope Electronic Monitor, a UV ring fluorescent lamp with a wavelength of 365 nm, and an image recording chamber with lighting controller.

Procedure

The research stages include sample preparation, image recording, image processing and analysis of the data, development of rice milling degree model, and the stages can be seen in Figure 1. The procedures for the research are explained as follow.

1) Sample collecting

Samples in the form of whole paddy grains were taken from a local paddy breeder under the supervision of Indonesian Center for Rice Standard Evaluation in Sukamandi, West Java. The varieties used in this stage are the Ciherang, IR64 and Mekongga. The three varieties were collected, 15 kg each that meets quality standards as commercial paddy rice, in order to obtain sample uniformity (pure variety).

2) Sample weighing

Samples in the form of whole grain were weighed, 100 g for each sample. The number of samples used were 105 samples for each variety, making the total number of samples being 315 for three varieties. Each sample then was packaged in plastic packaging and labeled for each treatment.

3) Husk removing

The husk was removed from the whole grain and then the kernel was weighed to obtained the yield and then the rice kernels were put again into the same plastic packaging.

4) Whole kernel selection

The husked rice produced in the previous step consists of whole rice, head rice, broken grains and rice groats. Sorting was carried out to select only whole kernels for further processing and then put again the whole rice kernels into the same plastic packaging.

5) Polishing process

The samples that contain only the whole rice kernels were polished with 35 levels of polishing degree based on process duration with the same machine and the same parameter setting. The duration applied were 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, and 34 seconds as treatments. After finishing the polishing process, each sample was weighed again and was put again into the same plastic packaging.

6) Polished kernel selection

Polishing process caused breakage to some kernels making the sample not being uniform. For better data, only whole kernels and kernels with small broken parts (head kernel) were selected for further analysis.

7) Measurement of milling degree

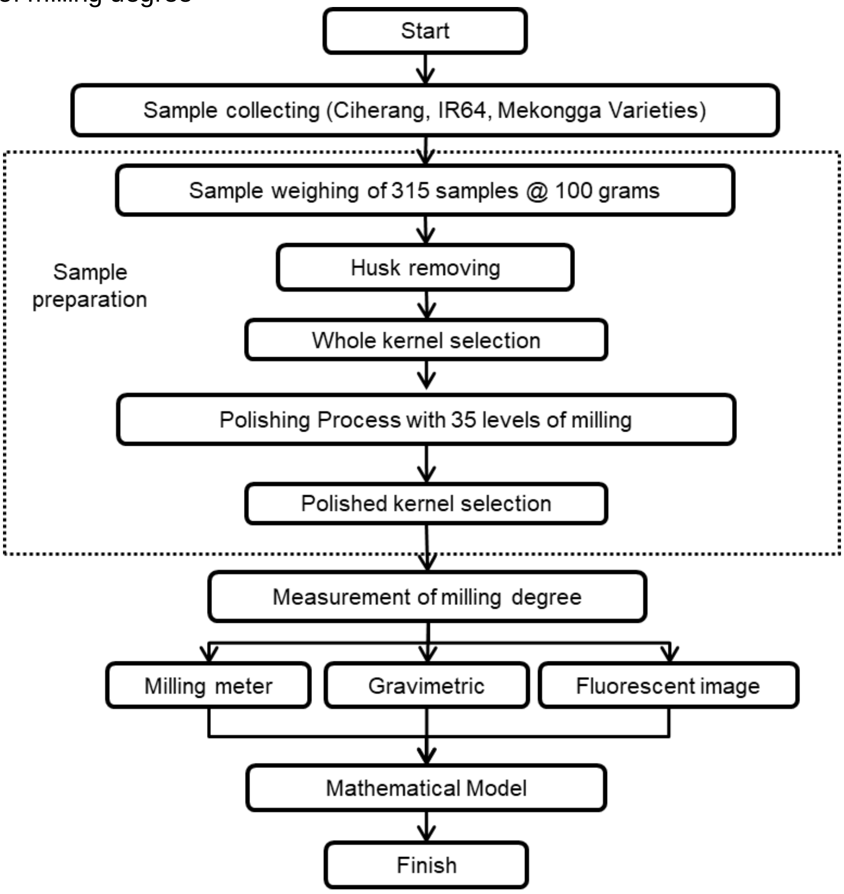

Fig. 1 - The development of a mathematical model for rice milling degree estimation using fluorescent images

Measuring the degree of milling of the polished rice kernels is done by knowing loss of sample weight after polishing with the initial condition is that the rice kernel before polishing which is known as gravimetric method (*Patria et al., 2021*). The DM in this research was calculated using Equation 1 where DM is milling degree, W_p is weight of milled rice (g) and W is weight of whole rice kernel (g).

$$DM = \frac{1-W_p}{W} \times 100\% \quad (1)$$

Milling degree measurements was also carried out using a rice milling meter that directly gives the results obtained: whiteness (%), transparency (%) and milling degree values (no unit). As for estimation of the milling degree based on fluorescence image by image processing and analysis, the equipment used was arranged as shown in Figure 2. The stages were carried out starting from sample preparation, image capturing and saving the image in the JPG format in the computer connected to the camera, and finally image processing and analysis to obtain the desired features using ImageJ image analysis software. The equipment used to capture image of arranged rice kernels, 6 rice kernels of that were placed on a tray which was covered with a black cloth. In the image capture process, a resolution of 1920 x 1080 pixels was applied and the distance between the camera and the object was 15 cm. Lighting was provided by an 8W UV fluorescent ring lamp, which was placed at the end of the camera lens.

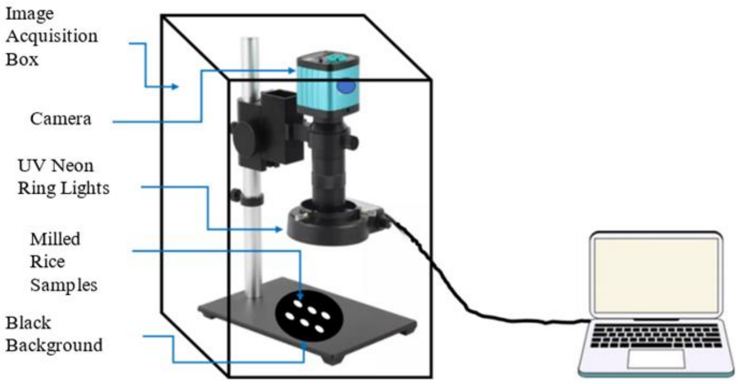

Fig. 2 - The development of a mathematical model for rice milling degree estimation using fluorescent images

Color analysis of digital images is carried out using two color models, namely red-green-blue (RGB) color model and hue-saturation-intensity (HSI) color model. According to *Ahmad, (2005*) color processing using RGB colors is easy and simple, because the color information in the computer is packaged in the same model. The RGB color model is an additive basic color model, that is, colors are formed by combining light energy from the three basic colors in various ratios. The HSI color model with hue (H), saturation (S) and intensity (I) color components, can be converted from the RGB color space. The HSI color model is the color model that best suits human's visual interpretation. Hue value expresses color position by angle where red is 0 or 360 degrees, green is 120 degrees and blue is 240 degrees. Any angle value between 0 and 360 stated a unique color according to the wavelength. Saturation value expresses strength of color where 0 is very weak and 1 is strongest color (saturated color). Intensity expresses the brightness of color where 0 means no light so any color will be black and maximum brightness will turn any color to white. The relationship between RGB and HSI color components are expressed by Equation 2 – 4.

$$\mathrm{H} = \mathrm{acos}\left(\frac{2R-G-B}{2\sqrt{(R-G)^2+(R-G)(G-B)}}\right) \tag{2}$$

$$\mathrm{S} = 1 - \frac{3*min(R,G,B)}{R+G+B} \tag{3}$$

$$\mathrm{I} = \frac{R+G+B}{3} \tag{4}$$

If $B > G$ then the hue value is 360-H. Color conversion from RGB to HSI can use the original RGB values.

Analysis

The RGB and HSI color components as the results of the fluorescence image processing were analyzed using linear regression. The linear regression equation can be calculated using Equation 5 where Y is degree of milling obtained using gravimetric method and milling meter, a is slope of the regression line, X is equal values of color components in RGB and HSI color models, and b is a constant.

$$Y = aX + b \tag{5}$$

According to (*Usman dan Akbar, 2008*) the R^2 value has no units (dimensions), the closer it is to 1, the stronger the relationship between variables. When $0.20< R^2 \le 0.40$ means the correlation is low, when $0.40< R^2 \le 0.60$ the correlation is somewhat low, when $0.60< R^2 \le 0.80$ the correlation is quite high, and when $0.80< R^2 \le 0.99$ the correlation is high, and 1 means the correlation is very high.

RESULTS AND DISCUSSION

Gravimetric and Milling Meter Correlation

According to *Khatun et al., (2019*), rice grains are composed of 5.9 – 6.4% bran including aleurone, 5.6 – 9.9% sub-aleurone, 82.5 – 83.8% endosperm, and 1.3 – 1.5 germ as shown in Figure 3.

Based on a literature study, a milling degree of 100% is assumed to be 11.5% by gravimetric method. In this study, the results of measuring milling degrees using the gravimetric method with milling degrees using a milling meter are as shown in Table 1.

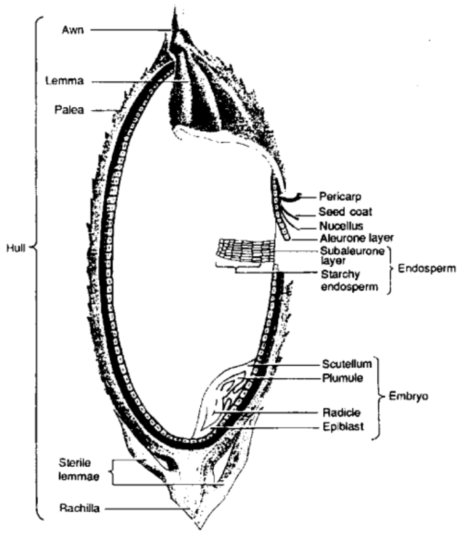

Fig 3 - Rice grain structure (*Khatun et al., 2019*)

Table 1
Degree of Milling Gravimetric and Milling Meter

No	Variety	Gravimetric (%)		Milling Meter	
		Range	Average	Range	Average
1	Ciherang	0 – 12.88	8.05±3.65	0 – 119.00	75.64±36.20
2	IR64	0 – 14.35	8.18±3.75	0 – 121.56	72.13±40.03
3	Mekongga	0 – 11.20	7.22±3.09	0 – 124.00	78.25±37.25

Rice milling meter type New MM1D made by SATAKE, Japan, has a degree of milling value from 0 - 199, and in the table, the degree of milling using the milling meter is above 100, so it is necessary to convert the milling meter value into a percentage of the degree of milling on a scale of 0 - 100%.

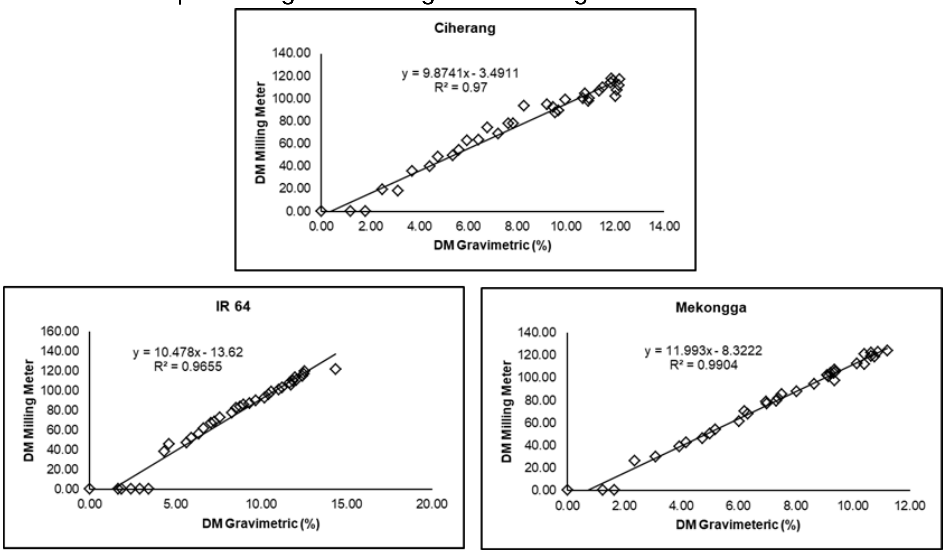

Fig. 4 - Relationship of milling degree analyzed by Gravimetric method and measured by milling meter

Figure 4 shows the relationship between the degree of milling analyzed by Gravimetric method and measured by milling meter. The R^2 value of the Ciherang variety is 0.97, the R^2 of the IR64 variety is 0.9655, and the R^2 of the Mekongga variety is 0.9904. The three varieties show high relationships between the degree of milling obtained using the two different methods. Based on this, the degree of milling using a milling meter can be used as the degree of milling of milled rice to build the mathematical model.

Correlation of Gravimetric, Milling Meter and Fluorescent Image

The number of samples used to estimate milling degree are 315, with 30 g/sample of 105 samples for each variety. For all of 105 samples of each variety, 35 different milling time treatments were applied with three repetitions. The color values generated in this study were obtained from six randomly selected rice grains in each sample to produce the images. The image recording results can be seen in Figure 5.

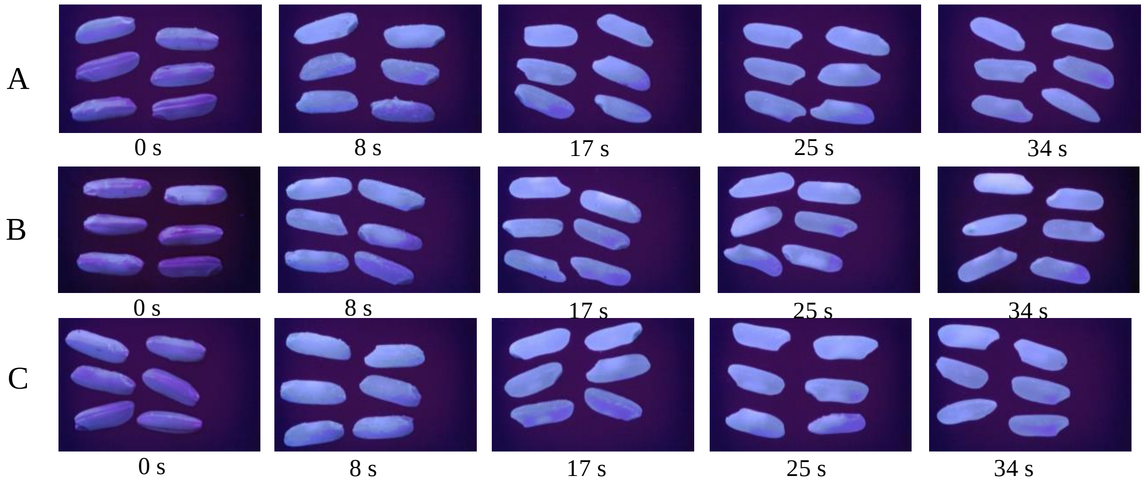

Fig. 5 - Image recording results of (A) Ciherang, (B) IR64, and (C) Mekongga varieties

The image obtained in the image recording is then analyzed with the ImageJ application. After receiving the RGB value, the value of six rice grains is averaged to become the value of 1 sample. The calculation results of each sample are then made into a graph using Microsoft Excel software.

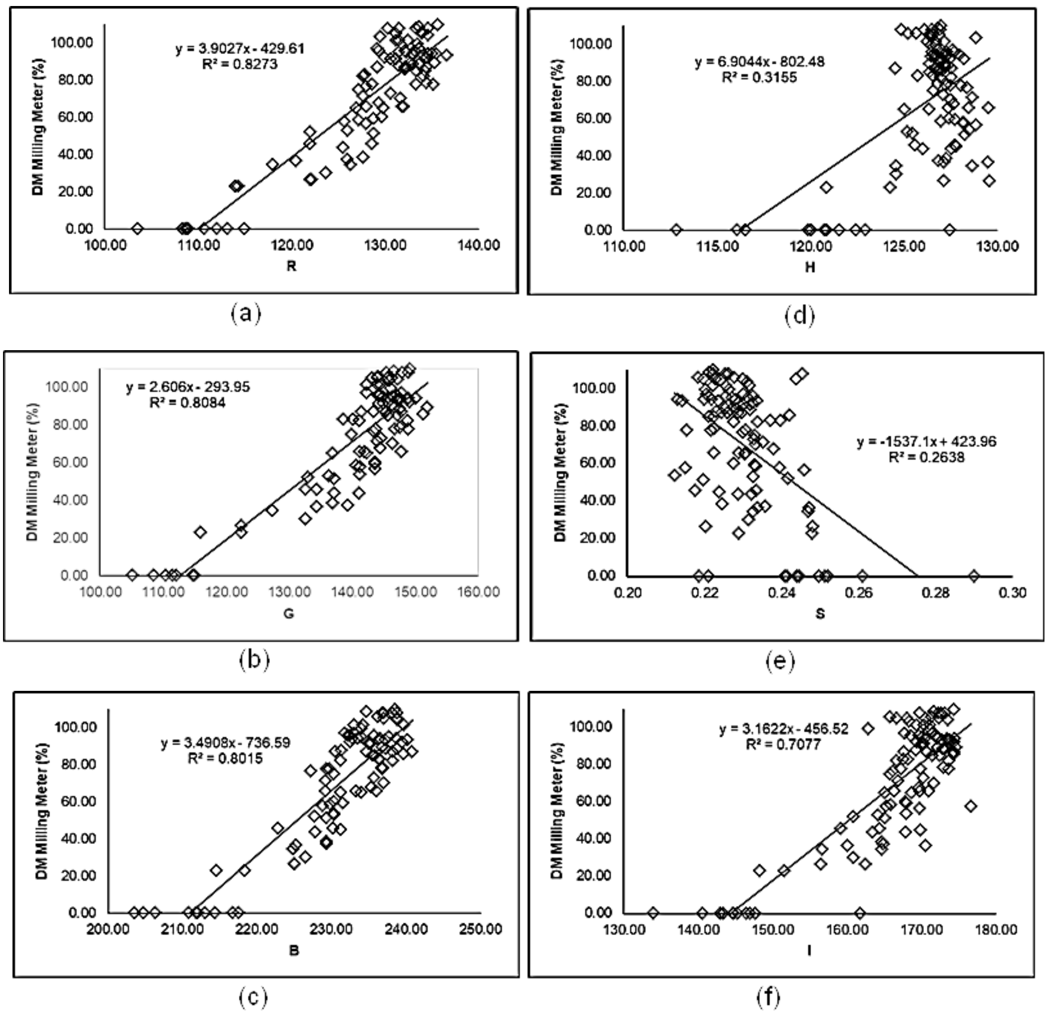

Fig. 6 - Correlation between the degree of milling measured by milling meter and estimated using fluorescence image on Ciherang variety using (a) red signal, (b) green signal, (c) blue signal, (d) hue color component, (e) saturation color component, and (f) intensity color component

In Figure 6, the correlation between the degree of milling using a milling meter and the color values of R, G, B of Ciherang varieties represented by R^2 are 0.8273, 0.8084, 0.8015, respectively, which is categorized as a high correlation and show that RGB color values have positive correlation with the length of milling time. The RGB color model in fluorescence images has the potential to be used to estimate the degree of milling rice of Ciherang variety. The relationship between the degree of milling using a milling meter with the HSI color model of Ciherang variety are 0.3155, 0.2638, 0.7077. For the three R^2 respectively and for the HSI color method, the correlation between the degree of milling and the color values of HSI is categorized as low to high. The strongest correlation of the Ciherang variety is between the degree of milling with image red signal and the estimation model equation is y = 3.9027x - 429.61.

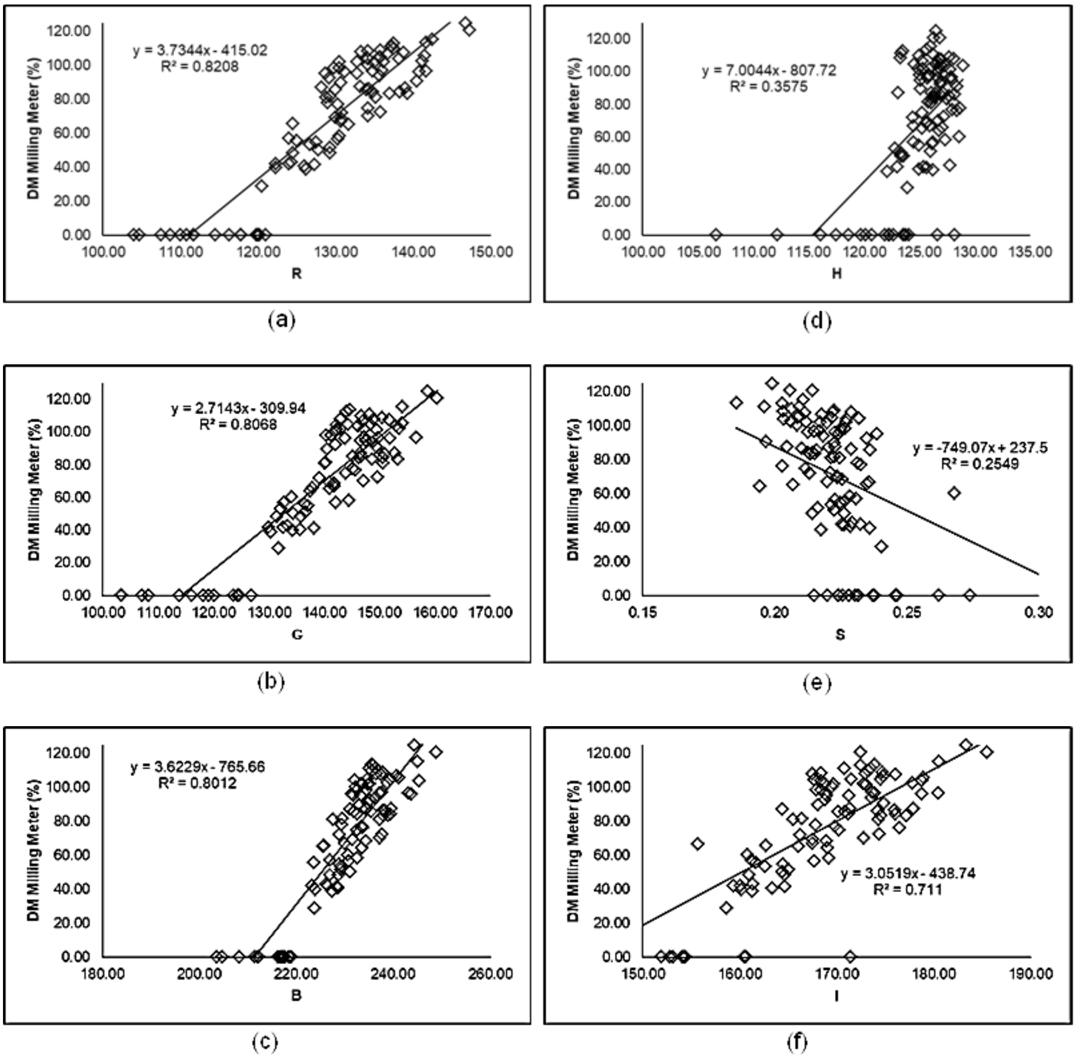

Fig. 7 - Correlation between the degree of milling measured by milling meter and estimated using fluorescence image on IR64 variety using (a) red signal, (b) green signal, (c) blue signal, (d) hue color component, (e) saturation color component, and (f) intensity color component

In Figure 7, the correlation between the degree of milling using a milling meter and the color values of R, G, B of IR64 varieties represented by R^2 are 0.8208, 0.8068, 0.8012, respectively, which is categorized as a high correlation and show that RGB color values have positive correlation with the length of milling time. The RGB color model in fluorescence images has the potential to be used to estimate the degree of milling rice for IR64 variety. The correlation between the degree of milling using a milling meter with the HSI color model of IR64 variety are 0.3575, 0.2549, 0.711, respectively. For the HSI color model categorized as low correlation to high correlation. The strongest relationship for IR64 varieties is between the degree of milling with image red signal and the estimation model equation y = 3.7344x - 415.01.

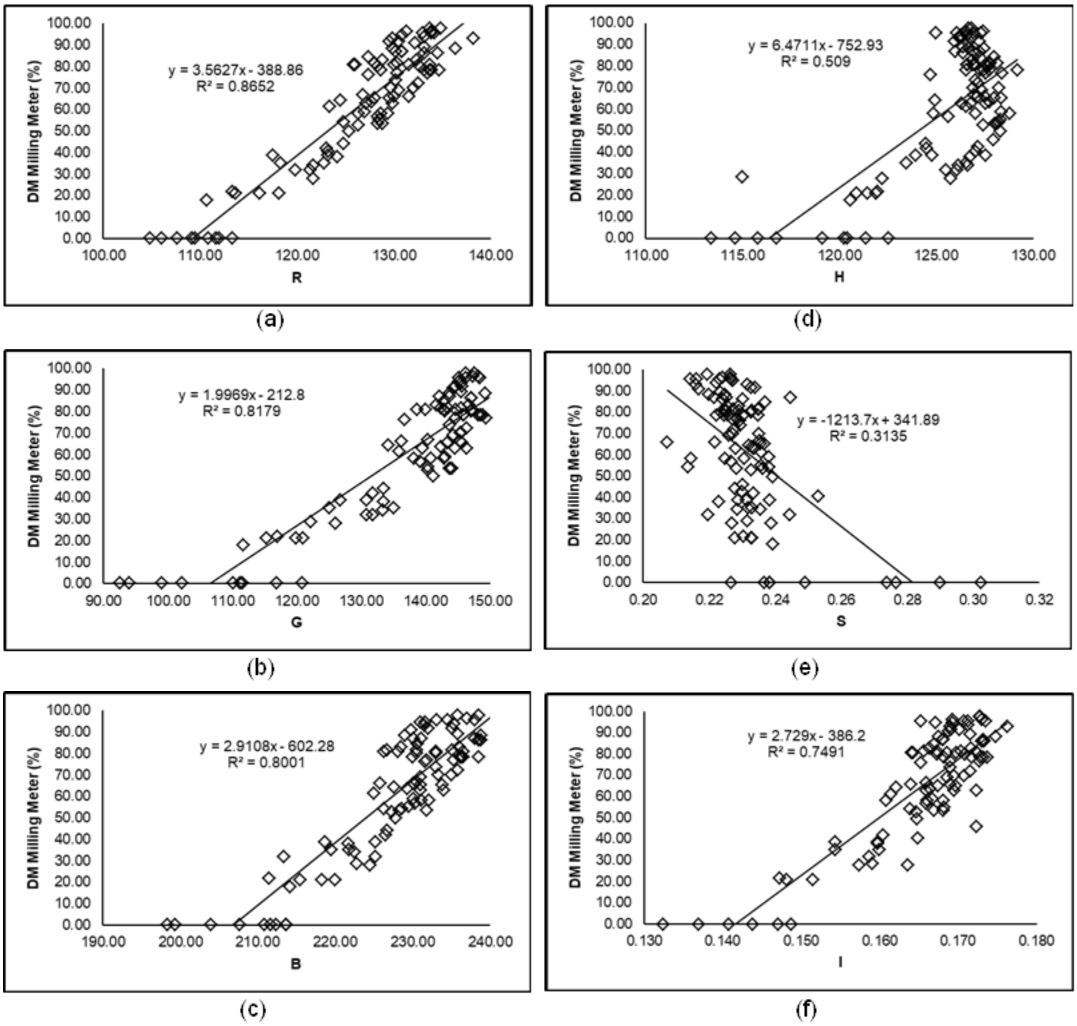

Fig. 8 - Correlation between the degree of milling measured by milling meter and estimated using fluorescence image on Mekongga variety using (a) red signal, (b) green signal, (c) blue signal, (d) hue color component, (e) saturation color component, and (f) intensity color component

In Figure 8, the correlation between the degree of milling using a milling meter and the color values of R, G, B of IR64 varieties represented by R^2 are 0.8652, 0.8179, 0.8001 respectively, which is categorized as a high correlation and show that RGB color values have positive correlation with the length of milling time. The RGB color model in fluorescence images has the potential to be used to estimate the degree of milling rice for Mekongga variety. The correlation between the degree of milling using a milling meter with the HSI color model of Mekongga variety are 0.509, 0.3135, 0.7491, respectively. For the HSI color model categorized as low correlation to high correlation. The strongest relationship of the Mekongga variety is the correlation between the degree of milling with image red signal and the estimation model equation y = 3.5627x - 388.86.

For the three varieties, the RGB color model has the potential to be used as a parameter for estimating the milling degree of milled rice, while the HSI color model cannot be used for estimating the milling degree. In the image analysis, the image red signal has the largest R^2 among the green and blue signals in the three varieties. According to (*Ahmad, 2005*), the RGB color model is an additive principal color model where colors are formed by combining the light energy of the three primary colors in various comparisons.

CONCLUSIONS

The mathematical model for estimating the milling degree of milled rice based on fluorescence images having the potential to be developed is the RGB color values with a coefficient of determination between 0.8001 - 0.8652, categorized as high for Ciherang, IR64 and Mekongga varieties.

The RGB color values shows that the image red signal has the highest coefficient of determination compared to green and blue signals. For all of the three varieties in this study, the Ciherang variety has a predictive model equation for the image red signal y = 3.9027x - 429.61, the IR64 variety has a predictive model equation for the image red signal y = 3.7344x - 415.01, and the Mekongga variety has a predictive model equation for the image red signal y = 3.5627x - 388.86.

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