Australian Journal of Basic and Applied Sciences, 9(28) Special 2015, Pages: 50-56

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Development of Fresh Harvested Paddy Quality Determination Model Using Color Indices

Norsolehah Azman, Siti Khairunniza-Bejo, Wan Ishak Wan Ismail and AimrunWayayok

Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia

ARTICLE INFO

Article history:
Received 23 June 2015
Accepted 25 July 2015
Available online 30 August 2015

Keywords:
paddy, maturity, moisture content, visible image, thermal image

ABSTRACT

Rice (*Oryza sativa L.*) is a staple food and a major source of dietary especially in Asian. Maturity and moisture content of paddy contributes a very high impact on the production of high quality rice. Wrongly harvesting time gives a low milling recovery, high value of immature seeds, high percentage of broken rice, poor grain quality and more chances of disease attack during storage. In order to ensure high quality rice, the rice need to be harvested at the right time with the right amount of moisture content without totally depends on the scheduled harvesting time based on the day after planting. This paper unveils the potential use of color indices to determine quality of fresh harvested paddy breed MR220 CL2 which are moisture content and maturity stage. Color properties of each paddy during ripening stage extracted from visible and thermal images were used as input parameters in developing the estimation models. The results had shown that all color indices gave significant relationship with maturity stage and moisture content. Red index gave the best model of paddy maturity and moisture content estimation compared to other color indices with 99.2% and 99.1% percentage of successful estimation, respectively. In conclusion, the developed models can be used as an alternative tool in determining the exact time to harvest paddy. This will ensure high quantity and quality of rice production.

To Cite This Article: Norsolehah Azman, Siti Khairunniza-Bejo, Wan Ishak Wan Ismail, and Aimrun Wayayok., Development of Fresh Harvested Paddy Quality Determination Model Using Color Indices. ***Aust. J. Basic & Appl. Sci.,*** *9(28): 50-56, 2015*

INTRODUCTION

Rice (*Oryza sativa L.*) production plays important roles in the agricultural sectors in Malaysia. It is the most important staple food for a large part of human population, especially in Southeast Asia such as Malaysia and Indonesia. The harvesting and post-harvesting operations of paddy crop and the storage of paddy are important as producing the crop, because this technology affects the quantity and quality of paddy and the finished product as rice. A number of characteristic determines the quality of paddy. These include moisture content and its maturity.

According to Padi Beras Nasional Berhad (BERNAS), the value of moisture content for freshly harvested paddy is approximately 25 to 26% while for drying and storage is about 13 to 14%. Improper drying and storage practices lead to low grain or seed quality. Besides that, the maximum quantity and quality of paddy and rice are depending on its maturity level. Mature grain is defined as rice kernel that developed completely during ripening stage and is ready to be harvested. At this level, at least three quarters of the grain of the panicle turn yellow. The grains increase in size and weight as starch and sugar was processed. Harvesting before maturity may result in lower milling recovery, high value of immature seeds, high percentage of broken rice, poor grain quality and more opportunities for pest infestation during storage of grain. According Malaysia Standard MS 84:1998, Specification and Grades for Paddy (First Revision), every 1% immature paddy will cause 1 kg of 100kg deduction for pricing. The high total milled and head rice recovery was achieved when rice was harvested at the right time with the right value of moisture content (Firouzi & Alizadeh, 2013; Wahid & Hajazi, 2004).

Rice production nowadays is becoming more challenging due to climate change (Wassamann *et al*., 2009). Recent analyses of climate change's effects on rice production have estimated the impact of high temperatures on paddy rice yield (Welch *et al*., 2010; Peng *et al*., 2004), physiological maturity of rice (Basak *et al*., 2010) and milling quality outcomes, which eventually determine edible rice yield (Counce *et al*., 2005). Therefore, rice shall be harvested at appropriate time without totally depends

Corresponding Author: Siti Khairunniza-Bejo, Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia,
Tel:+603-89464332; E-mail: skbejo@upm.edu.my.

on the scheduled harvesting time based on the Day After Planting (DAP).

In agricultural industry, the image processing techniques have been applied in various activities including moisture content estimation (Farid *et al*., 2014; Sumgap & Khairunniza-Bejo, 2011) and to determine maturity stage of agricultural product (Choi *et al*., 1995; Lee *et al*., 2008; Singh *et al*., 1992; Sirisathitkul *et al*., 2006). Teoh & Abu Bakar (2009) used Principal Component Analysis (PCA) based on transformation of Red (R), Green (G) and Blue (B) image captured from digital color camera to determine an immature paddy breed MR 220. The method successfully identified the immature paddy with mean accuracy of 99.8%. Khairunniza-Bejo & Munira (2014), used three different approaches of mature and immature paddy identification of paddy breed MR 219 i.e., Mean, Median and Otsu. Among these approaches, Median gave superior results with the average percentage of success of 96.15% during test validation. Similar to Teoh & Abu Bakar (2009), changes of maturity stage towards harvesting day were not being studied. Haw *et al*. (2014) used Hue index to determine maturity of paddy breed MR219 from 102 to 110 DAP. The results showed that Hue reduced as the maturity level increased resulting a final value of 32.3°±2° at the matured stage. This was due to the changed of floret color from green to yellowish towards maturity. Azman *et al*. (2014) used samples at two different dates of DAP to determine maturity stage of paddy breed MR220 CL2. The strongest significant relationship was gathered from G-B index, with R = -0.924. However, the method has the limitation on the threshold selection where it was done manually. At the same time, two different dates of DAP were not enough to represent the maturity condition of paddy during ripening stage. The first approach on investigating capability of thermal imaging for paddy quality determination was done by Farid *et al*. (2014). Samples were taken from three different days during ripening stages. Value of moisture content decreased as the mean of intensity increased. The results gave indicator on possibility of thermal imaging for paddy moisture content determination with the highest R^2=0.76 by using periodic function. Jamil & Khairunniza-Bejo (2014) used thermal image to detect paddy husk. The technique can be used to detect husk with 100% success rate for both 20% and 40% husk, 98.33% success rate for 60% husk and 97.67% rate success for 100% husk, while 94.33% rate success for 100% seed. Successful of detection was due to different heat transfer by husk and paddy seed.

Until today, the performance of color indices for paddy grain maturity and moisture content are still not been extended. Besides, the application of thermal imaging especially in paddy grain sector is promising but still new. Therefore, it gave strong motivation for us to study the performance of various color indices including visible and thermal imaging to determine the quality of paddy grain.

MATERIALS AND METHODS

Paddy Sample:

New breed of paddy type MR220 CL2 was used in this study. It is tolerant to imidazolinone. If proper management was done, it is able to control the problem of weedy rice and weeds that affect rice crops. In this study, the samples were collected on 92, 94, 96, 98 and 100 DAP started at 11.30 am. Fifteen samples with 50 grams each were collected at the same point for each day. The whole process took 1 ½ hours. The samples were put in the plastic bag and stored in the cooling box to avoid damage.

Paddy moisture content, expressed in percent wet basis (% w.b.), was measured immediately after data collection by using moisture analyzer type PM-410 at laboratory. This moisture analyzer can measure moisture content in the range between 8.0 to 35.0%.

Image processing:

Image acquisition:

An un-cooled focal planar array type infrared thermal camera (Model: E-60 FLIR) with a resolution of 320 x 240 pixels and a spectral range of 7.5 to 13.0 µm was used during image acquisition. While taking the images, the emissivity of paddy was set at 0.98 and the camera was fixed at a height of 50 cm above the sample. Fifty grams of paddy samples were spread in a single layer bowl. The rate of heating and cooling process was used to classify objects or to identify the abnormality between objects when using thermal imaging (Manickavasagan, 2007). Two lamps (240 V, 5 Watt) were placed at a distance of 10 mm from the paddy layer and were used to heat the paddy samples. Paddy samples were heated for 300 s. Then, the samples were allowed to cool for the next 120 s. Initially different time intervals were tested for heating and cooling, and the time intervals which gave clear difference between before and after heating or cooling without affecting physical properties of paddy were selected for this experiment i.e. 300 s for heating, 120 s for cooling. Images of the paddy top surface at 120 s during cooling of each sample were acquired. A total of 120 images which consist of 60 RGB images and 60 thermal images were captured and analyzed. The images were then saved in a JPEG (Joint Photographic experts group) format.

Image segmentation:

Image segmentation based on thresholding approach was done to separate paddy image with its background. Threshold (TH) value was selected by analyzing histogram of an image. All values below TH will be classified as background (0), while value above TH as paddy image (1), resulting a binary image. Connected component analysis will be applied to identify and remove any noise objects. Mean intensity of the paddy image was then extracted and used as input parameter to develop the estimation model.

Color indices:

In this study, five color indices had been used to analyze maturity stage and moisture content of paddy taken from 120 images. These color indices were extracted from visible and thermal images. Furthermore, a new color index which was developed based on combination of thermal and Red band has been introduced as in Equation 1.

$$Thermal\ Red\ Index = \frac{Thermal - R}{Thermal + R} \quad (1)$$

Color indices analyzed in this study were obtained from the average color of the whole paddy image. It will be used as the input parameter in developing the estimation model.

RESULTS AND DISCUSSION

Image analysis:

Figure 1 shows example of RGB images taken from 92, 94, 96, 98 and 100 DAP. Black is a background image. The images showed that during 92 DAP, the paddy were more green compared to 100 DAP. However, the green paddy still existed even during harvesting day (100 DAP). This condition happened due to the paddy characteristic that maintain green color in pericarp even after psychological maturity stage because chlorophyll in the seed coat faded away slowly (Chu *et al*., 2004). For thermal image, we found that the number of darker pixels were reducing as the number of DAP was increasing.

Samples of RGB and thermal image at different value of moisture content are shown in Figure 2. Through visualization, RGB image did not show any significant difference. Meanwhile, for thermal image, it was getting brighter with increasing value of moisture content.

Table 1: Correlation (R) between color indices with paddy maturity stage and moisture content.

COLOR INDICES	R (maturity stage)	R (moisture content)
R	0.927**	-0.982**
G	0.871**	-0.937**
B	0.699**	-0.740**
TRI	-0.849**	0.874**
THERMAL	0.385**	-0.450**

*. Correlation is significant at the 0.01 level (2-tailed).

Table 2: Linear, quadratic regression equation and R^2 for maturity stage and moisture content estimation.

Index	Linear regression	R^2 (linear)	Quadratic regression	R^2 (quadratic)
Maturity stage				
R	$DAP = 64.480(R) + 76.075$	0.859	$ms = 84.466(R) - 32.527(R^2) + 73.05$	0.859
G	$DAP = 64.055(G) + 74.943$	0.759	$ms = 114.108(G) - 76.943(G^2) + 66.917$	0.761
B	$DAP = 88.299(B) + 78.92$	0.488	$ms = 489.090(B) - 982.749(B^2) + 38.6$	0.537
TRI	$DAP = -48.343(TRI) + 114.$	0.722	$DAP = -43.525(TRI) - 6.281(TRI^2) + 1$	0.722
Thermal	$DAP = 26.366(T) + 77.646$	0.148	$ms = 186.935(T) - 120.173(T^2) + 24.3$	0.164
Moisture content				
R	$mc = -62.943(R) + 47.314$	0.964	$mc = -107.03(R) + 71.752(R^2) + 53.96$	0.966
G	$mc = -63.515(G) + 48.743$	0.879	$mc = -106.683(G) + 66.359(G^2) + 55.6$	0.880
B	$mc = -86.137(B) + 44.52$	0.547	$mc = -385.363(B) + 733.709(B^2) + 74.$	0.579
TRI	$mc = 45.841(TRI) + 10.247$	0.764	$mc = 55.572(TRI) - 12.685(TRI^2) + 8.4$	0.764
Thermal	$mc = -28.383(T) + 47.622$	0.203	$mc = -189.509(T) + 120.589(T^2) + 10$	0.221

Table 3: MSE, RMSE and percentage of accuracy value for linear and quadratic model of maturity stage estimation.

Colour index	MSE		RMSE		ACCURACY (%)	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
R	0.69	0.69	0.83	0.83	99.2	99.2
G	0.93	0.94	0.97	0.97	99.2	99.2
B	3.71	4.56	1.93	2.13	98.4	98.3
TRI	1.90	1.90	1.38	1.38	98.8	98.8
THERMAL	7.13	6.89	2.67	2.63	97.8	97.8

Table 4: t-test result. Correlation between actual and predicted value of maturity stage estimation.

Colour index	R (Linear)	Significant (2-tailed)	R (Quadratic)	Significant (2-tailed)
R	0.965	0.140	0.963	0.181
G	0.947	0.457	0.949	0.460
B	0.772	0.219	0.699	0.437
TRI	0.903	0.090	0.903	0.095
Thermal	0.356	0.623	0.381	0.764

Table 5: MSE, RMSE and percentage of accuracy value for linear and quadratic model of predicted moisture content.

Color index	MSE		RMSE		ACCURACY (%)	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
R	0.09	0.08	0.30	0.28	99.1	99.2
G	0.77	0.76	0.88	0.87	97.2	97.2
B	3.92	4.30	1.98	2.07	94.1	94.2
TRI	2.12	2.12	1.45	1.46	96.1	96.1
Thermal	6.98	6.59	2.64	2.57	91.9	92.3

Table 6: t-test result. Correlation between actual and predicted value of moisture content determination.

Color indices	R (Linear)	Significant (2-tailed)	R (Quadratic)	Significant (2-tailed)
R	0.995	0.403	0.995	0.536
G	0.956	0.911	0.960	0.955
B	0.735	0.461	0.700	0.652
TRI	0.869	0.372	0.869	0.356
Thermal	0.426	0.361	0.451	0.503

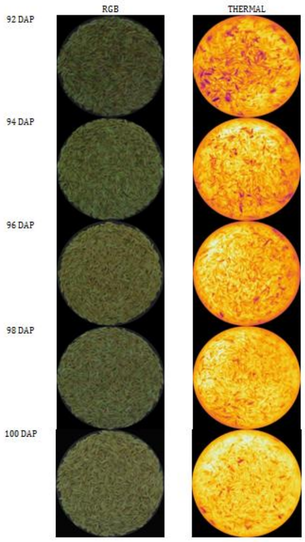

Fig. 1: Sample of RGB images and thermal images at different maturity stage starting from 92 DAP until 100 DAP.

Statistical analysis:

Table 1 shows results of Pearson's correlation between color indices with maturity stage and moisture content. In overall, there were significant correlation between all color indices ($p<0.01$) at the 0.01 level (2-tailed) relationship in both quality parameters. For maturity stage, positive significant relationship were found at R, G, B, and Thermal indices, while negative significant relationship were given by TRI index. Positive correlations indicated the changes in paddy color was proportional to the maturity stage while negative correlations gave the vice versa indication. During the ripening stage, the paddy seed started to change its physiological condition where the starch in grain is begin to become firm but still soft before it is matured. As the paddy meet its maturity stage, it color change from green to more yellowish gold. This is due to the reduction of chlorophyll content when it is matured. Chlorophyll absorbs red and blue light. Therefore, it gives lower reflectance during early ripening stage and higher reflectance during maturity stage. Thus, paddy with high chlorophyll content appears more green, while paddy with low chlorophyll content appears brighter (high-energy value) since there is less absorption and most of the energy were reflected back. Reduction of chlorophyll content was also causing decreasing value of the TRI index. It is also shown from the result that, the correlation value of R (0.927) during ripening stage was higher compared to the other indices. This value was then followed by G (0.871) and TRI (-0.849)). While other indices gave correlation value less than 0.8. Therefore, based on our analysis, we concluded that R index is the best indicator for maturity stage of paddy.

For moisture content, only TRI index gave positive relationship. R index gave the highest value of correlation which was -0.982, followed by G (-0.937) and TRI (0.874). Other indices gave less than 0.8 correlations (either negative or positive). R index, which is the longest wavelength in the visible spectrum, shows more suitable index to be used for moisture content determination. Red wavelength is closer to Near Infrared (NIR) wavelength (0.75 – 1.4

µm). In general, NIR band is useful for moisture content determination of agricultural products. Therefore, the closest position to the NIR gave strong reason on why Red gave better representative on moisture content determination compared to other band in our analysis. The result also shown that Red was slightly superior to Green with the difference of correlation of 0.045. Meanwhile, the new developed index, named TRI improved the capability of Thermal index where it can be seen that Thermal index alone did not give a good correlation with maturity and moisture content of paddy as compared to TRI.

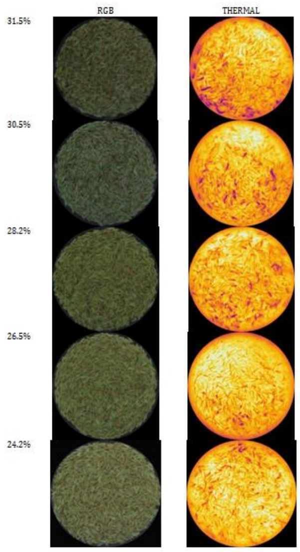

Fig. 2: Sample of RGB images and thermal images at different moisture content.

Model development for maturity stage and moisture content estimation:

Maturity stage and moisture content estimation models were developed in this study by employing a linear and quadratic equation to the color indices as tabulated in Table 2. Value of coefficient determination (R^2) for each model was calculated in order to observe how well the data fit the model. Based on this table, result shows that only R index gave R^2 greater than 0.8, which was 0.859 in linear and quadratic model. The results also shown that the performance of all indices in both regression analyses was similar in terms of value and its performance rank.

For moisture content estimation, the result showed that R and G indices gave R^2 greater than 0.85 in linear and quadratic. The highest value of R^2 can be found in R with 0.964 for linear and R^2 = 0.966 for quadratic. The results also showed that the performance of all indices in both regression models were not only similar in terms of values and its performance rank, but also slightly better compared to maturity stage.

Model validation and selection:

The developed models were validated using 15 samples of paddy taken at different maturity stage and moisture content. Accuracy of the models were analyzed based on validation results taken from one to one intersection of actual and predicted axis, the highest R^2, value of errors and t-test. Value of errors were calculated based on Mean Square Error (MSE), Root Mean Square Error (RMSE) and accuracy of the model defined as follows:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(M_p - M_a\right)^2 \qquad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(M_{p,i} - M_{a,i}\right)^2}{n}} \qquad (3)$$

$$\%\,Accuracy = 100 - \left(ABS\left(\frac{M_p - M_a}{M_a}\right)\right) X\ 100 \qquad (4)$$

Where M_p is the predicted value of paddy quality (moisture content or maturity stage), Ma is the actual value of paddy quality (moisture content or maturity stage) and n is the total number of sample.

Maturity stage:

In overall, the actual and predicted value of paddy maturity fitted well in the model developed using R, G and TRI with R^2 value of almost 1. R gave the highest value of R^2 with R^2 = 0.9302 using linear and R^2 = 0.9286 using quadratic model. It was followed by G with R^2 = 0.8446 in linear and R^2 = 0.8348 in quadratic and then TRI with R^2 = 0.8042 in linear and R^2 = 0.8021 in quadratic. Errors and percentage of accuracy for maturity stages determination in all developed model during validation process were shown in Table 3. It has been found that R gave the lowest value of MSE, which was 0.69 for both linear and quadratic models. The same condition also happened for RMSE result, which was only 0.83 for both linear and quadratic models. Meanwhile, all of the models gave high percentage of accuracy, which was 96%, and above. The highest accuracy was 99.2%, gathered from R and G in both linear and quadratic models.

Table 4 shows the t-test result between actual and predicted value of maturity stage estimation. All color indices gave no significant difference between actual and predicted value for all color indices with significant values greater than 0.05. Therefore, it can be concluded that the predicted values were accepted.

Moisture content:

In overall, the actual and predicted value of paddy moisture content estimation fitted well in the model developed using R and G indices with R^2 value greater than 0.8. R gave the highest value of R^2 which was 0.9896 in linear and 0.9906 in quadratic. It was followed by G with R^2=0.8637 in linear and R^2=0.8635 in quadratic. Table 5 summarizes the error and percentage of accuracy for moisture content estimation in all developed models during validation process. The lowest value of MSE can be gathered from R which was 0.09 and 0.08 for linear and quadratic model, respectively. The same condition also happened for RMSE results, with the value of 0.30 for linear and 0.28 for quadratic, respectively. All of the models gave high percentage of accuracy in predicting moisture content of paddy which were 90% and above. The highest accuracy was 99.2% gathered from R using quadratic model. The R index also gave the highest accuracy in linear model, which was 99.1%.

Table 6 shows the t-test result between actual and predicted value of moisture content determination. From the table, the results show that there was no significant difference between actual and predicted value for all color indices. Therefore, it can be concluded that the predicted value was accepted.

Results of the model validation has shown that both developed linear and quadratic models using R index gave the best performance of prediction in estimating the maturity stage and moisture content of paddy. The models gave high percentage of accuracy and lower percentage of errors. This might due to the characteristic of Red band, which relates with chlorophyll content. Visible spectral reflectance of plant canopy has been found to be useful for analysis of crop growth and yield (Saberioon *et al*., 2013). Normally, the pigment in green vegetation absorb more strongly at Red light due to higher chlorophyll content (Richardson *et al*., 2001). From this study, chlorophyll pigmentation absorption occurs at the kernel of paddy seeds. High absorption of Red occurs when paddy is still in immature stage as Red light is used for photosynthesis resulting to more reflection of Green light compared to when it is matured. When paddy is being matured, it will cause lower chlorophyll content resulting lower absorption in Red and lighter Green color. In addition, the moisture content of paddy was decreased with advancement in harvesting time. This is due to the paddy conditions, which is fully developed when matured.

Thus, the relevant models for paddy maturity stage and moisture content estimation are as follows:

a) Maturity stage

Linear model:

$$\textit{Maturity stage} = 64.480(Red)+76.075 \pm 0.83 \quad (5)$$

The approximation of percent error for linear model can be calculated as:

$$\left(1-\sqrt{0.859}\right)x\ 100 = 7.32\%$$

Quadratic model:

$$\textit{Maturity stage} = 84.466(Red)-32.52(Red^2) \pm 0.83 \quad (6)$$

The approximation of percent error for quadratic model can be calculated as:

$$\left(1-\sqrt{0.859}\right)x\ 100 = 7.32\%$$

b) Moisture content:

Linear model:

$$\textit{Moisture content} = -62.943(Red)+47.314 \pm 0.3 \quad (7)$$

The approximation of percent error for linear equation can be calculated as:

$$\left(1-\sqrt{0.964}\right)x\ 100 = 1.82\%$$

Quadratic model:

$$\textit{Moisture content} = -107.03(Red)+71.752(Red^2)+53.967 \pm 0.28 \quad (8)$$

The approximation of percent error for quadratic model can be calculated as:

$$\left(1-\sqrt{0.966}\right)x\ 100 = 1.71\%$$

Both linear and quadratic estimation models gave almost similar performance. However, linear model is more simple resulting faster computational time compared to quadratic model. Therefore, it was selected to determine the value of maturity stage and moisture content.

Conclusion:

In this research, color indices extracted from visible and thermal images were used to develop models to estimate quality of paddy based on its maturity stage and moisture content. Color properties of each paddy image from 92 to 100 DAP were investigated. From the result, it can be concluded that although R, G, B, TRI and Thermal gave good relationship and model of estimation for paddy maturity stage and moisture content, however, R was superior. R gave the highest significant correlation with maturity stage and moisture content which was 0.927 and -0.982, respectively. Furthermore, linear and quadratic models developed using R index gave the highest R^2 in both estimation models where it was 0.859 for maturity estimation. While for moisture content estimation, R^2 = 0.964 for linear and R^2 = 0.966 for quadratic. Result of validation has shown that the actual and predicted value fitted well in the model developed using R. R index also gave the lowest MSE and RMSE and the highest percentage of accuracy for both estimation models in linear and quadratic. Better performance of R index compared to other indices might be due to absorption of chlorophyll pigmentation at the kernel of paddy seeds. High absorption of Red occurs when paddy is still in immature stage as the Green seed is more compared to when it is matured. When paddy is being matured, it will cause lower absorption in Red, which results on the higher reflectance. Therefore, when paddy seeds are more matured, the reflectance of Red is higher. Furthermore, Red wavelength is closer to NIR wavelength. Thus, it can determine better value of moisture content as compared to thermal. The results also shown that thermal wavelength is too long for paddy moisture content determination. In overall, the developed models can be used as an alternative tools in determining the exact time to harvest paddy.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Ministry of Science, Technology and Innovation (MOSTI) Malaysia for sponsoring this research under EScience Fund, research number 06-01-04-SF1287.

REFERENCES

Azman, N.S., S. Khairunniza-Bejo, W.I.W. Ismail, A. Wayayok, 2014. Estimating maturity of paddy using RGB colour space. Journal of Advanced Agricultural Technologies, 1(2): 119-124.

Basak, J.K., M.A. Ali, M.N. Islam, M.A. Rashid, 2010. Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model. Journal of Civil Engineering (IEB), 38(2): 95-108.

Choi, K., G. Lee, Y.J. Han, J.M. Bunn, 1995. Tomato maturity evaluation using colour image analysis. Transactions of the ASAE, 38: 171-176.

Counce, P.A., R.J. Bryant, C.J. Bergman, R.C. Bautista, Y.J. Wang, 2005. Rice milling quality, grain dimensions and starch branching as affected by high night temperatures. Cereal Chem., 82: 645–648.

Farid, M., S. Khairunniza-Bejo, N.S. Azman, 2014. An approach to estimate moisture content of paddy rice via thermal imaging. Journal of Food, Agriculture & Environment, 12(1): 188-191.

Firouzi, S., M.R. Alizadeh, 2013. An investigation of the effects of harvesting time and milling moisture content of paddy on the quality of milled rice. International Journal of Biosciences, 3(10): 133-138.

Haw, C.L., W.I.W. Ismail, S. Khairunniza-Bejo, A. Putih, R. Shamshiri, 2014. Colour vision to determine paddy maturity. Int J Agric & Biol Eng., 7(5): 1-9.

Jamil, N., S. Khairunniza-Bejo, 2014. Husk Detection Using Thermal Imaging Technology. Agriculture and Agricultural Science Procedia, 2: 128-135.

Khairunniza-Bejo, S., N.S. Munira, 2014. Mature and immature paddy identification using image processing technique. Journal of Engineering Science and Technology, 9(3): 326-333.

Lee, D.J., J. Archibald, Y.C. Chang, C. Greco, 2008. Robust color space conversion and olor distribution analysis technique for date maturity evaluation. Journal of Food Engineering, 364-372.

Peng, S.B., J.L. Huang, J.E. Sheehy, Laza, R.C. R.M. Visperas, X.H. Zhong, 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci., 101: 9971-9975.

Richardson, A.D., 2002. An evaluation of noninvasive methods to estimate foliar chlorophyll content. New Phytologist, 185-194.

Saberioon, M.M., M.S. Amin, A.R. Anuar, A. Gholizadeh, A. Wayayok, S. Khairunniza-Bejo, 2014. Assessment of rice leaf chlorophyll content using visible bands at different growth stages at both the leaf and canopy scale. International Journal of Applied Earth Observation and Geoinformation, 35-45.

Singh, N., M.J. Delwiche, R.S. Johnson, J. Thompson, 1992. Peach maturity grading with color computer vision. ASAE Paper No, 92: 3029.

Sirisathitkul, Y., N. Thumpen, W. Puangtong, 2006. Automated chokun orange maturity sorting by color grading. Walailak J Sci & Tech, 3(2): 195-205.

Sumgap, N.H., S. Khairunniza-Bejo, 2011. Colour spaces for paddy soil moisture content determination. J. Trop. Agric. and Fd. Sc., 39(1): 1-13.

Teoh, C.C., B.H. Abu Bakar, 2009. Immature paddy quantity determination using image processing and analysis techniques. J. Trop. Agric. and Fd. Sc., 37(2): 241-248.

Wassamann, R., S.V. Jagadish, K. Sumfleth, H. Pathak, G. Howell, A. Ismail, 2009. Regional vulnerability of rice production in Asia to climate change impacts and scope for adaptation. Adv. Agron., 102: 91-133.

Welch, J.R., J.R. Vincent, M. Auffhammer, P.F. Moyae, A. Dobermann, D. Dawe, 2010. Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. Proc. Natl Acad. Sci. USA doi/10.1073/pnas.1001222107.