Colour vision to determine paddy maturity

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Abstract: Quality of harvested rice and its production are influenced by the timing of harvesting. Harvesting at the right stage gives the best yield and quality. The purpose of this research was to determine the best time for harvesting by using image processing technique. Parameters such as weight of florets, hue colour of florets, and hue colour of flag leaf were tested in the research. The trends of changes were observed in the process of maturity until the harvesting day. For Malaysia Rice (MR) variety 219, the corresponding hue value for florets maturation is 32.3° ±2°. In the period of maturity, the florets' hue value decreased from green to yellow and then remained constant at 32°. The maturity process proceeded gradually from the florets at the outermost spikelet to florets at the basal part. Florets at the basal part were matured seven days later than the florets at the terminal part. Results show that the colour changes of the leaf were uneven and hence did not give a good correlation with maturity. It was observed that the weight for a matured floret increased rapidly towards maturity, but remained constant after it reached the mature stage. There were some losses in weight due to the decrease of moisture contents in florets. Finally, it was concluded that the maturity of paddy can be observed through the colour and weight of florets. The MR219 mature floret has the hue colour of 32.3° ±2°, and the mature floret can weigh up to 31.25 mg.

Keywords: paddy maturity, colour vision, hue, paddy morphology, grain, *Oryza Sativa*

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1 Introduction

Paddy (*Oryza Sativa*) is a major food source in Asian countries. Many countries in Asia produce rice to support the local market. Some of Asian countries like Thailand, Vietnam and India have become main exporters and suppliers in the global rice market[1]. There are more than 500 thousand hectares paddy fields in Malaysia[2]. On an average, a Malaysian adult consumes 77 kg of rice per year[3]. As Malaysia imports 1.05 million metric ton per year, 48% of the total consumption is imported from Thailand and Vietnam[1]. The four common rice types in the Malaysian market are brown rice, white rice, fragrant rice and glutinous rice[4]. Among these types, white rice is the most common in the local market. Brown rice and white rice come from the same source while white rice is produced by polishing brown rice.

MR219, is the first Malaysia commercial indica rice variety developed by Malaysia Agriculture Research and Development Institute (MARDI) in 2001[5,22]. It is a high yield variety, producing 10 metric ton per hectare[6]. Each mature grain weighted 28 to 30 mg, and each panicle can obtain 200 grains. This variety has a short

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maturation period of 105 to 111 days, with fairy tall and strong culm[5]. MR219 variety rice is widely planted in Sekinchan, Selangor, one of the well-known rice fields in Malaysia[7]. Rice plants' growth is divided into three stages: the vegetative stage (from germination to panicle initiation), the reproductive stage (from panicle initiation to heading) and the florets filling or ripening stage (from heading to maturity)[8]. Paddy morphology was described in Figure 1. Weeks of growth stages were indicated at the bottom row of the figure, while the water needed for plants in different stages was indicated at second last row. Graphic and description of growing stages were shown in the first two rows, while the main activity in different stages and irrigation management were shown in the third and fourth rows.

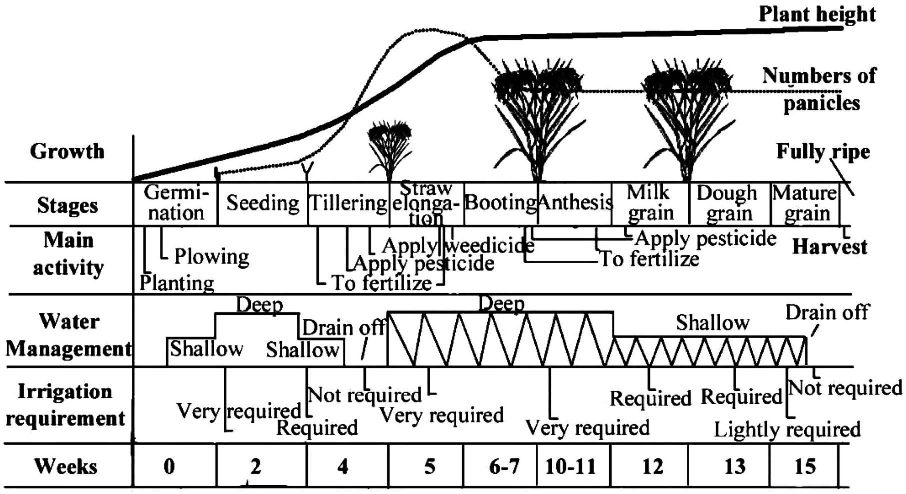

Figure 1 Rice plant morphology[17]

Quality of rice is determined by the yield of head rice after milling. Good quality rice contains a higher yield of head rice. A low yield of head rice lowers rice quality[9]. Perfect head rice can be obtained from mature florets. If the florets are immature, the rice is chalky or sometimes an unfilled kernel. Starch can be easily lost during the milling process of such rice. Overripe crops result in higher shattering losses[10]. Thus, it is important to determine the optimum time for harvesting paddy. There are few morphology changes shown on a paddy plant that indicates its maturity, such as shape, size, weight, colour, bulk density, equilibrium moisture content and chemical characteristics[11]. In the conventional way, farmer determines the maturity and the harvest time by counting the number of days after planting. If the paddy has a life span of 120 days, then farmers begin harvesting around this period. Paddy plants have some significant morphology growth, such as rice florets' increase in size and weight to accumulate sugars, starches, storage proteins and other storage compounds[8]. The colour of leaves' change from green to yellow during the ripening stage as nitrogen is transferred from leaves to seeds. Mature florets also change its colour from green to golden brown, but wet climate condition may delay the de-greening process of florets[12]. Farmers begin harvesting whenever the florets and leaf colour turn into yellow at the mature period. However, this is based on experience and naked-eye observation which is not always reliable. There are multiple wavelengths in light spectrum; each wavelength is a true colour. A true colour of a certain wavelength may look different when there is shadow interference[13]. Hue is the true colour, which has the colour value from 0° to 360°. Hue value is widely used in scientific research due to its unchanged characteristic, unlike RGB[14]. The colour of florets and leaves is recorded based on its hue value, as this can eliminate the climatic constraints, such as weather interferences and daylight interferences. The hue parameter is commonly used in ripeness prediction for fruits such as tomato[15] and oil palm fruit in Malaysia[16]. A scientific study needs to be carried out in order to obtain paddy's optimum maturity period. The focus of this study was on three physical parameters: florets colour, florets' weight, and flag leaf's colour.

2 Materials and methods

2.1 Site and variety preparation

The experiment was carried out in an actual paddy field in Sekinchan, Selangor during the harvest season from 12th to19th of June 2012. The seeds were sown in the field on 2nd of March 2012 and were harvested by farmers on 19th of June 2012, with the period of 110 growth days. The field area was 1.45 hectares with the plant spacing of 15 cm. There were six to eight panicles in each plant and each panicle had 80 to 110 florets. Variety MR 219 was used in the experiment. Its maturation period was around 105 to 111 days after sowing. The plant's height ranged between 76 to 78 cm. Weight of each seed was around 27.11 mg, and the yield was around 7 000 to 10 500 kg/ha[6].

Eighteen plants were selected as samples in a 3 m × 3 m plot, where six plants were tested in each of the three replications. Samples were selected from healthy plants without any pathogenic symptoms, and labelled from A_1 to A_6, B_1 to B_6 and C_1 to C_6 (Figure 2). The air humidity and temperature of the site were recorded every morning from 8:30 am to 10:00 am.

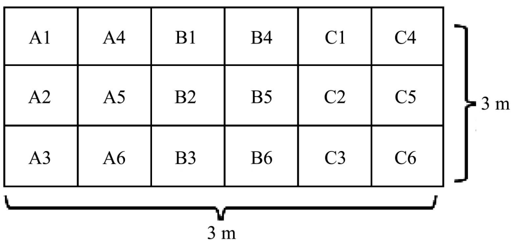

Figure 2 Samples distribution on 3 m × 3 m plot

2.2 Florets and leaf hue determination

A red, green and blue (RGB) camera, Nikon D5000 (Nikon, Tokyo, Japan), was used for snap shot on the spikelet of the sample with white background as shown in Figure 3. The pictures were then analyzed in Matlab software (Mathworks, Natick, MA) by converting the RGB to hue, saturation and value (HSV) to get the hue value of the florets as shown in Figure 4. The hue value of each point in Figure 4 was listed in Table 1. A picture of florets was equally divided into 3 parts (Figure 5), which were the terminal part, the middle part and the basal part, as ripeness progresses from terminal to basal gradually[10]. Three points were randomly selected in each portion to record the hue value, and then the mean value was obtained. In the next step, the trends of hue changes versus days after sowing (DaS) were analyzed.

Figure 3 RGB image of florets.

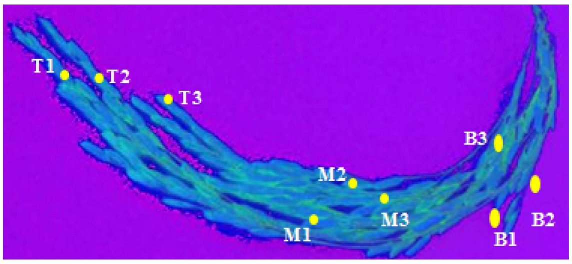

Figure 4 HUE image of florets.

Figure 5 The florets image showing basal, middle and terminal parts, each part make up from 33% of whole spikelet

Table 1 HUE value of samples

Parts	Sample	HUE/(°)
Terminal	T1	25.81
	T2	32.58
	T3	37.08
Middle	M1	39.60
	M2	39.24
	M3	37.44
Basal	B1	50.76
	B2	61.2
	B3	67.32

In the leaf's hue versus DaS experiment, the image of each sample's flag leaf was taken, as shown in Figure 6. The pictures were then analyzed in Matlab by converting RGB to HSV to obtain the hue value of the leaf, as shown in Figure 7. The hue value for point 1 was 54.36°, point 2 was 37.08°, and point 3 was 32.29°. Three random hue values were obtained from the basal, middle and terminal part of the leaf, respectively, and the mean values were calculated. The trends of changes of leaf hue versus DaS were then analyzed. These steps were repeated for all the six samples and three replications every day until the harvesting day.

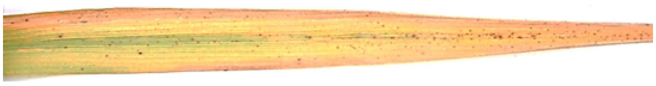

Figure 6 Original leaf picture

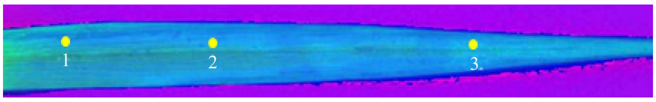

Figure 7 HUE image of leaf

2.3 Determination of florets' weight

In each divided portion, four florets were collected every day. This destructive test was done on the adjacent panicles of the marked panicles. Thus, everyday there were 12 florets to be collected in each plant. The florets were put in three dedicated boxes according to their portions. The florets were then weighed with a digital scale after florets in all the sample plants were collected. There were a total of 72 sample seeds in each portion (terminal, middle and basal). The trend of weight in each portion versus DaS was analyzed. The test was carried out every day until harvest. Finally, the relationship among florets hue, leaf hue, weight, and rice maturity was analyzed.

3 Results

3.1 Florets hue value

The air temperature and humidity of the field site were 32°C±2° and 80%±3% during the harvesting period. Figure 8 shows the trends of florets' hue evolution from day 103 to the harvest time at day 110. The trends of the florets taken from the terminal portion were shown in cyan lines, while the trends of the florets taken from the middle portion were marked in red colour, and the trends of the florets taken from the basal portion were in green colour. The average and standard deviation of floret's hue value at each part was recorded in Table 2. Regression equations of each sample at each part were recorded in Table 3 (the terminal part), Table 4 (the middle part), and Table 5 (the basal part). The paddy was harvested at day 110 after 14-day-old seedling sowed in the field.

Table 2 Mean hue value of grains at the terminal, the middle and the basal parts towards maturity

Part	Hue/(°)	Days after sowing							
		103	104	105	106	107	108	109	110
Terminal	Average	37.095	34.757	34.710	35.576	31.623	32.317	31.670	31.895
	σ	2.313	1.734	1.713	2.015	1.299	1.563	1.307	1.230
Middle	Average	47.571	41.567	42.114	40.771	36.069	34.968	33.965	33.507
	σ	6.145	4.392	5.422	4.137	1.910	1.853	2.202	1.759
Basal	Average	64.440	57.113	54.440	53.389	44.888	44.064	38.171	37.860
	σ	4.827	5.272	4.460	5.433	4.423	5.289	3.921	3.173

Table 3 Regression equation and R^2 for grain hue at the terminal portion

Sample	Prediction equation	R^2
A1 TML	$y = -1.2006x + 161.28$	0.8365
A2 TML	$y = -0.8394x + 124.31$	0.5436
A3 TML	$y = -1.0006x + 141.06$	0.8702
A4 TML	$y = -1.1604x + 157.56$	0.6415
A5 TML	$y = -0.2647x + 61.35$	0.1172
A6 TML	$y = -1.0473x + 145.74$	0.7759
B1 TML	$y = -0.7659x + 115.37$	0.5005
B2 TML	$y = -0.6174x + 99.968$	0.7244
B3 TML	$y = -0.5759x + 96.304$	0.3358
B4 TML	$y = -1.0091x + 140.45$	0.7117
B5 TML	$y = -0.9489x + 135.83$	0.7528
B6 TML	$y = -0.8487x + 123.77$	0.6277
C1 TML	$y = -0.5139x + 88.153$	0.3440
C2 TML	$y = -0.7041x + 108.65$	0.4729
C3 TML	$y = -0.9611x + 136.05$	0.3869
C4 TML	$y = -0.3001x + 65.201$	0.1921
C5 TML	$y = -0.296x + 63.801$	0.1321
C6 TML	$y = -0.4386x + 78.823$	0.2788
Average	$y = -0.7496x + 113.54$	0.7665

Table 4 Regression equation and R^2 for grain hue at the middle portion

Sample	Prediction equation	R^2
A1 MID	$y = -1.3397x + 180.78$	0.4100
A2 MID	$y = -2.0911x + 261.91$	0.5804
A3 MID	$y = -2.7247x + 328.58$	0.5509
A4 MID	$y = -1.4941x + 195.88$	0.4518
A5 MID	$y = -2.7519x + 331.34$	0.8082
A6 MID	$y = -1.311x + 178.57$	0.7168
B1 MID	$y = -1.3901x + 187.17$	0.5495
B2 MID	$y = -1.4526x + 192.02$	0.8731
B3 MID	$y = -1.8209x + 230.7$	0.7109
B4 MID	$y = -1.767x + 225.61$	0.7655
B5 MID	$y = -1.1506x + 159.79$	0.7163
B6 MID	$y = -1.4537x + 193.78$	0.3936
C1 MID	$y = -3.2664x + 389.07$	0.8552
C2 MID	$y = -0.9466x + 139.92$	0.2483
C3 MID	$y = -2.9586x + 356.39$	0.7669
C4 MID	$y = 0.0056x + 0.0862$	0.8439
C5 MID	$y = -1.9473x + 246.68$	0.4757
C6 MID	$y = -2.9603x + 358.45$	0.7586
Average	$y = -1.9356x + 244.96$	0.9097

Table 5 Regression equation and R^2 for grain hue at the basal portion

Sample	Prediction equation	R^2
A1 BSL	$y = -4.077x + 479.85$	0.8643
A2 BSL	$y = -3.0171x + 372.6$	0.8517
A3 BSL	$y = -4.598x + 539.73$	0.9240
A4 BSL	$y = -3.6403x + 435.74$	0.7799
A5 BSL	$y = -5.4194x + 623.85$	0.8168
A6 BSL	$y = -3.6566x + 440.29$	0.9199
B1 BSL	$y = -2.9214x + 362.89$	0.8971
B2 BSL	$y = -3.2391x + 396.38$	0.8606
B3 BSL	$y = -3.8226x + 449.07$	0.8293
B4 BSL	$y = -3.887x + 461.71$	0.8299
B5 BSL	$y = -4.3696x + 514.91$	0.8652
B6 BSL	$y = -3.3907x + 408.89$	0.9400
C1 BSL	$y = -3.5093x + 423.93$	0.8573
C2 BSL	$y = -3.4954x + 422.48$	0.8658
C3 BSL	$y = -4.3259x + 510.91$	0.9305
C4 BSL	$y = -5.04x + 590.06$	0.7889
C5 BSL	$y = -2.5511x + 318.51$	0.7473
C6 BSL	$y = -3.6971x + 447.57$	0.7723
Average	$y = -3.8143x + 455.52$	0.9623

Figure 9 shows the linear regression graph of florets taken from the terminal, the middle and the basal portions. The significant difference was less for terminal florets hue from day 103 to day 110 after sowing (R^2= 0.7665), as shown in Table 3. The hue value was almost stable at 32.3°±1.5° as shown in Table 2. This explains that the florets at the terminal remained yellowish and matured at day 107 onwards. However, the hue value of florets at the middle portion slightly decreased from 44.57°±6° at days 103 to 33.5°±1.7° at days 110, as shown in Table 2. The decreasing curve trend had more significant difference in the linear regression graph as shown in the graph in Figure 9 with R^2=0.9097 in Table 4. The colour gradually changed from yellowish green to yellow towards maturity, but the percentage of florets at the middle part that reached full maturity at day 110 was lower than that of the florets at the terminal part. Florets at the basal portion shows the most significant hue regression with R^2=0.9623 as shown in Figure 9 and Table 5. The hue decreased linearly from 64.4°±4.8° to 37.9°±3°. The trend could go lower if it was taken after harvest on day 110. This means the florets at the basal and the middle parts were yet to reach maximum maturity stage during the harvest period, which was true that the harvest take place when more than 80% of the rice is mature[10]. The hue value shown in the graph ranged from 29° to 72°. The colour value is presented in Figure 10.

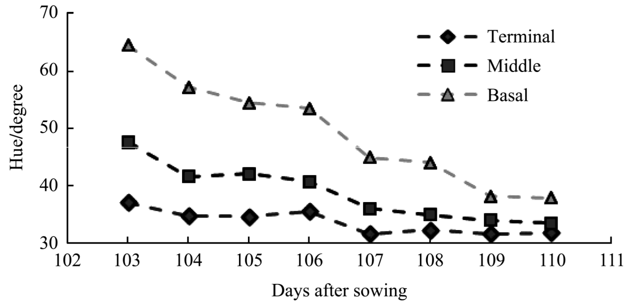

Figure 8 Hue evolution of florets from terminal portion, middle portion and basal portion

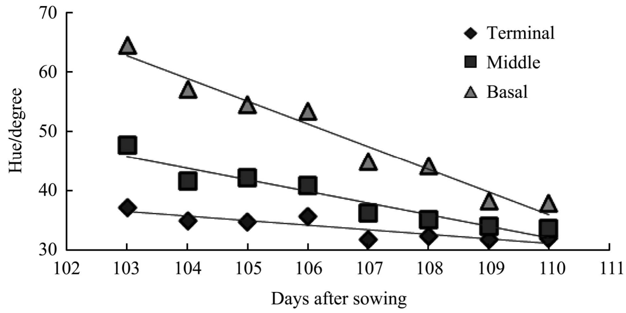

Figure 9 Grain hue regression graph at terminal, middle and basal part

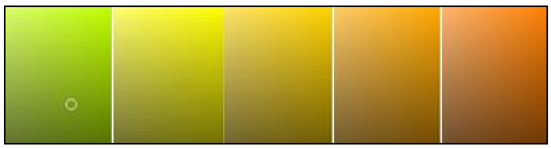

Figure 10 Hue Value (From left to right), 72°, 60°, 50°, 40°, and 29°

From the trends shown in Figure 8 and Table 2, we concluded that the hue value of the mature florets was 32.3°±2°. Florets at the terminal portion turn to yellow 7 days earlier than those at the basal portion, 4 days earlier than those at the middle portion. When the florets turned to yellow, the colour lasted.

3.2 Leaf hue value

Figure 11 shows the leaf's hue evolution from day 103 to harvest on day 110. The mean hue value on each day was recorded in Table 6. On the harvest day, not all flag leaves were yellow, and there were few leaves remained green. The mean hue was 48.08° on the harvest day, and the deviation between the minimum and the maximum hue value was 37°. The colour of leaves had a strong relationship in linear regression with maturity (mean R^2=0.9249) as shown in Figure 12 and Table 7. At the end of the harvest day, some of the leaves were yellow and some were still green. According to the research carried out by Michael L. Morris[12], stems and leaves in many rice varieties tend to remain green although the florets are fully ripe. Thus, researcher should avoid using the colour of stems and leaves as an indicator of floret's ripeness.

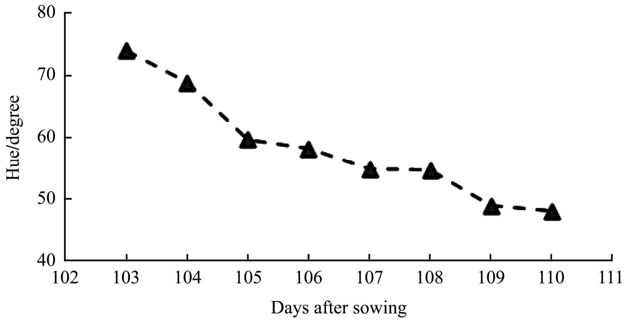

Figure 11 Evolution of leaf hue

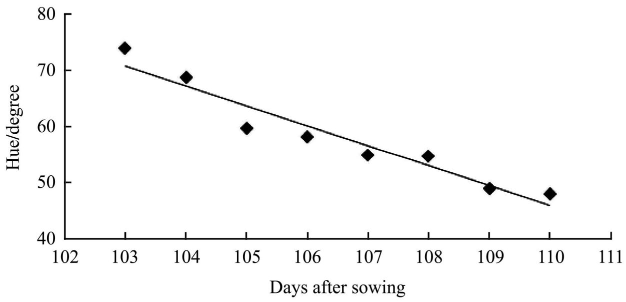

Figure 12 Leaf hue regression graph

Table 6 Mean hue value of leaf towards maturity

Hue/(°)	Days after sow							
	103	104	105	106	107	108	109	110
Average	73.960	68.808	59.668	58.176	54.880	54.712	48.920	48.077
σ	12.033	10.416	16.048	16.229	18.178	17.687	18.609	18.607

Table 7 Regression equation and R^2 for leaf hue

Sample	Prediction equation	R^2
A1	$y = -6.4736x + 736.16$	0.8023
A2	$y = -4.7923x + 564.3$	0.6135
A3	$y = -5.7629x + 668.48$	0.8940
A4	$y = -3.6433x + 446.77$	0.8919
A5	$y = -2.7986x + 370.3$	0.5625
A6	$y = -1.2886x + 214.66$	0.4070
B1	$y = -1.2154x + 184.01$	0.0750
B2	$y = -6.1304x + 707.4$	0.8390
B3	$y = -3.2319x + 406.86$	0.9000
B4	$y = -2.4773x + 312.71$	0.3457
B5	$y = -3.1829x + 386.76$	0.5109
B6	$y = -4.4637x + 531.55$	0.8466
C1	$y = -5.6757x + 650.29$	0.8478
C2	$y = -3.0326x + 368.06$	0.6642
C3	$y = -3.3753x + 399.31$	0.4917
C4	$y = -5.3007x + 629.93$	0.8209
C5	$y = -5299x + 301.25$	0.5652
C6	$y = -3.4071x + 428.28$	0.6914
Average	$y = -3.5569x + 437.22$	0.9249

From the observation on the trend of leaf colour in Table 6, Figure 11 and Figure12, it can be concluded that the flag leaf colour changed from green to yellow towards maturity, but it was not consistent and had high deviation compared to florets' colour evolution.

3.3 Florets weight

Figure 13 shows the evolution of florets weight of 72 seeds during the maturity. The weight of terminal florets and middle florets remained constant from day 103 to day 110. This concluded that florets at the terminal and the middle portion had reached its maturity after day 103, because mature florets will not increase its weight. The weight of mature florets did not increase and sometimes slightly decreased. This is due to the loss of moisture content in florets, and the development of starch and protein stopped[19]. The weight was maintained at 2.25 mg ± 0.05 mg. The regression for the grain weight at the terminal and middle parts was in the polynomial form. However, the weights of the basal florets increased linearly with R^2=0.6896 as shown in Table 8, and reached maximum weight at 2.32 mg on day 108 and remained constant after 108 days until harvest. The average seed weight was 31.25 mg which matched with the weight recorded by MARDI at around 27 mg. From the graph shown in Figure 13 and Figure 14, it can be concluded that the weight of florets reached its maximum and remained constant or slightly decreased after the maximum weight. The starch in the florets at the basal portion was still developing, while the florets at the terminal and the middle portions had stopped development. The weight of florets at the basal portion may lag 5 days behind than the florets at the terminal portion.

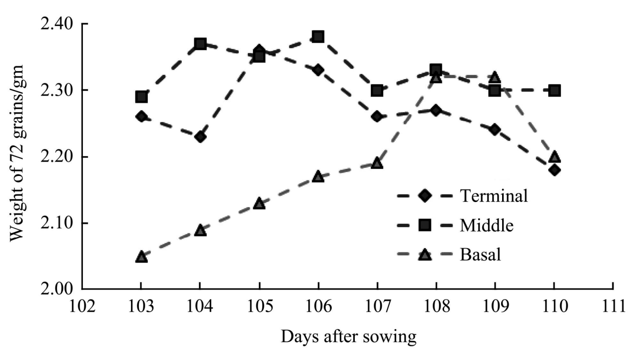

Figure 13 Evolution of grains' weight

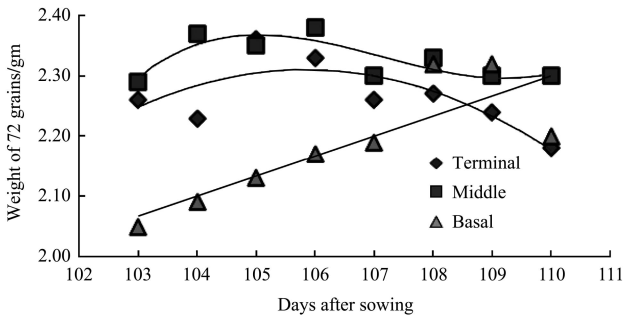

Figure 14 Regression between weight and days after sowing

Table 8 Regression equation and R^2 for leaf hue

Sample	Prediction equation	R^2
Terminal	$y = -0.0077x^2 + 1.6254x - 83.708$	0.6345
Middle	$y = 0.002x^3 - 0.6493x^2 + 69.529x - 2478.6$	0.6757
Basal	$y = 0.0332x - 1.3536$	0.6896

Table 9 Regression equation and R^2 for grains hue vs. weight

Sample	Prediction equation	R^2
Terminal	$y = 16.594x - 3.8998$	0.2002
Middle	$y = -247634x^3 + 2E{+}06x^2 - 4E{+}06x + 3E{+}06$	0.8837
Basal	$y = -8555x + 229.14$	0.7176

Table 10 Regression equation and R^2 for leaf hue vs. weight

Sample	Prediction equation	R^2
Terminal	$y = 17083x^3 - 117051x^2 + 267256x - 203287$	0.2108
Middle	$y = -484807x^3 + 3E{+}06x^2 - 8E{+}06x + 6E{+}06$	0.8319
Basal	$y = -81.37x + 233.42$	0.6763

3.4 Florets hue versus florets weight

The relationship between florets hue and florets weight was shown in Figure 15. Three lines represent the regression of grains' hue value from terminal portion, middle portion and basal portion respectively. The regression equation and R^2 value were listed in Table 9.

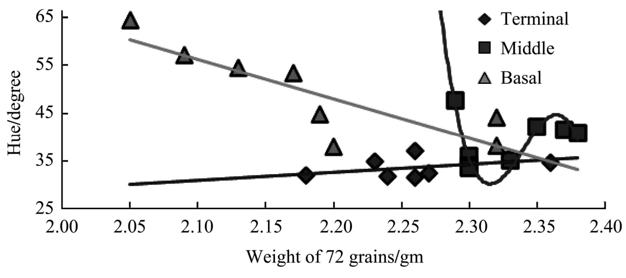

Figure 15 Regression of florets mean hue at terminal, middle and basal portion versus weight of grains.

For the florets in the terminal and middle portion, their linear regression was not significant. In the terminal portion, the relationship was not significant between florets' hue and its weight with R^2=0.2002. Hue value remained unchanged when the weight was increased. The maximum hue was 37.09° at the weight of 2.26 mg, and the maximum weight was 2.36 mg. recorded at the hue value of 34.71°. In the middle portion, the best regression between florets hue and its weight was a 3rd order polynomial regression relation (R^2=0.8837). The maximum hue was 47.5° at the weight of 2.29 mg, and the maximum weight of 2.38 mg. recorded at the hue value of 40.77°.

The florets in basal portion had shown the linear relationship between hue and weight with R^2=0.7176. From the graph, we can observe that while the weight was increasing towards maturity, the hue of the florets was decreasing. There was no significant linear relationship in the terminal portion and middle portion, because the weight has the minor fluctuating over the constant and the hue also fluctuate slightly at the mature hue. From Figure 15, we also observed that the hue fluctuated at 35° and the weight fluctuated around 2.33 mg. Thus, the optimum mature hue was 35° at the optimum weight for 72 florets of 2.33 mg. When the weight exceeded 2.33 mg, the florets hue began to fluctuate.

3.5 Flag leaf hue versus floret weight

Figure 16 shows the relation between leaf hue and grain weight at the terminal, the middle, and the basal parts. The weight of the florets at the terminal and the middle parts did not show any linear relation with leaf colour. The weight of the middle portion's florets and leaf hue was correlated by a 3rd order polynomial function (R^2=0.8319), and there was no significant correlation between leaf hue and weight of the terminal portion's florets (R^2=0.2108 for the 3rd order polynomial function.). However, the flag leaf colour showed a good correlation (R^2 = 0.6763) with florets' weight at the basal portion. Leaf's hue was inversely related to florets' weight as shown in Figure 16. Leaf hue decreased linearly when florets' weight increased, but when the weight was greater than 2.25 mg. (72 seeds), the hue value did not decrease, but fluctuated around 50.4°. Thus, it can be concluded that leaf colour changed to yellowish when the weight of florets increased. However, this linear relationship did not continue after the 72 florets' weight was over than 2.25 mg, and this was the time that the plant was mature.

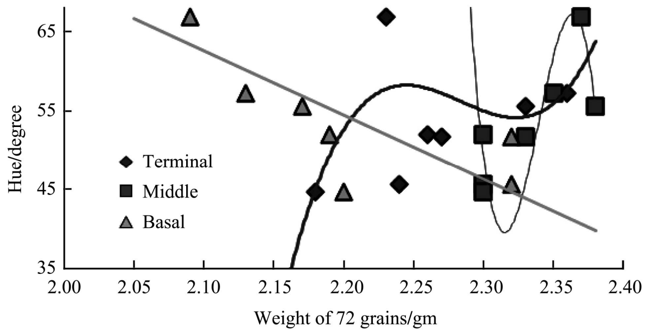

Figure 16 Correlation between leaf mean hue and florets weight

4 Conclusions and discussion

Results showed that floret colour changed from green to yellow towards maturity with the final hue value in the range of 32.3°±2° for MR219. Flag leaf colour also changed from green to yellow with the final value of 48°±18°. Weight increased towards maturity but remained unchanged after it reached mature stage. Maturity process began from the terminal part towards the basal part. The variation in maturity days between the terminal and the basal parts was more than seven days[19]. Although M. L. Morris[12] stated that leaf colour did not act as a reliable maturity indicator in some species, but for species MR219, the flag leaf colour did show colour changes. The flag leaf might not act as a good indicator for paddy maturity. This is because the flag leaf was drying rapidly towards maturity where some of the leaves may curl into a needle shape. Besides, leaves tend to be the host for some pests such as rice skippers and rice leaf folders. They attacked leaves and caused curling[20] and a white pale colour change. When a plant was growing towards maturity, the de-greening process resulted from the loss of nitrogen absorbed by mature florets caused leaves to change from green to yellow[12, 21].

Weight of florets increased towards maturity, but the hue value of florets and flag leaf decreased from green to yellow. However, the weight of florets might not increase but maintained when it reached the optimum maturity. The hue value of florets and leaf might not decrease as well when it reached optimum maturity. Optimum maturity varied within a floret between the terminal portion and at the basal portion. In this research, the data from the basal portion always give a good correlation, because towards the end of the harvest time, only the florets at the basal portion had already reached its optimum maturity, and the morphology changes towards maturity were still significant.

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