Determination of surface color of 'all yellow' mango cultivars using computer vision

Marcus Nagle[1*], Kiatkamjon Intani[1], Giuseppe Romano[1], Busarakorn Mahayothee[2], Vicha Sardsud[3], Joachim Müller[1]

(1. *Institute of Agricultural Engineering, Tropics and Subtropics Group, Universität Hohenheim, Garbenstrasse 9, Stuttgart, 70599, Germany*; 2. *Department of Food Technology, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom, 73000, Thailand*; 3. *School of Agro-Industry, Mae Fah Luang University, Chiang Rai, 57100 Thailand*)

Abstract: Image processing techniques are increasingly applied in sorting applications of agricultural products. This work has assessed the use of image processing for inspecting surface color of two Thai mango cultivars. A computer vision system (CVS) was developed and experiments were conducted to monitor peel color change during the ripening process. Conversion of RGB to CIE-LAB values was done via image processing and prediction models were developed to estimate color parameters from CVS data. Performance evaluations showed insufficient prediction for L values (R^2 = 0.42-0.58), but better results for A and B values (R^2=0.90-0.95 and 0.80-0.82, respectively). Compared to the calculated color values hue angle and chroma, a yellowness index computed from intermediate XYZ values was found to be much more adept at accurately predicting peel color from CVS data. Correlations were strong for both cultivars (R^2 = 0.93 for 'Nam Dokmai' and R^2 = 0.95 for 'Maha Chanok'). Results from classification analysis indicated satisfactory results for classifying fruits according to ripeness based on yellowness. Success rates of true positives in the categories unripe, ripe and overripe ranged 72%-92% for 'Nam Dokmai' and 98%-100% for 'Maha Chanok'. Therefore, it was shown that the CVS was capable of producing accurate color values for the two mango cultivars investigated. The findings of this study can be incorporated for development of a robust system for quality prediction and establishment of a CVS for automatic grading and sorting of mangos.

Keywords: mango, peel color, computer vision, image processing, fruit quality, Thailand
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1 Introduction

For agricultural products, color influences consumer perception more than any other factor. Color is often regarded as an indicator of flavor, edibility, shelf life and nutritional value, since it is related to the physical, chemical and sensory properties of food[1]. Many climacteric fruit crops (e.g. mango, papaya, banana) undergo significant color changes during postharvest ripening[2] and thus peel color becomes a main characteristic of fruit quality, playing a dominant role in consumer acceptance[3]. Thailand is one of the key mango producers globally. Production has increased by a factor of 2.7 in the last two decades, meanwhile becoming the second largest mango exporter in the world and reaching an annual harvest of almost 3.3×10^6 t in 2014[4,5]. However, local fruit sorting techniques are done by visual inspection, based on physical and morphological characteristics as well as on visual

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Biographies: Kiatkamjon Intani, MSc, Research interests: mechanics & design. Email: k_intani@uni-hohenheim.de. **Giuseppe Romano**, PhD, Research interests: sensors in food & agriculture. Email: giuseppe.romano@provincia.bz.it. **Busarakorn Mahayothee**, PhD, Professor, Research interests: food science & technology. Email: busarakornm@yahoo.com. **Vicha Sardsud**, PhD, Professor, Research interests: horticulture & processing. Email: vicha_cmu@hotmail.com. **Joachim Müller,** PhD, Professor, Research interests: postharvest technology, irrigation & energy. Email: joachim.mueller@uni-hohenheim.de.
***Corresponding author: Marcus Nagle**, PhD, Research interests: postharvest technology & sensors. University of Hohenheim, Institute of Agricultural Engineering (440e), Garbenstrasse 9, 70593 Stuttgart, Germany. Tel: +49 711 459 23119. Email: marcus.nagle@uni-hohenheim.de.

evaluation of external appearance[6]. Unfortunately, the current sorting methods are not consistent to properly classify fruits according to quality criteria closer to those required by international regulations. Thus, there is an essential need for inexpensive and non-destructive sensing technologies capable of sorting fruits according to their external and internal properties to meet the demands of high-value markets.

Visual inspection by humans is highly subjective, laborious and time-consuming. An alternative method is required which is suitable to evaluate quality characteristics of products, e.g. by image processing. In sorting lines, a computer vision system (CVS) is usually engaged to acquire and analyze digital images automatically. A CVS can be constructed using a standard illumination source, a camera for image acquisition coupled with hardware and software to capture and process the image. In the agricultural sector, the tasks of CVS are various[7], with many applications for the inspection of fruits and vegetables[8-12]. For fruits, CVS is commonly utilized for size and shape determination[13] and detection of defects[14-16]. For mango specifically, several works exist concerning the use of a CVS for size-mass measurements[17-19]. CVS is also widely developed for analyzing the color of foodstuffs[20-22], with many cases already presented for fruit products[23-26]. However, studies on the use of a digital color measurement system to determine the color of different mango cultivars is so far lacking. Color parameters of mango have already been evaluated to show significant correlations with fruit quality[28-33]. While the use of a CVS to obtain the color values of a green-red cultivar has been investigated[27], further studies are needed in order to realize a viable CVS for assessment of mango color and the approach of previous researchers should be extended to additional varieties. More investigation needs to be carried out to develop a fully-functioning automated sorting and grading system for commonly traded mango cultivars.

In the mango industry, scale charts are often used to evaluate fruit color by visual comparison[34,35]. Devices such as a colorimeter are able to precisely measure the surface color of products, but digital camera technology has the advantage of acquiring a large number of images and providing continuous spatial information without contact between the device and object. Digital imaging obtains the color of any pixel in the red, green and blue (RGB) bands. Different models have been tested in order to transform RGB readings into CIE-LAB color values[36]. However, RGB measurements obtained from a camera are device-dependent and calibration is required[21]. This study intends to investigate the application of image processing for measuring peel color in two typically exported Thai mango cultivars. The following objectives have been developed to be addressed in the study: identify a suitable and economic image acquisition unit for color evaluation of mango fruits; evaluate correlations between reference color values and image data; and test a prototype CVS for monitoring color change of mango fruits at different color stages during ripening.

2 Materials and methods

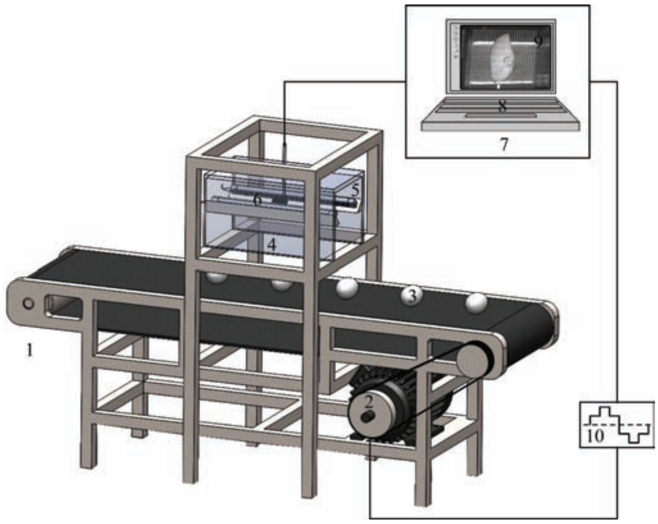
2.1 Materials

Two important export cultivars of Thai mango, namely 'Nam Dokmai' and 'Maha Chanok' were used for the experiments (Figure 1). 'Nam Dokmai' has a homogenous light yellow-green peel color, while a blend of yellow, green and red is characteristic for 'Maha Chanok'. Previous research on harvest maturity of the cultivar 'Nam Dokmai' has shown a high variability in peel color at harvest[34]. This range and variation of color makes it motivating to investigate such cultivars. Export-grade fruits harvested at a hard mature green stage[37] were obtained from a local distribution company. Fruits were checked for any external injuries and blemishes and were subjected to hot water treatment in order to reduce the presence of fruit flies, anthracnose and other diseases. For the evaluation of color, 80 fruits of each cultivar were used per trial. The sample weight of 'Nam Dokmai' and 'Maha Chanok' fruits were (393.7±71.1) g and (368.9±72.8) g, respectively. Fruits were allowed to ripen for up to eight days in baskets covered with tissue paper under natural atmospheric conditions (temperature of 31.8°C±1.2°C and relative humidity of 70.3%±5.7%), depending on fruit senescence (i.e., fruits which become senescent were no longer measured). Samples were continuously monitored during ripening by taking optical measurements daily to track the progress of color change. All trials were carried out in a randomized block format and were replicated three times.

Figure 1 Image showing the variations in peel color at harvest of two mango cultivars, 'Nam Dokmai' (top row) and 'Maha Chanok' (bottom row)

2.2 Computer vision system (CVS)

A prototype CVS was constructed for the purpose of this study (Figure 2). The main components of the system were a lighting unit, a conveyor unit and an image acquisition unit. The lighting unit consisted of a cubical structure (60 cm×30 cm×30 cm) built for illuminating the samples. Fluorescent lamps (Philips TLD 18W/865) were installed in parallel on both sides of the chamber at 45° angles to the center. The internal surfaces of the chamber were made white to uniformly illuminate the samples and reduce reflection from the fruit peel. Color temperature of the lighting was 6500K (D_{65}), which is standard for food color measurements. The average light intensity was more than 3000 lx, which exceeded the minimum requirement of 1000 lx for the observation angle of less than 10°. The illumination chamber was installed on the frame of the conveyor unit and covered to prevent the influence of ambient light. The dimension of the conveyor was 230 cm×62 cm. During experiments, the conveyer system was operated at a belt speed of 0.11 m/s. For image acquisition, a USB-camera (Logitech C905) was chosen to be installed in the system. The camera was positioned perpendicular to the conveyor at a distance of 44 cm above the belt. Images of the fruits oriented on the median plane were collected using frame-grabber software (Omega Unfold Inc., Canada) to carry out automatic acquisition. Camera settings were adjusted and optimized via the motion detection software. The settings of the CVS were calibrated based on the established procedures[21] using 130 color standard palettes (Pantone LLC, U.S.A.), which covered the range of colors typical for mango peel.



1. Conveyer assembly 2. Electric power drive 3. Fruit samples 4. Illumination unit 5. Light sources 6. Camera 7. Control unit 8. Computer 9. Frame-grabber software 10. Variable-frequency control

Figure 2 Diagram of the computer vision system (CVS) constructed for the study

2.3 Color measurements of fruits

Ten fruits were randomly selected per sampling date. Images of both sides of the fruits samples were captured using the CVS, one side at a time. Reference measurements were taken on respective fruits using a colorimeter (MiniScan XE PLUS, HunterLab, Reston, USA) at three positions per side: head, middle and tip, separately for both sides. The colorimeter was calibrated with standard black and white plates provided with the instrument. During the calibration, delta E* was kept under 0.07. Color data were acquired using the CIE L*a*b* color space, which is the most commonly applied system for measurement of food color due to the uniform distribution of colors and its close association with human perception[36]. The L*a*b* system has also been found to be the best color space for measurement of foods with curved surfaces[21].

2.4 Image processing and conversion of CVS data

Images in JPEG format were analyzed using ImageJ software (NIH, USA) to segment fruits from the background. An elliptical area along the longitudinal axis of the fruit image (i.e. the respective area where colorimeter measurements were taken) was selected for extracting the color values. RGB data were transformed into CIE L′a′b′ values by using conversion methods previously applied to other mango cultivars[27]. RGB values (ranging 0-255) were normalized to R′G′B′ by dividing each value by 255, respectively. The R′G′B′ values were converted to linear values (sRGB), gamma curve fitting was performed and sRGB values were changed to XYZ coordinates using International Telecommunication Union (ITU) coefficients. CIE L′a′b′ coordinates were calculated from XYZ values. The white reference values recommended by the European Broadcasting Union for fluorescent Illuminant F7 were used for the CIE XYZ specification based on the color temperature of the lamps used in this study. RGB values from the standard color palette images were treated in the same manner for calibration of the CVS system.

2.5 Color evaluation

The hue angle was calculated for the first quadrant [+a*, +b*] by using the following equation:

$$h° = \frac{180 \times \mathrm{Arc}\tan\left(\frac{b^*}{a^*}\right)}{\pi} \quad (1)$$

where, $h°$ is the hue angle; a^* and b^* are the color values in CIE L*a*b* color space. The other quadrants had to be handled to accommodate a 360° representation so that the results were expressed as positive signed numbers[38]. For the second [-a*, +b*] and third [-a*, -b*] quadrants, 180 was added to Equation (1) and for the fourth [+a*, -b*] quadrant, 360 was added to Equation (1). The chroma was calculated by using the following equation:

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

where, C^* is the chroma; a^* and b^* are the color values in CIE L*a*b* color space. The total change in color between samples on the first and the last day of ripening experiments was calculated by ΔE:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (3)$$

where, L^*, a^* and b^* are the color values in CIE L*a*b* color space. Additionally, a 'yellowness' index was calculated by using the equation proposed by Jha et al.[33]

$$I_y = \frac{1.2746X - 1.0574Z}{Y} \times 100 \quad (4)$$

where, I_y is the yellowness and X, Y, Z are the CIE chromatic values calculated either from measured L*a*b* or RGB values obtained from the CVS.

2.6 Data analysis and performance of the CVS

The values measured by colorimeter were compared with those estimated by the CVS. Data was analyzed using SAS software (SAS Institute Inc., USA) to evaluate correlations between image processing and colorimeter parameters. Coefficient of determination (R^2) and p-values were calculated to measure the strength of the association between the values obtained by different approaches to indicate the ability of the CVS to collect accurate color data from mango fruits. LAB-values obtained from the color standards, colorimeter and CVS were used to recreate colors of the image displayed on the monitor using a color simulation software developed by the Color Research Lab, Japan[39]. The similarity of the colors of the image displayed on the monitor was qualitatively evaluated.

Overall, large data sets were collected for both cultivars, e.g. 558 for 'Nam Dokmai' and 377 for 'Maha Chanok'. From these data pools, 375 measurements were randomly selected for each cultivar. For evaluation of the CVS, these data were separated into two groups: 300 samples were randomly assigned to the modeling set that was used to develop the prediction models and the remaining 75 samples were used as the test set to evaluate the models. Prediction models were formulated using general linear regression (GLR) in SAS software, and additionally, were first calibrated and then cross validated. Standard performance estimates were used to evaluate the models, including coefficient of determination (R^2), standard error of calibration (SEC), cross validation ($SECV$) and prediction (SEP) as well as *bias*:

$$SEC, SECV, SEP = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\check{y}_i - y_i)^2} \quad (5)$$

$$bias = \frac{1}{n}\sum_{i=1}^{n}(\check{y}_i - y_i) \quad (6)$$

where, $\check{y}_i$ is the predicted value of the i^{th} observation; y_i is the measured value of the i^{th} observation and n is the number of observations in the data set.

3 Results

3.1 Computer vision system

Results for comparison of the data sets are presented in Table 1. Regression analysis between the color parameters specified on the Pantone color palettes and the values measured by the colorimeter showed high statistical significance (p<0.0001). This indicated that the colorimeter was able to obtain accurate color data from the color standards. Comparing the values of the color standards against those measured by the CVS also showed strong statistical association, but the data sets demonstrated an exceedingly positive skew for L′ values and a moderate negative skew for a′ values. Thus, the relationships between color values as measured by colorimeter as compared with those predicted by CVS were accordingly affected. Color simulation done by entering tri-stimulus values into the color conversion software are shown in Figure 3 together with the original image from the CVS camera. As can be observed, colors were similar when produced from the standard palette values and the colorimeter, but considerably different from the CVS.

Table 1 Regression determinants, including slope (*m*), y-intercept (*b*) and coefficient of determination (R^2) for measurements taken on standard color palettes

Data sets	L			A			B		
	m	*b*	R^2	*m*	*b*	R^2	*m*	*b*	R^2
Pantone & colorimeter	1.07	−1.57	0.98	1.07	−0.28	0.92	1.10	−0.71	0.99
Pantone & CVS	1.20	−25.9	0.94	0.90	9.94	0.92	0.84	−3.19	0.98
Colorimeter & CVS	1.12	−21.7	0.94	0.74	9.00	0.77	0.76	−2.24	0.98

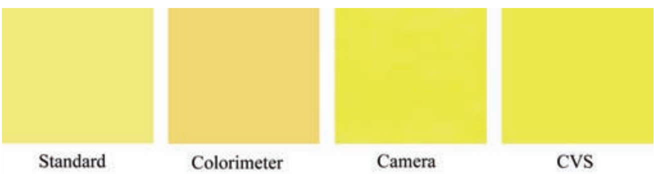


Figure 3 Camera image (camera) of standard color palette as compared with software-simulated colors using L*a*b* values from the color palette (standard) and colorimeter as well as L′a′b′ values obtained with the CVS

3.2 Color prediction by CVS

Descriptive statistics are presented for the calibration and validations sets in Table 2, where the comparability of the data sets can be examined. The GLR analysis of LAB-color parameters of 'Nam Dokmai' and 'Maha Chanok' mango as predicted by the CVS compared to those measured by colorimeter are presented in Table 3. Results showed statistically significant associations (p<0.0001), except for the correlation coefficient for the L-values. In many cases, the L′ predicted by the CVS was much lower than the actual L* measured by the colorimeter. This indicated that the illumination system for obtaining the fruit image considerably affected the RGB values. Evaluation of calibration models using residual analysis confirmed linearity of the models, based on the distributions of calibration and validation sets.

Table 2 Descriptive statistics of the calibration and validation sets for GLR prediction model development

Parameter	Calibration (n=200)			Validation (n=100)		
	Mean	SD*	Range	Mean	SD	Range
Nam Dokmai						
L	69.53	2.82	61.49-75.88	69.85	2.66	62.42-74.24
A	2.92	4.14	−3.95-13.57	2.20	3.93	−3.99-11.12
B	32.78	4.00	23.20-41.93	32.14	3.86	25.18-39.49
Maha Chanok						
L	69.51	3.44	55.30-75.66	69.32	2.90	55.41-75.33
A	7.19	6.18	−7.17-16.81	7.41	6.05	−7.89-16.71
B	41.70	4.51	31.78-51.31	41.78	4.06	31.96-50.26

Note: * SD = standard deviation of the mean value.

Table 3 Determinants of GLR models including slope (*m*), y-intercept (*b*) and coefficient of determination (R^2) for prediction of LAB color parameters

Cultivar	L			A			B		
	m	*b*	R^2	*m*	*b*	R^2	*m*	*b*	R^2
Nam Dokmai	0.46	35.44	0.42	0.73	13.95	0.90	0.47	8.20	0.80
Maha Chanok	0.69	16.73	0.58	0.81	18.65	0.95	0.56	4.94	0.82

Since a′ and b′ values were better estimated by the prediction models, the color indexes C^* and $h°$ were used to evaluate the performance. As well, I_y calculated from XYZ color parameters converted from the predicted LAB values were examined. Table 4 shows the calibration and validation results. I_y was found to have better correlation results for both cultivars, but slightly higher error and bias. Whereas both $h°$ and I_y were found to be accurately predicted for 'Maha Chanok', the I_y model performed much better for 'Nam Dokmai'. The results of prediction model analysis indicated that the CVS would be able to collect accurate color data from both mango cultivars and, in the case of I_y, can be used to monitor color change.

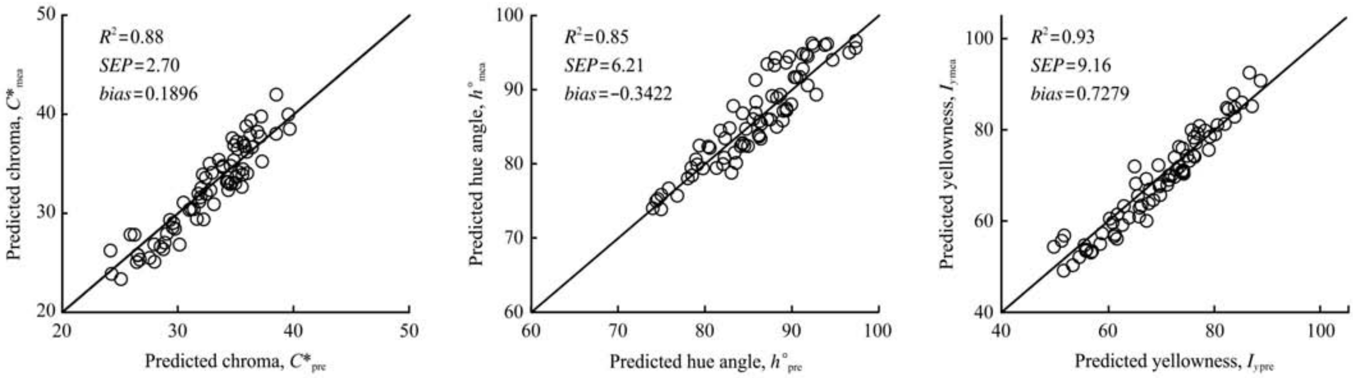
Table 4 Performance of GLR models for predicting color parameters chroma (C^*), hue angle ($h°$) and yellowness (I_y)

Parameter	Calibration (*n*=200)			Validation (*n*=100)		
	R^2	*SEC*	*bias*	R^2	*SECV*	*bias*
Nam Dokmai						
Chroma (C^*)	0.853	5.84	-0.0017	0.853	6.40	-0.3368
Hue angle($h°$)	0.868	3.01	-0.0012	0.849	2.55	0.2556
Yellowness (I_y)	0.911	10.26	-0.0010	0.901	9.81	0.5576
Maha Chanok						
Chroma (C^*)	0.86	2.83	-0.0013	0.87	3.15	0.0971
Hue angle($h°$)	0.95	3.39	-0.0002	0.95	4.06	-0.5784
Yellowness (I_y)	0.96	5.84	0.0017	0.96	6.65	0.2118

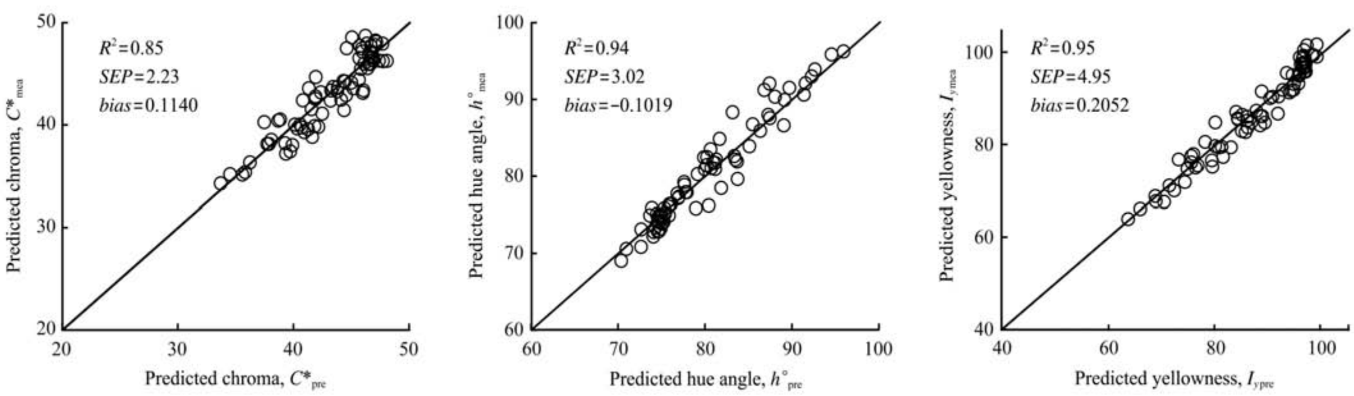
Note: R^2 Coefficient of determination, *SEC* standard error of calibration, *SECV* standard error of cross validation

3.3 Testing of color prediction models

The prediction models were tested using the subset of 75 test samples (Figure 4). Here, it can be seen that the error and *bias* was generally lower for C^*, but prediction ability was weaker with R^2 of 0.88 and 0.85 for ‘Nam Dokmai’ and ‘Maha Chanok’, respectively. Prediction of $h°$ was considerably better for ‘Maha Chanok’ than for ‘Nam Dokmai’. Strong R^2 values were found for prediction of I_y in both cultivars, but models showed higher error and *bias* as compared to other color parameters. The classification performance of the I_y models was evaluated, where ripeness classes were defined for each cultivar based on yellowness. For ‘Nam Dokmai’ fruits, unripe was defined as $I_y \leq 60$, ripe as $60 < I_y < 75$ and overripe as $I_y \geq 75$, while for ‘Maha Chanok’, unripe was defined as $I_y \leq 75$, ripe as $75 < I_y < 95$ and overripe as $I_y \geq 95$. Results of the classification analysis are presented in Table 5. The ability to classify ripeness (true positives) based on yellowness was substantially better for ‘Maha Chanok’ with 100% accuracy for unripe and overripe fruits and 98% accuracy for ripe fruits. The classification performance for ‘Nam Dokmai’ was slightly lower, with greater than 90% accuracy for ripe and overripe fruits, while almost 30% of unripe fruits were misclassified as ripe.



a. *Nam Dokmai*



b. *Maha Chanok*

Figure 4 Performance of the models for predicting color parameters chroma (C^*), hue angle ($h°$) and yellowness (I_y) using the test data set (n = 75); R^2 is the coefficient of determination and *SEP* is the standard error of prediction

Table 5 Classification results for prediction of mango ripeness according to yellowness (I_y)

Actual group	Predicted group		
	Unripe*	Ripe	Overripe
Nam Dokmai			
Unripe	72 (13)**	28 (5)	0 (0)
Ripe	0 (0)	92 (32)	8 (3)
Overripe	0 (0)	9 (2)	91 (20)
Maha Chanok			
Unripe	100 (9)	0 (0)	0 (0)
Ripe	2 (1)	98 (41)	0 (0)
Overripe	0 (0)	0 (0)	100 (24)

Note: * 'Nam Dokmai': unripe = $I_y \leq 60$, ripe = $60 < I_y < 75$, overripe = $I_y \geq 75$, 'Maha Chanok': unripe = $I_y \leq 75$, ripe = $75 < I_y < 95$, overripe = $I_y \geq 95$.

** Values give in percentage with absolute number of correctly classified fruits in parentheses.

4 Discussion

Mango fruits are typically harvested at the unripe 'mature green' stage for export. However, a high variability in stage of ripeness usually exists at harvest (Figure 1). Thus, there is a need for precise sorting processes which are able to group fruits by degree of ripeness. Based on the results of this study, the CVS system becomes a suitable option for general evaluation of the degree of ripeness of the studied mango cultivars based on prediction of yellowness.

The high global diversity of mango cultivars results in wide variations in phenotypical attributes. Mangos are classified into two races: monoembryonic (subtropical) and polyembryonic (tropical) with the generalization that subtropical cultivars usually exhibit the 'bicolor' characteristic of green peel with a red shoulder, while the tropical cultivars are normally considered to be 'all yellow' (although some mango cultivars can even exhibit extraordinary hues of red, purple and blue). Both cultivars included in this study can be considered the tropical 'all yellow' type, with the cultivar 'Maha Chanok' variably exhibiting development of a red shoulder. In addition, all 'Nam Dokmai' fruits used for the experiments were wrapped in carbon-lined bags during field growth stages. This production practice produces pale yellow instead of green fruits and increases the percentage of the skin area with golden yellow color after ripening[40]. Fruits with golden yellow color are comparably better in appearance, which is preferred by consumers.

In mangos, the green color represents chlorophyll content and the yellow color relates to carotenoid content, while anthocyanins are responsible for red shoulders. The light absorption behaviors of these pigments are distinctly different. Chlorophylls have absorption peaks in the blue (450-500 nm) and red (620-700 nm) part of the spectrum while carotenoids absorb most strongly the blue (450-500 nm) and anthocyanins show absorption peaks in the green-yellow (500-650 nm). In the case of the cultivars used in this study, it was mostly the yellow spectrum that was reflected back to the camera. In case of fruits which are not bagged during growth, peel color would be green at harvest and a red shoulder would be present in the case of 'subtropical' cultivars. Therefore, different ranges of the visible spectrum are being reflected in each case. The light source for the CVS color measurement was a standard fluorescent with a specific illumination spectrum. It could be that other broad-spectrum light sources such as halogen lamps might be more appropriate for measurement of yellow products. Congruently, the color of yellow bell peppers evaluated under halogen light was found good correlations between RGB values and b* values from the colorimeter[25].

Previous research found that the applied conversion models could be used for bicolor fruits, namely the 'B74' cultivar[27]. In this study, the calibration model was tested for the color measurement of two Thai cultivars. The study showed that the color measurement of the 'Maha Chanok' was more accurate than the 'Nam Dokmai'. Therefore, it may be that the proposed calibration models are more suitable for bicolor fruits[41]. It should be noted, however, that the range of colors was broader for 'Maha Chanok' than for the 'Nam Dokmai' which was quantified by the difference in ΔE values (14.18±6.91 and 10.98±1.81, respectively), which indicated the color difference between samples at the beginning and end of ripening. Nonetheless, other research has demonstrated the ability of CVS data obtained under a similar setup and using the same conversion models correlated well with those from visual and instrumental color assessment of bananas[23]. According to other studies, advanced modeling approaches for the calculation of LAB-values from RGB values might improve results[36,42]. This may explain the increase of errors introduced by using the direct model. However, the advantage of the direct model would be less execution time of calculation processes.

5 Conclusions

According to the findings of this study, it can be concluded that there was a good estimation of CIE-LAB values by using RGB values from the CVS. Results indicated that *L* values were considerably influenced by the illumination system, whereas both A and B values could be accurately predicted. In addition, a yellowness index calculated from XYZ values from image processing was found to be most suitable for the color estimation of the examined mango cultivars. This study showed that an economical USB camera could be successfully applied for color measurement of the two mango cultivars investigated. However, fine-tuning of the CVS system would undoubtedly help to achieve a higher accuracy of the color measurement. For example, broad-spectrum and more uniform illumination, optimal conveyor speed and optimization of camera settings would all be possible strategies for improvement. The developed CVS shows an encouraging potential for the application in automatic sorting and grading of fruits for the mango handling industry in countries where yellow mango cultivars are produced.

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