J. Hortic. Sci.
Vol. 21(1), 2026

https://doi.org/10.24154/jhs.v21i1.3310

Short Communication

Analysis of the associations between color coordinates and pigments in colored mango progenies

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ABSTRACT

The composition of pigments in mango peel and pulp is an important quality determinant due to their role in consumer attraction and nutrition of the fruit. An experiment was conducted to evaluate the coloring parameters of F_1 progenies of Alphonso×Vanraj cross combination. The study revealed that compared with the female parent Alphonso (17.11 mg/100 g), the male parent Vanraj showed significantly higher peel total anthocyanin content (29.74 mg/100 g). In contrast, the peel carotenoid content of Alphonso was twice as that of Vanraj. The total anthocyanin and carotenoid contents in the peel of the progenies ranged from 6.01-29.74 mg/100g FW and 5.04-45.08 mg/100 g FW, respectively. Peel had significantly higher carotenoids compared to the pulp. Correlation studies revealed the associations between color coordinates and pigments. h° (hue angle) was strongly positively correlated with chlorophyll and carotenoids of the peel and negatively correlated with peel anthocyanins. Thus, hue angle can be used as a non-destructive method to predict the pigments of mango peel. Principal component analysis revealed clusters within the progenies on the basis of the observed pigments and color coordinates. This study elucidates the associations between of color coordinates and pigments in the peel and pulp of mango highlighting the indirect selection of progeny.

Keywords: Anthocyanin, carotenoid, color coordinates, correlation, principal component analysis

INTRODUCTION

Among several quality indices, fruit color is the first and vital factor that contributes to market acceptance. The color of fruits is determined by pigments such as chlorophylls, carotenoids, anthocyanins, and betalains. Way back, the chlorophyll content in mango peel was found to be a reliable indicator of the stage of maturity of fruit. Recently, interest in the anthocyanins and carotenoid pigments of mango fruit has increased because of their health benefits (Ajila et al., 2007). The antioxidant properties of these compounds contribute to their therapeutic value in preventing neurological diseases, cardiovascular diseases, cancer, and diabetes in humans (Skates et al., 2018). Chlorophyll is another widely distributed photosynthetic pigment in mango fruit that masks the contributions of carotenoids and anthocyanins, resulting in the retention of the green color.

However, there is limited information on the pigment composition of mango peel and pulp, and reports on the associations between color coordinates and pigments in mango are contradictory. Hence, this research was conducted in the progenies of Alphonso×Vanraj cross combination to explore the relationship among the coloring parameters of various colored progenies.

The color parameters of 28 progenies of Alphonso and Vanraj were evaluated for two consecutive seasons during 2022-2023. Fruits were harvested from fruit block, ICAR- Indian Institute of Horticultural Research, Bengaluru, India, at full mature stage and ripened at room temperature. Both the peel and pulp samples were frozen in liquid nitrogen separately and stored at “80°C until further analysis. The color coordinates were analyzed in triplicates using a color reader, 3nh colourimeter (Model NR200) for both the peel and pulp. The results were expressed on the basis of the CIELAB color system (L*, a*, b*, c*, and h°). L* indicates brightness [0 (black) to 100 (white)], a* represents green (negative) to redness (positive), b* stands for blue (negative) to yellowness (positive), c* indicates chroma value (0 at the center and

Table 1 : Color coordinates of progenies of Alphonso×Vanraj cross combination

Parent/Progeny	L*	a*	b*	c*	h°	L*	a*	b*	c*	h°
			Peel					Pulp		
Alphanso	50.58	17.9	45.41	48.38	66.15	53.72	12	47.02	47.85	76.78
Vanraj	38.84	26.33	19.47	32.99	37.34	51.57	8.43	42.33	40.47	79.45
R1P3	60.58	6.74	49.1	49.73	86.5	53.37	9.4	31.6	32.43	73.93
R1P5	54.5	18.65	35.38	26.34	69.15	50.91	12.81	44.7	47.45	73.94
R1P7	40.76	7.53	16.6	18.44	66.43	51.53	7.77	37.92	38.63	78.38
R1P9	60.38	5.56	45.38	49.62	89.19	51.23	8.22	40.82	44.13	79.37
R1P10	48.82	12.75	41.9	45.15	71.83	51.26	5.41	42.92	42.79	81.73
R1P11	56.87	15.94	36.74	42.99	67.38	54.12	11.23	44.87	43.9	75.97
R1P12	46.41	16.39	24.8	36.53	54.43	52.53	10.57	46.77	39.9	72.13
R1P13	48.24	23.04	31.12	37.14	52.57	51.57	11.22	42.15	44.48	75.15
R1P14	57.34	4.51	47.88	46.54	85.03	52.7	9.5	40.27	41.33	77.73
R1P18	44.15	12.5	30.53	42.27	61.73	51.3	11.5	40.6	42.57	72.97
R1P19	58.67	11.36	34.27	44.22	74.48	54.93	10.7	33.33	34.6	72.27
R1P21	56.4	8.49	44.59	45.41	86.33	50.9	11.63	39.47	41.4	74.13
R1P22	44.73	30.77	43.35	50.66	51.68	51.9	12.08	42.67	44.5	75.97
R1P23	38.49	10.53	29.9	47.1	59.2	52.5	11.57	38.63	32.47	71.4
R1P24	40.63	-0.59	26.17	39.75	106.37	51.17	11.53	38.03	39.1	73.13
R1P25	49.27	-10.26	35.33	38.37	102.77	49.8	6.93	44.43	44.6	81.33
R1P26	51.67	-4.48	28.82	34.57	106.43	53	12.67	39.1	35.5	70.5
R1P29	48.18	14.36	34.18	40.3	59.05	50.32	12.03	42.25	42.68	75.97
R1P30	48.27	20.33	34.76	39.27	64.53	49.53	12.5	42.47	30.1	74.5
R1P31	46.62	24.38	39.4	42.07	53.27	51.43	11.5	47.37	48.4	77.07
R1P33	52.4	23.87	34.84	42.11	56.5	54.18	8.1	44.42	44.68	81.2
R1P35	64.22	6.55	53.65	52.64	83.47	49.88	8.8	44.68	44.58	79.3
R2P5	49.43	10.55	35.8	37.5	54.43	50.43	9.5	42.8	43.13	75.2
R2P11	38.33	15.42	36.83	42.67	61.43	49.53	10.7	42.27	41.37	71.27
R2P12	46.53	13.52	34.3	34.6	59.4	56.7	11.5	35.3	35.33	74.3
R2P14	50.18	14.23	40.34	47.27	54.43	50.8	14.43	42.57	41.6	70.43
R2P15	64.43	6.52	51	65.57	92.57	51.1	8.6	40.47	35.67	69.53
R2P16	69.37	7.37	53.71	58.87	94.5	50.1	8.43	41.6	39.5	70.4
SE(m)	1.45	0.79	1.54	1.77	1.51	NS	0.7	1.49	1.65	1.69
CV (%)	4.93	11.09	7.18	7.19	3.69	NS	11.72	6.24	6.99	3.91

increases according to the distance from the center) and h° gives hue angle expressed in degrees 0° (red), 90° (yellow), 180° (green), and 270° (blue).

Total anthocyanin content in peel was estimated as per Shivashankara et al. (2010) and the chlorophyll content of the peels was analyzed following Hiscox & Israelstam (1979). The total carotenoid and lycopene contents were extracted as per Lichtenthaler (1987) using phase separation method. Data were expressed as mean and standard deviation of three replications followed by ANOVA. Pearson's correlation analyses and principal component analysis (PCA), were performed using SPSS software. Relationship between hue angle and pigments was worked out by using regression.

Color coordinates of the peel and pulp

Data presented in Table 1 showed that peel and pulp color coordinates of the Alphonso×Vanraj progenies. Yellow peeled progenies expressed higher L* values compared to others. Lightness depicts the luminosity which reflects the yellow color of the peel. The green progenies showed least and negative a* values followed by yellow progenies and significantly highest values were observed in the red progenies. b* values were higher in yellow-colored progenies and is attributed to the carotenoid content. The L*, a* and b* values of the Alphonso peel are 50.58, 17.90 and 45.41, respectively and for Vanraj were 38.84, 26.33 and 19.47, respectively. A lower L* and b* coupled with higher a* indicates the darker reddish peel of

Table 2 : Concentration of pigments in the progenies of Alphonso Vanraj cross combination

Parent/Progeny	TSS	Total anthocyanin (mg/100 g FW)	Total chlorophyll (mg/g FW)	Total carotenoids (mg/100 g FW)		Total lycopene (mg/100 g FW)	
	Pulp	Peel	Peel	Peel	Pulp	Peel	Pulp
Alphanso	18.18	17.11	0.06	32.44	12.06	8.84	0.3
Vanraj	16.95	29.74	0.04	15.56	8.4	5.27	0.46
R1P3	18.5	8.48	0.11	37.85	12.42	13.63	0.29
R1P5	16.58	19.73	0.04	10.26	3.65	5.3	0.24
R1P7	14.47	21.06	0.04	12.36	3.65	7.36	0.17
R1P9	17.95	11.9	0.14	36.48	2.92	11.42	0.24
R1P10	13.97	19.01	0.05	14.56	2.8	6.86	0.15
R1P11	16.45	23.04	0.05	12.69	3.29	6.89	0.14
R1P12	18.43	18.6	0.04	13.26	17.53	8.08	0.31
R1P13	17.8	22.66	0.03	16.15	27.4	6.94	0.52
R1P14	18.9	17.41	0.14	41.79	22.65	13.44	0.58
R1P18	16.1	23.46	0.08	12.69	10.23	5.99	0.27
R1P19	17.8	18.68	0.05	10.25	6.58	6.56	0.17
R1P21	17.1	17.22	0.13	32.48	21.19	13.97	0.46
R1P22	19.42	16.68	0.03	13.69	6.21	6.86	0.3
R1P23	19.1	18.52	0.05	17.48	15.34	6.46	0.3
R1P24	16.7	6.42	0.2	8.49	4.38	2.23	0.21
R1P25	16.1	6.53	0.2	5.26	5.85	3.37	0.21
R1P26	17.17	6.01	0.21	4.48	5.11	2.61	0.12
R1P29	17.97	25.04	0.04	13.69	5.85	6.41	0.29
R1P30	18.1	25.6	0.05	17.25	10.23	5.23	0.31
R1P31	17.3	18.02	0.05	15.24	8.04	5.8	0.29
R1P33	18.12	14.13	0.04	12.49	8.04	10.66	0.29
R1P35	15.97	16.73	0.14	39.45	9.13	11.33	0.33
R2P5	16.8	18.93	0.04	11.69	13.15	7.55	0.29
R2P11	11.6	23.7	0.05	13.26	18.27	6.84	0.4
R2P12	18.1	20.74	0.05	10.49	10.23	5.75	0.29
R2P14	14	23.7	0.05	14.28	13.15	5.8	0.33
R2P15	16.47	15.88	0.14	30.26	9.5	11.69	0.12
R2P16	23.03	13.41	0.14	35.21	10.23	13.06	0.26
SE(m)	0.27	1.09	0.01	1.59	0.65	1.18	0.02
CV (%)	2.76	10.6	20.69	15.46	11.03	26.51	12.72

Vanraj than the red blush of Alphonso. Fukuda et al. (2014) reported that red peeled Irwin had a lower L* and higher a* than yellow peeled Nam Doc Mai. The c* was significantly greater in yellow progenies which indicated the purity of their yellow color. Alphonso and Vanraj showed 66.15 and 37.34 of hº, respectively indicating mixture of yellow and red in Alphonso and dominant red color in Vanraj. The h° values of the progenies ranged from 51.68-106.43 indicating their wide variation of color. Similar results were also obtained by Nambi et al. (2015) and Wongkaew et al. (2021).

The L* values for the pulp did not significantly differ among the parents and progenies (Table 1). The a* and b* values of the progenies varied from 5.41-14.43 and 31.60-46.77, respectively. The observed positive a* and b* values are attributed to the presence of carotenoids in the pulp. Hue angle in the observed range (69.53-81.73) indicates the strong yellow to mild orange color of the pulp. Positive values for color coordinates in pulp of mangohave been reported (Nambi et al., 2015; Muralidhara et al., 2019).

Pigment composition of parents and progenies

On the perusal of the data presented in Table 2 encompasses the concentration of pigments in Alphonso×Vanraj progenies. The green peeled progenies recorded the highest chlorophyll content followed by yellow and the red peeled progenies showed least chlorophyll content. Significantly highest total anthocyanin content was reported in Vanraj

Table 3 : Correlation coefficient of color coordinates and pigments in peel

Colorimeter scales peel	Anthocyanin peel	Chlorophyll peel	Carotenoid peel	Carotenoid pulp
L*	-0.321*	0.379**	0.644**	-0.095
a*	0.637**	-0.794**	-0.125	0.232
b*	-0.27	0.276	0.748**	0.083
c*	-0.226	0.276	0.628**	0.004
h°	-0.762**	0.885**	0.292	-0.059

* represents the significance of r values *$p \leq 0.05$, **$p \leq 0.01$

(29.74 mg/100 g) followed by R1P30 (25.60 mg/100 g). Anthocyanin content has been reported in many mango varieties such as in Kent (22.33 mg/100 g) (Mugwagwa & Chimphango 2019), Badami (565 mg/100 g) and Raspuri (360 mg/100 g) (Ajila et al., 2007).

The total peel carotenoid content of yellow peeled progenies was significantly high followed by red and green peeled progenies. This implies that the yellow color of the peel is predominantly attributed to its carotenoid content. The total carotenoid content in the peels ranged from 4.48 to 41.79 mg/100 g and that of pulp ranged from 2.80 to 27.40 mg/100 g. Interestingly, the parents and progenies recorded more carotenoid content in the peel than in the pulp. Muralidhara et al. (2019) also reported higher carotenoids in the peel compared to the pulp. The total lycopene content in the peel ranged from 2.23 to 13.97 mg/100 g and in pulp (0.12 to 0.58 mg/100 g).

Correlation coefficient

Significant correlations were observed with color coordinates and pigments in the peel. There is a positive correlation between total anthocyanins and a*, while, L* and h* are negatively correlated and the same is vice versa for total chlorophylls (Table 3). The a* depicts color in terms of positive values for red and yellow and negative values for green. Hence a* might be positively correlated with anthocyanin and inversely correlated to chlorophyll. Kasim et al. (2011) suggested that anthocyanins were negatively correlated with color parameters (a* b*, c*, and hº) in cherry laurel (*Prunus laurocerasus* L.). The carotenoid content of the peel is positively correlated with L*, b* and c* (Table 3). Karanjalker et al. (2020) also reported similar results.

Precisely hue angle (h°) of peel showed positive correlation with the total peel chlorophyll (r=0.885), while, it is negatively correlated with total anthocyanins (r=-0.762). Based on these results, we developed regression models (Fig. 1a) which showed the linear relationship between hue angle and total anthocyanins of peel (R^2=0.641). Total chlorophyll content was related by an exponential function (R^2=0.831) and total carotenoid contents by a polynomial function (R^2=0.810) to hue angle of peel (Fig. 1b and c). This led to medium to good predictions of pigments based on hue angle of peel. Thus, hue angle serves as an indirect measure to predict the pigments of mango peel. Various nondestructive methods for mango peel color evaluation were suggested (Yahaya et al., 2014; O'Brien et al., 2024). Further, no significant correlation was observed between the total pulp carotenoid content and the color coordinates of either the peel or the pulp (Table 3 & 4). This finding is contrary to Muralidhara et al. (2019) as they observed a positive relationship for total pulp carotenoids and L*, a*, b* of peel and stated that peel color was the best indicator for estimating total carotenoids content compared to the pulp color.

Table 4 : Correlation coefficient of color coordinates and pigments in pulp

Colorimeter scales pulp	Carotenoid pulp
L*	-0.016
a *	0.182
b *	0.002
c *	-0.063
h °	-0.224

Principal component analysis (PCA)

The first four components cumulatively accounted for 74.95% of the variability, with PC1 and PC2 contributing 32.72% and 18.83%, respectively. The biplot focusing on PC1 and PC2 depicted the associations of genotypes with the observed color parameters (Fig. 2). PC1 contributed 32.72% of the

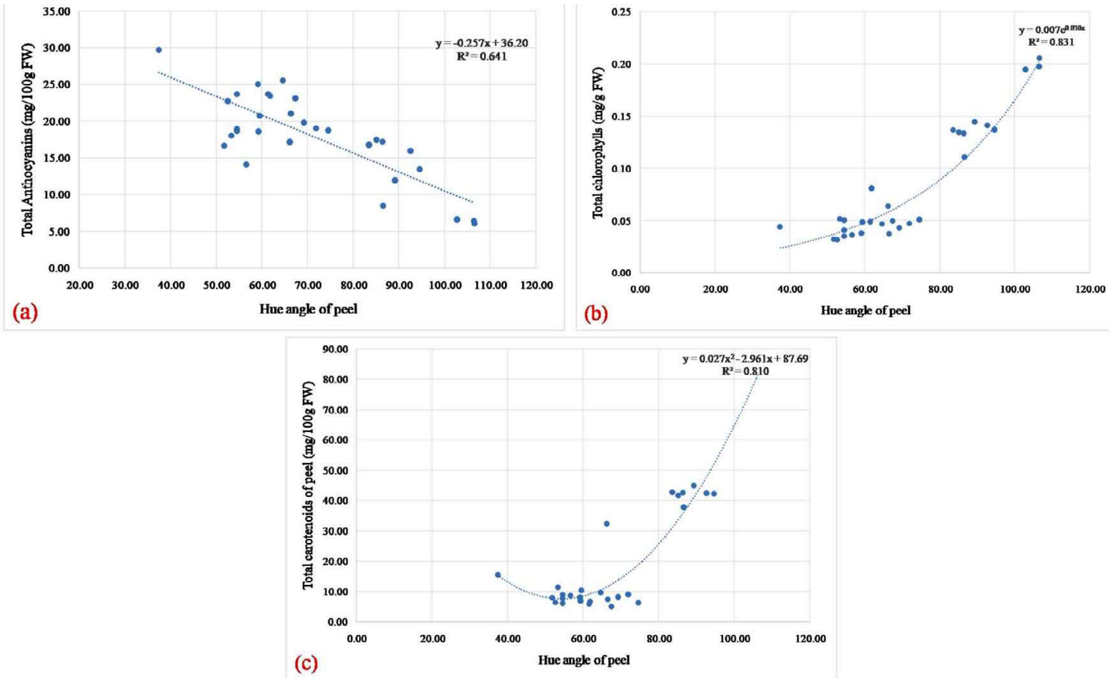

Fig. 1 : Relationship of hue angle of peel with (a) total anthocyanins (b) total chlorophylls (c) total carotenoids of peel of mango progenies

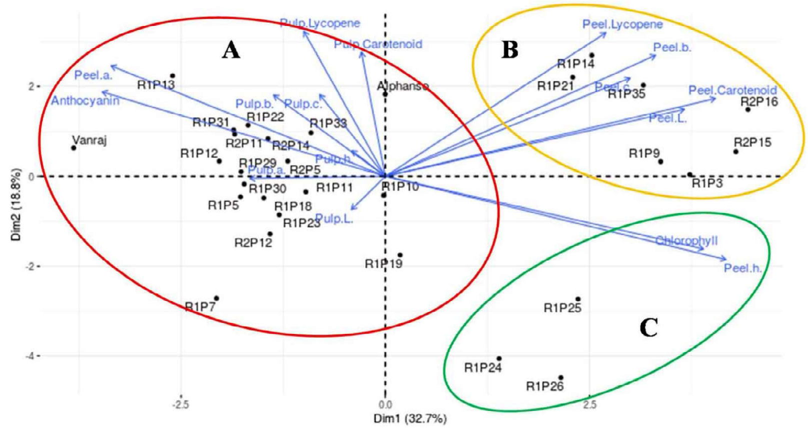

Fig. 2 : Biplot of principal component analysis

total variability with a positive influence on the carotenoids, lycopenes and chlorophylls of the peel, L*, b*, c* and hº of the peel. It was inversely related to the carotenoids and lycopene of the pulp, peel anthocyanin, L*, a*, b*, c*, hº of the pulp and peel a*. PCA categorizes the progenies into 3 separate classes on the basis of observed color parameters. Class A comprises all the red peeled progenies and their parents as well. Class B is formed by all yellow peeled progenies and Class C encompasses the green progenies. Similar work was reported by Liu et al. (2013) and Rastegar & Rahimzadeh (2023) who performed PCA based on physico-chemical and antioxidant properties of various mango cultivars.

CONCLUSION

The present study delineated the complex roles of chlorophylls, carotenoids, and anthocyanins in influencing the coloring mechanism of both the peel and pulp of mango progenies. Compared with the pulp, the mango peel contained more carotenoids. The study clarifies the relationship between color coordinates and pigment composition. Hue angle can be used as a non-destructive method to predict the pigments in mango peel. Further, the PCA clustering emphasized the complex coloring mechanisms and allowed the progenies to be differentiated based on all the color coordinates and pigments determined in the study.

ACKNOWLEDGEMENT

The authors express their gratitude to the Division of Fruits Crops, ICAR- Indian Institute of Horticultural Research, Bengaluru, India, for providing facility, and Post Graduate School, Indian Agricultural Research Institute, New Delhi for providing the fellowship during the research period.

REFERENCES

Ajila, C. M., Naidu, K. A., Bhat, S. G., & Rao, U. J. S. P. (2007). Bioactive compounds and antioxidant potential of mango peel extract. *Food Chemistry*, *105*(3), 982–988. https://doi.org/10.1016/j.foodchem.2007.04.052

Fukuda, S., Yasunaga, E., Nagle, M., Yuge, K., Sardsud, V., Spreer, W., & Müller, J. (2014). Modelling the relationship between peel colour and the quality of fresh mango fruit using Random Forests. *Journal of Food Engineering*, *131*, 7–14. doi.org

Hiscox, J. D., & Israelstam, G. F. (1979). A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany*, *57*(12), 1332–1334. doi.org

Karanjalker, G. R., Dinesh, M. R., Shivashankara, K. S., & Ravishankar, K. V. (2020). Morphological and biochemical characterization of peel of different coloured mango cultivars. *International Journal of Chemical Studies*, *8*(3), 106–116. https://doi.org/10.22271/chemi.2020.v8.i3b.9211

Kasim, R., Sulusoglu, M., & Kasim, M. U. (2011). Relationship between total anthocyanin level and colour of natural cherry laurel (*Prunus laurocerasus* L.) fruits. *African Journal of Plant Science*, *5*(5), 323–328.

Lichtenthaler, H. K. (1987). Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. *Methods in Enzymology*, *148*, 350–383. doi.org

Liu, F. X., Fu, S. F., Bi, X. F., Chen, F., Liao, X. J., Hu, X. S., & Wu, J. H. (2013). Physico-chemical and antioxidant properties of four mango (*Mangifera indica* L.) cultivars in China. *Food Chemistry*, *138*(1), 396–405. doi.org

Mugwagwa, L. R., & Chimphango, A. F. A. (2019). Box-Behnken design based multi-objective optimisation of sequential extraction of pectin and anthocyanins from mango peels. *Carbohydrate Polymers*, *219*, 29–38. https://doi.org/10.1016/j.carbpol.2019.05.015

Muralidhara, B. M., Veena, G. L., Bhattacherjee, A. K., & Rajan, S. (2019). Antioxidants in ripe peel and pulp of twelve mango (*Mangifera indica*) cultivars. *The Indian Journal of Agricultural Sciences*, *89*(10), 1580–1584. doi.org

Nambi, V. E., Thangavel, K., & Manohar, D. J. (2015). Scientific classification of ripening period and development of colour grade chart for Indian mangoes (*Mangifera indica* L.) using multivariate cluster analysis. *Scientia Horticulturae*, *193*, 90–98. doi.org

O'Brien, C., Falagan, N., Kourmpetli, S., Landahl, S., Terry, L. A., & Alamar, M. C. (2024). Non-destructive methods for mango ripening prediction: Visible and near-infrared spectroscopy (visNIRS) and laser Doppler vibrometry (LDV). *Postharvest Biology and Technology*, *212*, Article 112878. https://doi.org/10.1016/j.postharvbio.2024.112878

Rastegar, S., & Rahimzadeh, M. (2023). Impact of maturity and genotype on the physicochemical properties of mango (*Mangifera indica* L.) fruit. *Erwerbs-Obstbau*, *65*(6), 1647–1655. https://doi.org/10.1007/s10341-023-00920-w

Shivashankara, K. S., Jalikop, S. H., & Roy, T. K. (2010). Species variability for fruit antioxidant and radical scavenging abilities in mulberry. *International Journal of Fruit Science*, *10*(4), 355–366. https://doi.org/10.1080/15538362.2010.530097

Skates, E., Overall, J., DeZego, K., Wilson, M., Esposito, D., Lila, M. A., & Komarnytsky, S. (2018). Berries containing anthocyanins with enhanced methylation profiles are more effective at ameliorating high fat diet-induced metabolic damage. *Food and Chemical Toxicology*, *111*, 445–453. https://doi.org/10.1016/j.fct.2017.11.032

Wongkaew, M., Kittiwachana, S., Phuangsaijai, N., Tinpovong, B., Tiyayon, C., Pusadee, T., Chuttong, B., Sringarm, K., Bhat, F. M., Sommano, S. R., & Cheewangkoon, R. (2021). Fruit characteristics, peel nutritional compositions, and their relationships with mango peel pectin quality. *Plants*, *10*(6), Article 1148. https://doi.org/10.3390/plants10061148

Yahaya, O. K. M., MatJafri, M. Z., Aziz, A. A., & Omar, A. F. (2014). Non-destructive quality evaluation of fruit by color based on RGB LEDs system. In *2nd International Conference on Electronic Design (ICED)* (pp. 230–233). IEEE.

(Received : 2.8.2024; Revised : 5.2.2026; Accepted : 10.2.2026)