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Comparison of Fruit Color and Quality Changes During Fruit Development in 'Kinnow' and 'W. Murcott' Mandarins

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Abstract
This study assessed variation in fruit color coordinates and internal quality attributes during fruit development in 'Kinnow' and 'W. Murcott' mandarins. With progression of fruit development, green colored fruit, with high titratable acidity (TA) (2.92 ± 0.51%), ascorbic acid (42.11 ± 3.33 mg ml^{-100}), low maturity index values (2.50 ± 0.31) and juice content (25.07 ± 1.75%), developed into yellowish-orange colored fruits, with low TA (0.82 ± 0.2%) and ascorbic acid content (28.72 ± 1.48 mg/100 ml) as well as a concomitant improvement in maturity index (14.76 ± 0.85) and juice yield percentage (47.46 ± 3.90%), at full maturity stages. β-carotene content also significantly increased ($p < 0.05$) with the advancement of fruit maturity and varied from 0.89 ± 0.35 to 26.28 ± 4.6 µg g^{-1} FW. Regardless of maturity stages, β-carotene was found to be higher in the peel of fruits than in the pulp and also showed a significant correlation with color coordinate values. At the full maturity stage, 'Kinnow' exhibited maximum color development, β-carotene content, total soluble solids (TSS), maturity index value and juice yield percentage compared to 'W. Murcott'. The maturity index showed a maximum association with peel C* for 'W. Murcott' peel and for pulp b* in 'Kinnow' mandarin.

Keywords Fruit development · Citrus · Color coordinates · Physical quality parameters · Biochemical quality parameters

Introduction

Citrus fruits are consumed fresh or as fruit juice and have health-related benefits due to their primary and secondary metabolites (Lado et al. 2016; Liu et al. 2012; Sidana et al. 2013). In India, citrus are cultivated over an area of 1050 thousand hectares with a total production of 12.74 MT (National Horticulture Board 2017). Citrus acreage in the Punjab province is 60980 ha, with 'Kinnow' mandarin contributing an area of 55470 ha and annual citrus production of 1.31 MT (Anonymous 2020a). The dominance of mandarins over the sweet orange varieties is due to their high yield potential and greater juice content. The flavor of mandarin fruit is actually the blend of basic taste, aroma and taste-bud sensations that are anticipated synchronously by the brain during eating (Goff and Klee 2006; Zou et al. 2016). Since non-climacteric in nature, citrus fruit ripens on the tree and its maturity assessment relies on the visual examination conducted at field level. In European Union markets, the maturity indices used to determine fruit quality comprise juice percentage, total soluble solids (TSS), acidity level and their ratios (TSS/acidity), with fruit surfaces having minimum coloration (Lado et al. 2014). However, in domestic markets, consumption of fresh citrus fruits primarily depends on the preferences of consumers, who decide their acceptability primarily based on fruit peel coloration. It is worth mentioning that the color of citrus fruits shows deviation with respect to climate, diurnal and seasonal temperature as well as growing conditions (Cronje et al. 2013; Porras et al. 2014; Nawaz et al. 2019b). The color break in Clementine mandarins is related to onset of lower soil temperature in late summer or early fall (Mesejo et al. 2012). In tropical zones, the maturity index in citrus fruits does not rely on peel coloration since this invariably fails to exhibit a change in colour (Stewart and Wheaton 1973). In these areas, other factors like fruit size and shape can be considered as maturity indices for commercial harvest in citrus fruit (Nawaz et al. 2018, 2019a). There are wide variations in mandarin fruits with regard to internal quality attributes such as juice yield, TSS, titratable acidity (TA) and

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their ratio since maturity indices and color do not in isolation designate the internal quality of harvested fruits (Tadeo et al. 2008). Furthermore, evidence demonstrated that peel and pulp maturation are not fully coordinated. Deciding the norms regarding the precise and consistent determination of citrus fruit maturity is not an effortless task since it includes physiological alterations occurring in two distinct and non-dependent tissues: color variations taking place in the fruit peel and compositional alterations appearing in the flesh (Tadeo et al. 2008). Thus, internal fruit attributes such as TSS, TA and solid/acid ratio as well as antioxidants (ascorbic acid) are also obscure quality parameters that require standard laboratory procedures and approaches for meticulous estimation. Hence, to ascertain the harvest quality of fruit for the commercial and nutritional needs of the market, it is imperative to investigate the dynamics of fruit colour coordinates and quality components during fruit development in 'Kinnow' and 'W. Murcott' mandarins. Therefore, the objectives of this research were: 1) to determine fruit color and quality changes in two mandarin cultivars during development and 2) to elucidate the relationship between fruit coloration and maturity index at different developmental stages in these mandarins.

Materials and Methods

Fruit Materials

Fruits of 'Kinnow' (*Citrus nobilis* Lour × *Citrus deliciosa* Tenora) and 'W. Murcott' mandarins (also called 'Afourer', which is an open pollinated seed of 'Murcott' [*C. reticulata* × *C. sinensis*] Kahn and Chao 2004) were harvested during the 2019–20 period from an orchard of the Punjab Agricultural University (PAU), Fruit Research Station, Jallowal-Lesriwal, Jalandhar (latitude, 31° 19′ 33.6540″ N and longitude, 75° 34′ 34.2480″ E, located at an altitude of 228 m). The experimental plants were 5 years old, budded on 'Carrizo' citrange rootstock (*Citrus sinensis* Osb. X *Poncirus trifoliate* L. Raf.) and spaced at 6 m × 3 m. The soil type of the plot was sandy loam and plants were treated with a uniform dose of fertilizers according to guidelines laid down by the Punjab Agricultural University, Ludhiana, India. Fruit sampling was carried out during the morning hours at monthly intervals from August to January until optimum maturity (TSS: 12.10 ± 0.77 °Brix for 'Kinnow'; 10.70 ± 0.70 °Brix for 'W. Murcott') (Mahajan et al. 2018; Anonymous 2020b). Healthy fruits from the selected cultivars were randomly picked at each interval with the help of fruit clippers and immediately transported to the laboratory of the Department of Fruit Science, PAU, Ludhiana. At each sampling stage, 20 fruits per replication were used for analysis. Fruits were cleaned with distilled water and wiped dry at room temperature, following which the peel and pulp (consisting of juice sacs and segment epidermis) portions were separated manually. Fruit juice was extracted using a kitchen citrus juicer and was filtered through a stainless steel sieve with 1.0-mm mesh for further analysis.

Evaluations

Physical Evaluation

Fruit Weight Average fruit weight was measured with an electronic balance with 0.01-g accuracy.

Peel Thickness Peel thickness was measured with a digital Vernier caliper (Mitutoyo, Japan) on both sides of the fruit, and mean data were expressed in millimeter (mm).

Juice Content The juice content was expressed in percentage (%) and was calculated with the following equation:

$$\text{Juice content}(\%) = \frac{\text{weight of fruit juice (g)}}{\text{total fruit weight (g)}} \times 100$$

The weight of fruit juice and an individual fruit was taken with electronic balance.

Fruit Color Evaluation Peel, pulp and juice color of fruits were measured using the Color Flex meter (Hunter lab Color Flex, Hunter Associates Inc., Reston, VA, USA) with the method described by Hunter (1975). The instrument was calibrated with standard white and black ceramic tiles before use. Fruit peel and pulp color along the equatorial axis of each fruit at two opposite spots were recorded in CIE coordinates (L^*, a^*, b^*). Similarly, an aliquot of fresh juice was taken in the colorless glass petri dish for color measurement. The color coordinate L^* measures the luminosity between black (0) and white (100), a^* varies from a negative value (green) to a positive value (red) and b^* varies from negative value (blue) to positive value (yellow). Chroma (C^*), which determines the length of the color vector in the plane generated by a^* and b^*, and hue angle ($h°$), which represents the position of such vectors, were calculated by $(a^{*2} + b^{*2})^{1/2}$ and $\tan^{-1}(b^*/a^*)$, respectively, as given by McGuire (1992).

Chemical Evaluation

Total Soluble Solids (TSS) For the determination of TSS, one drop of fruit juice was placed on a digital hand refractometer (ATAGO, PAL-1, Japan) with a range of 0–53 °Brix. During measurement, the temperature of the sample was also noted and a correlation was applied. The final value was expressed in °Brix.

Titratable Acidity (TA) TA was estimated by titrating 2 ml fresh juice against 0.1 N NaOH solution up to pH 8.1 and phenolphthalein as an indicator (AOAC 2000). The obtained results were expressed as a percentage (%) in terms of citric acid, since this is a dominant organic acid in citrus. Juice acidity: $(\%) = 0.0064 \times \frac{\text{Volume of 0.1 N NaOH used}}{\text{volume of juice taken}} \times 100$.

Maturity Index The maturity index is an indicator of fruit sweetness and was calculated as the ratio of TSS/TA.

Ascorbic Acid Ascorbic acid was estimated using the visual titration method (AOAC 2000). A total of 2 ml fresh fruit juice was added to metaphosphoric acid, and titration was performed against 2, 6-dichlorophenol-indophenol dye until the appearance of a light pink color that persisted for 15 s. The final results were expressed in mg/100 ml ml of juice.

$$\text{Ascorbic acid}(\text{mg ml}^{-100}\text{ juice}) = \frac{\text{Dye factor} \times \text{Vol. of dye} \times \text{Vol. made} \times 100}{\text{Weight of sample} \times \text{Vol.of aliquot}}$$

Total Sugars

Extraction Total sugars were estimated in a known volume of juice of fresh fruits by using the method suggested by Lane and Eynon (AOAC 1990). Lead acetate and potassium oxalate were added to 10 ml fresh juice to precipitate the extra material in juice and to remove excess lead acetate. The filtered solution was then made up to 100 ml by adding distilled water. This aliquot was further used for total sugar estimation according to the method described by Dubois et al. (1956).

Estimation Diluted sugar extract with a volume of 30 µl was taken (lying within the dimensions of pure sugar standards) and admixed with 1 ml of phenol reagent (5%), followed by the addition of 5 ml concentrated H_2SO_4. The test tubes were then subjected to vortexing, and these test tubes were later kept for 10 min at room temperature and another 20 min under moving tap water for cooling. The orange color was developed and its optical density was estimated at 490 nm with distilled water as blank. The final result of total sugars was calculated from the glucose standards (10–100 µg) run simultaneously and was expressed in percentages (%).

Carotenoid Extraction Carotenoids were determined in the form of β-carotene from the peel and pulp of selected cultivars with the method described by Ranganna (1977). A homogenous representative sample (5 g) of fruit peel and pulp was kept to dry for 3 h in a hot air oven at 40–45 °C; afterwards, this was crushed with 5 g of Na_2SO_4 using a pestle and mortar, and a petroleum ether and acetone mixture (97:3) was taken for softening the cell wall. All operations were carried out in the presence of dimmed light to prevent isomerization and photodegradation of carotenoids. This extraction was filtered through filter paper, and color intensity was read at 452 nm in Spectronic 20D+ (Thermo Fischer Scientific, Madison, WI, USA). Petroleum ether was used as a blank, and β-carotene content in fruit peel and pulp was calculated as µg g^{-1} FW.

Statistical Analysis

All physical and chemical evaluations were recorded in quadruplicate and presented as means ± standard deviations. The statistical difference between time intervals was identified from one-way analysis of variance (ANOVA) using the least significance difference ($p < 0.05$). The correlation coefficients between fruit color coordinates and maturity index were obtained through Pearson’s correlation coefficients ($p \leq 0.01$) using SAS 9.3 (the SAS system for Windows, Version 9.3, SAS Institute, Cary, NC, USA).

Table 1 Fruit weight, peel thickness, juice content and ascorbic acid of ‘Kinnow’ and ‘W. Murcott’ fruits during fruit development

Month	Fruit weight (g)		Peel thickness (mm)		Juice content (%)		Ascorbic acid (mg/100 ml)	
	‘Kinnow’	‘W. Murcott’	‘Kinnow’	‘W. Murcott’	‘Kinnow’	‘W. Murcott’	‘Kinnow’	‘W. Murcott’
Aug	31.97 ± 6.45^{d}	29.57 ± 6.31^{d}	4.60 ± 0.22^{a}	3.78 ± 0.38^{a}	25.16 ± 2.52^{d}	25.07 ± 1.75^{c}	39.28 ± 1.44^{a}	39.61 ± 2.59^{ab}
Sept	108.13 ± 19.26^{c}	95.93 ± 14.67^{c}	4.03 ± 0.26^{b}	3.56 ± 0.4^{ab}	36.94 ± 6.28^{c}	34.84 ± 4.73^{b}	40.71 ± 2.35^{a}	42.11 ± 3.33^{a}
Oct	132.97 ± 10.94^{b}	117.20 ± 24.5^{bc}	3.93 ± 0.17^{b}	3.27 ± 0.22^{bc}	42.13 ± 2.76^{bc}	40.41 ± 5.56^{ab}	38.19 ± 1.65^{ab}	37.86 ± 2.16^{bc}
Nov	154.60 ± 17.62^{ab}	127.53 ± 11.75^{ab}	3.58 ± 0.24^{c}	3.12 ± 0.22^{cd}	45.93 ± 1.44^{ab}	44.89 ± 2.63^{a}	36.03 ± 1.65^{b}	35.43 ± 2.52^{cd}
Dec	163.63 ± 20.48^{a}	135.70 ± 22.21^{ab}	2.92 ± 0.15^{d}	2.96 ± 0.1^{cd}	47.13 ± 2.42^{ab}	45.08 ± 2.92^{a}	32.41 ± 2.12^{c}	31.69 ± 3.36^{de}
Jan	167.70 ± 8.86^{a}	142.33 ± 12.72^{a}	2.64 ± 0.14^{d}	2.77 ± 0.18^{d}	47.46 ± 3.90^{a}	45.46 ± 5.31^{a}	28.72 ± 1.48^{d}	29.45 ± 1.6^{e}

[a] Data are expressed as means ± standard deviation ($n = 4$)
[b] Different superscripts between rows represent significant differences between fruit developmental stages ($p < 0.05$)

Results and Discussion

Fruit Physical Quality (Fruit Weight, Peel Thickness and Juice Content)

Fruit weight during the fruit development period varied from 29.57 ± 6.31 g in 'W. Murcott' to 167.70 ± 8.86 g in 'Kinnow' (Table 1). The maximum increment in fruit weight was noted from August to September and continued to significantly increase ($p < 0.05$) up to October; thereafter, fruit growth was non-significant in both cultivars. The increment in fruit weight could be attributed to an increase in cell size and an accumulation of food substances in the intercellular spaces in fruits (Bollard 1970). A similar analysis in 'Nagpur' mandarins was also described by Bhatnagar et al. (2012), who showed that fruit weight varied from 65 to 140 g between July and November. Ladaniya and Mahalle (2011), during their investigations on the sweet orange cultivar 'Mosambi', recorded a linear increase in fruit weight from 180 to 250 days after fruit set.

Peel thickness in two commercial cultivars altered from 4.60 ± 0.22 to 2.64 ± 0.14 mm. Thicker fruit peel was observed in immature green colored fruits, which declined during fruit development, with the minimum value being recorded in the fully matured fruits (Table 1). Between the two cultivars, greater peel thickness was observed in 'Kinnow' during August (green color fruit stage; 4.60 ± 0.22 mm) compared to the 'W. Murcott' cultivar (3.78 ± 0.38 mm), which may be due to cultivar differences as reported by Muramatsu et al. (1999) in citrus fruits.

Juice percent was also considered as another parameter in determining the maturity index of citrus fruits (Deka et al. 2006). This varied from 25.07 ± 1.75 to 47.46 ± 3.90% during the fruit development period (Table 1), which is in line with the findings of Altaf et al. (2008) in mandarin fruits. Juice content increased from August to November with significant variations ($p < 0.05$), showing no changes thereafter. Comparing the two cultivars, 'Kinnow' exhibited higher physical fruit quality in terms of fruit weight, juice content and fruit peel thickness compared to 'W. Murcott' during the different developmental stages.

Fruit Internal Quality (TSS, TA, Total Sugars, Ascorbic Acid and Maturity Index)

Various internal quality parameters of fruits including TSS, total sugars and TA content were significantly influenced during fruit developmental stages in both mandarin cultivars (Table 2). TSS content increased linearly from August (7.29 ± 0.38 °Brix for 'W. Murcott'; 7.54 ± 0.84 °Brix for 'Kinnow') to January (10.70 ± 0.76 °Brix for 'W. Murcott'; 12.10 ± 0.77 °Brix for 'Kinnow'), with significant variations ($p < 0.05$). Similarly, total sugar content was lowest during August (1.96 ± 0.08% for 'W. Murcott'; 2.31 ± 0.2% for 'Kinnow') and then exhibited an increasing trend with considerable changes ($p < 0.05$) until full maturity (6.47 ± 0.54% for 'W. Murcott'; 7.32 ± 0.43% for 'Kinnow'). The results of the present study regarding TSS and sugars are in agreement with earlier investigations by Hardy and Sanderson (2010) in citrus fruits.

The highest TA was recorded in immature fruits in the August sampling (2.61 ± 0.39% for 'Kinnow'; 2.92 ± 0.51% for 'W. Murcott'), then exhibited a declining trend with noticeable variations ($p < 0.05$) and was observed to be lowest at the full maturity stage (0.82 ± 0.2% for 'Kinnow'; 0.91 ± 0.23% for 'W. Murcott'). A similar trend for TA in mandarin fruits during maturity at different locations was reported by Roakaya et al. (2016). During fruit development, acids are rapidly consumed in citrus fruits as part of respiration processes, as reported by Giovannoni (2001). Higher ascorbic acid accumulation was observed in green colored fruits during the August–September period (39.28 ± 1.44 to 42.11 ± 3.33 mg/100 ml), with slight statistical alterations between months as displayed in Table 1. During the color development phase, ascorbic acid was converted to 2-3-dioxy-L-gluconic acid by losing L-ascorbic acid (Mapson 1970). Giuffre (2019) also discovered

Table 2 Total soluble solids (TSS), titratable acidity (TA), maturity index and total sugars of 'Kinnow' and 'W. Murcott' fruits during fruit development

Month	TSS (°Brix)		TA (%)		Maturity index		Total sugars (%)	
	'Kinnow'	'W. Murcott'	'Kinnow'	'W. Murcott'	'Kinnow'	'W. Murcott'	'Kinnow'	'W. Murcott'
Aug	7.54 ± 0.84[c]	7.29 ± 0.38[d]	2.61 ± 0.39[a]	2.92 ± 0.51[a]	2.89 ± 0.53[e]	2.50 ± 0.31[d]	2.31 ± 0.2[e]	1.96 ± 0.08[e]
Sept	8.19 ± 0.78[c]	7.80 ± 0.8[cd]	2.07 ± 0.35[b]	2.61 ± 0.47[a]	3.96 ± 0.29[de]	2.99 ± 0.87[d]	3.66 ± 0.34[d]	2.87 ± 0.22[d]
Oct	8.59c ± 0.68[bc]	8.51 ± 0.42[bc]	1.79 ± 0.55[bc]	1.52 ± 0.17[b]	4.80 ± 1.03[cd]	5.60 ± 0.33[c]	4.35 ± 0.27[c]	4.07 ± 0.36[c]
Nov	9.45 ± 0.65[b]	8.72 ± 0.55[b]	1.65 ± 0.3[bc]	1.41 ± 0.48[bc]	5.73 ± 1.13[c]	6.18 ± 1.54[bc]	5.85 ± 0.44[b]	5.05 ± 0.53[b]
Dec	10.87 ± 1.22[a]	9.07 ± 0.46[b]	1.29 ± 0.18[cd]	1.14 ± 0.34[bc]	8.43 ± 1.74[b]	7.96 ± 1.78[b]	6.18 ± 0.52[b]	5.63 ± 0.49[b]
Jan	12.10 ± 0.77[a]	10.70 ± 0.76[a]	0.82 ± 0.2[d]	0.91 ± 0.23[c]	14.76 ± 0.85[a]	11.76 ± 2.04[a]	7.32 ± 0.43[a]	6.47 ± 0.54[a]

[a] Data are expressed as means ± standard deviation ($n = 4$)

[b] Different superscripts between rows represent significant differences between fruit developmental stages ($p < 0.05$)

the declining pattern of ascorbic acid in Bergamot (*Citrus bergamina* Risso) fruits, ranging from 867 (October) to 341 g L^{-1} (March) during the fruit ripening period. The maturity Index, which correlates TSS/TA ratio, is an important parameter associated with quality attributes of citrus fruits, although it is most commonly used as a method for the estimation of harvest maturity of sub-tropical mandarins. The maturity index pattern during fruit development demonstrated an inverse correlation between TA and TSS (Table 2). The maturity index was observed to be lower (2.89 ± 0.53 for ‘Kinnow’; 2.50 ± 0.31 for ‘W. Murcott’) in green colored fruits during the month of August, when TSS was low, while TA was at a relatively higher level. It exhibited an increasing trend with significant variations ($p < 0.05$) during fruit development, reaching its maximum at full maturity (11.76 ± 2.04 for ‘W. Murcott’; 14.76 ± 0.85 for ‘Kinnow’).

Overall, immature fruits in the month of August possessed a higher level of TA and ascorbic acid concentration with the lowest TSS, total sugars and low maturity index, and vice-versa in mature fruits in the month of January.

Carotenoid Content

During fruit maturation, the carotenoid content of peel and pulp in terms of β-carotene rapidly increased in relation to color development of mandarin fruits (Table 3). Irrespective of fruit development stages, β-carotene was higher in the fruit peel than the pulp in both cultivars, which was also in agreement with the findings of Kato (2012) and Alquezar et al. (2008) in citrus fruits. β-carotene content varied from 0.89 ± 0.35 to 26.28 ± 4.65 μg g^{-1} FW during the fruit development period. Values in the present study were lower in the range than those observed in the findings of Mansour (2018) in sour orange (*Citrus aurantium*) at different fruit color stages (0.48 ± 0.01 to 0.81 ± 0.03 mg^{-1} FW). However, these results are in agreement with the findings of Alquezar et al. (2008) and Rodrigo et al. (2004) in flavedo of orange (*Citrus sinensis* L.) and Zheng et al. (2016) in grapefruit during fruit development and maturation. In the context of the present cultivars, ‘Kinnow’ (26.28 ± 4.65 μg g^{-1} FW) in peel and ‘W. Murcott’ in pulp (13.25 ± 4.29 μg g^{-1} FW) contained higher concentrations of β-carotene at the full fruit maturity stage. Hence, green colored fruits were rich in chlorophyll content, and during different maturity stages breakdown of chlorophyll leads to an enhancement in the concentration of β-carotene, which was responsible for the

Table 3 β-carotene content (μg g^{-1} FW) of ‘Kinnow’ and ‘W. Murcott’ fruits during fruit development

Month	‘Kinnow’		‘W. Murcott’	
	Peel	Pulp	Peel	Pulp
Aug	5.96 ± 0.76^{d}	0.98 ± 0.26^{d}	6.22 ± 0.98^{c}	0.89 ± 0.35^{c}
Sept	8.36 ± 1.24^{cd}	2.71 ± 1.06^{cd}	8.54 ± 2.55^{c}	1.28 ± 0.47^{c}
Oct	11.82 ± 2.84^{bc}	4.95 ± 0.74^{bc}	14.54 ± 1.71^{b}	1.99 ± 0.61^{c}
Nov	15.77 ± 4.26^{b}	6.59 ± 0.89^{b}	15.84 ± 4.55^{b}	6.32 ± 2.75^{b}
Dec	21.97 ± 1.56^{a}	10.48 ± 3.04^{a}	23.63 ± 2.93^{a}	9.27 ± 1.65^{b}
Jan	26.28 ± 4.65^{a}	12.41 ± 1.43^{a}	25.10 ± 3.07^{a}	13.25 ± 4.29^{a}

[a] Data are expressed as means ± standard deviation ($n = 4$)
[b] Different superscripts between rows represent significant differences between fruit developmental stages ($p < 0.05$)

Fig. 1 ‘Kinnow’ (*KN*) and ‘W. Murcott’ (*WM*) fruits during different fruit maturity stages

Table 4 Fruit color analysis of 'Kinnow' and 'W. Murcott' fruits during fruit development

Colors	Cultivar	Fruit portions	Month					
			Aug	Sept	Oct	Nov	Dec	Jan
*L**	'Kinnow'	Peel	31.53 ± 2.23^{d}	35.89 ± 2.19^{d}	41.95 ± 3.18^{c}	54.29 ± 2.78^{b}	60.99 ± 4.82^{a}	62.74 ± 3.41^{a}
		Pulp	73.14 ± 4.8^{a}	65.49 ± 6.08^{b}	62.14 ± 4.67^{bc}	59.58 ± 2.84^{bcd}	55.95 ± 4.16^{cd}	54.43 ± 5.66^{d}
		Juice	35.48 ± 3.24^{c}	37.99 ± 3.42^{bc}	39.43 ± 2.74^{abc}	40.41 ± 2.63^{abc}	42.51 ± 5.39^{ab}	44.83 ± 4.96^{a}
	'W. Murcott'	Peel	31.14 ± 2.85^{d}	35.96 ± 2.23^{cd}	38.44 ± 4.35^{c}	50.49 ± 3.41^{b}	53.09 ± 4.23^{ab}	55.95 ± 3.44^{a}
		Pulp	69.20 ± 3.06^{a}	65.69 ± 3.99^{ab}	62.10 ± 6.86^{bc}	61.27 ± 4.19^{bc}	60.36 ± 4.23^{bc}	57.19 ± 2.96^{c}
		Juice	32.46 ± 1.58^{d}	34.24 ± 1.94^{cd}	36.58 ± 2.06^{c}	37.57 ± 2.52^{c}	44.57 ± 2.24^{b}	53.14 ± 3.69^{a}
*a**	'Kinnow'	Peel	–6.46 ± 1.25^{c}	–6.03 ± 1.57^{c}	–3.63 ± 1.31^{c}	2.47 ± 0.86^{b}	31.12 ± 5.28^{a}	34.44 ± 1.59^{a}
		Pulp	2.42 ± 0.7^{c}	2.51 ± 1.03^{c}	4.20 ± 1.73^{c}	8.22 ± 1.04^{b}	9.57 ± 2.15^{b}	17.16 ± 3.3^{a}
		Juice	–3.15 ± 1.17^{d}	–1.39 ± 0.82^{d}	4.77 ± 1.7^{c}	8.93 ± 2.27^{b}	11.54 ± 1.99^{a}	13.16 ± 0.78^{a}
	'W. Murcott'	Peel	–6.27 ± 1.67^{d}	–5.15 ± 1.06^{d}	–2.34 ± 0.23^{d}	8.22 ± 3.54^{c}	15.77 ± 4.9^{b}	36.42 ± 6.02^{a}
		Pulp	–2.20 ± 0.69^{d}	–0.18 ± 0.46^{d}	3.15 ± 1.56^{c}	6.41 ± 2.47^{b}	10.53 ± 0.93^{a}	12.23 ± 2.88^{a}
		Juice	–3.01 ± 1.43^{d}	–1.61 ± 0.63^{d}	3.23 ± 0.43^{c}	6.25 ± 1.97^{b}	9.03 ± 0.75^{a}	10.14 ± 2.59^{a}
*b**	'Kinnow'	Peel	15.81 ± 1.81^{d}	17.96 ± 2.3^{d}	31.42 ± 1.71^{c}	51.13 ± 3.02^{b}	60.27 ± 3.46^{a}	62.63 ± 3.58^{a}
		Pulp	26.39 ± 1.1^{d}	27.49 ± 1.19^{cd}	28.61 ± 1.37^{cd}	29.93 ± 1.86^{bc}	32.88 ± 3.38^{b}	37.72 ± 3.45^{a}
		Juice	24.79 ± 1.47^{d}	28.74 ± 1.85^{c}	30.62 ± 1.56^{bc}	32.89 ± 2.37^{b}	38.82 ± 1.99^{a}	40.36 ± 1.87^{a}
	'W. Murcott'	Peel	12.92 ± 1.06^{d}	14.68 ± 1.8^{d}	28.72 ± 1.96^{c}	31.46±2^{c}	42.62 ± 3.15^{b}	51.70 ± 5.12^{a}
		Pulp	23.92 ± 1.08^{d}	24.72 ± 0.82^{d}	26.28 ± 1.96^{cd}	27.55 ± 1.64^{bc}	29.89 ± 1.39^{b}	33.05 ± 2.37^{a}
		Juice	23.88 ± 2.14^{d}	24.70 ± 1.56^{cd}	27.85 ± 3.17^{bc}	30.92 ± 2.12^{ab}	31.46 ± 3.67^{ab}	33.05 ± 2.35^{a}
h°	'Kinnow'	Peel	112.20 ± 2.67^{a}	108.60 ± 2.22^{a}	96.60 ± 2.85^{b}	87.24 ± 4.41^{c}	62.69 ± 3.29^{d}	61.19 ± 3.98^{d}
		Pulp	84.80 ± 2.43^{a}	84.78 ± 2.13^{a}	81.64 ± 3.58^{a}	74.65 ± 1.4^{b}	73.77 ± 1.95^{b}	65.54 ± 2.22^{c}
		Juice	97.20 ± 2.59^{a}	92.80 ± 1.51^{b}	81.15 ± 2.93^{c}	74.81 ± 3.11^{d}	73.44 ± 2.34^{d}	71.94 ± 0.48^{d}
	'W. Murcott'	Peel	115.90 ± 4.31^{a}	109.30 ± 1.65^{b}	94.70 ± 4.31^{c}	75.36 ± 5.21^{d}	69.69 ± 4.59^{d}	54.84 ± 2.18^{e}
		Pulp	95.30 ± 1.45^{a}	90.40 ± 3.64^{b}	83.17 ± 2.87^{c}	76.90 ± 4.19^{d}	70.60 ± 0.79^{e}	69.69 ± 3.03^{e}
		Juice	97.20 ± 2.97^{a}	93.70 ± 1.27^{b}	83.39 ± 2.03^{c}	78.58 ± 2.91^{d}	73.99 ± 0.55^{e}	72.95 ± 3.07^{e}
*C**	'Kinnow'	Peel	17.08 ± 2.14^{d}	18.95 ± 2.67^{d}	31.63 ± 1.76^{c}	51.19 ± 3.04^{b}	67.83 ± 4.96^{a}	71.48 ± 3.91^{a}
		Pulp	26.50 ± 1.13^{d}	27.60 ± 1.2^{cd}	28.92 ± 1.29^{cd}	31.04 ± 1.99^{bc}	34.24 ± 3.83^{b}	41.44 ± 4.49^{a}
		Juice	24.99 ± 1.52^{d}	28.77 ± 1.86^{c}	30.99 ± 1.69^{c}	34.08 ± 2.71^{b}	40.50 ± 2.28^{a}	42.45±2^{a}
	'W. Murcott'	Peel	14.36 ± 1.66^{d}	15.56 ± 2.04^{d}	28.82 ± 1.97^{c}	32.52 ± 2.77^{c}	45.45 ± 4.51^{b}	63.24 ± 7.52^{a}
		Pulp	24.02 ± 1.13^{d}	24.72 ± 0.82^{d}	26.47 ± 2.13^{cd}	28.29 ± 2.11^{c}	31.69 ± 1.62^{b}	35.24 ± 3.22^{a}
		Juice	24.07 ± 2.25^{c}	24.75 ± 1.58^{c}	28.04 ± 3.2^{bc}	31.55 ± 2.4^{ab}	32.73 ± 3.73^{a}	34.57 ± 2.95^{a}

[a] Data are expressed as means ± standard deviation ($n = 4$)

[b] Different superscripts between rows represent significant differences between fruit developmental stages ($p < 0.05$)

orange-yellowish color of fruit peels at full maturity. However, variations in *β*-carotene content of the selected cultivars may be due to climate, temperature, geographical region, precipitation, sunshine exposure and different stages of maturation, which was also observed by Boudries et al. (2007, 2012) in Algerian Date and mandarin cultivars.

Color Attributes

Fruit color variations in peel, pulp and juice of 'Kinnow' and 'W. Murcott' mandarins during fruit development were evaluated in CIE *L**, *a**, *b**, *C** and *h*° coordinates and are presented in Table 4, while the variation in external fruit color development is shown in Fig. 1. During different fruit development stages, the peel and juice CIE *L** values of both the mandarins increased significantly with fruit maturity, varying from 31.14 ± 2.85 to 62.74 ± 3.41, while in fruit pulp, it was recorded as highest in the month of August (73.14 ± 4.8 for 'Kinnow'; 69.20 ± 3.06 for 'W. Murcott'), significantly ($p < 0.05$) declining thereafter until October; it then decreased with non-significant variations and was observed to be lowest in the month of January (54.43 ± 5.66 for 'Kinnow'; 57.19 ± 2.96 for 'W. Murcott'). The present findings are in agreement with the observations of Soares et al. (2007) in guava fruit and Singh et al. (2015) in the 'Star Ruby' cultivar of grapefruit. In the context of cultivars, the peel of 'Kinnow' and the pulp and juice of 'W. Murcott' showed more lightness at the full maturity stage.

The fruit peel of both the mandarins retained their green color until October, with a slight variation in *a** value (–6.46 ± 1.25 to 2.34 ± 0.23), thereafter turning reddish-yellow in color with considerable differences ($p < 0.05$) and attaining a value of 34.44 ± 1.59–36.42 ± 6.02 at full maturity. The color break in mandarin fruits during October coincides with the onset of the low seasonal temperature of the region. In contrast, the pulp and juice did not develop reddish coloration at full maturity, as observed in peel. Likewise, at commercial harvest, the peel of 'W. Murcott' exhibited a higher a^* value, while the pulp and juice of 'Kinnow' exhibited a greater a^* value than 'W. Murcott'. The b^* value in mandarin fruits significantly ($p < 0.05$) increased during fruit development and varied from 12.92 ± 1.06 to 62.63 ± 3.58. At full maturity stages, the peel of both cultivars (62.63 ± 3.58 for 'Kinnow'; 51.70 ± 5.12 for 'W. Murcott') displayed a more yellowish color than pulp (37.72 ± 3.45 for 'Kinnow'; 33.05 ± 2.37; 33.05 ± 2.37 for 'W. Murcott') and juice (40.36 ± 1.87 for 'Kinnow'; 33.05 ± 2.35 for 'W. Murcott'). The change in color of the fruit peel, and to some extent in the case of pulp and juice, was attributed to an accumulation of β-carotene content at later maturity stages, which was also studied by Arias et al. (2000) in peel and pulp of tomato and by Yoo and Moon (2016) in lemon peel. In the context of the present cultivars, the peel, pulp and juice of 'Kinnow' exhibited a greater development of yellowish color than 'W. Murcott' cultivars at the final harvest stage.

The hue angle ($h°$) ranged from 115.90 ± 4.31 to 61.19 ± 3.98 in different portions of the fruits during development. The $h°$ value of fruit peel significantly declined ($p < 0.05$) with the onset of fruit maturity and with a slight alteration in fruit pulp and juice. At full maturity, 'W. Murcott' exhibited a higher hue angle value in fruit pulp and juice (69.69 ± 3.03 and 72.95 ± 3.07, respectively), while 'Kinnow' displayed higher $h°$ in fruit peel (61.19 ± 3.9) than 'W. Murcott' (54.84 ± 2.18). A similar declining pattern of hue value during fruit development was also reported by Singh et al. (2015) in grapefruits and Barragan-Iglesias et al. (2018) in papaya. The chrome value (C^*) significantly ($p < 0.05$) increased with fruit development and varied from 14.36 ± 1.66 to 71.48 ± 3.91 until full maturity. The purity of color was more in the peel than in the pulp and juice in both mandarins. The present results are in agreement with the findings of Soares et al. (2007) in guava fruits in relation to maturity. 'Kinnow' showed more color intensity at fruit maturity than 'W. Murcott' in all three fruit portions.

Correlation Analysis

To elucidate the relation of fruit color coordinates L^*, a^*, b^*, C^* and $h°$ with the maturity index, Pearson's correlation coefficient was evaluated and is shown in Table 5. The correlation coefficients analyzed for changes in fruit color coordinates were significantly ($p < 0.05$) correlated with the maturity index of both the cultivars. In the case of 'Kinnow', pulp exhibited a stronger relation with the maturity index compared to the peel. The C^*value of pulp (r = 0.996) showed a positive and highly significant correlation ($p < 0.01$) with the fruit maturity index compared to peel (r = 0.865). The L^*value of juice also exhibited a stronger correlation ($p < 0.01$) with the fruit maturity index than the peel and pulp of 'Kinnow' fruits (r = 0.841, r = –0.813 peel and pulp, respectively). Whereas in the case of 'W. Murcott' fruits, the C^*value of peel (r = 0.997) demonstrated a stronger and more positive correlation with the maturity index than pulp and juice (r = 0.985 and 0.944 for peel and pulp, respectively). In the context of the present cultivars, the change in peel and pulp color of 'W. Murcott' and 'Kinnow' fruits, respectively, significantly correlated with the onset of the optimum fruit maturity stage.

These correlation coefficients showed that fruit peel and pulp color is an important indicator for internal quality attributes. Similar results of correlation studies were also reported by Lee and Castle (2001) in "Early Gold" and "Budd blood" orange juices and by Conesa et al. (2019) in lemon fruits, thereby justifying the present studies.

Conclusion

This study describes quality and color changes in different portions of fruit during development in 'Kinnow' and 'W. Murcott' mandarins. The results demonstrate an im-

Table 5 Pearson correlation coefficient comparing the relationship of fruit color coordinates with the maturity index of 'Kinnow' and 'W. Murcott' fruits during fruit development

Color coordinates		Maturity index	
Fruit parts		'Kinnow'	'W. Murcott'
Peel	L^*	0.841*	0.906*
	a^*	0.906*	0.972**
	b^*	0.825*	0.984**
	h^0	–0.883*	–0.960**
	C^*	0.865*	0.997**
Pulp	L^*	–0.813*	–0.942**
	a^*	0.978**	0.955**
	b^*	0.993**	0.992**
	h^0	–0.943**	–0.923**
	C^*	0.996**	0.985**
Juice	L^*	0.928**	0.978**
	a^*	0.828*	0.936**
	b^*	0.901*	0.932**
	h^0	–0.750^{NS}	–0.913*
	C^*	0.907*	0.944**

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)
^{NS} Non-significant

provement in fruit quality of 'Kinnow' and 'W. Murcott' mandarins during development in terms of an increase in fruit weight, TSS, juice content and reduction in peel thickness and acid contents. All portions of fruit exhibited color development with the advancement of fruit maturity. This study demonstrated that for 'Kinnow' mandarin, pulp C* coordinate and for 'W. Murcott' peel C* can be used as maturity indices to determine the commercial harvest of fruit. In the context of the present cultivars, the 'Kinnow' cultivar exhibited greater color development as well as higher maturity index and β-carotene content than 'W. Murcott' at the full maturity stage. Hence, our findings have generated valuable information for citrus fruit quality breeding and consumer guidelines.

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Conflict of interest J. Singh, T.S. Chahal, P.P.S. Gill and S.K. Jawandha declare that they have no competing interests.

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