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Proposal and validation of colour index for Kinnow mandarin (*Citrus nobilis* × *Citrus deliciosa*)

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ABSTRACT

Kinnow (*Citrus nobilis* Lour × *Citrus deliciosa* Tenora) acceptability by consumer and processors depends on their bright orange colour, size and other quality traits like TSS and acidity. More bright orange coloured Kinnow fruits are preferred. The objective of this study is to propose an index for growers and researchers to know the harvesting date and better quality of fruits respectively. Kinnow fruits of varying colour gradient were harvested from ten treatments. These ten treatments were different doses of N: P: K. They acted as a source to produce variability in Kinnow peel colour, which was utilized for index formulation and validation. They were compared with a standard. Standard comprised of most uniform bright orange coloured fruits of Kinnow orange. The observations for *L, a* and *b* were recorded by *Hunterlab*. There were total eleven colour indexes studied. Out of eleven indexes, seven were previously validated by other workers for different fruit crops. Four indexes were formulated in this study to validate them for Kinnow along with remaining seven indexes. Index *a/b* showed highest positive correlation with total carotenoid content of peel (0.548 and 0.519 respectively). It recorded minimum value for standard (0.52±0.02) indicates that lower values for these indices will represent brighter colour of kinnow.

Key words: Chroma, Colour index, Hue, *Hunterlab*, Kinnow, Nutrition

Kinnow (*Citrus nobilis* Lour × *Citrus deliciosa* Tenora), a hybrid mandarin known for its attractive orange coloured fruits, high juice content and better fruit quality than other citrus fruits (Singh 2001). It revolutionized citrus industry in India, Pakistan and Bangladesh (Sharma and Saxena 2004, Sharma *et al*. 2006, Jhalegar *et al*. 2015). In general, the marketability of Kinnow is judged by two parameters; colour and size. Size can be quantified in terms of fruit length, fruit width and weight. But, colour is a matter of perception based on visualization and can't be expressed in mathematical values to understand it well. This is the problem for researchers to explain quality of Kinnow based on colour. Therefore, color index can be a good solution to judge the colour of Kinnow mandarin.

Colour is a matter of perception and subjective interpretation. Colour is the single most important product-intrinsic sensory cue when it comes to setting people's expectations related to the likely taste and flavour of food and drink (Spence *et al.* 2015). Colour is also a quality indicator of fruits (Clydesdale 1993), as it directly indicates the content of carotenoids, anthocyanins and other pigments known for health benefits. There are various methods for measurement of colour (Hunter and Harold 1987). Some of the most popular systems are RGB (red, green and blue), which is used in colour video monitors; *HunterLab*, Commission Internationale de l'Eclairage's (CIE) *L*a*b**, CIE XYZ, CIE *L*u*v**, CIE Yxy, and CIE LCH. *HunterLab* colour system is based on *L, a* and *b* measurements. In this system we measure *L, a* and *b* values from instrument and then calculate chroma [$C^* = (a^{*2} + b^{*2})^{1/2}$] and hue angle [$h^* = \tan^{-1}(b^*/a^*)$] with the help of these three parameters.

However, all these measurements don't give a clear-cut indication about the colour of fruits. Considering these problems in mind, researchers used two different approaches to express colour of fruits. In first approach, scientists have directly employed the colour values of the CIELAB system or those of the *HunterLab* system to study the colour of different fruits and beverages (Da Porto *et al*. 1992, Bakker *et al*. 1993, Echavarri *et al*. 1993). In another approach, scientists have worked on the development of colour indexes for proper visualization of colour in fruits and their products. These indices are the mathematical expression of CIELAB or *Hunter Lab* parameters. For instance, Carreno *et al.* (1995) proposed an index for the objective evaluation

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of the colour of red table grapes and the expression of the index was (180-*H*)/ (L^*+*C*). The ratio, *a/b* has been used for determination of colour index in tomatoes, apples, citrus and carambola fruits (Stewart and Wheaton 1971, Little 1975, Ferre *et al*. 1987, Campbell *et al*. 1989). In tomato fruit, the index, COL = $(2000 \times a) / (L \times (a^2 + b^2)$ 0.3 has been frequently used to determine colour (Hobson 1987, Dodds *et al*. 1991). Furthermore, for colour determination in de-greened citrus fruit, the index, CCl = $(1000 \times a) / (L \times b)$ has been proposed (Jimenez-Cuesta *et al*. 1981). Manera *et al.* (2013) developed a colour index which is expressed as MIc (Maturity index) = $L^* \cdot a^* \cdot b^{*-1}$ in pomegranate. Considering these points in mind, we proposed to use these indices for adequate and proper colour determination in Kinnow mandarin along with indices formulated by us.

MATERIALS AND METHODS

The experiment was conducted on Kinnow mandarin harvested from four year old Kinnow orchard located at Todapur farm of IARI, Pusa, New Delhi during 2013-14. There were nine treatments and one control. The treatments were T_1 (250:600:160), T_2 (250:600:240), T_3 (250:600:320), T_4 (300:600:160), T_5 (300:600:240), T_6 (300:600:320), T_7 (400:600:160), T_8 (400:600:240), T_9 (400:600:320) and T_{10} [control (no fertilizers were applied)]. Here, the different treatments were used as source of colour variation in fruit because the different doses of nutrients produced fruits vary in colour (also vary in carotenoid content). These treatments were compared with one standard. Standard comprised of bright orange coloured fruits of the same orchard fertilized with common recommended dose of fertilizer. The Kinnow fruits were harvested at full maturity (TSS: acid ratio 12:1 to 14:1). All possible care was exercised to harvest fruits from all direction of tree and canopy heights. Similarly, fruits were harvested randomly from randomly-selected plants in the orchard for standard. There were three replications for each treatment. Freshly harvested Kinnow fruits were brought to the laboratory, washed thoroughly with tap water to remove adhering dirt and dust, grouped into three, having three fruits in each group. The numerical determination of the colour was done by *Hunterlab.* The measuring area had a diameter of 8 mm. Standard illuminant C (Y_0=100; X_0=98.072; Z_0=118.225) was used as reference. Three measurements were made around the equatorial belt of each fruit and the mean value was reported in the data. *L, a, b* was recorded from the instrument. *L* value represents lightness [0 (black) to 100 (white)]. The *a* values changes from –*a* (greenness) to +*a* (redness) while the *b* value is from –*b* (blueness) to +*b* (yellowness). *H* (Hue angle), *C* (chroma) and other indexes were calculated. In total, 11 colour indexes were studied. Out of eleven indexes, seven were previously validated by other workers for different fruit crops. Four indexes were formulated in this study to validate them for Kinnow along with remaining seven indexes. Indexes I_1 (*L*), I_2 (*a*), I_3 (*b*), I_4 (*H*), I_5 (*C*), I_6 (*a/b*) and I_7 $(1000 \times a^*)/(L^* \times b^*)$ have been used by other researchers (Carreno *et al.* 1995), these indexes studied for their validation in Kinnow. Whereas, indexes I_8 $[(L+b) \times 100]$, I_9 $(L \text{x} b)$, I_{10} $[(L+b+C)/100]$ and I_{11} $[(b+C) \times L]/100$ were formulated for this study.

Data were analyzed by analysis of variance (ANOVA) using SAS 9.3 software in randomized block design with three replications. Further, a multiple comparison was done by using Tukey's HSD test. All other statistical analysis was done using MS Excel 2007. Pearson Correlation Coefficient for total carotenoids content and different indexes were calculated by using SAS 9.3 software.

RESULTS AND DISCUSSION

The results of the research are presented in two tables. Table 1 comprised of various colour indexes for different treatments including the standard. In this table, the effort was to find out the values for each index for every treatment. So, that trend can be established with respect to standard and indexes having similar trend can be grouped in to one group. In Table 2, matrix of Pearson correlation coefficients for different indices along with total carotenoid content presented. Here, the objective was to find out the significant positive correlation of various colour indexes with total carotenoid content. So, that the appropriate colour indexes can be select.

Relation between tristimulus parameters, colour indexes of standard and different treatments

Our results revealed that the mean values for *L, a, b, H, C* and for different colour indexes varied greatly among the treatments and one standard (Table 1). The logic of comparing of treatments with standard was that the values of above mentioned parameters do not represent trueness in colour of fruits. Based on the pattern of similarity with standard, difference in colour indexes could be categorized into three groups. In other words, if the value of standard was minimum for any index, then those indexes kept in different group than those in which it was maximum. The indexes were grouped as under.

In group-I, those indexes were kept, in which maximum value calculated for standard, followed by T_2 and minimum with control. This group comprised indexes such as I_3, I_8, I_9, I_{10} and I_{11}. In this group, fruits of standard recorded maximum value (71.71, 13282.2, 4382.27, 2.14 and 93.27, respectively), followed by fruits which received T_2 treatment (39.77, 11334.67, 2926.51, 1.67 and 68.37, respectively) and minimum in fruits harvested from the trees which received no treatment (34.52, 10177.67, 2324.04, 1.49 and 55.14, respectively) for five indexes.

In group-II those indexes were kept in which maximum value calculated for standard after that no set pattern followed. This group comprised indexes I_4 and I_5. In I_4, the higher value after standard (1.92) was recorded with the treatment T_3 (1.25) which differed non-significantly with the treatment T_2 (1.13) and minimum with the T_7 (0.99). In case of I_5, the maximum value after standard (80.91) was recorded by T_6 (54.62) which differed non-significantly with the treatment T_7 (54.22). Minimum value is recorded

Table 1 Various colour indexes for different treatments

Treatment	I_1 (L)	I_2 (a)	I_3 (b)	I_4 (H)	I_5 (C)	I_6 (a/b)	I_7 $(1000\times a^*)/(L^*\times b^*)$	I_8 $(L+b)$x100	I_9 (Lxb)	I_{10} $(L+b+C)/100$	I_{11} $[(b+C)$ x $L]/100$
T_1	70.86±3.17^{ab*}	36.74±4.01	36.58±1.37^{c}	1.00±0.08^{c}	51.87±3.71^{bc}	1.00±0.08^{a}	14.15±0.64^{a}	10744±448.86^{c}	2594.69±208.63^{c}	1.59±22.97^{b}	62.78±6.31^{b}
T_2	73.58±1.26^{a}	35.23±2.24	39.77±0.58^{b}	1.13±0.09^{bc}	53.15±1.07^{bc}	0.89±0.07^{ab}	12.06±1.16^{ab}	11334.67±183.83^{b}	2926.51±92.30^{b}	1.67±0.01^{b}	68.37±0.82^{b}
T_3	73.35±2.55^{ab}	31.18±3.27	38.75±2.25^{bc}	1.25±0.06^{b}	49.75±3.80^{bc}	0.80±0.04^{b}	10.95±0.19^{b}	11210±474.59b^{c}	2846.09±259.43^{bc}	1.62±0.09^{b}	65.01±6.59^{b}
T_4	70.83±1.32^{ab}	37.44±4.81	37.67±0.77^{bc}	1.02±0.13^{c}	53.17±3.72^{bc}	0.99±0.12^{a}	14.03±1.79^{a}	10850±176.67^{bc}	2668.43±87.09^{bc}	1.62±0.04^{b}	64.34±3.07^{b}
T_5	70.58±1.03^{ab}	37.12±5.67	37.90±0.37^{bc}	1.04±0.17^{c}	53.16±3.74^{bc}	0.98±0.16^{a}	13.91±2.44^{a}	10848±138.70^{bc}	2675.11±64.51^{bc}	1.62±0.02^{b}	64.25±1.51^{b}
T_6	71.86±0.18^{ab}	38.58±2.30	38.64±0.38^{bc}	1.00±0.05^{c}	54.62±1.87^{b}	1.00±0.05^{a}	13.89±0.70^{a}	11050.33±54.08^{bc}	2776.95±33.65^{bc}	1.65±0.02^{b}	67.02±1.70^{b}
T_7	70.99±1.17^{ab}	38.46±1.93	38.21±0.95^{bc}	0.99±0.05^{c}	54.22±1.75^{b}	1.01±0.05^{a}	14.18±0.58^{a}	10920±202.82^{bc}	2713.03±107.94^{bc}	1.63±0.04^{b}	65.64±2.88^{b}
T_8	70.25±1.41^{b}	36.28±3.25	37.22±0.37^{c}	1.03±0.09^{c}	52.00±2.26^{bc}	0.97±0.09^{a}	13.89±1.41^{a}	10746.33±178.22^{c}	2614.70±78.88^{bc}	1.59±0.03^{b}	62.68±2.00^{b}
T_9	71.60±1.72^{ab}	35.61±6.61	38.03±1.70^{bc}	1.09±0.17^{bc}	52.19±5.68^{bc}	0.93±0.14^{ab}	13.00±1.60^{ab}	10963±340.69^{bc}	2724.86±184.98^{bc}	1.62±0.09^{b}	64.68±6.77^{b}
T_{10}	67.25±1.96^{c}	32.43±3.30	34.52±1.73^{d}	1.07±0.07^{bc}	47.39±3.29^{c}	0.94±0.07^{ab}	13.96±1.05^{a}	10177.67±367.63^{d}	2324.04±1182.01^{d}	1.49±0.07^{c}	55.14±4.73^{c}
S	61.11±0.27^{d}	37.46±1.27	71.71±0.92^{a}	1.92±0.08^{a}	80.91±0.68^{a}	0.52±0.02^{c}	8.55±0.33^{c}	13282.2±80.60^{a}	4382.27±48.48^{a}	2.14±0.01^{a}	93.27±0.89^{a}

Table 2 Matrix of Pearson correlation coefficients for different indices

	Total carotenoid content	I_1 (L)	I_2 (a)	I_3 (b)	I_4 (H)	I_5 (C)	I_6 (a/b)	I_7 $(1000\times a^*)/(L^*\times b^*)$	I_8 $(L+b)$ x 100	I_9 (L x b)	I_{10} $(L+b+C)/100$	I_{11} $[(b+C)$ x $L]/100$
Total carotenoid content	1.000											
$I_1(L)$	-0.229	1.000										
I_2 (a)	0.383	0.030	1.000									
$I_3(b)$	-0.302	0.935	0.240	1.000								
I_4 (H)	-0.534	0.487	-0.842	0.316	1.000							
$I_5(C)$	0.147	0.481	0.880	0.672	-0.485	1.000						
I_6 (a/b)	0.548*	-0.471	0.854	-0.300	-0.997	0.504	1.000					
$I_7(1000\times a^*)/(L^*\times b^*)$	0.519	-0.694	0.688	-0.533	-0.964	0.263	0.962	1.000				
I_8 $(L+b)$x100	-0.266	0.987	0.126	0.980	0.417	0.576	-0.401	-0.632	1.000			
I_9 (Lxb)	-0.286	0.978	0.140	0.988	0.407	0.590	-0.391	-0.621	0.999	1.000		
I_{10} $(L+b+C)/100$	-0.109	0.875	0.486	0.958	0.055	0.840	-0.036	-0.299	0.927	0.933	1.000	
I_{11} $[(b+C)$ x $L]/100$	-0.125	0.900	0.441	0.968	0.103	0.810	-0.084	-0.346	0.945	0.950	0.998	1.000

*Significant at 10% level of significance.

with the control (47.39).

In group-III those indexes were kept in which minimum value calculated for standard. This group comprised of indexes I_1, I_6 and I_7. In case of L (I_1), minimum value was recorded with standard (61.11) followed by control (67.25). The maximum value (73.58) was recorded by the treatment T_2. In index I_6, standard recorded minimum value (0.52) followed by the treatment T_3 (0.80). Maximum value (1.01) was recorded by T_7, which differed non-significantly with the treatments T_1, T_4, T_5, T_6 and T_8. In case of index I_7, similar to index I_6, the minimum value was recorded for standard (8.55) followed by T_3 (10.95). The maximum value (14.18) was recorded by the treatment T_7. The treatment T_7 differed non-significantly with the treatments T_1, T_4, T_5, T_6, T_8 and T_{10}. So, the indexes I_6 and I_7 were similar. In group-IV, those indexes were kept in which the difference among treatments were non-significant. The index I_2 was placed in this group.

When we measure colour of fruit through *HunterLab,* basically we measure three parameters, i.e. *L*, *a* and *b*. These are three independent parameters which represents different aspects of colour. *L* value represents lightness and changes from 0 (black) to 100 (white). The *a* values change from *–a* (greenness) to *+a* (redness) while the *b* value is from *–b* (blueness) to *+b* (yellowness) (Sahin and Sumnu 2006). These *L, a* and *b* values help to calculate other expressions for colour like chroma and hue angle which are somewhat more expressive for colour of an object. Chroma defines colour saturation and the hue angle (*h**) denotes colour shadiness (0°=red-purple, 90°= yellow, 180°= bluish-green and 270°=blue). But, matter of fact is that none of these parameters represent colour in true sense. In other words, no one can imagine the colour of the object on the basis of these values. They only express one aspect of colour.

Hence, some workers used them in combination of two or more in the form of colour indexes to make them more expressive in representation of colour. They formulated indexes and standardize for their target crop (Manera *et al*. 2011 and McGuire 1992). The same idea followed in this study also.

Correlation between colour indexes with carotenoid content

In Table 2, the Pearson correlation coefficient between colour indexes and carotenoid content of peel of Kinnow orange are presented. This correlation study was performed to find the suitability of index(es) for colour measurement of Kinnow orange. Higher positive correlation was recorded by group-III indexes (I_6 and I_7). However, highest significant positive correlation (0.548) was found with the index I_6 (*a/b*) only. Group-I indexes recorded the negative and non-significant correlation with total carotenoid content. Group-II indexes were also had non-significant correlation. Group -IV is recorded the positive but non-significant correlation. In this study, the tristimulus factors unable to express colour alone (I_1, I_2, I_3, I_4 and I_5) and also in some indexes (I_7, I_8, I_9, I_{10} and I_{11}); where they failed to show significant positive correlation with total carotenoid content. Indexes I_8, I_9, I_{10} and I_{11} showed negative correlation may be due to wrong combination of tristimulus parameters, *C* and *H*. Index $I_7 (1000 \times a^*)/(L^* \times b^*)$ showed positive correlation but, it was non-significant. Although it was found good for citrus (Jimenez-Cuesta *et al*. 1981). Only Index I_6 (*a/b*) showed significant higher degree of correlation with carotenoid content. In I_6 (*a/b*) has two variables *a* and *b*. As far as, the variable a is concerned the treatments differed non-significantly. So, in index I_6, *b* is the deciding factor. More positive values of *b* represent more yellowness. So, more value for *b* means more yellowness and lower a/b ratio. Hence, standard recorded lowest value (0.52) followed by treatment T_3 (0.80). So, index *a/b* validated for colour determination of Kinnow orange. This index has also been used for determination of colour index in tomatoes, apples, citrus and carambola fruits (Stewart and Wheaton 1971, Little 1975, Ferre *et al*. 1987, Campbell *et al*. 1989). Other indexes were not found good enough for colour determination and also did not have significant positive correlation.

Index *a/b* is suitable for peel colour representation in Kinnow and can be used in different experiments related to measurement of peel colour. It would be useful for researchers to represent their results in terms of indexes.

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