Journal of Food Measurement and Characterization (2021) 15:1463–1474
https://doi.org/10.1007/s11694-020-00734-4

ORIGINAL PAPER

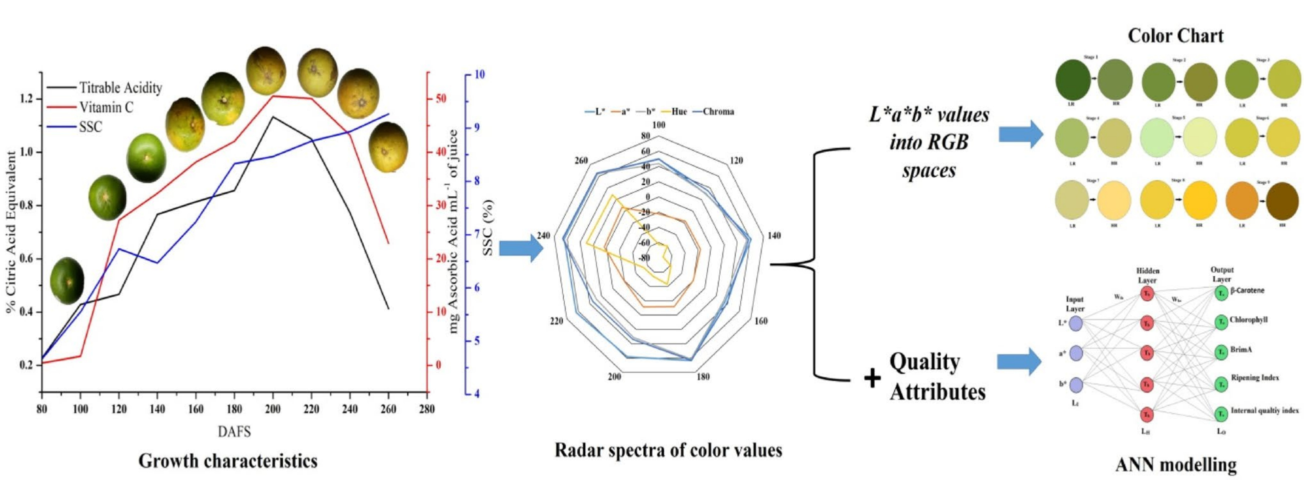
Development of rapid and non-destructive technique for the determination of maturity indices of pomelo fruit (*Citrus grandis*)

Arun Kumar Gupta[1] · Manisha Medhi[1] · Sourav Chakraborty[1] · Monica Yumnam[1] · Poonam Mishra[1]

Received: 20 April 2020 / Accepted: 2 November 2020 / Published online: 17 November 2020

Abstract
Quality of fruit and the subsequent eating attribute is closely linked factors that have a significant effect on marketability and have always been correlated with harvest maturity. In the present investigation, the main focus was given on the development of an inexpensive and rapid tool for identification of appropriate plucking time in the field through colour chart and ANN modeling. The effect of maturity on growth attributes, biochemical properties, and quality attributes of pomelo fruit was thoroughly investigated. A systematic change in the growth attributes, colour properties, and biochemical properties of juice was observed with maturity. Quality attributes such as BrimA and internal quality index have presented inconsistent trends over maturity. In contrast, a regular, systematic change was observed in the ripening index, chlorophyll, and β-carotene content with maturity. A colour chart mentioning various ripening stages was created based on color properties, which were successfully used for the maturity classification. Besides, a correlation between colour parameters (*L*, a*, b**), and quality attributes was successfully established using ANN, where 3-5-5 was found the best architecture.

Graphic abstract



Keywords Pomelo · Maturity · Naringin · Quality attributes · Colour chart · ANN

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11694-020-00734-4) contains supplementary material, which is available to authorized users.

✉ Poonam Mishra
mpoonam1@rediffmail.com; poonam@tezu.ernet.in

Extended author information available on the last page of the article

Highlights

1. Ripening index may be a suitable maturity index for pomelo fruit due to its systematic trend over maturity.

2. The colour chart developed based on peel colour can be effectively used for the classification of different maturity stages of pomelo fruit.
3. ANN model is effectively used for the prediction of optimum maturity and quality attributes of pomelo fruit.

Introduction

Rutaceae is a large botanical family in which the dominant members are sweet orange (*Citrus sinensis*), mandarin or tangerine orange (*Citrus reticulata*), grapefruit (*Citrus paradisi*), lemon (*Citrus limon*), lime (*Citrus aurantifolia*), and pomelo (*Citrus grandis*) [1]. Pomelo fruit having a unique shape, flavor, colour, and g all quality attributes that are attractive to consumers and is believed to be an ancestor of grapefruit [2]. Southeast Asia and Indo-China regions believed to be native regions of this most abundant citrus fruit [2]. Pomelo being an acidic and bitter nature, is mostly used for flavouring vegetable dishes, fish, meat, salads. Also, pomelo is an excellent source of many nutrients including dietary vitamin C, carotenoids, foliate, dietary fibre, potassium [2] phenols (caffeic, p-coumaric, ferulic and sinapic acid) and flavanone glycosides (naringenin, didymin, neoeriocitrin, naringin, neohesperidin, and poncirin) [3]. Currently, there is an increasing interest in citrus fruit because its consumption appears to be associated with a reduced risk of certain chronic diseases such as obesity, diabetes, cancers, and cardiovascular disease [4, 5].

Physicochemical qualities and storage life of fruit depends on the various physiological and biological changes which occur during fruit development and maturity. Information on such changes is useful to assess the stage of fruit maturity for harvesting and subsequent processing. Ripening is the process where fruits attain their desirable flavour, quality, colour, palatable nature, and other textural properties, which are associated with the change in composition, i.e., conversion of starch to sugar [6]. Citrus ripeness often evaluated by measuring physical (size, juice yield, weight, firmness, and colour) and chemical parameters (Total soluble solids (TSS), titrable acidity (TA) and TSS: TA), however, most of the time when the quality of fruit is measured these parameters do not match with the consumer preference. Various indices are used to determine harvest maturity for citrus fruit. However, differences in cultivars and growing environment affect the reliability of these indices [7]. Even, available data on citrus fruits indicate that measurement of any of the parameters mentioned above lands on the unsatisfactory outcome.

Thus, to estimate the maturity or predict, it could be better to combine the other physicochemical parameter to produce satisfactory results [8]. Quality attributes such as BrimA (Brix minus acids) adopted as an alternative of soluble solid content and acidity (SSC: TA) to predict the maturity of fruits with a high correlation of sweetness and flavor along with the similar likelihood to human perception of good taste. Focusing on various parameters, Vásquez-Caicedo et al. [9] suggested a ripening index (RPI) based on the combination of different properties of the fruit, including firmness (F), TA, and SSC. In contrast, an internal quality index (IQI) was proposed by Cortés et al. [10], which considers colour properties such as luminosity (L^*), chromaticity (C^*), and hue angle (h^*), F and SSC. Recently, Munera et al. [11] used RPI and IQI parameters to relate the spectral information for the monitoring of nectarine ripeness and concluded that RPI and IQ have great potential as a non-destructive technique for monitoring of nectarine ripeness.

The current techniques for harvesting are mainly based on visual inspection of colour, size, and shape of the fruit. Most of the time, due to its subjective nature, visual inspection is suffering from numerous disadvantages, including variable, tedious, inconsistent, and laborious [12]. At present, computer vision systems are widely employed to monitor the bruise, defects, and classify the horticultural products based on shape, size, and various quality attributes. In such a context, colour becomes an important parameter for most food products [12–16]. However, numerous methods have been employed to predict the ripeness level of citrus fruits in combination or alone, but the application of artificial neural network (ANN) to map between colour parameters and maturity indices of pomelo has not been thoroughly investigated. Also, it is essential to understand the changes that happen during the maturity and the factors responsible for the maturity of citrus for effective acceptability, utilization, transportation, and selling [11]. Hence, the present study is intended to investigate the effect of maturity on the physical, biochemical properties, and quality attributes of pomelo fruit, where growth characteristics, compositional changes, and phytochemical properties were determined. The result of biochemical attributes of pomelo may provide a better understanding to the inevitable changes in the pomelo fruit during the maturity, which could be helpful in the optimal selection for processing, handling and transportation of pomelo fruit. Besides, colour properties of fruit peel were effectively utilized to develop an inexpensive colour chart for classification of the maturity stages of pomelo fruit. The developed chart will be helpful to the fruit growers and harvester, which may be a useful tool for quick evaluation of the maturity of the fruit with the maximum bioactive components. After that, a colour chart based on colour space (RGB) was generated. Also, colour parameters were correlated with quality attributes (BrimA, ripening index, and internal quality index, chlorophyll, and β-carotene) to study the feasibility of ANN to predict the changes in pomelo during ripeness.

Materials and methods

Materials

Pomelo fruit at different maturity days was collected from the horticulture department of Tezpur University, Assam, India. All the necessary chemicals used in the analysis were of analytical grade and were obtained from Merck Millipore, India.

Sample collection and preparation for juice analysis

The healthy fruits were collected randomly during the growing season of 2018 (March to October) from six healthy trees of pomelo. The experiment was composed of thirteen collection periods (20–260 Days after fruit set (DAFS)). The fruit was harvested randomly at an interval of 20 days and divided into three equal batches, representing the replicates. Due to the immature fruit juice sac from 20–80 DAFS, it was difficult to collect the juice therefore chemical and phytochemical properties of the sample of 20–80 DAFS could not be analyzed. The juice was extracted through the laboratory juicer (Philips HR1832/00) and filtered by the 3-layered cheesecloth. The filtered juice samples were centrifuged (Eppendorf 5430R, Hamburg) at 3150 rotation centrifugal force (rcf) for 10 min to obtain a clear fluid and stored in a screw-capped bottle at 5 °C for further analysis.

Compositional yield, chemical analysis, and phytochemical properties

The compositional yield of pomelo fruit and chemical analysis of juice is presented in Supplementary. The naringin content of fruit juice was calculated as per the method suggested by Davis [17]. β-Carotene in peel was estimated as per the procedure outlined by Biswas et al. [18], where a fine paste of flavedo was mixed with 5 mL of chilled methanol followed by centrifugation at 1370 rcf for 10 min. The absorbance of the extract was determined at 449 nm, and concentration was calculated using the standard of 0–32 mg mL^{-1}. Chlorophyll content was determined in peel by the method of Qudsieh et al. [19], and the amount of chlorophyll was calculated using spectrophotometric Eqs. (1 and 2). The absorbance was measured at 664, 647, and 630 nm. The formulas used to calculate the amount of chlorophyll were as follow:

$$\text{Chlorophyll } a = 11.85\ OD_{664} - 1.54\ OD_{647} - 0.08\ OD_{630} \tag{1}$$

$$\text{Chlorophyll } b = 21.03\ OD_{647} - 5.43\ OD_{664} - 2.66\ OD_{630} \tag{2}$$

$$\mu\text{g of chlorophyll } g^{-1} = \frac{C_v}{10w} \tag{3}$$

where v is the volume of acetone in mL (15 mL), w is the weight of peel in g, chlorophylls a and b are the chlorophylls substituted for C in the above equation, and C is the value of chlorophyll a plus the values of chlorophyll b.

Ripening index (RPI) and internal quality index (IQI)

RPI and IQI for pomelo fruit were calculated as per the Eqs. 4 and 5 respectively [11] and were used to relate the color values (L^*, a^*, b^*) obtained from pomelo with their physiological, biochemical and phytochemical properties of different level of maturity.

$$\text{RPI} = \ln \frac{100 \times F \times TA}{SSC} \tag{4}$$

where, F = firmness (N), TA = titrable acidity, SSC = soluble solid content

$$\text{IQI} = \ln \frac{100 \times F \times L^* \times h^*}{SSC \times C^*} \tag{5}$$

where, F = firmness (N), L^* = lightness value, h^* = hue, C^* = chroma, SSC = soluble solid content.

The firmness of pomelo fruit was estimated using TA.HD-plus texture analyzer (Stable Micro Systems, UK) provided with a 2 mm cylindrical probe (P/2) and 100 kg of load cell size. The crosshead speed during the puncture test was 1 mm s^{-1}. The maximum force, expressed in Newton (N), was registered on the top side of the fruit. TA and SSC were calculated, as discussed in Supplementary Sect. 2.4. The color properties of fruit peel where six different portions such as A-F were considered (Supplementary Fig. 1b, c) for measurement of L^*, a^*, b^* values using Color Flex (Hunter Associates Laboratory Inc., Reston, VA, USA). Hue and chroma values were calculated as per the Eqs. 6 and 7.

$$h^* = \tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{6}$$

$$C^* = \left(a^2 + b^2\right)^{1/2} \tag{7}$$

Development of color chart for maturity classification

The colour chart was created using the color space (RGB) to define the maturity of pomelo fruit, where nine experimental stages of pomelo fruit starting from 100 to 260 DAFS were selected for the development of colour chart. The colour values of the fruit were collected from six different parts of the fruit (Supplementary Fig. 1b, c). The CIE colour values were converted in MATLAB 2015R, and the representative colour value is drawn from the six different portions of the fruit, and the mean value was calculated.

Modeling of pomelo maturity indices (Quality attributes) based on color properties

For the construction of the ANN network, weights are essential parameters that connect various processing elements. The feed forward back propagation algorithm was used for the development of the model by considering color parameters as input and quality attributes as output. For the execution of ANN, the back propagation algorithm is used, which adjusts weights based onthe minimization of errors. Input and output of the ANN architecture are composed of different neurons containing in input (L_I), hidden layers (L_H) and output layers (L_O). The input and output of the hidden layer for i^{th} neuron is denoted by H_{ii} and H_{oi} respectively. The weights for input to hidden layers are dented by W_{ih}, whereas for hidden to output layers are denoted by W_{ho}. The final output of the output layer is denoted by O_j [20].

The mathematical expression for H_{ij} which is a linear function of inputs (X_i) and weights (W_{ih}), is given by the following equation

$$sum = \sum_i X_i W_{ih} \tag{8}$$

During the processing of ANN architecture, bias (T_i) values were introduced as extra inputs to hidden (T_h) and output (T_o) layers. A *tansig* transfer function is also used for the calculation of the neural network. The mathematical expression of *tansig* function is shown in Eq. (9).

$$f(sum) = \frac{2}{1 + e^{-2sum}} - 1 \tag{9}$$

Hence, the mathematical expression for H_{oi} is given by the following equation

$$H_{oi} = \frac{2}{1 + \mathrm{e}^{-2(\mathrm{H_{ij}}+\mathrm{T_h})}} - 1 \tag{10}$$

The final output of the output layer namely O_j is given by the following mathematical expression

$$O_j = W_{ho} H_{oj} + T_o \tag{11}$$

For the mapping of ANN, the experimental data were divided into three parts; the program was developed in MATLAB R2015a for the ANN modeling. ANN network composed of four neurons in the input layer, two neurons in output layers. Neurons in the hidden layer were varied until the highest value of the coefficient of determination (R^2) and the minimum value of root mean square error (RMSE) were obtained.

For the mapping between colour and quality attributes, experimental data of nine experimental stages of six different sections of the fruit were considered. The neurons in the input and output layers were three and five, respectively. The trial and error approach was executed to decide the number of neurons in the hidden layers. Each run of the ANN algorithm consisted of 2000 iterations with a learning rate varied from 0.5 to 1. For each ANN architecture, 2000 iterations were repeated 10 times, which yields a total NNs of 20,000. The experimental data were fitted in MATLAB code after dividing data into three parts, such as 70% for training, 15% for testing, and 15% for validation.

Statistical analysis

Data were statistically analyzed using package IBM SPSS Statistics Version 20.0, Armonk, NY: IBM Corporation, and the values were presented as means and standard deviation. Also, Duncan's multiple range test ($p < 0.05$) was performed to separate means.

Results and discussion

Effect of maturity on the physiology of pomelo fruit

Pomelo fruit was studied for growth characteristics and compositional changes at various maturity days to determine the optimum harvesting period starting from 20 to 260 DAFS (Fig. 1a). The result of physical parameters hasrevealed an increasing trend with maturity where fruit weight (1230 g), fruit length (143.44 cm), fruit volume (1362 mm), fruit without peel (1000 g), specific gravity (1.01), and volume of juice (572 mL) were registered highest at 260 DAFS. The juice percentage was increased as maturity progressed, and 46.48% of the juice was recovered at 260 DAFS of pomelo (Supplementary Table S1a). The increase in juice content might be accounted for the accumulation of water and solutes to the juice vesicles and a decrease in the percentage of peel weight [21]. The specific gravity of pomelo fruit increased from 0.87 to 1.01 (from 20 to 260 DAFS) due to an increase in the juice content and SSC of the juice. With an increase in maturity, changes in the physical properties of fruit were seen and were evidence of progress in fruit maturity. The weight of flavedo, seed, segment, and pulp was found maximum at 260 DAFS, whereas albedo and peel weight were maximum at 200 DAFS (Supplementary Table S1b).

Colour values of pomelo fruit peel were studied in terms of L^*, a^*, b^*, and derived values such as hue and chroma (Fig. 1b). Highest L^*, a^*, and b^* values were observed at 240, 260, and 240 DAFS, respectively, while the initial stage of pomelo development has shown minimum values

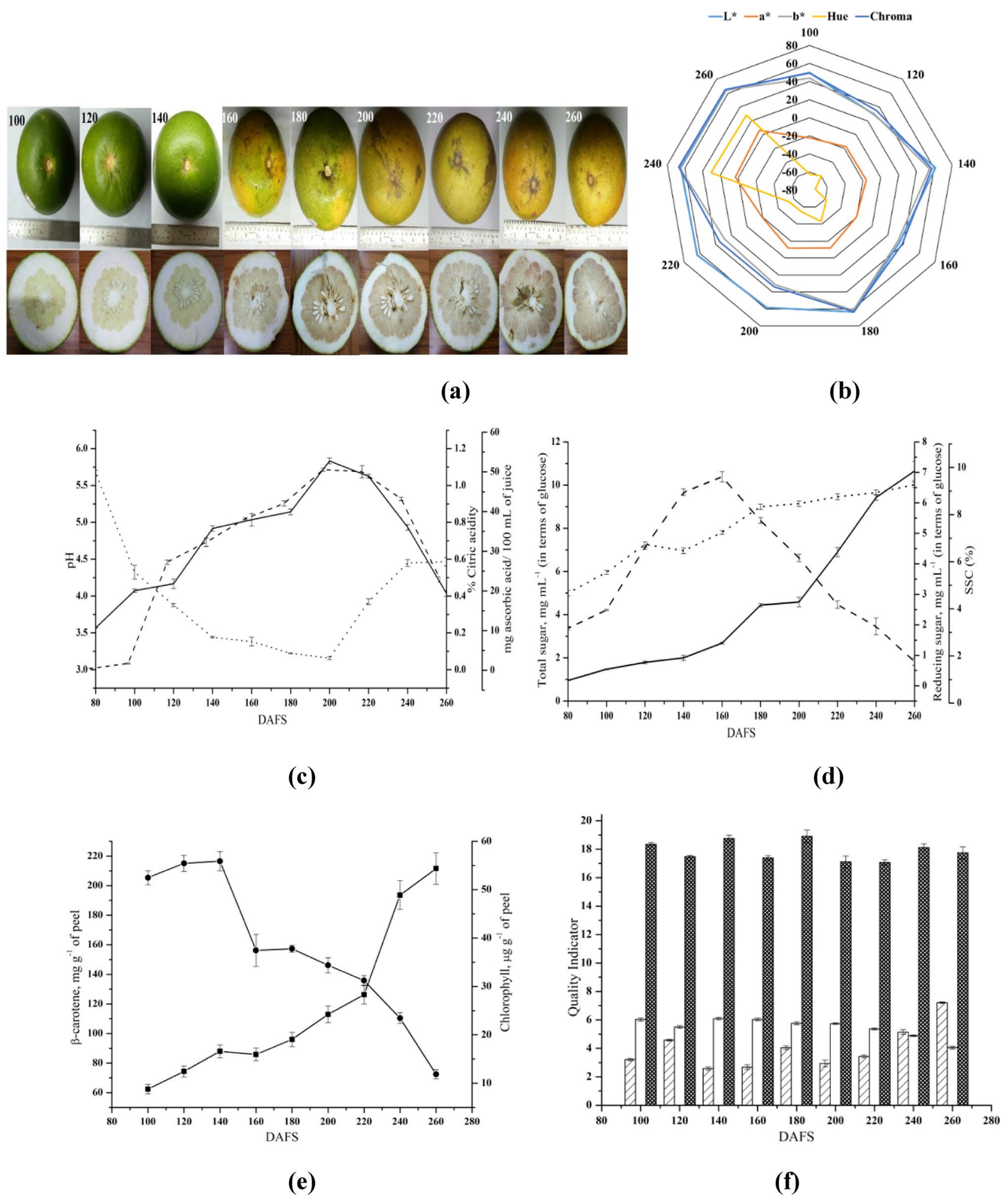


Fig. 1 **a** Pomelo fruit (whole and cut out section) at various maturity days (100–260 DAFS); **b** Radar spectra of color values of pomelo fruit at various maturity days; **c** Comparison between pH (………), titrable acidity (—) and vitamin C (- - -); **d** Comparison between TSS (………), total sugar (- - -) and reducing sugar (—); **e** Comparison between β-carotene (■) and chlorophyll (●); and **f** Comparison between BrimA (//), Ripening index () and Internal quality index (▓) (Columns are mean and bars are standard deviation)

of *L**, *a** and *b**. As maturity progressed, lightness, hue, and chroma values of peel were increased parallelly due to a decrease in chlorophyll content and an increase in carotenoid content [22]. An increase in *b** value shows the increase in yellowness in the peel. Hue value was recorded maximum at 260 DAFS while the minimum at 140 DAFS and change in hue value of peel presented quadrant shift from the second (green to yellow) to first quadrant (reddish to purple). Peel colour started to turn yellow at 180 DAFS, and optimum colour correspond to harvesting was developed during 200–220 DAFS. The rind colour and firmness are considered as non-destructive parameters and have an essential role in maturity prediction [23, 24].

Effect of different stages of maturity on biochemical properties of pomelo fruit juice

The specific gravity of juice increased up to 140 DAFS (1.06), and after that, a reverse trend was observed (Table 1). An increase in specific gravity usually corresponds to the accumulation of starch and soluble solids and depends upon the relative increase or decrease in weight and volume. Conversion of insoluble polymeric molecules like pectin, cellulose, and starch into simpler carbohydrates during the progression of maturity increased from 100 to 260 DAFS [6].

Organic acids and sugars, the critical components of SSC are considered as the main maturity index of fruit [25]. The drop in pH (4.32 to 3.15) and an increase in TA (0.42 to 1.13% citricacid equivalent) were observed until 200 DAFS. After that, changes in pH and TA were opposite to each other. (Fig. 1c). The ripe pomelo juice had a lesser pH when it was compared to unripe fruit. The change in pH is attributed to the dilution effect could be a probable reason for the decrease in acidity over the maturity because as the fruit matures, acid gets diluted results in lower acidity [21].The change in pH is always linked with the acidity of fruits; the lower pH of juice correspondingly indicates higher acidity of juice [26]. Butkhup and Samappito [27] reported that due to respiration or conversion of sugar, organic acids drop during ripening of fruit.In general, the maturity of citrus often accompanied bythe accumulation of soluble sugars and loss of acidity.

A gradual decreasing trend in vitamin C after 200 DAFS was seen over the maturity (Fig. 1c). An increase in vitamin C content ascribed to the residual effect of precursors needed for vitamin C synthesis; however, beyond 200 DAFS oxidation of vitamin C by ascorbic acid oxidase might be a probable reason for decreased vitamin C content in the juice [1, 26]. Citrus fruits such as oranges, tangerines, and grapefruit also showed a decreasing trend of vitamin C content over maturity [28], indicating that early harvest or mid-harvest fruit has more ascorbic acid than late-season fruit. The content of ascorbic acid in citrus fruits can be influenced by genotype, pre-harvest cultural practices, climatic conditions, fruit maturity, harvesting procedures, and post-harvest management [29].

The soluble solids content of pomelo juice has presented two phases of the change, which was evident during the development stage and after the attainment of maturity. SSC was increased from 5.55 to 8.93% with maturity (Fig. 1d). SSC is composed of sugars (80%), acidity (10%) and nitrogenous compounds (10%) [30]. The findings of juice clarity comply with the soluble solids and present a positive relation of SSC with maturity. An increase in SSC during the ripening period of different fruits was reported [31, 32]. Total sugar content increased till 160 DAFS, and after that, it started to decrease from 8.36 to 1.83 mg mL^{-1} (Fig. 1d). The total sugar content in juice reached a maximum value during the middle phase of fruit development, and it started to convert into reducing sugar over maturity. Starch hydrolysis produces glucose and fructose, which plays an important role in fruit ripening as the substrate of respiration [33].

Table 1 Biochemical changes in pomelo fruit at various stages of maturity

Days after fruit set	Clarity (%T)	Specific gravity	SSC: Acidity	Naringin content (μg/mL)	ABTS (% inhibition)
100	7.81 ± 0.44^{i}	0.99 ± 0.00^{d}	11.83 ± 0.30^{b}	40.27 ± 4.99^{a}	38.65 ± 1.79^{d}
120	14.29 ± 0.31^{gh}	1.01 ± 0.00^{c}	10.88 ± 0.69^{c}	14.87 ± 0.22^{c}	30.16 ± 0.47^{f}
140	15.28 ± 0.86^{gh}	1.06 ± 0.00^{a}	8.43 ± 0.20^{de}	15.52 ± 0.28^{b}	27.03 ± 0.56^{g}
160	18.10 ± 0.47^{f}	1.01 ± 0.01^{c}	7.92 ± 0.32^{e}	9.30 ± 0.27^{d}	30.14 ± 0.48^{f}
180	28.39 ± 0.54^{e}	1.01 ± 0.00^{c}	8.56 ± 0.28^{de}	7.56 ± 0.13^{e}	86.27 ± 0.63^{c}
200	31.28 ± 0.95^{d}	1.02 ± 0.01^{b}	7.47 ± 0.19^{ef}	6.25 ± 0.11^{e}	90.90 ± 0.69^{b}
220	53.11 ± 1.03^{c}	1.01 ± 0.01^{c}	8.33 ± 0.03^{de}	4.91 ± 0.04^{f}	93.44 ± 0.35^{a}
240	84.00 ± 1.00^{b}	1.03 ± 0.00^{b}	11.55 ± 0.36^{b}	0.66 ± 0.07^{g}	33.93 ± 0.51^{e}
260	91.33 ± 1.52^{a}	1.04 ± 0.00^{b}	20.00 ± 0.56^{a}	0.53 ± 0.02^{g}	16.32 ± 1.91^{h}

Values are mean ± standard deviation of three determinations (n = 15). Values followed by different superscript in a column are significantly different ($p \leq 0.05$)

The reducing sugar of juice was increased from 0.12 to 7.04 mg mL^{-1} in 260 DAFS. It has reported that fructose and glucose content of mandarin fruit increased from 13.06 to 36.72 mg mL^{-1} and 16.53 to 19.77 mg mL^{-1}, respectively, during ripening [34].

SSC: acid ratio of juice increased with maturity; however, a regular increasing trend could not be noticed (Table 1).A ratio of 6 or higher is acceptable for the commercial marketability of pomelo fruit [30].

Effect of different stages of maturity on naringin content and phytochemical properties of pomelo fruit

Pomelo is a good source of naturally synthesized bitter components, i.e., naringin. Immature fruit juice had a significantly higher amount of naringin content (40.27 μg mL^{-1}) than the juice of mature stages (0.53 μg mL^{-1}) (Table 1). Flavedo exhibits a higher level of naringin than the other parts of fruits [35]; most of the secondary metabolites of plants tend to accumulate in growing tissues and organs [36]. Even the synthesis of flavonoids in citrus fruits is regulated via the phenylalanine pathway, which is highly regulated in nature [37]. However,the reduction in naringin content during maturation is may be due to the increase in the diameter of fruit and dilution of flavonoid [22, 38].

β-carotene content of peel at various maturity days was estimated and presented in Fig. 1e. An increasing trend in β-carotene content appeared during the maturity of pomelo (62.43–211.51 mg g^{-1} of peel). Kato et al. [39] explained that the expression of genes such as *PDS, ZDS, LCYb,* and *ZEP* increases as the maturity of citrus fruit progressed. So carotenoid accumulation increased due to the increased interaction of the expression of the above-mentioned genes. Chlorophyll content of peel was seen highest at initial stages (52.46 μg g^{-1} of peel) while lowest at mature stages (11.94 μg g^{-1} of peel) (Fig. 1e). The reduction in green colour occurs mainly due to the loss in structural chlorophyll caused by several factors including changes in pH (mainly due to leakage of organic acids from the vacuole), influenced by the accumulation of organic acids in the vacuoles, oxidative and enzymatic reactions, leading to the synthesis or unmasking of carotenoids in the vacuoles [27].

Radical scavenging activity of juice at various days of maturity was evaluated in terms of ABTS (Table 1). ABTS value of juice was increased with maturity and attained maximum scavenging activity at 220 DAFS and, after that, showed a decreasing trend. The total antioxidant capacity of fruits is attributed to the combined activity of various antioxidants, including vitamin C and phenolics, rather than being a credit to any particular antioxidant and concordant with the result of Yoo et al. [40].The loss in antioxidant activity on the attainment of maturity may be due to the drop in phytochemical content in the fruit during ripening [41].

Evaluation of different quality attributes for maturity determination

Quality attributes of juice, such as BrimA, RPI, and IQI, were calculated at different maturity levels, and a significant difference was observed ($p < 0.05$) (Fig. 1f).No systematic trend was observed in the BrimA index, where an increasing trend was seen from 140 to 180 DAFS and decreasing gradually from 200 to 260 DAFS. Initial days of maturity exhibits high acidity and lower SSC, which affected the BrimA or SSC/TA parameters [42]. BrimA mainly depends on SSC and TA with a constant factor (k), and change in one of these two factors can significantly affect the result. The probable reason for the inconsistent trend of BrimA was the increased value of SSC and decreased value of TA with maturity.The coefficient of determination (R^2) for the relation between DAFS and BrimA was found at 0.73. The finding of Obenland et al. [42] supports the findings of the present study. Although in the present study, BrimA is not found a suitable maturity indicator; however, it may overcome the ambiguity of SSC: TA as a standard for citrus fruit. BrimA was found to effectively correlate better with the perception of sweetness or sourness of pomelo juice.

The RPI is used as a quality factor to determine the maturity level of fruits considering firmness, soluble solid content, and titrable acidity of the fruit. RPI of pomelo fruit was gradually decreased from 140 to 260 DAFS (Fig. 1f) and was mainly due to the progressive decrease of firmness and increase of SSC over maturity. The firmness of pomelo fruit at the onset of maturity was 47N at 100 DAFS, which decreased to 12N at 260 DAFS. The change in firmness attributed to the change in the structure of pectin polymers in the cell wall during ripening [6]. Initially, the juice content was too low due to immature juice sac and lack of juice in the pulp, which confers the highest firmness and low SSC (5.5%) and TA (0.42%). It has been reported that, as the fruit attains maturity, the rate of starch hydrolysis is faster. At the onset of the ripening of fruit, the starch content present in fruit tissue is not sufficient to account for all the sugars, and this indicates that maturing fruit continues the import of sugar until the harvest [43]. As it is evident from Fig. 1f, the change in RPI was proportional to the maturity of pomelo fruit (decreased from 6.02 to 4.05). RPI of pomelo fruit showed the R^2 (0.90) with DAFS. Thus, considering all the factors of RPI of pomelo, it can be concluded from his study that, the fruit having RPI of 5.3–5.7 may possess acceptable sensorial attributes along with desirable chemical properties.

The IQI was performed for pomelo fruit to classify the maturity stages based on peel colour properties (L^*, C^* and h^*), firmness of pomelo fruit (F), SSC, and TA of fruit juice.

From the result, it was observed that no regular trend of IQI throughout the pomelo maturity and the maximum value (18.91) was noticed at 180 DAFS while the minimum value (17.07) at 220 DAFS (Fig. 1f). According to Munera et al. [11], the immature fruit shows a higher IQI than the mature fruits. In colour properties, hue and chroma are derived properties, which also considers a^* and b^* value of fruits and from Fig. 1f it can be seen that how these values change over the maturity and affect the adjacent properties significantly as a result of an inconsistent IQI index. The relation between IQI and DAFS was established where R^2 of 0.07 was observed. Herrero-Langreo et al. [44] suggested that the wide variation in the colour properties of fruit details the heterogeneous distribution in the ripeness of fruit. In the study of Munera et al. [11], where IQI index was found better than RPI for persimmon fruit variety, but in our study, RPI gave better understanding to classify maturity indices over IQI.

In the present investigation, the studied quality attributes of pomelo gave a better insight into the inevitable changes in the pomelo fruit and their correlation with others parameters during the maturity, which could be helpful in the optimal selection and transportation of pomelo fruit.

Development of color chart for maturity classification

Figure 2 illustrates the estimated representative colour for nine stages (gap of 20 days) of pomelo fruit, where LR stands for the lower range and HR for a higher range. The colour chart and findings of growth attributes, biochemical properties, and quality attributes were correlated to develop a useful colour chart for the quick determination of stages of maturity of pomelo fruit with maximum possible retention of phytochemical properties. As it is evident from Fig. 1a, b, and Fig. 2, the colour chart obtained from colour space allows us to predict an appropriate time of fruit maturity and also in determining the optimum harvesting period. Based on colour chart and other properties, the harvesting period 200–220 DAFS was found optimum for pomelo.

Colour based mapping of the maturity indices by applying ANN

Determination of maturity properties of fruits based on color features is a challenging aspect to keep up product quality during fruit processing. For accomplishing this particular

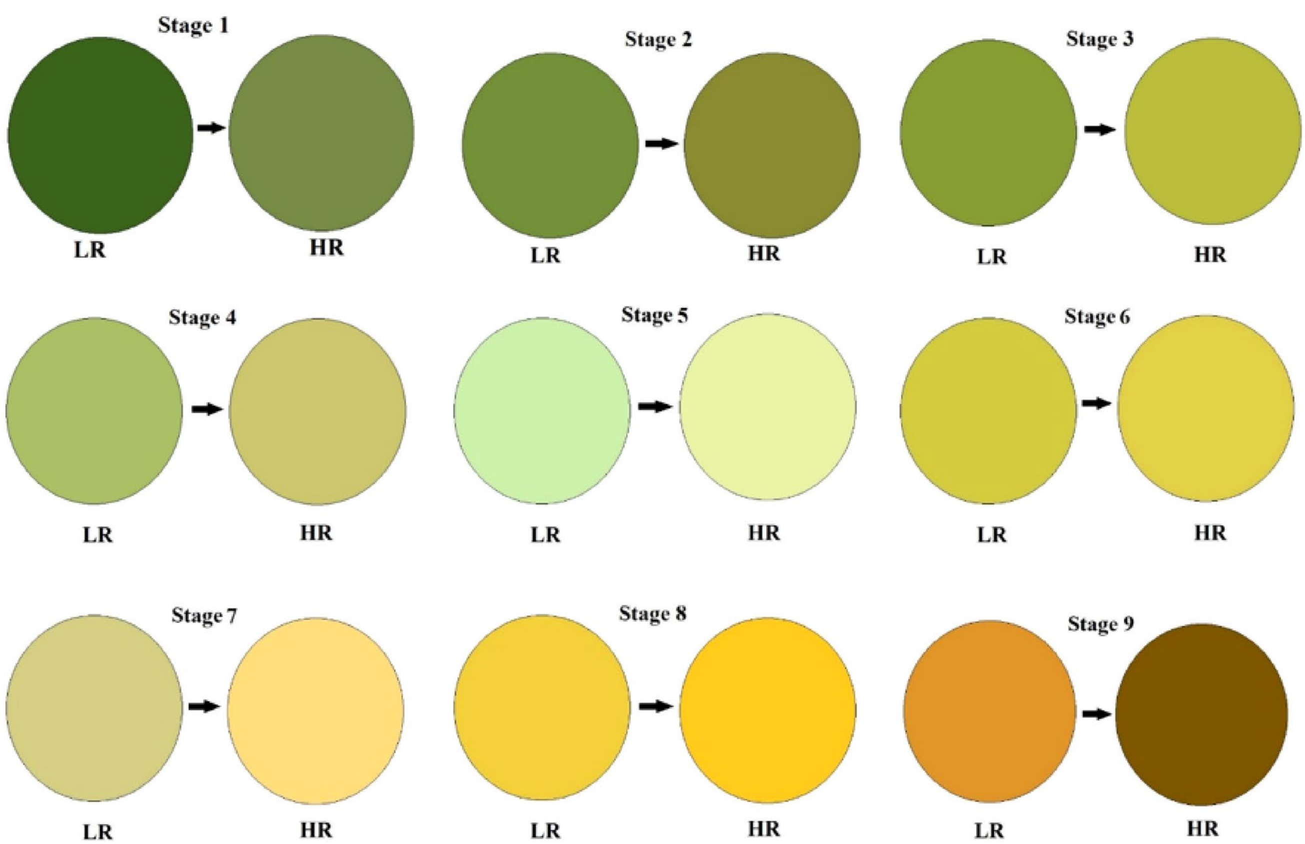


Fig. 2 Color chart based on color spaces to discriminate the maturity stages (Stage 1–9 corresponds to 100–260 DAFS) of pomelo fruit where LR stands for lower range and HR for Higher range (Color figure online)

aspect, a mathematical relationship between the color features and maturity properties is always needed. In the present study, ANN modeling was applied for the mapping of colour parameters and various maturity indices of pomelo fruit. The best network was selected based on the highest R^2 (0.99) and lowest RMSE values. Figure 3b show the selection of ANN architectures. Best ANN architecture as observed from Fig. 3b was three neurons in the input layer, five neurons in the hidden layer, and five neurons in the output layer (3-5-5). The plots for the training, testing and validation stages of ANN between target and predicted outputs are illustrated in Fig. 3c. Adequacy of the developed ANN model can also be observed from the stage wise illustration of the figure. Weight and bias values of the best ANN architecture ('W_{ih}', 'W_{ho}', 'T_h' and 'T_o') were determined by a random number of generations in the developed code. The matrices for these values are given as follows:

$$W_{ih} = \begin{pmatrix} 0.57 & -3.60 & -4.50 \\ 5.58 & 3.97 & -2.89 \\ 4.08 & 9.98 & 1.51 \\ 4.67 & 3.56 & 0.34 \\ 5.66 & 4.55 & -1.47 \end{pmatrix}$$

$$W_{ho} = \begin{pmatrix} 0.23 & -3.09 & 1.21 & -1.35 & 4.65 \\ -0.19 & 1.77 & -0.70 & 0.77 & -2.78 \\ -0.09 & -0.21 & 0.83 & -0.55 & 0.73 \\ -0.22 & 0.92 & -0.72 & 0.24 & 0.65 \\ 0.44 & -0.73 & -0.13 & 1.52 & 1.19 \end{pmatrix}$$

$$T_h = \begin{pmatrix} -3.25 \\ 2.43 \\ -5.45 \\ 2.12 \\ 2.65 \end{pmatrix} T_o = \begin{pmatrix} 0.53 \\ -0.41 \\ 0.10 \\ 1.55 \\ 1.64 \end{pmatrix}$$

Hence, in the present investigation, different colour parameters (L^*, a^*, b^*) were used to predict the pomelo fruit maturity indices with the help of the developed ANN model. The model successfully developed a correlation between the colour parameters and various maturity indices along with the growth characteristics and biochemical properties of pomelo fruit. This ANN model with the architecture of 3-5-5 can be used for the forecasting of pomelo fruit maturity based on color features. If any processor has colour features estimated as decided based on color chart (as referenced in the past segment) then different maturity properties of the fruit can be evaluated by utilizing this 3-5-5 ANN architecture. A similar type of maturity kinetics of various fruits and vegetables based on colour parameters are reported by various researchers [44–48].

Conclusion

In the present investigation, the effect of maturity on the growth characteristics, biochemical properties, phytochemical properties, and quality attributes of pomelo fruit was investigated. Quality indicators presented a significant correlation with DAFS, where RPI and chlorophyll were found to decrease while β-carotene and BrimA increased with maturity. A color chart was developed for the determination of an appropriate plucking time of the pomelo fruit. The developed chart also correlates the stages and chemical changes that occur in the fruit during ripening. By considering color parameters as input and quality indicators as output variables, ANN architecture was mapped where 3-5-5 was found as the best ANN architecture for the prediction of pomelo maturity. The model can be applied for the prediction of various maturity indices of the fruit based on color values obtained at different stages. Among all the quality attributes, RPI of pomelo fruit showed the highest R^2 (0.90) with DAFS, which predict its better suitability as a maturity standard than other for pomelo fruit and this study can be considered as an informative and pioneering approach for the processor of pomelo fruit products and beverages.

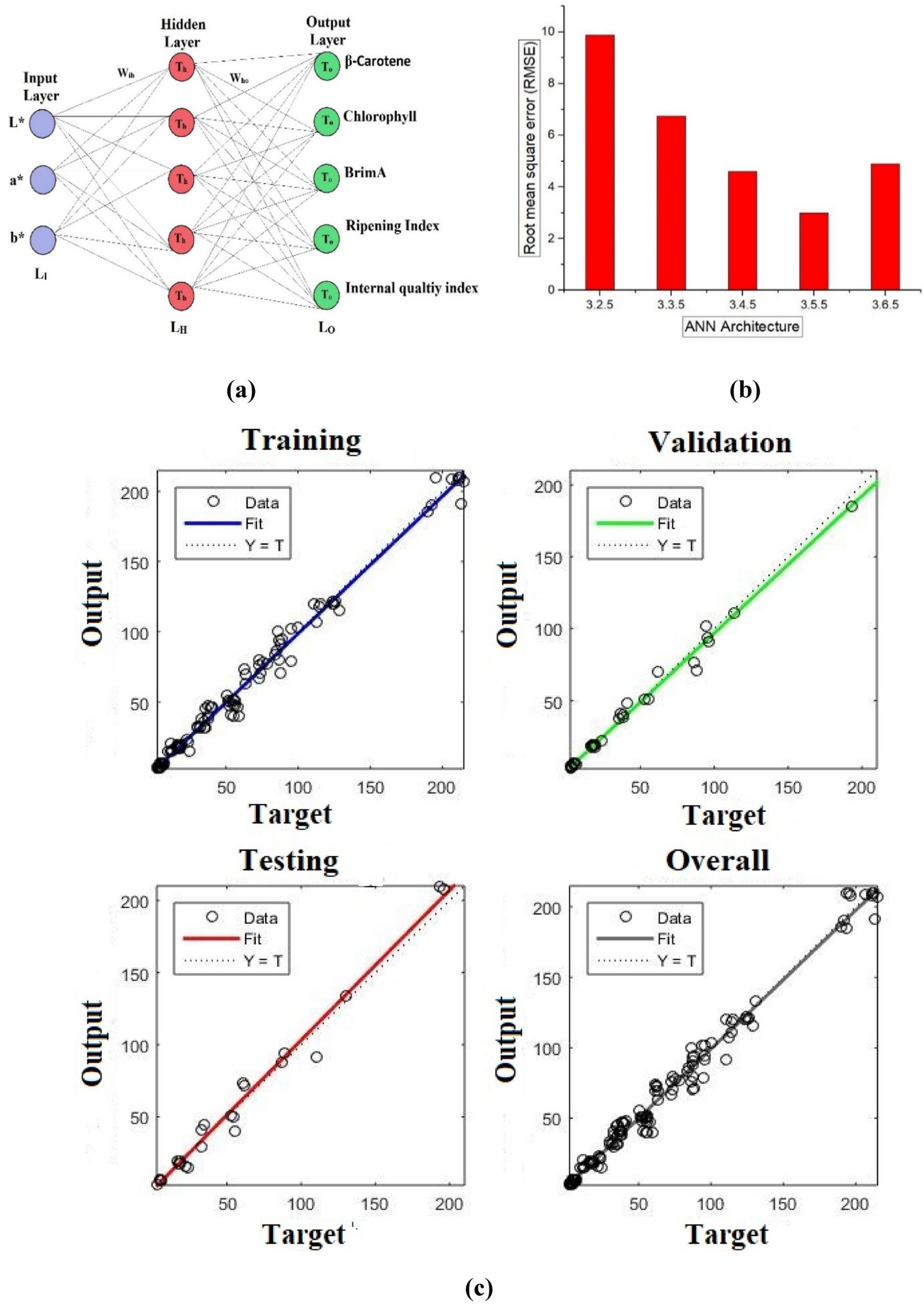


Fig. 3 **a** Best ANN architecture **b** selection of ANN model **c** plot between experimental and predicted ANN values for maturity prediction

Acknowledgements The authors are grateful to the SERB-DST (sanction no: EMR/2016/006550), India, for funding this research and also would like to acknowledge to UGC-National Fellowship for OBC for providing Junior Research Fellowship to one of the co-authors.

References

1. X. Liu, J. Li, J. Chen 2014 Citrus: molecular phylogeny, antioxidant properties and medicinal uses, Nova Science Publishers, Inc. New York. Ch-4, 51–72.
2. M.W. Cheong, X.Q. Loke, S.Q. Liu, K. Pramudya, P. Curran, B. Yu, Characterization of volatile compounds and aroma profiles of Malaysian pomelo (*Citrus grandis* (L.) Osbeck) blossom and peel. J. Essent. Oil Res. **23**, 34–44 (2011)
3. C.M. Stinco, R. Fernández-Vázquez, D. Hernanz, F.J. Heredia, A.J. Meléndez-Martínez, I.M. Vicario, Industrial orange juice debittering: Impact on bioactive compounds and nutritional value. J. Food Eng. **116**, 155–161 (2013)
4. H. Kelebek, S. Selli, Determination of volatile, phenolic, organic acid and sugar components in a Turkish cv. Dortyol (*Citrus sinensis* L. Osbeck) orange juice. J. Sci. **91**, 1855–1862 (2011)
5. H. Zheng, Q. Zhang, J. Quan, Q. Zheng, W. Xi, Determination of sugars, organic acids, aroma components, and carotenoids in grapefruit pulp*s*. Food Chem. **205**, 112–121 (2016)
6. S.K. Kalra, D.K. Tandon, B. P. Singh, Mango 1995 In. Salunkhe, D.K., Kadam, SS (eds). Handbook of Fruit Science and Technology-production, composition, storage and processing. Mercel Dekker, Inc., New York, 123–169
7. M. Bouzayen, A. Latché, P. Nath, J.C. Pech, *"Mechanism of Fruit Ripening", in Plant Developmental Biology-Biotechnological Perspectives* (Springer, New York, NY, USA, 2010)
8. C.H. Crisosto, Stone fruit maturity indices: a descriptive. Postharvest News Information **5**, 65–68 (1994)
9. A.L. Vásquez-Caicedo, A. Heller, S. Neidhart, R. Carle, Chromoplast morphology and β-carotene accumulation during postharvest ripening of mango cv. 'Tommy Atkins.' J. Agr. Food Chem. **54**, 5769–5776 (2006)
10. V. Cortés, C. Ortiz, N. Aleixos, J. Blasco, S. Cubero, P. Talens, A new internal quality index for mango and its prediction by external visible and near-infrared reflection spectroscopy. Postharvest Biol. Technol. **118**, 148–158 (2016)
11. S. Munera, C. Besada, J. Blasco, S. Cubero, A. Salvador, P. Talens, N. Aleixos, Astringency assessment of persimmon by hyperspectral imaging. Postharvest Biol. Technol. **125**, 35–41 (2017)
12. W. Castro, J. Oblitas, M. DeLaTorre, C. Cotrina, K. Bazan, H. AvilaGeorge, Classification of cape gooseberry fruit according to its level of ripeness using machine learning techniques and different color spaces. IEEE Acess **7**, 27389–27400 (2019)
13. W. Castro, J. Oblitas, T. Chuquizuta, H. Avila-George, Application of image analysis to optimization of the bread-making process based on the acceptability of the crust color. J. Cereal Sci. **74**, 194–199 (2017)
14. S.F. Oliveira, F.J. Gonçalves, P.M. Correia, R.P. Guiné, Physical properties of *Physalis peruviana* L. Open Agric. **1**, 55–59 (2016)
15. F. Avila, M. Mora, M. Oyarce, A. Zuñiga, C. Fredes, A method to construct fruit maturity color scales based on support machines for regression: application to olives and grape seeds. J Food Eng. **162**, 9–17 (2015)
16. D. Wu, D.W. Sun, Color measurements by computer vision for food quality control-a review. Trends Food Sci. Technol. **29**, 5–20 (2013)
17. W.B. Davis, Determination of flavanones in citrus fruits. Anal. Chem. **19**, 476–478 (1947)
18. A.K. Biswas, J. Sahoo, M.K. Chatli, A simple UV-Vis spectrophotometric method for determination of β-carotene content in raw carrot, sweet potato and supplemented chicken meat nuggets. LWT-Food Sci. Technol. **44**, 1809–1813 (2011)
19. H.Y.M. Qudsieh, S. Yusof, A. Osman, R. Abdul Rahman, Effect of maturity on chlorophyll, tannin, color, and polyphenol oxidase (PPO) activity of sugarcane juice (Saccharum officinarum var. yellow cane). J. Agr. Food Chem. **50**, 1615–1618 (2002)
20. K.K. Dash, S. Chakraborty, Y.R. Singh, Modeling of microwave vacuum drying kinetics of bael (Aegle marmelos L.) pulp by using artificial neural Nnetwork. J. Inst. Eng. India Ser. A. (2002). https://doi.org/10.1007/s40030-020-00431-x
21. R. Bharali, L. Saikia, Physico-chemical changes associated with growth and development of pummelo (Rabab Tenga, white flesh, Citrus grandis L.) fruit. J Food Sci. Tech. Mys. **41**, 696–699 (2004)
22. E.V. Miller, J.R. Winston, H.A. Schomer, Physiological studies of plastid pigments in rinds of maturing oranges. J. Agric. Res. **60**, 259–267 (1940)
23. M. Olmo, A. Nadas, J.M. García, Non-destructive methods to evaluate maturity level of oranges. J. Food Sci. **65**, 365–369 (2000)
24. J.W. Sites, H.J. Reitz, The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. Part II. Titratable acid and the soluble solids/titratable acid ratio of the juice. Proc. ser. Soc. hort. Sci. **55**, 73–81 (1950)
25. P.N. Kale, P.G. Adsule, Citrus 1995 In DK Salunkhe, SS Kadam, VN Reinhod (eds) 'Handbook of fruit science and technology: production, composition, storage and processing', New York, 39–65
26. R. Mansour, Determination of nutritional composition in citrus fruits (*C. aurantium*) during maturity. Nutr. Food Sci. **49**, 299–317 (2019)
27. L. Butkhup, S. Samappito, Changes in physic-chemical properties, polyphenol compounds and bantiradical activity during development and ripening of MAOLUANG (*Antidesma bunius* L, Spreng) fruit. J. Fruit Ornam. Plant Res. **19**(1), 85–99 (2011)
28. M.S. Ladaniya, *Commercial Fresh Citrus Cultivars and Producing Countries. Citrus Fruit: Biology, Technology and Evaluation* (Academic Press, San Diego, 2008), pp. 13–65
29. L. Samukelo, A. Mditshwa, S. Zeray, U. Linus, An overview of preharvest factors affecting vitamin C content of citrus fruit. Sci. Hortic. **216**, 12–21 (2017)
30. J. Lado, M.J. Rodrigo, L. Zacarías, Maturity indicators and citrus fruit quality. Stewart Postharvest Rev. **10**, 1–6 (2014)
31. H. Karlıdag, I. Bolat, Determination of the chemical and physical properties of some apricot cultivars growing at different altitudes in Malatya, Turkey. V. Nat. Hort. Congr. **1**, 782–785 (2007)
32. B. Prinsi, A.S. Negri, C. Fedeli, S. Morgutti, N. Negrini, M. Cocucci, L. Espen, Peach fruit ripening: a proteomic comparative analysis of the mesocarp of two cultivars with different flesh firmness at two ripening stages. Phytochem. **72**, 1251–1262 (2011)
33. FC Doerflinger, JF Nock, Y AlShoffe, X Shao, CB Watkins 2014 Non-destructive maturity assessment of'Empire'apples treated with preharvest inhibitors of ethylene perception and production with a delta absorbance (DA) meter. In XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes. 1119, 227-234
34. F. Li, L. Gong, Z. Deng, A. Gentile, G. Long, D. Li, Seed, sugar and acid characteristics of 'Zaomi' ponkan (*Citrus reticulate*

Blanco), a spontaneous mutant of 'Xinnu.' Sci. Hortic. **225**, 707–715 (2017)
35. M. Zhang, C. Duan, Y. Zang, Z. Huang, G. Liu, The flavonoid composition of flavedo and juice from the pummelo cultivar (*Citrus grandis* (L.) Osbeck) and the grapefruit cultivar (*Citrus paradisi*) from China. Food Chem. **129**, 1530–1536 (2011)
36. P.S. Jourdan, C.A. McIntosh, R.L. Mansell, Naringin levels in citrus tissues: II. Quantitative distribution of naringin in *Citrus paradisi* MacFad. Plant Physiol. **77**, 903–908 (1985)
37. P.R. Chaudhary, H. Bang, G.K. Jayaprakasha, B.S. Patil, Variation in key flavonoid biosynthetic enzymes and phytochemicals in "Rio Red" grapefruit (*Citrus paradisi Macf*) during fruit development. J. Agr. Food Chem. **64**(47), 9022–9032 (2016)
38. J. Castillo, O. Benavente, J.A. del Rio, Hesperetin 7-O-glucoside and prunin in Citrus species (*C. aurantium* and *C. paradisi*). A study of their quantitative distribution in immature fruits and as immediate precursors of neohesperidin and naringin in *Citrus aurantium*. J. Agr. Food Chem. **41**, 1920–1924 (1993)
39. M. Kato, Y. Ikoma, H. Matsumoto, M. Sugiura, H. Hyodo, M. Yano, Accumulation of carotenoids and expression of carotenoid biosynthetic genes during maturation in citrus fruit. Plant Physiol. **134**, 824–837 (2004)
40. K.M. Yoo, K.W. Lee, J.B. Park, H.J. Lee, I.K. Hwang, Variation in major antioxidants and total antioxidant activity of yuzu (*Citrus junus* Sieb ex Tanaka) during maturation and between cultivars. J. Agr. Food Chem. **52**, 5907–5913 (2004)
41. U.A. Fischer, R. Carle, D.R. Kammerer, Identification and quantification of phenolic compounds from pomegranate (*Punica granatum L.*) peel, mesocarp, aril and differently produced juices by HPLC-DAD–ESI/MSn. Food chem. **127**(2), 807–821 (2011)
42. D. Obenland, S. Collin, B. Mackey, J. Sievert, K. Fjeld, M. Lu, Determinants of flavor acceptability during the maturation of navel oranges. Postharvest Biol. Technol. **52**, 156–163 (2009)
43. R. G. Atkinson, D. A. Brummell, J. N. Burdon, K. J. Patterson, R. J. Schaffer 2015 Fruit growth, ripening and post-harvest physiology. In B. Atwell, P. Kriedemann, C. Turnbull (Eds), Plants in Action. Chapter 11.
44. A. Herrero Langreo, L. Lunadei, L. Lleó, B. Diezma, M. Ruiz Altisent, Multispectral vision for monitoring peach ripeness. J food sci. **76**(2), 178–187 (2011)
45. M. Paulraj, C.R. Hema, K. Pranesh, S. Sofiah, M. Radzi 2009 Color recognition algorithm using a neural network model in determining the ripeness of a banana in Proc. Int. Conf. Man-Mach. Syst. Arau, Malaysia: Univ. Malaysia Perlis. 2B71–2B74
46. M.S.B.S. Rizam, A.R. Farah Yasmin, M.Y. Ahmad Ihsan, K. Shazana, Non-destructive watermelon ripeness determination using image processing and artificial neural network (ANN). Int. J. Elect. Comput. Eng. **3**, 332–336 (2009)
47. DJ Damiri C Slamet 2012 Application of image processing and artificial neural networks to identify ripeness and maturity of the lime (Citrus medica). 1 171 179
48. N. Fadilah, J. MohamadSaleh, Z. AbdulHalim, H. Ibrahim, S. Ali, S. Salim, Intelligent color vision system for ripeness classification of oil palm fresh fruit bunch. Sensors **12**, 14179–14195 (2012)

Affiliations

Arun Kumar Gupta[1] · **Manisha Medhi**[1] · **Sourav Chakraborty**[1] · **Monica Yumnam**[1] · **Poonam Mishra**[1]

[1] Department of Food Engineering and Technology, Tezpur University, Tezpur, Assam, India