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Maturity Indices of Kinnow Mandarin (*Citrus reticulata* L.) Fruit Based on Image Processing Technologies – A Review

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ABSTRACT

Kinnow mandarin is a popular citrus fruit in northern India. Citrus cultivars differ in numerous ways, including color, texture, flavor, harvesting time, nutritional content and so on.Consumer acceptance of Kinnow mandarin is determined by their rich orange color, size and other quality characteristics such as TSS and acidity. Since there is a high link between the intrinsic ripeness and the outer rind colour of the fruit, evaluating maturity based on color characteristics is suitable approach. Kinnow's marketability is determined by two factors: Color and size. Fruit length, breadth and mass could all be used to determine size. Color, on the other hand, is a matter of interpretation predicated on vision and could be described in mathematical terms in order to examine it. To evaluate the degree of acidity, sugar and flavonoids in fruit with greenish to fairly deep peel-coloration during prior maturation stage under various environmental circumstances,fruit internal composition with regard to color change is necessary. The purpose of this review was to explore into whether the interior quality of the fruit varied as a result of skin color-break and size variations. It offers a quantitative indication for standardization for fruit ripening stages. As a result, during grading, it became a critical factor to develop an indication that accurately represents the true ripening stage.

Keywords Kinnow, Color, Acidity, Sugar, Size.

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INTRODUCTION

Fruits and vegetables account for approximately 90% of horticultural output in India. India is the world's second-largest producer of vegetables and fruits, including first-place finishes in papaya, mango, kinnow mandarin, cashew nut, arecanut, potato and okra. The nation provides just 1% to the worldwide market because to inadequate post-harvest management methods and a lack of trained personnel. Meanwhile, the most visible item is fresh fruit waste, which accounts for 30 to 35 % of total output at different stages of handling such as harvesting, grading, sorting, packing, and so on (Pathmanaban *et al.* 2019). After the harvesting phase in an agriculture fresh produce process, post - harvest storage system is one of many options. The improvement of post - harvest storage techniques is one approach to ensure food security. Heat, moisture, Carbon dioxide and ethylene gases are produced during storage of post - harvest products. Fruit and vegetable physical and chemical changes after postharvest treatments are significantly nonlinear, including respiration and qualitative loss (Salehi 2020). For the last several decades, the horticulture sector has witnessed considerable technological advancements focused at decreasing food post - harvest loss, with non-destructive (ND) technologies being more widely used for fruit quality assessment and assurance. Optical and acoustic vibration, computer vision methods, computerized tomography, electronics noses, near infrared spectrophotometry, hyperspectral imaging and smart packaging are just a few of the approaches available. These developing ND methods for quality monitoring and evaluation, as well as packaging and storage options, are regarded as the key actors that will assist achieve extended quality preservation in fruit and vegetables in future implementations. Future trends also favor the use of intelligent packaging, which includes ND sensors for chemical, biological, or physical properties, as well as the radio-frequency identification into packaging systems, to track the total stability of product throughout transportation or storage (Nturambirwe Opara 2020).

External (visible) as well as internal characteristics affect fruit and vegetable quality. Internal quality properties include pH value, carotenoids, ascorbic acid, sugar, flavonoids content, phenolic content, total antioxidant and body firmness, total soluble solid content (TSS), total acidity (TA), ratio of total soluble to total acidity. Size, shape, skin color and overall appearance are indeed the basic external quality characteristics. Antioxidant, nutritional and enzymatic activity, as well as texture, are the most significant quality criteria for vegetables (Abasi *et al.* 2018). Fruit maturity indices are determined using both destructive and non-destructive methods. The destructive technique is used to determine the characteristics of fruits, but it is costly, requires expertise, and results in material damage. When compared to destructive methods, the non-destructive technique (NDT) is more dependable, less costly and there is no risk of material damage. Mechanical, biochemical, sensorial, physiological, optical, electrochemical, electromagnetic and magnetic characteristics are used in non-destructive techniques to determine fruit ripeness. The result of NDT is provided in real-time and without delay. This technique may be utilized in both an *insitu* and *exsitu* setting. Size, form, abscission characteristics, color and other physical qualities are all involved. Sensors can readily assess these characteristics in most NDT in a different kind that may assess chemical composition such as starches, total carbohydrate, acidity, dry matter and ethylene production (Arunkumar *et al.* 2021). Photographic images are the primary source of data and valuable information in agriculture, but estimating or processing photographic data statistically is difficult. As a result, image processing techniques helps in the processing of images and the perseverance to extend their evaluation. By electronically detecting a photo, interpreting and recognizing the characters and providing information to an overall quality sorting and grading machine, machine vision technology imitates the effect of human eyesight in evaluating the quality of fresh fruits and vegetables (Bhargava & Bansal 2021). In this reviews, application of image processing for evaluation of ripening of kinnow mandarin, bruise reorganization, maturity indices standardization was discussed.

Quality attributes

Color, flavor (taste and smell), texture and nutritional value are the four main characteristics used to evaluate the quality of fresh fruit and vegetables. The appearance of a product determines whether it is accepted or rejected in the market. As a result, among the most important quality characteristics is appearance. Aroma relates to a product's odor, while flavor encompasses both aroma and taste (spiciness, sweetness). The taste and inner quality, which is evaluated by soluble solid content (SSC) (primarily sugars), Titratable Acidity (TA), Soluble Solid to Acid (SSC/TA) and Texture, influence the consumer's satisfaction (Pathmanaban *et al.* 2019). The quality of fruits and vegetables is affected by a vast number of genes as well as the surrounding environment. There may be many varieties of a single fruit or vegetable species. Although there were significant variations across varieties, the ripening process continued during storage period with elevations in color intensities and reductions in acidity, as well as improvements in phenolics and anthocyanins influencing fruit or vegetable quality (Zhang *et al.* 2018). An automated monitoring system based on signal impulse response was used to examine apple firmness variations during cold storage. A spinning disc for locating fruit samples, an electro-magnetic oscillating mechanism, a camera and microphone, a computer and a sensing element to determine the position of apples were all incorporated in the gadget. They claimed that the method is highly repeatable and that it is more sensitive to hardness variations than a penetrometer. The gadget performed well when stored in a cold environment (Abasi *et al.* 2018). Mobile application for watermelon ripeness assessment based on sonic impulse response has been created. The amplitude input generated from watermelon samples at three locations (bottom, middle and top) was compared to maturity indices (sweetness and size). They discovered a negative relationship between the sweetness rating and the primary frequency peak. Furthermore, in the case of big watermelon samples, the accuracy of the Android application was superior. The created program may be used to identify watermelon ripeness, according to the data (Pintor *et al.* 2016). Taste is often described in terms of a balance of sweet and salty characteristics that indicate maturity and taste in fruits and vegetables. Total soluble solids (TSS) level is a reasonable indication of overall amount of sugar and also most fruit and vegetables should have a minimum solids composition to become harvested. Sugar and acids are present in soluble solid, as are minor quantities of soluble vitamin, protein, polyphenolic compounds, mineral and pigment (Petropoulos *et al*. 2017).

Image processing technologies

Conventional visual inspection is labor-intensive and susceptible to human mistakes and unpredictability, computer vision techniques have become more helpful in the fruit sector. Earlier studies have shown that image processing can detect quality characteristics in agricultural commodities with excellent precision. A computer vision-based method was designed to evaluate the maturity indices of Kinnow mandarins. The research shows that the model invented via second order polynomial transformation is effective for calculating the fruit maturity indices. The shifting skin color of the fruit show a significant correlation well with experimentally determined physico chemical characteristics (Hadimani and Mittal 2019). Defect detection on a variety of foods has been studied in the context of food quality inspection. The Hyper spectral imaging (HSI) technology and multi-spectral imaging methods were used in earlier studies to identify flaws on particular apple varieties. Using on multispectral imaging metadata, other researchers formulated an algorithm based on hyperspectral imaging to detect citrus black spots. Within the spectral region of 480 nm to 950 nm, multispectral images of citrus fruits were taken. The NDVI of the VNIR bands enhanced citrus black spot identification effectiveness from 92.0 % to 96.7 % (Bulanon *et al.* 2013). Depending on HSI analysis of spectral characteristics of apples, a multi-spectral image processing system with appropriate filters was developed and excellent separation of dead skin, fungus and microbial contamination, and bruises were acquired via PCA or the chlorophyll-absorption peaks (Mehl *et al*. 2002). According to a recent research, combining Raman spectroscopy (SORS) with the RI system may detect the seven different maturity stages of tomato by monitoring the decrease of the lutein and carotene concentration. This gives you precise results for different stages (premature & mature green, red and mild red, pink). The development of Raman Peaks is measured using SID (Spectral information divergence) (Qin *et al.* 2012). Various studies were carried out and the results ultrasonic signal to monitor growth changes in various fruit types such as kiwi, avacado, and mango, and the results were recognized as a quick and accurate quality assessment. When compared to other methods, an ultrasonic technology coupled with a computer vision system yields more precise findings in determining fruit ripeness (Tao *et al*. 2018). Thermographic imaging system with emissivity difference was used to determine the levels of maturity of fresh palm fruits. During digital imaging, a (FLIR E60 and T440) camera is employed, as well as a thermometer for temperature measurements. The emissivity of oil palms is 95 % for overripe, underripe and ripe palms, according to the findings (Zolfagharnassab *et al.* 2016). A microwave lens, one antenna as either a transmitter, an absorbance or luminescence sensor, a lighting source and a PC with appropriate software to analyze and handle data constitute together a standard microwave imaging system. Microwaves selectively contact to the unbound water compounds, resulting in localized heating. The Bristol University laboratory has investigated the microwave imaging technique for determining fruit ripeness by estimating water content rather than color. While reconstructing the internal area itself of the fruit, the algorithm is used to recognize and record the difference due to variations with in the dielectric properties of the interior tissue. The system can detect seeds underneath grapefruit, lemon and differentiate among seedless and seeded samples, accordingly (Hussain *et al*. 2018, Ghavami *et al.* 2019; Sachin *et al.* 2020).To identify early rottenness in oranges, hyperspectral fluorescence imaging technology was being used. The optimised band combination was determined using the Optimum Index methodology. Based on the optimum bands ratio images and two threshold settings, a detection accuracy of 100% was obtained (Li *et al*. 2012). Scanning laser Doppler vibrometery technique is employed to acquire the large data even without touch with an outer surface of fruit. This technique mainly being used assess the mechanical characteristics to changes in composite materials and biological materials. The ripened fruit have greater hardness as comparison to matured fruit lead to acquired beneficial characteristics of a substance. Using the ''resonance signature" of the fruits, they can categorize the stages of fruits to sort and grade purposes. This technique extensively used in mango ripeness evaluation because the hardness of mango decreased progressively during developing to stages of ripeness, thus the resonance spectra also gradually reduced which vanished there at ripened stage (Arunkumar *et al.* 2021). Food quality has been assessed using both spatial and temporal protons magnetic resonance imaging (MRI) methods. The MRI method was used to evaluate fruit ripening in citrus, persimmon and oil palm fruit in order to identify cellular structure, moisture condition of internal characteristics and fungal growth inhibition. When light passes through a sample, it transmits, absorbs and reflects. That's how laser backscattering imaging (LBI) operates. Some photons are reflected as a result of light contact with the interior constituents of biological tissue and they include information about the sample's physical characteristics, molecular structure, color and shape. In one further research, multiple ripening stages of bananas were identified with 97.3 % using optimum wavelengths of 532 nm, 660 nm, 785 nm, 830 nm, and 1060 nm. Nearly invisible wavelengths of 532 nm, 660 nm and 785nm provide the best results. Although the absorption coefficient exhibited a negative connection, the scattering coefficient revealed a positive association among various ripening stages (Pathmanaban *et al.* 2019). Another investigation was carried out with the goal of determining the potential of dielectric power spectroscopy in determining sugar content in sugarcane. This technique is effective for estimating sugar content at 0-6 MHz as well as sugar-water solution at 6-10 MHz, according to the results (Naderi-Boldaji *et al.* 2015). The sample location may affect TSS content prediction using NIR spectroscopy, particularly for vegetables and fruits with a thicker peel. TSS equations derived from NIR spectra (500–1010 nm) significantly differed with regard to the sampling site. The stylar-end location predicted the TSS concentration of melons better than the equatorial sampling point. The soluble solid concentration of Newhall navel oranges too was discovered to be dependent on spectral data collected from various locations (Cakmak 2019).

Fruit maturity correlation

The ripeness of a fruits and vegetables is one of the most important markers for determining its inside composition. This feature is critical in determining the harvesting, transportation, marketing, and food consumption logistic operations. The interior quality of Kinnow fruits was investigated using the peel coloration during early maturity as a criterion. Fresh fruit quality encompasses nutritional content (mineral, protein, carbohydrates, dietary fiber, vitamins and polyphenols), visual appeal (deterioration and defect-free, color, dimensions, smooth finish, and morphology), flavor (tartness, fruitiness, fragrance and sourness/ acidity) and texture (firmness, toughness, juiciness and crispness) (Singh *et al.* 2021, Venthodika *et al.* 2021). Green-colored fruits had greater acidity, homogeneous polyphenols and enhanced reducing sugars having acidic taste once maturity approaches, but yellow-colored fruits had reduced acidity, richer sugar and total soluble solid components to give considerable sweetness(Nawaz *et al*. 2019). Models for estimating tomato ripeness have been suggested based on the usage of several chromaticity models. The Lab model, for example, enables the Minolta (a*/b*) to detect the six stages of tomato ripeness. A research of the firmness and color of the tomato was performed; they found that the required firmness though for commercialisation was 1.46 Nmm-1; they also discovered that the value from Minolta to (b*) shift from slightly negative to relatively positive magnitude throughout the stages of pink ripeness of the tomato. Fresh tomatoes may be readily sold when their Minolta (a*/b*) ratio reaches 0.6- 0.95 (Rupanagudi *et al*. 2014). The TSS/acid ratio is a commercial indication of citrus fruit inner maturity that is used all over the world. There is a significant correlation here between inner maturity and the exterior peel color of the fruit, measuring maturity based on color information. The closest correlation of (a*) 0.878 with TSS was found among the color coordinates, indicating the divergence of greenish to reddish color with sugar concentration. The strong 0.952303 correlation between (L*)and (b*) shows the color transition from deep green to pale green yellow (Hadimani and Mittal 2019). Persistent infestations of the pests result in scarring and a reduction in the quality of the fruit. They can be recognized when the fruit has achieved its usual mature color because of contrast in between sound rind and the defective one is great, but they are more challenging to notice at earlier phases of growth, once the rind remains green or becoming orange/yellow (Cubero *et al.* 2016). The frequency impulses generated from watermelon specimens at three locations (bottom, middle and top) was compared to maturity indices (sweetness and size). They discovered a negative relationship between the sweetness index and the primary frequency peak. Furthermore, in the case of big watermelon samples, the precision of the Android mobile application was improved (Pintor *et al.* 2016). Highly efficient mango detection and sorting method was developed. The mango's exterior quality characteristics were retrieved from the obtained image and implemented to determine the mango's classification. The mango's extracted characteristics were perimeter, projected area, roundedness and % defect. The mango's damaged regions were predicted correctly. Even when the mango's location was altered, the program correctly segmented it (Ganiron 2014). Although there were significant variations across varieties, the maturing process progressed during post - harvest storage involving rise in color intensity and reductions in acidity, as well as improvements in phenolics and anthocyanins, influencing fruit or vegetable quality. With growing maturity, the physio-chemical elements of fresh fruit and vegetables change. Study collected hyperspectral imaging data of three distinct maturity stages to evaluate the astringency of persimmons in order to minimize the impacts of maturity variation. To eliminate the scattering effects in the initial spectra, the standard normal variate (SNV) was employed. The findings showed that the pre-processing technique could effectively remove the impacts of maturity variation (Munera *et al.* 2017). Fluorescent illumination provided sufficient light to generate high-quality pictures for the computer vision system used to evaluate mangos. Mass of the fruit was found proportional to the Feret diameter, projected area and perimeter, but not to their roundness. The proposed geometry-based method is basic, but it effectively classified mangos into three mass classes with high accuracy using projected area and feret diameter as the indication (97 %) (Momin *et al.* 2017).

Features extraction

A characteristic in a fruits and vegetables images could be linked to shape, color, strength, size, composition, flavor, or a defect. Feature descriptors are widely employed for object identification and image recognition; they describe an image or a portion of one by preserving valuable information while discarding the unnecessary information. The objective of feature is to improve recognition rates by extracting features. These characteristics provide clear data that may be used for quality evaluation and analysis in the food industry. Color, texture and morphological characteristics are often used to assess vegetable and fruit defects and ripeness (Naik and Patel 2017, Bhargava and Bansal 2021). Color features may be retrieved from pictures after the color spaces have been defined. Many scholars have proposed many color characteristics, such as the color correlogram, color coherence vector, color moments and color histogram, among others. Color moment is one of them and it's both simple and powerful. The mean, standard deviation and skewness are the most frequent moments (Pathare *et al.* 2013; Bhardwaj *et al.* 2021). The red, green and blue inputs were reduced to two-dimensional color space coordinates using diffuse illumination and normalized brightness. For categorization, peach color was matched to typical peach maturity colors. Another study utilized color machine vision to separate Golden Delicious apples for damage detection. For comparison with example pictures, a color model was utilized as a reference. Satisfactory results were obtained after two further rounds of segmentation refinement utilizing either whole-fruit parameters or locally calculated values. Image analysis was utilized to estimate the maturity stage of tomatoes based on their color (Du and Sun 2004). Size is also measured in terms of length and breadth. Furthermore, despite area and perimeter, width and length are not clearly defined and therefore difficult to acquire due to the irregular shape of most of the food items examined (Zheng *et al.* 2006). Shape is an important graphical feature for image data description that is ambiguous due to the difficulty of measuring shape resemblance. The two types of shape descriptors are region-based (dependent on the object's total area) and contour-based. The aspect ratio, roundness and compactness of a shape are all factors to consider. Previously, the greatest width, length and diameter were employed to determine the size of the fruit. To sort apples, dates, papaya and eggplant, all of the aforementioned characteristics are incorporated. Diameters are used to sort strawberries, lemons and citrus. A prototype machine vision system predicated schedule grading and sorting was developed and implemented (Al Ohali 2011). The measures obtained from size are capable of expressing forms that can still be imitated by certain regular objects, such as a circle, ellipse or rectangle, but they can't be used to measure shapes that are extremely irregular, such as the shape of a fruit's whole body. Temporal juncture and Fourier descriptor are much more powerful when dealing with such shapes. The Fourier descriptor is preferred to the spatial moment since it is unaffected by size, position or orientation (Zheng *et al.* 2006). The texture of the fruit is influenced by its freshness and high sugar content. By identifying intensity distribution between pixels, it may also be used to separate distinct patterns in pictures. Texture may be studied using both quantitative and qualitative methods. Six textural characteristics, namely coarseness, contrast, line-likeness, roughness, directionality and regularity, were quantified. Subjective analysis identifies four characteristics: Correlation, contrast, entropy and energy. Statistic texture, structural texture, model-based texture and transform-based texture are examples of texture characteristics.Texture characteristics have been discovered to include valuable information for evaluating the quality of fruits and vegetables, such as the categorization of apple grade after drying with a 95% accuracy rate and the forecasting of sugar content in oranges with a 0.83 correlation coefficient. Furthermore, images of the interior structure of food items may be obtained with the use of imaging modalities (SI) and magnetic resonance imaging. More quality characteristics of fruits and vegetables may be discovered by using texture analysis, namely the co-occurrence matrix (COM) technique, to these pictures of interior structure (Thybo *et al*. 2004; Bhargava and Bansal 2021).Texture-based automated detection and categorization of four types of exterior defects linked with kinnow mandarins was the subject towards another study. LBP outscored another texture characteristic, while the merger of Gray-level co-occurrence matrix (GLCM) and Gray-level run length matrix (GLRLM) features showed the highest variance abilities over all selected features. Altogether, the findings show that the suggested models are acceptable for use in kinnow mandarin real-time defect classification (Hadimani and Garg 2021).

Prediction and validation of maturity indices

Due to the great degree of changeability in this crop, determining the best maturation stage for kinnow mandarin fruit can be difficult. Peel color, sugar content (TSS, %), titrable acidity (TA %) and TSS: TA ratio and juice content (%) are the more relevant maturity indices relying on current technologies. Maturity indices are also dependent on the target markets and emerging areas, therefore there are no universal or absolute values and different producer countries may use different maturity standards.The healthy peel of market citrus and mandarin should be orange in color, and abnormalities and stains ought to be distinctly separate colors. The major aims of machine vision post - harvest inspection of orange fruits is to measure size and color, as well as identify the appearance of defects, in order to classify the fruit depending on the quality given by these attributes. Another research implemented RGB and HSI color space color and texture traits to distinguish between seven typical citrus fruit abnormalities. The HSI color space produced the best outcomes, overall effectiveness ranging from 63% in the instance of scaling infestation to 100% inside the instance of stem-end breakage (Lopez *et al.* 2011). Studies showed that TSS had a very high correlation to the coloration parameters. The strong correlation of 0.878 with TSS was found among the color coordinate (a*), illustrating the shift of green to red color with the subsequent sugar concentration. The remarkable 0.952303 correlation value 0.952303 between (L*) and (b*) shows a color change from deep greenish to pale yellow. Parameters (a*) and (b*), on the other hand, have a significant correlation of 0.889738 (Hadimani and Mittal 2019). In citrus, fruit color is a significant quality attribute that has a direct influence on customer perception and recognition. The carotenoid composition (with over 100 distinct substances have also been observed in citrus fruit) are responsible for a range of color nonlinearities in different species, ranging from yellow in lemons and white grapefruits to red in red grapefruits, as well as a wide range of orange tones in oranges, mandarins, and crossbreeds (Lado *et al*. 2018). Fruit maturity is determined by the color of the fruit. Because color is one of the most important factors in determining ripeness, color categorization has been expanded to determine the ripeness of fruits depending on color differences within another variety. The R/G ratio was used to classify maturity levels. Furthermore, color study revealed that the color parameter was similarly effective in classifying maturity. The classifications matched the results of a human vision evaluation. As a result of the visual interpretation of fruits, one may categorize the citrus fruits based on color and ripeness, that is significant for fruits value addition (Iqbal *et al.* 2016). Using a machine vision system and also an NIR spectroscopy installed on a portable device, researchers were able to examine both the exterior (color and size) and interior (TSS and acidity) aspects of citrus fruits while harvested (Kohno *et al.* 2011). Internal composition of Kinnow mandarin fruit was examined. Ten fresh fruits were picked in the field, ranging in hue between deep green to completely red or yellow, then grouped into the sequence of deep green to dark red or yellow using a Chroma meter from been labeled 1 to 10. Alongside a rising pattern of sugars, total soluble solids (TSS), and pH, a gradual decrease of titratable acidity (TA), ascorbic acid and total soluble salts was observed in red colored fruits juice. In the rind, red colored fruits had the lowest chlorophyll content and the most carotenoid. Phenolic concentration in juice was comparable, with a downtrend in rind from greenish to reddish color fruits. Both rind and juice of reddish color fruit showed a rising trend in total anthocyanins. Because greenish yellow Kinnow contain higher ascorbic acid, polyphenol and the reducing sugars than reddish color Kinnow, both forms are excellent for exportation (Nawaz *et al.* 2019).

CONCLUSION

This paper reviews and outlines the non-destructive methods used to determine fruit maturity indices. It emphasizes the application of various image processing technologies in the area of fresh fruits and vegetables in the food industry. Shape, color, size, texture, and defect are the most significant quality features of agricultural goods. A machine vision system is used to replace manual food inspection, providing genuine, equitable, and non-destructive results. In each stage, an effort was made to investigate and compare the different methods/algorithms provided by researchers. These approaches may be used to replace traditional methods such as ocular examination and other harmful methods. Furthermore, other qualitative evaluations like as ripeness, maturity, firmness, and various physicochemical characteristics may be analysed more effectively utilizing these methods. Although these technologies are more expensive than human evaluation, they seem to be more precise and also save time to a higher extent. Furthermore, these methods may accurately anticipate a number of internal characteristics that are difficult to evaluate directly.

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