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USING IMAGE PROCESSING TO EVALUATE THE QUALITY OF ORANGE FRUITS IN A NON-DESTRUCTIVE MANNER

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Abstract

The aim of this research is to develop an image processing system that relies on machine vision to evaluate the chemical and physical properties in a non-destructive, fast and effective way to evaluate the quality of the orange fruits. Chemical and physical features such as TSS, titrated acidity, pH, TSS/T.acidity, liquid percentage, chlorophyll a, chlorophyll b, total chlorophyll and carotenoids were estimated. The results of the study showed that there is a relationship between the chemical and physical properties and the ripening of fruits. Relationships between R/G ratio range, G/R ratio, R/(R+G+B) range, NDVI1 index, VARI index, and VARI1 with some properties such as acidity, liquid percentage, pH, (TSS), TSS/ T.Acidity, chlorophyll a, chlorophyll b as well as the concentration of carotenoids at different ripening days. Correlation coefficient and multiple regression analysis were obtained by testing the correlation between (TSS), acidity, TSS/T. acidity, chlorophyll a, chlorophyll b and carotenoids, and ratios R/G ratio, R/(R+G+B), NDVI index and VARI index and VARI1 for orange fruits. The results showed that the mean of the indices of VARI, VARI1, NDVI1, and the R/G range provided a better indicator of the concentrations (TSS), acidity, TSS/T. acidity, and chlorophyll a and b for orange fruits. R/(R + G + B) ratio gave the highest regression coefficient with carotenoids (R^2=95***). while NDVI1 index gave the highest regression coefficient with chlorophyll a and chlorophyll b (R^2=91***and R^2=92***), respectively.

Key words: *image processing, orange fruits quality, RGB Index, chemical composition*

INTRODUCTION

The citrus fruit industry in Egypt is among the fastest-growing agribusiness industries in the country. Also, Egypt is one of the largest exporters in the world of some products such as oranges. citrus fruits in Egypt produced about 4.25 million tons of cultivated areas and amounted to about 0.42 million feddans in 2019/2020 (ASB, 2020) [2]. The average production of oranges in 2018 was 10.41 tons/ feddan, and increased to 10.64 tons/ feddan in 2020 (FAO, 2021) [12]. In 2020, Egypt became the first exporter of oranges in the world. The production and export of oranges increased dramatically over the past three decades. Egypt's exports also amounted to nearly 2 million tons of citrus, worth 661 million dollars (El-Khalifa et al 2022) [9].
Ahmed et al. (2011) [4] showed Orange juice is a rich source of water-soluble vitamins, ascorbic acid, and antioxidants important for our health. Citrus fruits provide a large amount of vitamin C, potassium, pectin, and folic acid, and also contain a large group of plant-based antioxidants that protect human health. Extensive studies focusing on the edible part of citrus fruits have shown that their juices and extracts possess important antioxidants because they are an important source of phenolic compounds, especially phenolic acids, and flavanones (Ramful et al 2010) [22]. Apart from the importance of orange juice color in product quality, it is important to measure the transaction accurately as it has been demonstrated that color measurements can be used to rapidly estimate carotene content for quality control purposes using some techniques (Meléndez - Martínez et al 2010) [20]**.** Orange juice is a rich source of water-soluble vitamins, ascorbic acid, and antioxidants important for

our health (Ahmed et al 2011) [4].

Wanitchang et al. (2010) [25] stated that the common destructive method for measuring the ripening and growth of dragon fruit is to analyze the total acid, pH, and total soluble solids, as well as the percentage of total soluble solids and the total weight converted into a major component, which is used to determine the individual maturity index. (Fouda et al. 2013) [13] used the Envi program to analyze orange images to help get some color properties which, there are the relations between it (VARI, R/G ratio band, and average of RGB bands indices) with carotenoids and chlorophyll a&b. this study aimed at the effect of citrus area analysis in terms of skin color and size in the RGB color model related to the ripeness, sweetness of citrus fruits. The relationship between citrus weight, body area, and fruit color was analyzed, and sweetness was measured by a refractometer. So was the Selection of size based on the image analysis results, as it was found to be related to citrus weight (Ahmad et al 2010) [3]. The study demonstrated the application of image processing to characterize the taste of oranges. The features are RGB component, color component ratio R/G and R/B. The results show that image processing can be used to classify the taste of oranges (Adelkhani et al 2013) [1].

According to colour vision systems are more useful for colour inspection. Red, green, and blue (RGB) components of an image can be represented by decoding a colour camera output into three images. Intensity, saturation, and hue images can be created by recombining the three elements of a colour image in hardware or software, which may make further processing easier (Ismail and Razali 2012) [16]. the vegetation index was correlated with the difference The natural (red–blue)/(red + blue) chlorophyll b, TSS content, titrated acidity and carotenoids, with R^2 values of 0.57, 0.57, 0.59 and 0.53, respectively. Our data showed that the newly developed index (NDVI-VARI)/(NDVI-VARI) showed highly significant and close correlations with chlorophyll, chlorophyll a and chlorophyll t readings, where R^2 = 0.78, 0.71 and 0.71, respectively (Elsayed et al 2016) [11]. Fouda et al 2017 [14] showed that the ENVI software package was used to analyze orange fruit images. The results showed significant correlations with some chemical and color indicators. The results obtained in this study show that the R/G ratio indices contribute to the understanding of total soluble solids and anthocyanins. Kaur et al (2018) [17] proposed a system based on the use of image processing techniques to identify the different ripening stages of the plum cultivar. The results showed that the RGB indicators of the fruit images were related to the chemical properties. It showed a strong correlation between the average intensity of green color and fruit acidity (R^2 = 0.9966). Also, the large variance in TSS was explained by the variance in the R/G ratio (R^2 = 0.8464). showed the development of many vegetation indices. The NDVI index was found to be the most studied and commonly used. Other indicators have been developed that use RGB data such as the Visible Atmosphere Resistance Index (VARI) (Costa et al 2020) [8].

The aim of this research is to use an image processing method to estimate the characteristics of oranges in a non-destructive and easy way including TSS, ph, titrated acidity, ripeness index TSS/T, chlorophyll a and b, carotenoids and the liquid percentage. The research is to detect the quality of navel oranges at different stages of ripeness using image indicators (RGB).

MATERIALS AND METHODS

This research was conducted in the laboratory of the Faculty of Agriculture, Tanta University. Navel oranges were randomly selected at different growth stages. The experiment was conducted in 2021 to predict the quality of Navel orange fruits by estimating chemical properties using image processing during different growth stages (Photo 1).

A Navel orange sample was selected from a private farm in Gharbia Governorate at different growth stages. The fruits were picked by hand and at random. Fruit samples were numbered one by one.

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Computer vision system

The system consists of a photographic box with a black, non-reflective fabric attached to a 20-megapixel digital camera. The camera was installed at a height of 25 cm from the bottom of the shooting box. The position of the two light sources has been adjusted to provide uniform light intensity. The photos were taken to capture shadow-free fruit images. After the images were taken, they were stored on a personal computer for analysis. Capture Cards (WINFAST DV2000, 320H X 240V). A personal computer was used to analyze the images.

Image	Color
	Dark Green
	yellowish green
	Orange

Photo 1. Orange images at different maturity stages
Source: designed by authors.

ENVI program: ENVI (Environment for Visualization Image) is the ideal software for the visualization, analysis, and presentation of all types of digital images. There are many ENVI handlers available, covering almost all the functionality available in ENVI interactive programs. Each processing routine is an IDL procedure or function and is used like any other IDL routine. A full index of these functions and a full reference page for each function can be found in the ENVI Reference Guide (available from ENVI Help)**.**The image processing steps up to an average value with three different RGB bands and image indices are shown in Fig. 1.

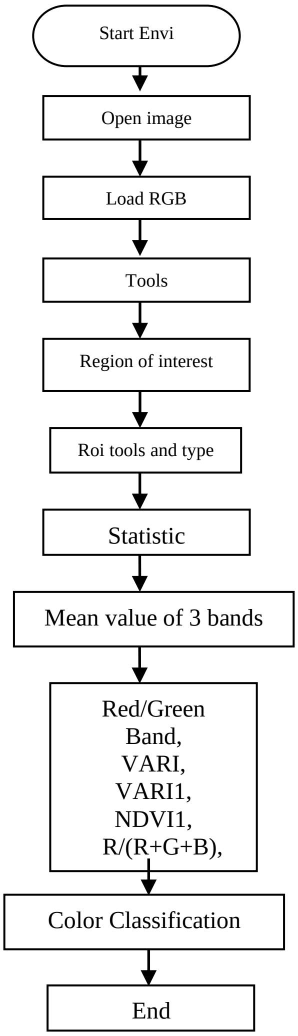

Fig. 1. Image processing steps until an average value with three different bands (RGB) and image indices.
Source: designed by authors.

Measurements

-The TSS: was estimated by reading a single digital refractometer taken from juice extracted from Orange fruits.

-Titrated acidity: The titrated acidity of Orange fruit juices was determined as a percentage of anhydrous citric acid by titrating a given volume of known juice with 0.1 N standard NaOH using 1% phenolphthalein as an indicator according to A.O.A.C. (1990) [5]**.**

-Maturity index (TSS /TA): TSS/ TA ratio was calculated from the soluble solid content values divided by the total acids values.

- **The pH** value was measured by using a pH meter.

-spectrophotometer: it was used for measuring the absorption at wavelengths 480, 645, and 663 nm chlorophyll a (chl,a), chlorophyll b (chl,b), and carotenoids (car.) content of crude extracts in different plants were determined following the method of (Arnon, 1949) [6].

Chlorophyll a mg/g = 12.7(A663) – 2.69(A645) $\times \frac{V}{1{,}000 \times W}$

Chlorophyll b mg/g = 22.9(A645) – 4.68(A663) $\times \frac{V}{1{,}000 \times W}$

Chlorophyll t mg/g= 20.2(A645) + 8.02 (A663) $\times \frac{V}{1{,}000 \times W}$

Total carotenoids(mg/g) =[A_{480} + (0.114 × A663) – (0.638 – A645)] $\times \frac{V}{1{,}000} \times W$

where:
A = absorbance at specific wavelengths.
V = final volume of chlorophyll extract.
W = fresh weigh of tissue extracted.

Calculations of image indices

Table 1. Various image indices have been studied and compared in this work using equations

Index abbreviation	Formulae	References
VARI	(Green − Red)/(Green + Red − Blue)	Gitelson et al. (2003) [15]
VARI1	(Green−VARI)/(Green +VARI + Blue)	Elsayed et al. (2016) [11]
NDVI1	(Red − Blue)/(Red + Blue)	Kawashima and Nakatani (1998) [18]
RGRI	R/G	Elmetwalli and Salah (2015) [10]
Nomalized Red (Rn)	R/(R + G + B)	Kumaseh et al (2013) [19]
GRRI	G/R	Aynalem et al. (2006) [7]

Source: [7, 10, 11, 15, 18, 19].

RESULTS AND DISCUSSIONS

Relation between Total Soluble solids (TSS) and image indices

The Total soluble solids (TSS) content of Navel orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the Total soluble solids content is low, and it increases with increase the maturity of the fruit (orange), therefore the Total soluble solids affected the image analysis collected from fruits. The correlation coefficient for the association between different band ratio indices and the measured (TSS) of Navel orange fruit is shown in Figure 2.

At various growth stages, most of the tested image analyses were remarkably significantly correlated with the measured (TSS). GRRI and Rn have the highest significant correlations for predicting the (TSS) concentration of Navel orange fruit. Overall various tested image indices, VARI, VARI1 and NDVI1 were also shown as the optimum indices for predicting (TSS) with a high determination coefficient of 0.90.

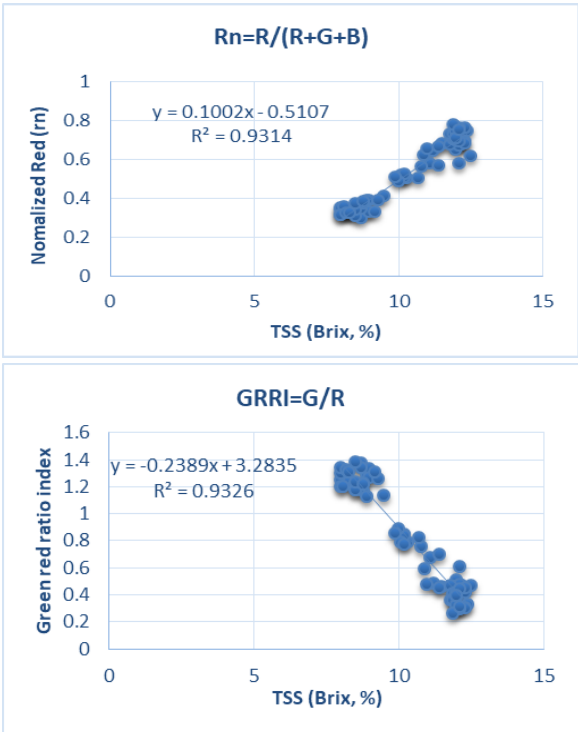

Fig. 2. Relation between Total Soluble solids (TSS) and image indices
Source: Own research results.

Figure 2 shows the relationship between GRRI and Rn and the (TSS) content of Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between both indices and the (TSS) content of orange fruits (R^2 = 0.93). Kaur et al (2018) [17] found that the large variance in TSS was explained by the variance in the R/G ratio (R^2 = 0.8464). Elsayed et al (2016) [11]found that the vegetation index was also correlated with the difference The natural (red–blue)/(red + blue) TSS content, R^2 values of 0.57.

Relation between Titrated acidity (T. acidity) and image indices

The Titrated acidity (T.acidity) content of Navel orange fruit is linked to the fruit growth stage.

At the first growth stage (green fruit), the Titrated acidity content is high, and it decreases with increase the maturity of the fruit (orange), therefore the Titrated acidity affected the image analysis collected from fruits.

The correlation coefficient for the association between different band ratio indices and the measured (T.acidity) of Navel orange fruit is shown in Figure 3.

At different growth stages, most of the tested image analyses were remarkably significantly correlated with the measured (T.acidity). NDVI1and VARI1 have the highest significant correlations for predicting the (T.acidity) concentration of Navel orange fruit.

Overall various tested image indices, VARI, Rn and GRRI were also shown as the optimum indices for predicting (T.acidity) with a high determination coefficient of 0.80.

Figure 3 shows the relationship between GRRI and Rn and the (T.acidity) content of Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between NDVI1and VARI1 indices and the Titrated acidity (T.acidity) content of orange fruits (R^2 = 0.91), (R^2 =0.86), respectively.

Kaur et al (2018) [17] showed a strong correlation between the average intensity of green color and fruit acidity (R^2 = 0.9966). Elsayed et al (2016) [11] found that the vegetation index was also correlated with the difference The natural (red–blue)/(red + blue) titrated acidity, R^2 values of 0.59.

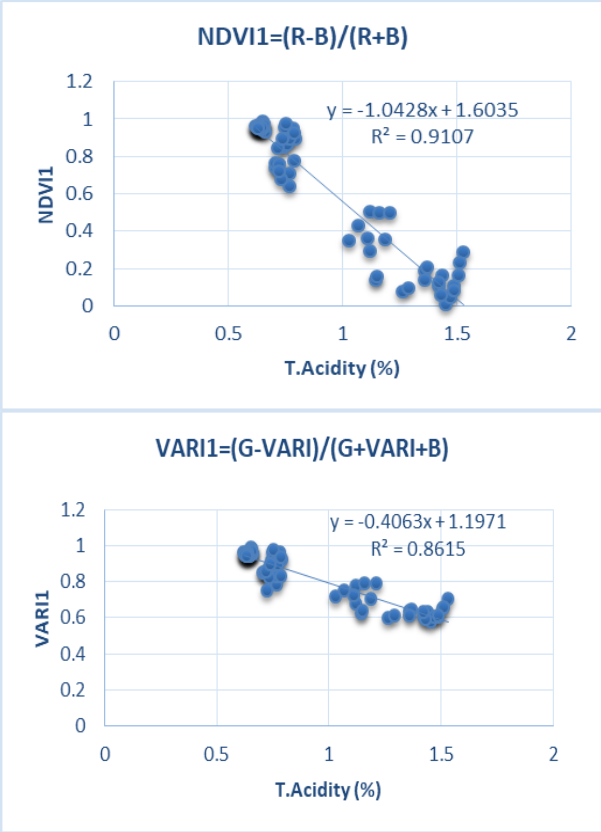

Fig. 3. Relation between Titrated acidity (T.acidity) and image indices
Source: Own research results.

Relation between Chlorophyll a (Chl, a) and image indices

The Chlorophyll a (Chl, a) content of Navel orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the (Chl, a) content is high, and it decreases with increase the maturity of the fruit (orange), therefore the (Chl, a) affected the image analysis collected from fruits. The correlation coefficient for the association between different band ratio indices and the measured (Chl, a) of Navel orange fruit is shown in Figure 4.

At different growth stages, most of the tested image analyses were remarkably significantly correlated with the measured (Chl, a). NDVI1and GRRI have the highest significant correlations for predicting the (Chl, a) concentration of Navel orange fruit. Overall various tested image indices, VARI, Rn, RGRI and NDVI were also shown as the optimum indices for predicting (Chl, a) with a high determination coefficient of (R^2 =0.85). Figure 4 shows the relationship between GRRI and Rn and the (Chl, a) content of

Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between NDVI1and GRRI indices and the (Chl, a) content of orange fruits (R^2= 0.91), (R2=0.88), respectively. Rasool et al (2022) [23] found that the image index (VARI) and (GRVI) showed the highest coefficients of determination for the fruit chlorophyll a of (R^2=0.85 and R^2=0.86), respectively. Elsayed et al (2016) [11] Our data showed that the newly developed index (NDVI-VARI)/(NDVI-VARI) showed highly significant and close correlations with chlorophyll a, where (R^2= 0.71).

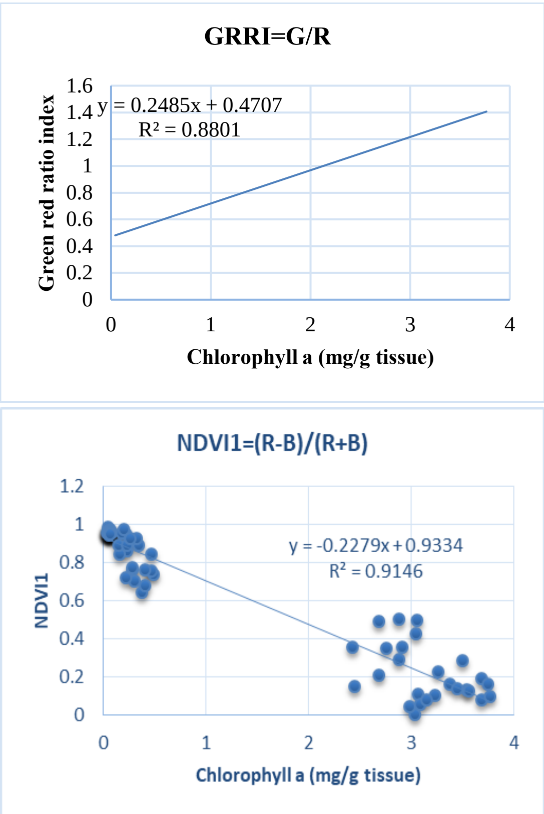

Fig. 4. Relation between Chlorophyll a (Chl, a) and image indices
Source: Own research results.

Relation between Chlorophyll b (Chl, b) and image indices

The Chlorophyll b (Chl, b) content of Navel orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the Chlorophyll b (Chl, b) content is high, and it decreases with increase the maturity of the fruit (orange), therefore the Chlorophyll b (Chl, b) affected the image analysis collected from fruits. The correlation coefficient for the association between different band ratio indices and the measured Chlorophyll b (Chl, b) of Navel orange fruit is shown in Figure 5. At different growth stages, most of the tested image analyses were remarkably significantly correlated with the measured Chlorophyll b (Chl, b). NDVI1and RGRI have the highest significant correlations for predicting the Chlorophyll b (Chl, b) concentration of Navel orange fruit. Overall various tested image indices, VARI, Rn, GRRI and NDVI were also shown as the optimum indices for predicting Chlorophyll b (Chl, b) with a high determination coefficient of (R^2=0.85).

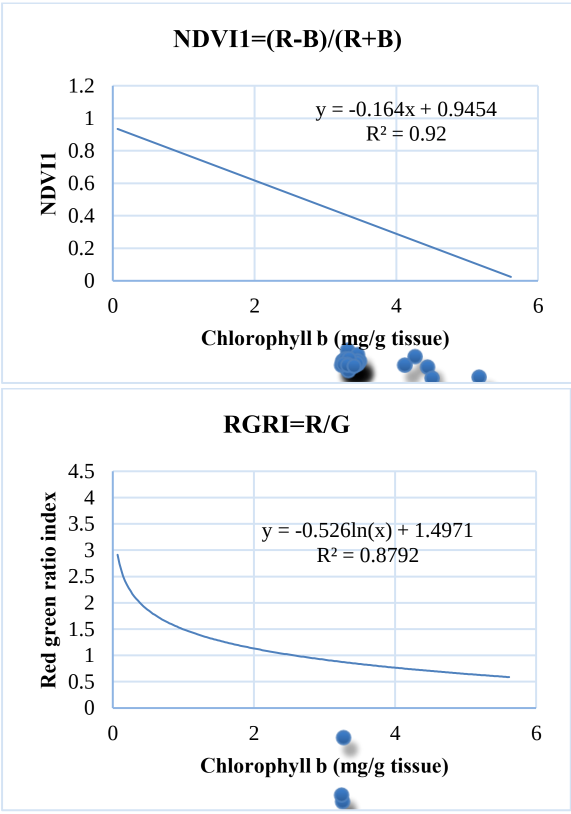

Fig. 5. Relation between Chlorophyll b (Chl, b) and image indices
Source: Own research results.

Figure 5 shows the relationship between GRRI and Rn and the Chlorophyll b (Chl, b) content of Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between NDVI1and RGRI indices and the Chlorophyll b (Chl, b) content of orange fruits (R^2= 0.92), (R^2=0.87), respectively. Rasool et al (2022) [23] found that the image index

(VARI) and (GRVI) showed the highest coefficients of determination for the fruit chlorophyll a of (R^2=0.85 and R^2=0.86), respectively. Elsayed et al (2016) [11] found that the vegetation index was also correlated with the difference The natural (red–blue)/(red + blue) chlorophyll b, R^2 values of 0.57.

Relation between Carotenoids (Car) and image indices

The Carotenoids (Car) content of Navel orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the Carotenoids (Car) content is low, and it increases with increase the maturity of the fruit (orange), therefore the Carotenoids (Car) affected the image analysis collected from fruits.

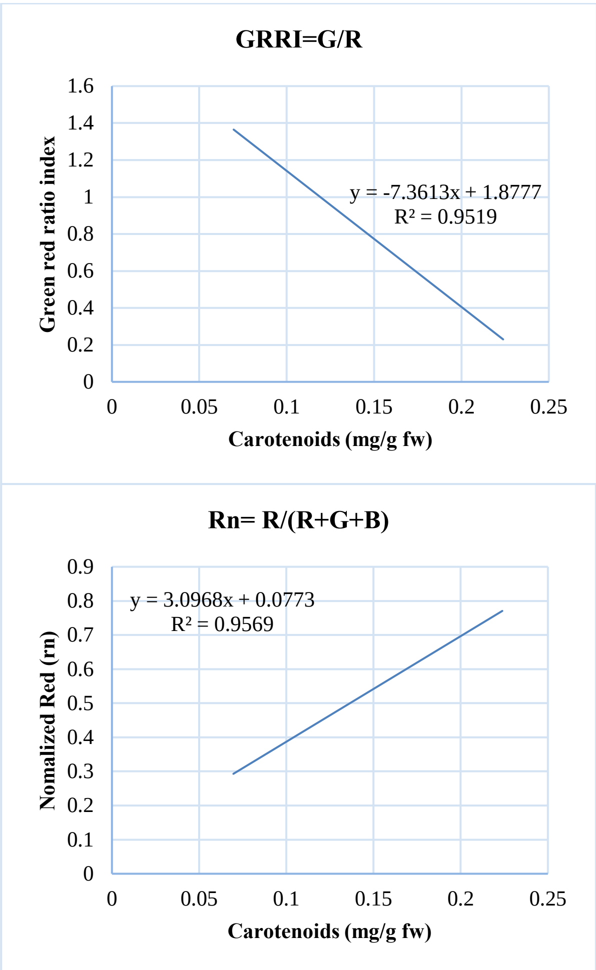

Fig. 6. Relation between Carotenoids (Car) and image indices
Source: Own research results.

The correlation coefficient for the association between different band ratio indices and the measured Carotenoids (Car) of Navel orange fruit is shown in Figure 6.

At various growth stages, most of the tested image analyses were remarkably significantly correlated with the measured Carotenoids (Car). GRRI and Rn have the highest significant correlations for predicting the Carotenoids (Car) concentration of Navel orange fruit. Overall various tested image indices, VARI, VARI1 and NDVI1 were also shown as the optimum indices for predicting Carotenoids (Car) with a high determination coefficient of (R^2= 0.90).

Figure 6 shows the relationship between GRRI and Rn and the Carotenoids (Car) content of Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between both indices and the Carotenoids (Car) content of orange fruits (R^2= 0.95). Elsayed et al (2016) [11] found that the vegetation index was also correlated with the difference The natural (red–blue)/(red + blue) carotenoids, R^2 values of 0.53.

Relation between liquid percentage and image indices

The liquid percentage content of Navel orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the liquid percentage content is low, and it increases with increase the maturity of the fruit (orange), therefore the liquid percentage affected the image analysis collected from fruits. The correlation coefficient for the association between different band ratio indices and the measured liquid percentage of Navel orange fruit is shown in Figure 7.

At various growth stages, most of the tested image analyses were remarkably significantly correlated with the measured liquid percentage. GRRI and Rn have the highest significant correlations for predicting the liquid percentage concentration of Navel orange fruit. Overall various tested image indices, VARI, VARI1, RGRI and NDVI1 were also shown as the optimum indices for predicting liquid percentage with a high determination coefficient of (R^2=0.70).

Figure 7 shows the relationship between GRRI and Rn and the liquid percentage content of Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between GRRI and Rn indices and the liquid percentage content of orange fruits (R^2= 0.75), (R^2=0.77), respectively. Salah et al. (2022) [24] Juice content of orange fruit should depend on R672/R550 which produced the highest correlations (R^2 = 0.91).

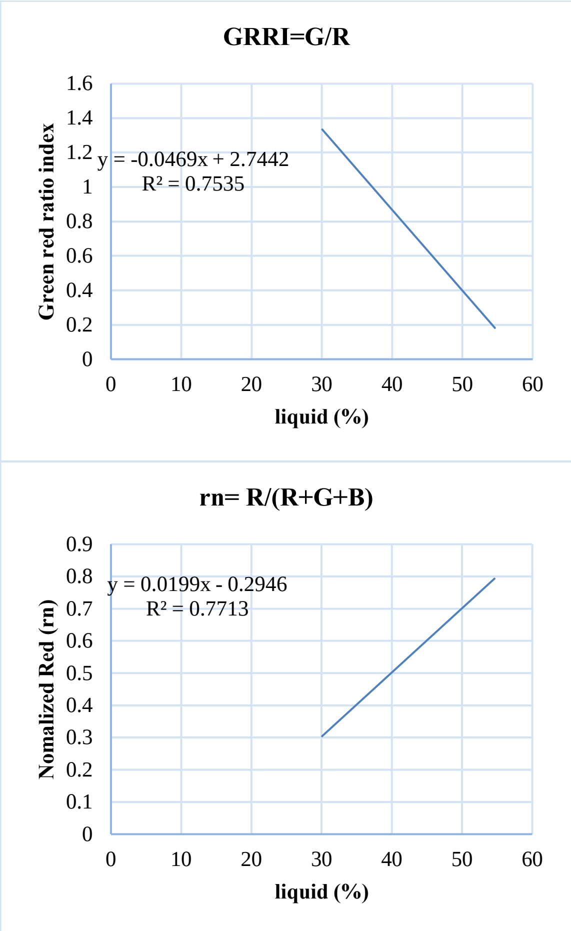

Fig. 7. Relation between liquid percentage and image indices
Source: Own research results.

Relation between Maturity index (TSS /TA) and image indices

The Maturity index (TSS /TA) content of Navel orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the Maturity index (TSS /TA) content is low, and it increases with increase the maturity of the fruit (orange), therefore the Maturity index (TSS /TA) affected the image analysis collected from fruits. The correlation coefficient for the association between different band ratio indices and the measured Maturity index (TSS /TA) of Navel orange fruit is shown in Figure 8.

At various growth stages, most of the tested image analyses were remarkably significantly correlated with the measured Maturity index (TSS /TA). GRRI and Rn have the highest significant correlations for predicting the Maturity index (TSS /TA) concentration of Navel orange fruit. Overall various tested image indices, VARI, VARI1, RGRI and NDVI1 were also shown as the optimum indices for predicting Maturity index (TSS /TA) with a high determination coefficient of (R^2=0.90).

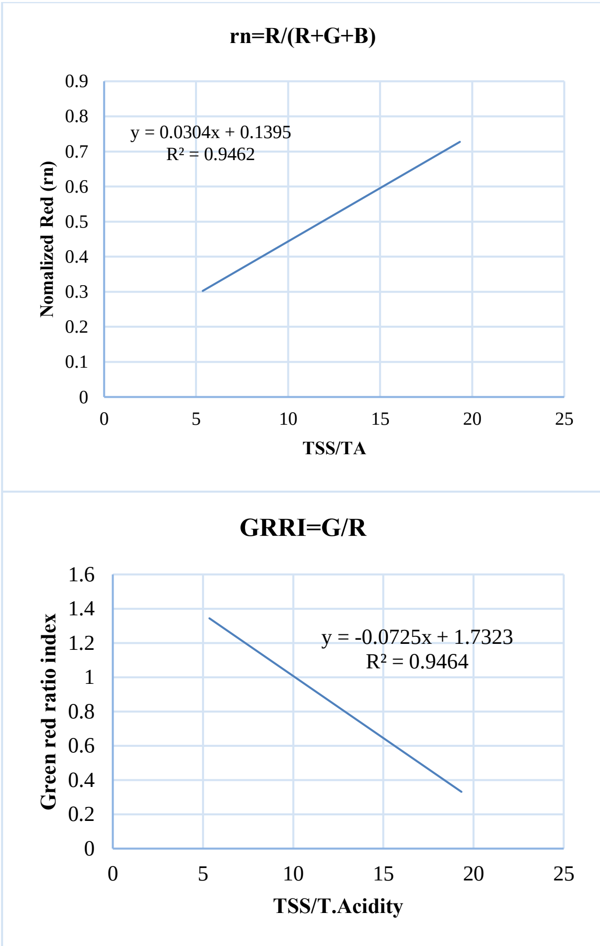

Fig. 8. Relation between Maturity index (TSS /TA) and image indices
Source: Own research results.

Figure 8 shows the relationship between GRRI and Rn and the Maturity index (TSS /TA) content of Navel orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between both indices and the Maturity index (TSS /TA) content of orange fruits (R^2 =

0.94). Pires et al. (2022) [21] found that the non-destructive assessment of the maturity of Citrus based on a prediction of internal quality characteristics (IQA). Which gave a good predictive performance for maturity index (MI) (R^2 = 0.80; RMSEP = 1.38; SDR = 2.2). Salah et al. (2022) [24] maturity index of orange fruit should depend on R672/R550 which produced the highest correlations (R^2 = 0.96).

CONCLUSIONS

An image processing technique was found to be an appropriate and accurate method for evaluating the quality of orange fruits. Relationships between the range of R/G ratio, G/R, Rn, VARI, VARI1, NDVI1 index with TSS, titrated acidity, chlorophyll a and b, carotenoids, liquid percentage, and maturity index (TSS/TA) were determined. Multiple regression analysis and correlation coefficient tested the association between TSS, titrated acidity, chlorophyll a and b, carotenoids, liquid percentage, Maturity index (TSS /TA) and various range ratios including G/R ratio and Rn to determine the optimal index sensitivity of fruit quality. The results showed that the range of R/G ratio, G/R, Rn, VARI, VARI1 and NDVI1 index provided a better index for the concentrations of TSS, titrated acidity, chlorophyll a and b, carotenoids, liquid percentage and Maturity index (TSS /TA).

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