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Hyperspectral Reflectance as a Tool to Measure Ripeness of Orange Fruits

Shimaa Salah ; A. H. Elmetwalli and M. S. Ghoname*

Agricultural Engineering Department, Faculty of Agriculture, Tanta University, Egypt.

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ABSTRACT

This work assesses the availability of depending hyperspectral indices to predict the chemical content of orange fruit under different growth stages. Using hyperspectral indices measurements to quantify varying chemical components of orange fruit including (chlorophyll, Ascorbic acid, Carotenoids, pH, Soluble Solids (%), juice percentage (%), titratable acidity results were expressed and maturity index. R_{672}/R_{550} gave the maximum correlation value for predicting the concentration of chlorophyll (a) with R^2 = 0.92. For predicting chlorophyll (b) that (NDI) indices show strong significant relationships with R^2=0.84. PSR gave the highest correlations for predicting the concentration of total chlorophyll of orange fruit at different growing stages with R^2 = 0.88 while for predicting the carotenoid concentration of orange fruit, it should depend on R_{672}/R_{550} which produced the highest correlation R^2 = 0.85. R_{672}/R_{550} was the best indices for predicting the ascorbic acid content of orange fruit at different growing stages with R^2 = 0.947. for predicting Soluble solids (SS) there is a high correlation with R_{672}/R_{550} and PSI, respectively which give the same R^2 =0.939. R_{672}/R_{550} showed high correlations for predicting the pH value of orange fruit with R^2 = 0.94 Predicting Juice content and maturity index of orange fruit should depend on R_{672}/R_{550} which produced the highest correlations R^2 = 0.91 and 0.96 respectively. PSR produced the highest correlations for predicting the titratable acidity of orange fruit were R^2 = 0.92.

Keywords: Hyperspectral reflectance, orange, chemical composition

INTRODUCTION

Orange is an economical crop that has various medical importance. From an economical point of view, Oranges are significant organic product crops financially, overall, from 4,63 million ha starting in 2019 (FAO, 2020). For Egypt, the orange industry is a significant part of the Egyptian public pay. The average orange yield in 2018 was 10.41 ton/feddan but in 2020 expanded to 10.64 ton/feddan. Orange creation expanded essentially in Egypt from 3085986 tons to 3157960 tons during 2018-2020 (FAO, 2021). Region reaped expanded additionally from 124577 to 124725 ha, individually. Orange juice considers a wealthy exporter of water-soluble vitamins which are important for our health, ascorbic acid, and antioxidants (Ahmed *et al*., 2011).

The ascorbic acid's role in our health is its capacity to remove free radicals and reactive oxygen types. It is possible to protect our cells from oxidative harm because of blocks lipid peroxidation by the renewal of vitamin E from oxidization (Guarnieri *et al*., 2007 Du, 2012). Orange includes a lot of minerals such as magnesium, calcium, potassium, thiamine, polyphenols, and flavonoids. It also treated atherosclerosis, LDL, circulatory strain, stomach sores, and stones of the kidney (Etebu and Nwauzoma, 2014).

For maximizing the efficiency of the economical use of the crop, sorting and grading are required to distinguish the fruits that reached external and internal maturity to meet the internal and external marketing specifications for export. Sorting agricultural products particularly fruits into classes according to their chemical properties is very important to reach international standards and thus maximize the final income. Human graders might make various decisions on a similar item in various cases and on the off chance that done by human graders it will be tedious likewise (Ajay and Amar, 2014). Areej *et al*., (2015) detailed that tone and size are the main elements for the precise arrangement and arranging of citrus. Orange evaluating precisely is restricted as of now. Normally, the orange reviewing is done physically.

The manual strategy was decided because this technique is quicker. Anyway, this technique is not proficient because of the need number of laborers. Utilizing labor supply to grade the orange is abstract since it is just considering human gathering. Arrangement results will often be inconsistence and experience erroneous evaluation because of weariness on natural eyes, (Putri, 2021). To increase the quality of sorted fruits, more accurate techniques (e,g image processing, spectral measurements) are needed to enhance the value of the products. Image processing is normally a technique used by researchers to determine the physical properties of fruits.

Hyperspectral imaging considers a new technique (Hall *et al*., 2002 & Gowen *et al*., 2007) that gathers data concerning how items mirror and retain light as an element of their frequency. This data is gathered in a wide band of the electromagnetic range and with an enormous otherworldly goal. Contrasting hyperspectral imaging and normal photography, in the previous, a large number of limited frequency groups are estimated while in the last just three wide frequency groups are estimated. In hyperspectral imaging, the frequencies estimated might be outside the band of frequencies where light is noticeable to the natural eye. The current work applies neighborhood hyperspectral imaging innovation to quality control in grape creation. Hyperspectral imaging strategy is one of the nondestructive innovations which exploit spectroscopic and imaging

*** Corresponding author.**
E-mail address: mohamed.ghonaim@agr.tanta.edu.eg
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procedures, giving phantom and spatial data at the same time (Lu *et al*., 2017). Wei *et al*., (2017) stated that categorizing maturity navel oranges with many multispectral indices are to depend on diffuse transmittance hyperspectral imaging. The indicator $(T670 + T760 - T640)/(T670 + T760 + T640)$ has a good performance for ripeness detection with the CCR of 96.0% by k-NN method.

(Wu and Sun (2013) showed that hyperspectral imaging could be utilized as an un-damaging finesse assessment of food and rural items. A hyperspectral imaging framework (imaging spectrometer) utilizing a business webcam has been planned and created. This framework had the option to catch two-layered spectra (in discharge, transmission, and reflection modes) straightforwardly from the scene in the ideal frequencies (Balooch, *et al*., 2018). Throughout recent years, hyperspectral imaging is one of the quickest developing apparatuses for non-disastrous examinations in various fields (Garini *et al*., 2006). The penetrometers estimations are to a great extent utilized because they are somewhat all-around related to the human view of solidness, however, there are issues engaged with the utilization of tests of differed calculations. Furthermore, the gadgets utilized for estimations are costly, and these procedures are slow, damaging, and not entirely versatile for arranging the line of leafy foods (Aboudaoud *et al*., 2012).

Physical and Chemical characteristics change during maturity, forming the final fruit quality at harvesting (Iglesias, 2007). Through the maturity of orange pulp, destroying citric acid led to reducing titratable acidity and raising total soluble solids (basis carbohydrates and minor quantities of proteins, lipids, and minerals) (Bermejo and Cano, 2012). Citrus organic products sugar can express by Brix rate, while sugar content in mature Valencia as g per100 g of juice. Sweet, squeezed orange was 14%, Brix (Ersus and Cam, 2007; Moufida and Marzouk, 2003). Fouda *et al*. (2013) 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. The important indicator to determine the quality of the citrus natural products was sugar/ acidity and its express flavoring quality (Goldenberg *et al*., 2014). Yalınkılıç *et al*. (2012) indicated that during the growth of orange fiber ph increased from 4.44 to 4.56. Abobatta, (2015) Valencia orange Juice % (w/w) was 30.17 to 49.43%, TSS/Acid ratio was 7.61 to 8.8, and vitamin C (mg/100g) was 37.19 to 54.8 (mg/100g). Grilo *et al*. (2017) showed that during harvest stages, the TA (g per 100 mL) decreased from 1.04±0.022 to 1.02±0.018 & TSS (%) increased from 12.2±0.21 to 13.0±0.16, and the ratio TSS/TA increased from 11.6±0.335 to 12.9±0.33 for the Valencia orange variety. Zvaigzne *et al*., (2017) Samples of juice to detect total soluble solid was 11.43 ± 0.00 °Brix, Total acidity was 0.79 ± 0.05 %, pH Ratio was 3.65 ± 0.00[a,] and vitamin "C" 53.65 mg·100 ml^{-1}in fresh unfrozen orange juice Navel.

From the abovementioned review, this investigation was based on the hypothesis that remote detection techniques can effectively detect various orange fruit chemical properties and this method considers nondestructive to know the chemical composition and then determine the maturity stage and this doesn't take a lot of time, accurate, high economic return and cheap while traditional ways depend on experience, not accurate and destructive.

The overall aim of this work was to evaluate the ability to use high spectral indices measurements to quantify varying orange fruit properties including pH, Soluble Solids (SS) (%), juice content (%), (Carotenoids, chlorophyll a, total chlorophyll, and chlorophyll b (mg/100g f.w), titratable acidity results were expressed as a citric acid percentage (%), Ascorbic acid (mg/100 ml), and maturity index (SS/TA) because of using image processing takes a lot of time.

Our main goal was to detect the chemical composition of the orange under different growth stage levels using high spectral indices.

MATERIALES AND METHODES

The main experiment was held at the laboratory of the faculty of agriculture, Tanta University. Orange fruit was selected randomly at various growth stages. The experiment was held in 2021 to predict the chemical composition of orange fruit using hyperspectral indices during different growth stages

Valencia orange sample variety was picked from the private farm at different growth stages. The fruits were picked manually and randomly selected. The fruit samples were numbered one by one.

Spectroradiometer model (ASD spectroradiometer) Boulder, Co 80301 USA). The range of this device is from 350 nm to 1075 nm, spectral sampling of 1.4 nm at 350-1000 nm, wavelength reproducibility of 0.1 nm, and wavelength accuracy of 1 nm.

The pH meter Model Fisherbrand™ FE150, the USA with an accuracy of 0.01was used to determine juice pH value.

UV-VIS spectrophotometer model UV1901PC with the range of 190 nm to 1100 nm, spectral bandwidth of 1nm; accuracy of wavelength ≤ ± 0.3nm, and wavelength reproducibility ≤ 0.1nm. It is used for measuring the absorption of wavelengths of 470,653 and 666 nm to determine chlorophyll and carotenoid using Eq. from (1) to Eq. (4).

Experimental procedure

The experiment was held in five following steps to determine and predict the chemical composition using high spectral indices as follows: -

1. Select several orange fruits in different maturity stage levels

Orange fruit was picked from a local farm in various maturity stages level. An equal number of fruits were used for each stage of maturity from green through yellow. The fruits were numbered according to their growth stage. Every stage had three replicates to reduce the relative error.

2. Spectral data collection

Spectral reflectance measurements were collected in a controlled dark room with a dimension of 2.5 * 2.5 * 2.7 m.A passive–reflectance spectroradiometer was employed to collect reflectance from orange fruit using an artificial illumination source. A non-reflective paint with roughly zero reflectance was used to cover the walls for minimizing the reflectance from the walls and floor. The detector and 300 W halogen lamps (2 lamps) were fixed on tripods. To maximize the scanning area, the detector was fixed at a distance of 70 cm from the fruit. A white Spectral on the reference panel (reflectance ≈ 100%) was used for calibrating the device. Over the whole growing season, the distance between the samples and the device was fixed. The VIS and NIR ranges were used to derive spectral indices. Table 1 shows examples of commonly used spectral indices.

3. Chemical constituents' measurements

varying properties of orange fruit including pH, Fruit Mass (gm), Soluble Solids (SS) (%), juice content (%), (Carotenoids, chlorophyll b, total chlorophyll, and chlorophyll a) (mg/100g few), titratable acidity results were expressed as a citric acid percentage (%), Ascorbic acid (mg/100 ml), and maturity index (SS/TA).

Titratable acidity (TA) (%)

Random samples of 100g of fruits at the full growth stage from each experimental plot were used to calculate the TA. of juice by titration with a 0.1N of NaOH (Sodium hydroxide) solution using phenolphthalein indicator, as the method described in A.O.A.C. (1990).

Fruit Mass (gm)

The mass of fruit samples was measured using a digital balance with accuracy up to 0.0001gm.

pH

PH was measured in juice by using a pH meter

Juice content (%)

It is determined by the weight of the orange fruit and orange juice volume in the same fruit

Soluble solids (S.S, %)

A refractometer (abb model) was used to measure the percentage of a solid soluble content in 10 fruits per treatment at the fully ripe stage and the data were expressed as Brix (%) according to (Cheour *et al*., 1991).

Maturity index (SS/TA)

It was identified by the value of Soluble solids (S.S.) and Titratable acidity (TA)

Ascorbic acid (mg/100 ml)

Dichlorophenol indophenol was used to measure vitamin C in the same samples to measure total acidity by the method described in A.O.A.C. (1990).

Pigments

The concentrations of chlorophyll a, b, total chlorophyll, and total carotenoids were determined according to Dere *et al*. (1998). Orange peel (0.1 g) was cut into a portion for 24 h at 4°C in 20 ml methanol (96%) and then filtered through Whatman 47 mm GF/C filter paper. The absorbance of each filtrate was measured against a blank of 96% methanol at wavelengths of 666 and 653 nm for chlorophyll a and b, respectively, and 470 nm for carotenoids by using Double Beam Spectrophotometer. Results were expressed as mg g^{-1} fresh mass (FW) and calculated using the following formulas:

$$\text{Chlorophyll (Chl.) a} = 15.65\ A666 - 7.34\ A653 \quad (1)$$

$$\text{Chlorophyll (Chl.) b} = 27.05\ A653 - 11.21\ A666 \quad (2)$$

$$\text{Total chlorophyll} = \text{Chl. a} + \text{Chl. b} \quad (3)$$

$$\text{Carotenoids} = [((1000A470) - (2.86\ \text{Chl. a} + 129.2\ \text{Chl. b}))/245] \quad (4)$$

4. Calculations of spectral indices

Various spectral indices have been studied and compared in this work using equations in table 1.

Table 1. Examples of spectral indices calculated from laboratory darkroom spectroradiometer

NOTATION	FORMULAE	REFERENCE
Normalized Difference Vegetation Index (NDVI)	(NIR-Red)/(NIR+Red)	Rouse *et al*., (1974)
Water Band Index (WBI)	(R_{950}/R_{900})	Riedell and Blackmer (1999)
(Ratio Vegetation Index RVI)	(NIR/R)	Jordan (1969)
PSI	$(R_{550}-R_{531})/(R_{550}+R_{531})$	Gamon, *et al*. (1992)
Soil-Adjusted Vegetation Index (SAVI)	((NIR1 band-Red band)/(NIR1 band +Red band+0.5))×(1+L)) ;L=0.5	(Huete,1988)
Normalized Water Index-1(NWI-1)	$(R_{970}-R_{900})/(R_{970}+R_{900})$	Babar *et al*. (2006)
Normalized Water Index-2 (NWI-2)	$(R_{970}-R_{850})/(R_{970}+R_{850})$	Babar *et al*. (2006)
NDVI hy	$(R_{800} - R_{680})/(R_{800} + R_{680})$	Blackburn 1998
$GNDVI_{br}$	(NIR-green)/ (NIR+green)	Buschmann and Nagel (1993) and Gitelson *et al*. (1996)
$GNDVI_{hy}$	$(R_{780} - R_{550})/(R_{780} + R_{550})$	Gitelson *et al*. (1996)
Simple Ratio Pigment Index (SRPI)	(R_{430}/R_{680})	Pen˜uelas and Inoue (1999)
Normalized Total Pigment to Chlorophyll a Ratio Index (NPCI)	$(R_{680} - R_{430})/(R_{415} + R_{430})$	Riedell and Blackmer (1999)
Normalized Phaeophytinization Index (NPQI)	$(R_{415} - R_{435})/(R_{415} + R_{435})$	Penuelas *et al*. (1995b)
Difference Vegetation Index (DVI)	NIR-Red	(Charles and Lautenschlager ,1983)
Pigment-specific simple ratio ($PSSR_b$)	R_{800}/R_{650}	Sims and Gamon (2002)
Pigment-specific normalized difference($PSND_b$)	$(R_{800} - R_{650})/(R_{800} + R_{650})$	Blackburn (1998)
$R_{shoulder}$	$Aver(R_{750} : R_{850})$	
Normalized difference index (NDI)	$R_{800} - R_{680}$	Hill *et al*,2014) and (Hestir *et al*., 2008)
SR hype	R_{800}/R_{680}	Blackburn (1998)
PSR	R_{680}/R_{430}	
Structure Insensitive Pigment Index (SIPI)	$(R_{800} - R_{445})/(R_{800} - R_{680})$	Penuelas *et al*. (1995a)
Yellowness Index (YI)	$(R_{580} - 2R_{630} + R_{680})/(50 \times 50)$	Adams *et al*. (1999)
Simple Ratio Index (SR)	NIR/Red	Birth and McVey (1968)
Specific leaf area vegetation index (SLAVI)	NIR/(Red+NIR)	(Lymburner *et al*, 2000)
OSAVI	[(NIR-Red)/(NIR+Red+L)] *(1+L), L = 0.16	(Rondeaux *et al*,1996)
VI1	NIR/(green-1)	Vina (2002)
VI2	$R_{800}/(R_{694} - 1)$	Vina (2002)
Renormalized Difference Vegetation Index (RDVI)	$\sqrt{NDVI \times DVI}$	(Roujean and Breon, 1995)
Selectivity index (SI)	Red/NIR	
Infrared percentage vegetation index (IPVI)	NIR/(NIR+Red)	Crippen, 1990)
Chlorophyll index green (CI_{green})	(NIR / Green) -1	(Raymond *et al*,2011)
Chlorophyll Index Red Edge ($CI_{red\ edge}$)	(NIR / Red edge) -1	(Ahamed *et al*, 2011)
R_{672}/R_{550}	(R_{672}/R_{550})	Datt (1998)
Near-infrared spectroscopy (C NIR)	$(Aver(R_{840} - R_{870})/Aver(R_{720} + R_{740}))-1$	

5- Statistical analysis

Statistical analysis was done using SPSS 22 programmed and Sigma plot programmed. Regressions were determined to evaluate the relationship between the spectral reflectance indices presented in Table 1 and the chemical parameters. Coefficients of determination and significance levels were determined.

RESULTS AND DISCUSSION

Figure 1. represents the Spectral reflectance curves for orange fruits under different growth levels. Spectral reflectance is affected by the maturity stage. The spectral reflectance curves of yellow obtained higher values than the reflectance curves of green and orange at the wavelength range of (514 to 556 nm). The spectral reflectance curves of orange obtained higher values than the reflectance curves of yellow and green. The changes were observed in the red edge (675 to 682 nm) under fruit growth stages. There was a clear difference in the water band at 975nm under fruit growth stages. Changes in the color of the fruit, thus the changes in the spectral specifications of orange skin gave a significant difference in pigment content and their compounds in fruits during the growth process. In the range of chlorophyll absorption (between 675 nm and 682 nm), both orange and yellow fruit species had high reflectance, compared with green fruit, whereas considerable spectral characteristics were not observed in the NIR range (845 to 975 nm) with high reflectance values. In the range, 905-982 wavelength range, which relates to the moisture content, decreasing in reflectance (also for unripe fruits) was observed.

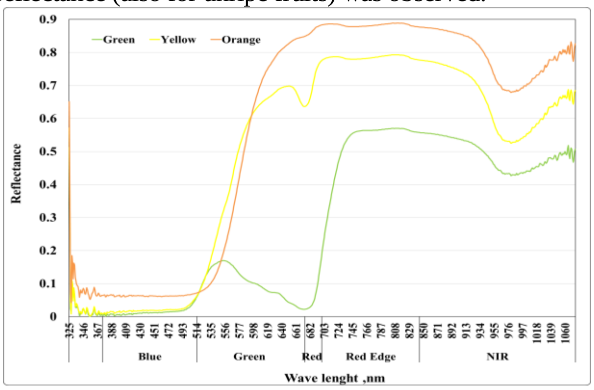

Fig 1. Spectral Reflectance Curves for orange fruits under various growth levels

Chlorophyll a

Chlorophyll(a) content of orange fruit is closely linked to the growth stage and, therefore, greatly affected the spectral reflectance collected. In general, the spectral reflectance collected from fruits at late stages at which fruits have low chlorophyll(a) concentration showed a highly significant positive increase in the VIS portion of the electromagnetic and also a significant negative increase in the NIR range compared with spectra collected at early growth stages. This can be attributed to the effects of decreasing chlorophyll(a) and pigment absorption. The coefficient of correlation for the association between the measured chlorophyll(a) and different spectral indices is illustrated in Figure 2. The results further showed that most of the spectral indices gave a significant correlation with the measured chlorophyll (a) at different growth stages. R_{672}/R_{550} and PSI have the highest significant correlations for detecting the chlorophyll (a) concentration of orange fruit. Overall R_{672}/R_{550} was the best at detecting chlorophyll. Some other spectral indices DVI, SRPI, and NPQI also gave high significant correlations for predicting the chlorophyll content of orange fruits at various growth stages. Figure 2 shows the relationship between R_{672}/R_{550} and PSI and chlorophyll (a) content of orange fruit at different growing stages. Both figures show strong significant relationships between both indices and chlorophyll(a) content of orange fruit ($R^2 > 0.91$; $p = 0.000$). Moreover, some tested spectral indices such as WBI, SIPI, and VI1 showed a very weak relationship with the concentration of measured chlorophyll (a). Previous investigations assessed the potential of non-contacting techniques to quantify fruit quality parameters (Nagy *et al.*, 2016). Merzlyak *et al.*, (2003) found that R_{800}/R_{640} was positively correlated with the total concentration of chlorophyll (a) ranging between 0.4-11 nmol/cm^2 ($R^2 > 0.93$). They also revealed that the index $(R_{678}-R_{500})/R_{800}$ can be a reliable index to estimate the ratio between chlorophyll and carotenoid ($R^2 = 0.88$). In another study, Nagy *et al.*, (2016) noticed that the reflectance at 678 nm can be efficient to distinguish low chlorophyll a.

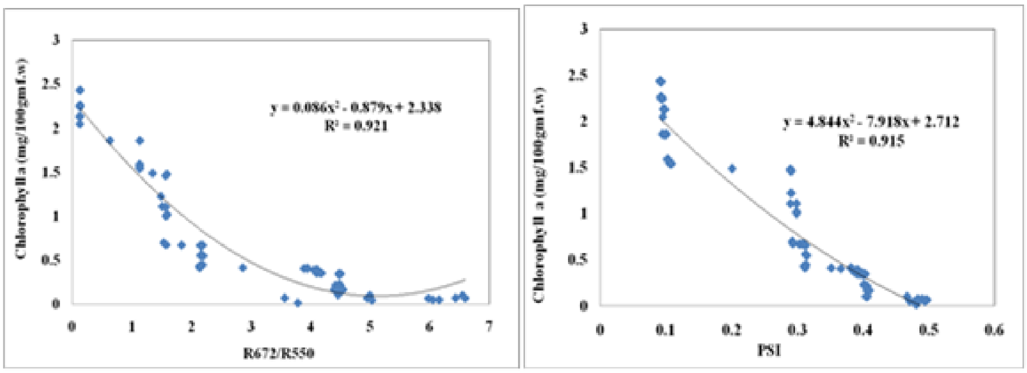

Fig.2. Relation between Chlorophyll(a) and spectral indices

Chlorophyll b

The coefficient of correlation for the association between the measured chlorophyll (b) and different spectral indices is presented in Figure 3. The results further indicated that most of the spectral indices gave a significant correlation with the measured chlorophyll (b) at different growth stages. SRPI and NDI have the highest significant correlations for detecting the concentration of chlorophyll (b) in orange fruit. Overall, NDI was the best at predicting chlorophyll(b). Some other spectral indices NDVI, RVI, and SAVI also produced a high significant correlation for detecting chlorophyll (b) content of orange fruits at various growth stages. Figure 3 shows the association between SRPI and NDI and chlorophyll (b) content of orange fruit at different growing stages. Both figures gave strong significant relationships between both indices and chlorophyll (b) content of orange fruit ($R^2 > 0.81$; p = 0.000). Moreover, some tested spectral indices such as SIPI, R_{550}, and VI2 showed very weak relationships with the measured chlorophyll(b) concentration.

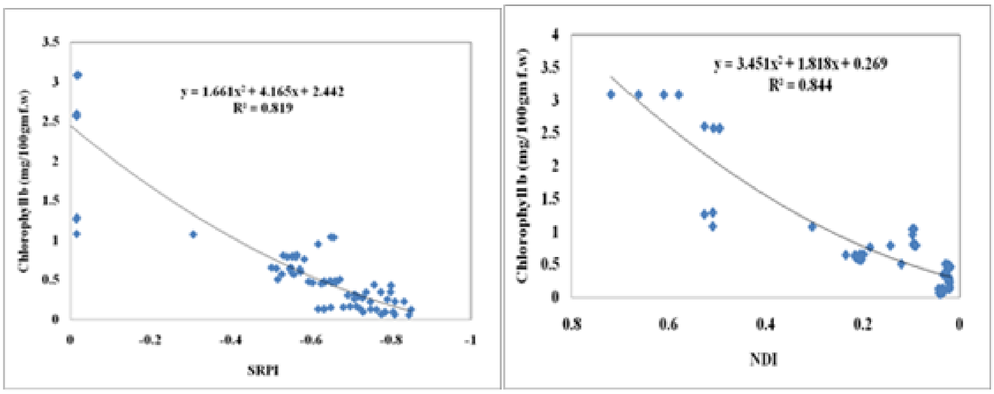

Fig.3. Relation between Chlorophyll(b) and spectral indices

Total chlorophyll a,b

Figure 4 illustrated the association between the total measured chlorophyll a, and b and different spectral indices. A lot of data demonstrates that the spectral indices recorded a significantly different correlation with the total measured chlorophyll (a,b) for growth stages. PSR and SRPI have the highest significant correlations for detecting the concentration of total chlorophyll (a,b) of orange fruit. From various tested spectral indices, PSR was the most suitable indices for detecting total chlorophyll (a,b). NDVI $_{hy}$, NDI, and R_{675}/R_{700} have high significant correlations for detecting the concentration of the total chlorophyll (a,b) of orange fruits at various growth stages. The association between PSR and SRPI and the total chlorophyll (a,b) content of orange fruit at different growing stages is shown in Figure 4. The previous two indices give strong significant relationships with total chlorophyll a,b content of orange fruit ($R^2 > 0.82$; p = 0.000). Some other spectral indices such as $R_{860}/(R_{550}\times R_{708})$, $R_{550,}$ and VI2 presented very weak relationships with the total measured chlorophyll (a,b) concentration. Previous investigations assessed the potential of non-contacting techniques to quantify fruit quality parameters (Gitelson and Merzlyak, 1997). Merzlyak *et al.*, (2003) found that Two indices, R_{800}/R_{700} and R_{800}/R_{640}, showed a high correlation with chlorophyll content (R^2= 0.94) and (R^2= 0.93).

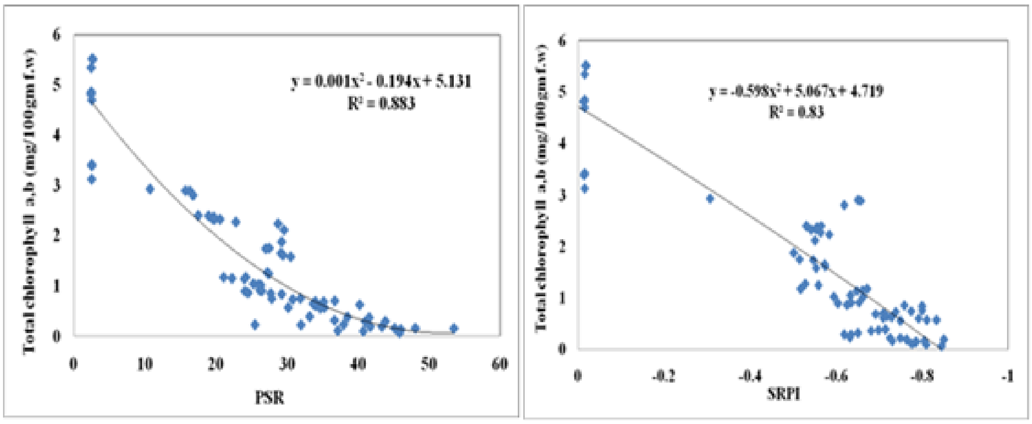

Fig. 4. Relation between Total chlorophyll (a,b) and spectral indices

Carotenoids

When comparing the spectral signatures obtained from orange fruits at various growth stages, the results indicated that the spectral reflectance collected from green fruit is higher than the spectral reflectance obtained from yellow and orange-colored fruit over the blue and green regions. Carotenoid content has greatly affected the spectra collected at varying growth stages as the spectral reflectance increases in blue, green, and red regions, which may be attributed to a decrease in chlorophylls. In the NIR region, spectral reflectance is obtained from various growth stages.

The correlation coefficient for the association between different spectral indices and the measured carotenoid of orange fruit is depicted in Figure 5. At various growth stages, most of the tested spectral indices were remarkably significantly correlated with the measured carotenoids. R_{672}/R_{550} and YI gave the highest significant correlations for detecting the concentration of carotenoid in orange fruit. Overall various tested spectral indices, R_{672}/R_{550} were also shown the optimum index for predicting carotenoids with a high determination coefficient of 0.854. Some other spectral indices such as DVI, SRPI, and NPQI also produced a highly significant correlations for predicting the carotenoid content of orange fruit at various growth stages. Figure 5 shows the association between R_{672}/R_{550} and YI and the carotenoid content of orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between both indices and carotenoid content of orange fruits ($R^2 > 0.80$). WBI, SIPI, and NWI1 showed non-significant relationships with the measured carotenoid content. Merzlyak *et al*., (2003) found that two indices, (R800/R520-R800/R700) and (R800/R520-R800/R500) showed a high correlation with carotenoids content (R^2= 0.8) and (R^2= 0.83).

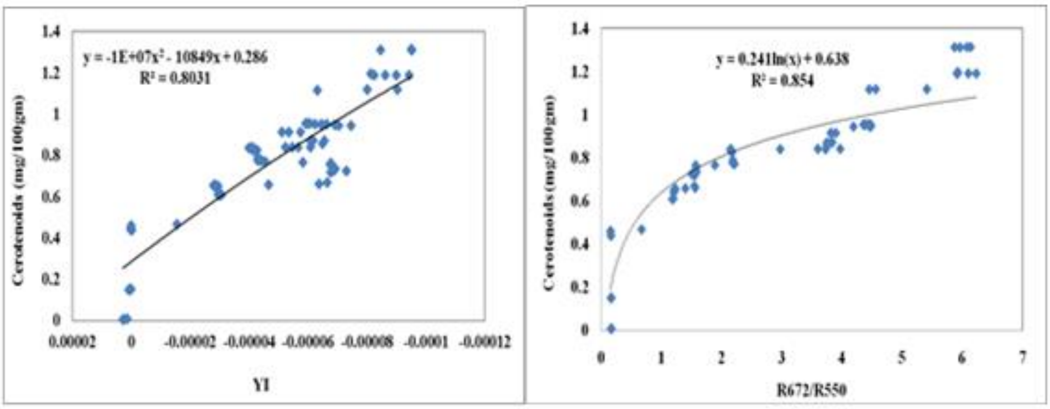

Fig.5. Relation between Carotenoids and spectral indices

Ascorbic acid content

The concentration of ascorbic in orange fruit is closely linked to the growth stage. In the first growing stage (green fruit), the concentration of ascorbic acid is slightly low and increased gradually with the transformation of color pigment from green to orange through yellow. Data showed that the spectral reflectance collected from green fruit is more than that obtained from yellow and orange-colored fruit over the blue and green regions. Ascorbic acid content has greatly affected the spectra collected at varying growth stages as the reflectance increases in blue, green, and red regions, which may be attributed to chlorophylls decreasing and other accessory pigments.

The coefficient of correlation for the association between the measured ascorbic acid content and different spectral indices is demonstrated in Figure 6. The results further proved that a lot of spectral indices have a significant correlation with the measured Ascorbic acid content at different growth stages. Data showed that R_{672}/R_{550} and PSI gave the highest significant correlations for detecting the concentration of ascorbic acid. Among different tested spectral indices, R_{672}/R_{550} was the best when calculating the concentration of ascorbic acid with a high determination coefficient of 0.947. Another spectral index SRPI, NPQI, and C420 also produced high significant correlations for predicting the ascorbic acid content of orange fruits at various growth stages. The relationship between R_{672}/R_{550} and PSI and the ascorbic acid content of orange fruit at different growing stages is presented in Figure 6. From Figure 5 it is obvious that both indices have strong significant relationships with the ascorbic acid content of orange fruit ($R^2 > 0.94$; $p = 0.000$). Some tested spectral indices such as WBI, NWI-1, NWI-2, $R_{shoulder,}$ and SIPI showed very weak relationships with the measured ascorbic acid content.

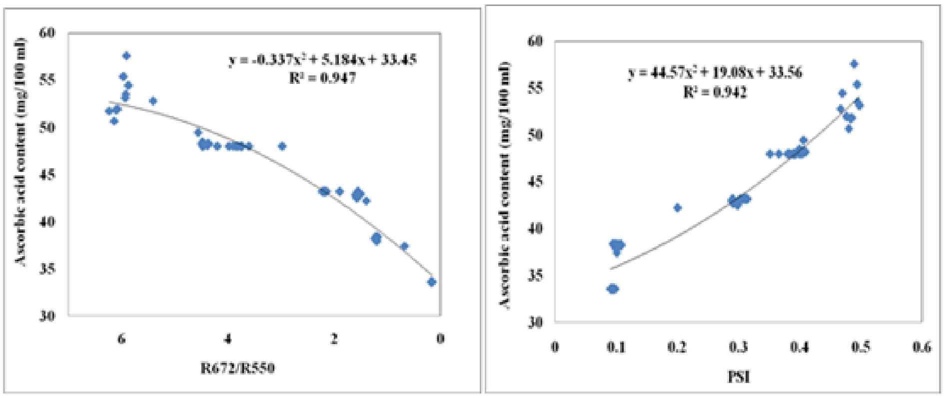

Fig.6. Relation between Ascorbic acid content and spectral indices

Soluble solids (SS)

The soluble solids (SS) content of orange fruit is linked to the fruit growth stage. At the first growth stage (green fruit), the soluble solids content is low, and it increases with increase the maturity of the fruit (orange), therefore the soluble solids affected the spectral reflectance collected from fruits. In general, the spectral reflectance collected from fruits at late stages at which fruits have a high concentration of Soluble solids (SS) showed a highly significant positive increase in the VIS portion_of the electromagnetic and also a significant negative increase in the NIR range compared with spectra collected at early growth stages. This can be attributed to the effects of chlorophyll decreasing and an increase in carotenoid pigment absorption.

The correlation coefficient for the association between different band ratio indices and the measured Soluble solids (SS) of orange fruit is shown in Figure 7. At various growth stages, most of the tested spectral indices were remarkably significantly correlated with the measured

Soluble solids (SS). R_{672}/R_{550} and PSI have the highest significant correlations for predicting the Soluble solids (SS) concentration of orange fruit. Overall various tested spectral indices, R_{672}/R_{550} and PSI were also shown as the optimum indices for predicting Soluble solids (SS) with a high determination coefficient of 0.939. Some other spectral indices such as R_{800}/R_{550}, R_{750}/R_{550}, and C_{green} also have high significant correlations for detecting the Soluble solids (SS) content of orange fruit at various growth stages. Figure 7 shows the relationship between R_{672}/R_{550} and PSI and the Soluble solids (SS) content of orange fruit at various growth stages. It is obvious from the graphs that there are strong significant correlations between both indices and the Soluble solids (SS) content of orange fruits (R^2 > 0.93). In contrast, WBI, NWI-1, NWI-2, $R_{shoulder}$ showed non-significant relationships with the measured Soluble solids (SS) content.

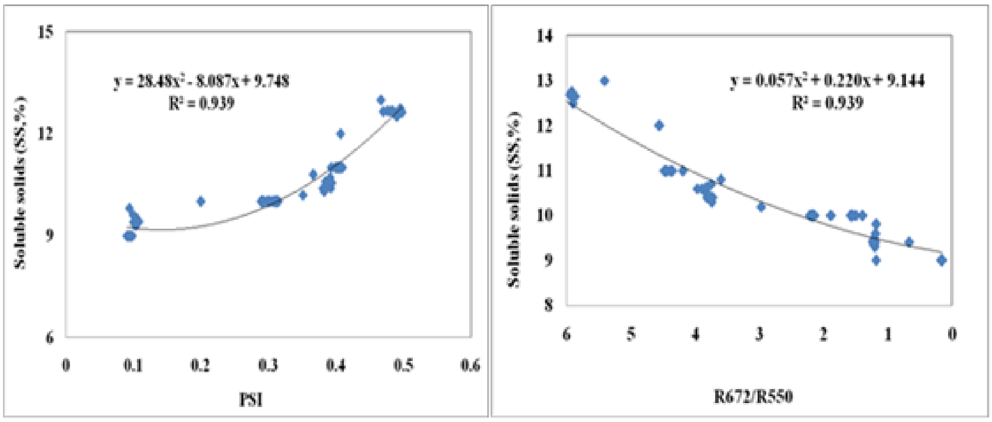

Fig.7. Relation between Soluble solids (SS) content and spectral indices

Elsayed and Ghazy (2017) found that the spectral index R970/R964, showed the highest coefficients of determination for the fruit soluble solids content (R^2=0.86)

Acidity value (pH)

pH value was low at the early growth stage (green) and increased with the transformation of fruit from green to orange. The spectral signatures obtained from orange fruits are greatly affected by growth stages. Spectral signatures obtained from orange fruits at various growth stages were compared and the results indicated that the spectral reflectance collected from green fruit is greater than the spectral reflectance obtained from yellow and orange-colored fruit over the blue and green regions. The spectral reflectance increases in blue, green, and red regions, which may be a result of decreasing pH value and other accessory pigments. In the NIR region, spectral reflectance is obtained from various growth stages.

Figure 8 demonstrated the association between the measured pH value and different spectral indices. Data revealed that most spectral indices gave a significant correlation with the pH value for growth stages. PSI and R_{672}/R_{550} gave the highest significant correlations for predicting the pH value of orange fruit. Among various tested spectral indices, R_{672}/R_{550} was the most suitable indices for predicting pH value with a high determination coefficient of 946. PSR, R_{800}/R_{550}, and R_{800}-R_{550} gave high significant correlations for predicting the total pH value of orange fruits at various growth stages. The relationship between PSI and R_{672}/R_{550} and the pH value of orange fruit at different growing stages is shown in Figure 8. The previous two indices give strong significant relationships with the pH value of orange fruit (R^2 > 0.91; p = 0.000). Some other spectral indices such as WBI, NWI-1, and R $_{shoulder}$ presented very weak relationships with the total measured pH value. Elsayed and Ghazy (2017) showed that the spectral index R_{970}/R_{726} showed the highest coefficients of determination for the pH (R^2= 0.78).

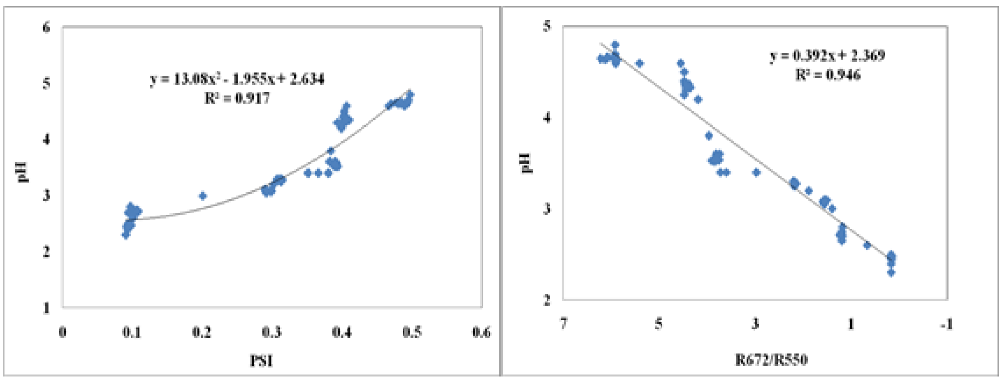

Fig.8. Relation between pH and spectral indices

Juice content

Figure 9 illustrated the association between the Juice content and different spectral indices. Most all spectral indices gave a significant correlation with the total measured Juice content for growth stages. PSI and R_{672}/R_{550} gave the highest significant correlations for predicting the Juice content of orange fruit. Among various tested spectral indices, R_{672}/R_{550} was the most suitable indices for predicting Juice content with a high determination coefficient of 917. R_{800}-R_{550}, R_{700}-R_{670}, and PSR produced high significant correlations for predicting the Juice content of orange fruits at various growth stages. The relationship between R_{672}/R_{550} and PSI and Juice content of orange fruit at different growing stages is shown in Figure 9. The previous two indices give strong significant relationships with the Juice content of orange fruit ($R^2 > 0.85$; p = 0.000). Some other spectral indices such as WBI, NWI-1, NWI-2, and VI1 presented very weak relationships with the Juice content.

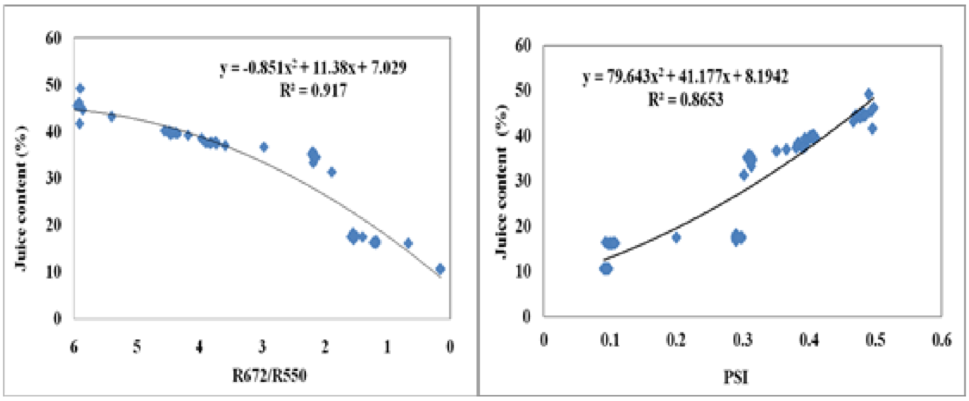

Fig.9. Relation between Juice content and spectral indices

Maturity index

The coefficient of correlation for the association between the measured maturity index and different spectral indices is depicted in Figure 10. The results further proved that most hyperspectral indices gave a significant correlation with the measured maturity index at different growing stages. Results showed that R_{672}/R_{550} and PSI gave the highest significant correlations for predicting the maturity index of orange fruit. Among different tested spectral indices, R_{672}/R_{550} was the best at the determination of maturity index with a high determination coefficient of 0.965. Another spectral index DVI, NPQI, and SRPI also gave high significant correlations for detecting the maturity index of orange fruits at various growth stages. The relationship between R_{672}/R_{550} and PSI and the maturity index of orange fruit at different growing stages is presented in Figure 10. From Figure 9 it is obvious that both indices have strong significant relationships with the maturity index of an orange fruit ($R^2 > 0.92$; p = 0.000). Some tested spectral indices such as WBI, SIPI, VI2, and $R_{860}/(R_{550}*R_{708})$ showed a very weak relationships with the measured maturity index.

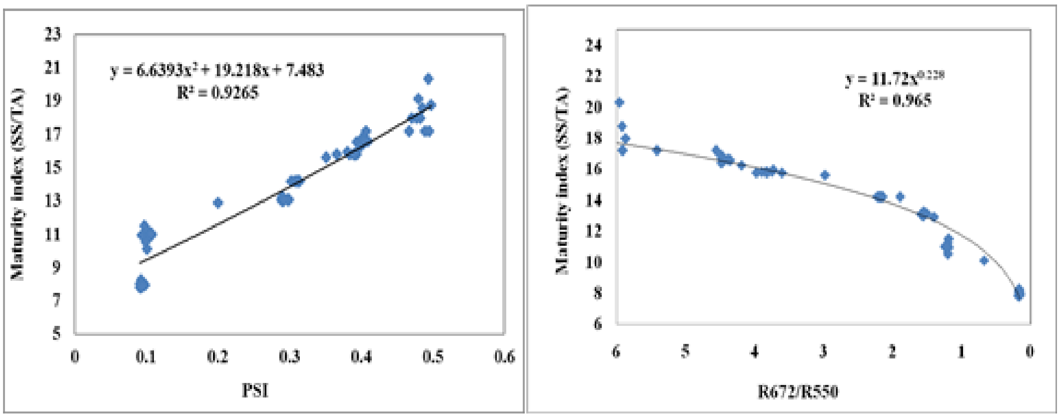

Fig.10. Relation between Maturity index and spectral indices

Titratable acidity

The coefficient of correlation for the association between the measured titratable acidity and different spectral indices is shown in Figure 11. The results further approved that most of the spectral indices gave a significant correlation with the measured titratable acidity at different growing stages. PSR and SRPI gave the highest significant correlations for predicting the titratable acidity of orange fruit. Overall PSR was the best at predicting titratable acidity with a high determination coefficient of 0.925 Some other spectral indices NDVI, RVI, and R_{725}/R_{675} also produced high significant correlations for predicting titratable acidity of orange fruits at various growth stages. Figure 11 shows the relationship between PSR and SRPI and the titratable acidity of orange fruit at different growing stages. Both graphs show strong significant relationships between both indices and the titratable acidity of an orange fruit ($R^2 > 0.87$; p = 0.000). Moreover, some tested spectral indices such as VI2, SIPI, and R_{550} showed very weak relationships with the measured titratable acidity. Elsayed and Ghazy (2017) found that the spectral index R_{970}/R_{964} showed the highest coefficients of determination for the fruit titratable acidity (R^2= 0.82).

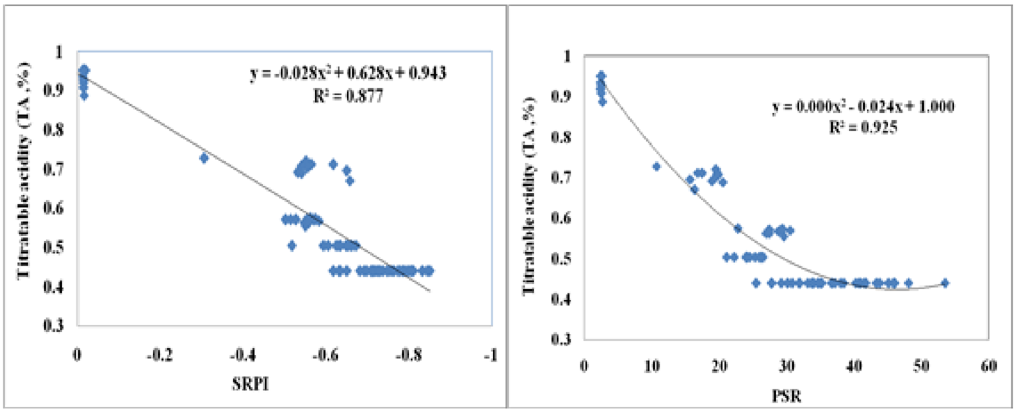

Fig.11. Relation between titratable acidity and spectral indices

CONCLUSION

Using high spectral measurements as a noon destructive technique for predicting the chemical composition of orange fruit. The main results of the current work could be summarized as follows:

1- Most of the hyperspectral indices give a significant correlation with chemical composition.
2- Some of the hyperspectral indices presented high significant relation with the chemical composition
3- hyperspectral indices are a good indicator for detecting the chemical composition of fruit.

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الاستشعار الطيفى كأداة لقياس نضج ثمار البرتقال

شيماء صلاح ، عادل هلال المتولى و محمد غنيم
قسم الهندسة الزراعية – كلية الزراعة –جامعة طنطا

الملخص

اجريت هذه التجربة بهدف تقييم إمكانية استخدام المؤشرات الطيفية كأداة لقياس التركيب الكيميائى خلال مراحل نمو ثمار البرتقال .استخدمت المؤشرات الطيفية لقياس الخواص الكيميائية المختلفة لثمار البرتقال بما في ذلك كلوروفيل أ ، كلوروفيل ب ، الكلوروفيل الكلي ، الكاروتينات ، حمض الأسكوربيك ، الرقم الهيدروجيني ، المواد الصلبة القابلة للذوبان ،النسبة المئوية لمحتوى العصير، الحموضة ، مؤشر النضج .وأظهرت النتائج كذلك أن معظم المؤشرات الطيفية أنتجت ارتباطا كبيرا مع كلوروفيل أ المقاس في مراحل النمو المختلفة وكان أعلى ارتباط مع المؤشر الطيفى R_{672}/R_{550} قيمته هى $R^2 = 0.92$ أما بالنسبة للتنبؤ بالكلوروفيل ب كان أعلى ارتباط مع المؤشر (NDI) وكانت $R^2 = 0.84$ وأيضا أنتج PSR أعلى الارتباطات الهامة للتنبؤ بمحتوى الكلوروفيل a ، b من فاكهة البرتقال في مراحل النمو المختلفة $R^2 = 0.88$ وبالنسبة للتنبؤ بتركيز الكاروتينات لفاكهة البرتقال يجب أن يعتمد على R_{672}/R_{550} الذي أنتج أعلى ارتباط $R^2 = 0.85$ أما مع حمض الاسكوربيك كانت أفضل المؤشرات للتنبؤ بمحتواه مع R_{672}/R_{550} وكانت $R^2 = 0.947$ والمواد الصلبة القابلة للذوبان (SS) فى البرتقال في مراحل نمو مختلفة ظهرت مع المؤشران R_{672}/R_{550} وPSI وكانت قيمة متماثلة للمؤشرين $R^2 = 0.939$. ظهراعلى ارتباط مع المؤشر الطيفى R_{672}/R_{550} للتنبؤ بقيمة الأس الهيدروجيني لفاكهة البرتقال كانت $R^2 = 0.94$.يجب أن يعتمد التنبؤ بمحتوى العصير ومؤشر نضج فاكهة البرتقال على R_{672}/R_{550} الذي أنتج أعلى الارتباطات الهامة $R^2 = 0.91$ و $R^2 = 0.96$ على التوالي .أنتج PSR أعلى الارتباطات الهامة للتنبؤ بالحموضة لفاكهة البرتقال و كانت $R^2 = 0.92$

الكلمات المفتاحية: الاستشعار الطيفى، البرتقال،التركيب الكيميائى