IMAGING ANALYSIS TECHNIQUE FOR ASSESSING ORANGE MATURITY

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ABSTRACT

The objective of the present study was to develop a computer vision and image analysis program to serve as a simple and suitable technique for external fruit inspection and for predicting orange fruits maturity through the image analysis technique. The ENVI software package was utilized for image processing and analysis. The study also investigated the effectiveness of some color bands including R/G ratio, average of RGB bands (intensity) and VARI indices for predicting biochemical properties including chlorophyll a and b, carotenoids, acidity, pH, tss, and tss/acidity. Absorbance of the extracts was read by a spectrophotometer at specific wavelengths of 470, 645 and 662 nm to determine chlorophylls and carotenoids concentrations. The results revealed that the computer vision and image analysis program could be used to differentiate orange maturity stages. The results also showed that there is a strong response between both chlorophyll and carotenoids of orange fruits and the band ratios used in this research. R/G band ratio, average of RGB and VARI indices showed sensitive band ratios to different orange biochemical properties.

Keywords: image analysis, computer vision, orange, carotenoids, RGB, band ratios.

INTRODUCTION

The citrus industry is an important component of the Egyptian national income. Harvested orange area in Egypt is about 101421 ha and production is 2577720 tones (FAO,2013). Color is the most important feature for accurate classification of citrus using machine vision which serves the important role of quality control system for agricultural products. Kondo et al. (2000) used a machine vision system to identify orange properties including sugar content and acid content based on the information obtained from fruit features (e.g. color, shape and roughness).

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They concluded that R/G band ratio can successfully be employed to predict sugar content or pH from the fruit appearance with a reasonable accuracy. Brosnan and Sun (2002) found that computer vision systems have been used increasingly in industry for inspection and evaluation purposes as they can provide rapid, economic, hygienic, consistent and objective assessment. With the idea of precision and more environmental friendly agriculture becoming more realistic the potential for computer vision in this area is immense with the need in field crop monitoring, assessment and guidance systems. Leemans *et al.* (2002) presented a machine vision system with color camera to grade apples into four categories based on European standards. They employed a quadratic discriminant classifier (QDC) and a multi-layer perceptron (MLP) for classification, and achieved 78 and 72% classification accuracies for mono and bicolored apples. Raji and Alamutu (2005) reviewed recent developments and applications of image analysis and computer machine vision in sorting agricultural materials and products in food industries. Ahmad et al. (2010) found that the analysis of the area of citrus related to its size, and the skin color in the RGB color model related to sweetness and ripeness of citrus. The relationship between area of the citrus fruit and its weight was analyzed as well as fruit color. Khojastehnazhand et al. (2010) developed an image processing based technique to measure volume and mass of citrus fruits such as lemons, limes, oranges, and tangerines. The technique used two cameras to provide perpendicular views of the fruit coefficient of determination (R^2) for lemon, lime, orange, and tangerine which were 0.96, 0.97, 0.98, and 0.96 respectively. The characterization results for various citrus fruits showed that volume and mass are highly correlated. Wanitchang et al. (2010) showed that a common destructive method for measuring the maturity and growth of Dragon fruit is to analyze its content of total soluble solids, total acids, ratio of total soluble solids, total acidity and weight ratio. The data were transformed into a principal component analysis to represent a single maturity index. Ismail and Razali (2012) showed that color vision systems were more effective for color inspection. A color camera output can be de-coded into three images to represent the red, green and blue (RGB) components of the full image.

The three components can be recombined in a software package or hardware to produce intensity, saturation and hue images, which are more convenient for subsequent processing. Color is considered a fundamental physical property of agricultural products and foods.

The reported research aimed to develop a simple and suitable technique for predicting orange fruits maturity, and also to study the relationships between different indices including R/G band ratio, VARI and average of RGB bands and biochemical properties of orange fruits at different maturity stages.

MATERIALS AND METHODS

The present work investigated the potential of image analysis techniques to detect the response of orange maturity over harvesting stages. The experimental work was undertaken at a private farm in Wadi Elnetron, Bohira Province, Egypt.

Valencia orange

Orange *(Citrus aurantum)* fruits samples were collected for identifying different biochemical measurements including concentration of chlorophyll *a* and *b,* carotenoids and other properties such as acidity, percentage of liquid, pH, total soluble solid (tss), tss/acidity.

Computer visioning system

The system consisted of an imaging box with non reflective black cloth connected to a digital camera of 16.4 Megapixels. The camera was mounted at 25 cm from the bottom of the imaging box. The position of the two light sources was adjusted to provide uniform light intensity. Images were taken to capture images of fruit free from shadows. Following capturing images, they stored on a personal computer for the analysis. Capture cards (WinFast DV2000 with a resolution of 320H X 240V). A personal computer was used for analyzing the images. Figure 1 shows different parts of the imaging system including camera, light source, imaging box and computer.

Image Analysis system: orange fruit samples were captured by the camera, transferred to the PC through the capture card, digitized, and stored on the PC. The ENVI software package was used to analyze the images of orange fruits and three bands, RGB, (red, green, blue) were derived for each image. Fig. 2 shows the whole procedure followed until obtaining the R, G, B colors.

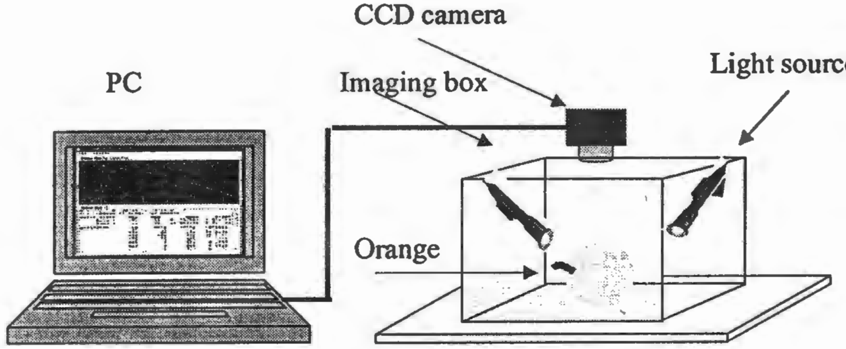

Fig.1 Image acquisition system supported with ENVI programme

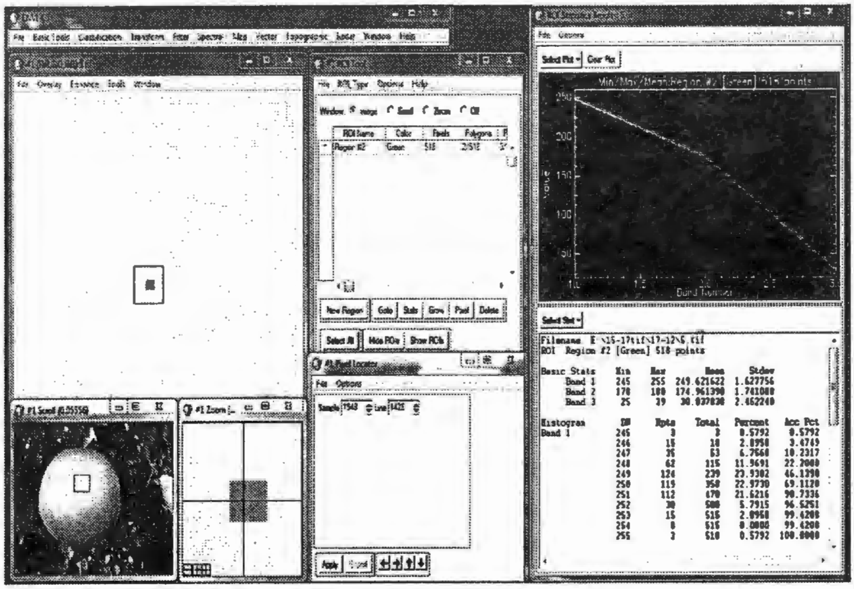

Fig.2 A window of ENVI programme showing the spectral signature and associated statistics obtained from an orange fruit

Color evaluation: Using the most popular color model RGB color space. The color was presented with R, G and B, the amount of information is tripled. The RGB system is sensitive to lighting and other surrounding conditions. To evaluate the color of captured images of fruits, the acquired RGB color information was transformed:

Average intensity was converted according to Abdesselam and Abdullah (2000) as follows: I= (R + G +B)/3

The Red/Green ratio was determined according to Blasco et al. (2009) who used a threshold on the R/G ratio, Visible Atmospheric Resistant Index (VARI) was determined according to (Gitelson et al., 2002) as follows:

$$VARI = \frac{green - Red}{green + Red - blue}$$

Spectrophotometer measurements and determination of biochemical properties

A spectrophotometer with a spectral range of 390 to 900 nm was used to measure the absorbance of extracts at specific wavelengths of 470, 645 and 662 nm to determine chlorophyll and carotenoids concentration. The concentration of chlorophyll a and b, and carotenoids were calculated according to Dere et al. (1998) as follows:

$Chl_a = 11.75\ A_{662} - 2.35\ A_{645}$

$Chl_b = 18.61\ A_{645} - 3.96\ A_{662}$

$Carx{+}c = (1000\ A_{470} - 2.27\ Chl_a - 81.4\ Chl_b) / 227$

Where A_{662}, A_{645}, and A_{470}, are the absorbance at 662, 645 and 470 nm wavelengths.

The tss was estimated from a single digital refractometer reading taken from the combined juice extracted from the orange. pH value was measured by a pH meter. Liquid percent was calculated as the difference between total weight of an orange fruit and juice weight extracted from the same fruit divided by total weight. Acidity percent was calculated as a ratio between the volume of NaOH and juice volume.

RESULTS AND DISCUSSION

Optical properties of orange peel pigment content in relation to their ripeness

To demonstrate how optical properties may be used to assess fruit maturity, the absorption coefficients of orange samples were examined at different ripeness stages (green, yellow and orange). Fig. 3 shows changes in the pattern of the absorption spectra observed for orange samples at different ripeness stages. Orange samples of green color would contain a large amount of chlorophyll a and chlorophyll b since it had a strong absorption peak at 662 and 645 nm, respectively. As orange fruit ripeness from the green stage to the orange stage, its chlorophyll content decreases, while carotenoids is produced and starts to increase and thus a trend of the decreasing absorption at 662 nm and increasing absorption at 470 nm from the green stage to orange stage. The peaks at 470 and 645 nm wavelengths can be used to differentiate between various maturation stages and thus can be used to calculate indices. This pattern of changes was clearly observed from the absorption spectra of the green and orange when orange fruits were fully ripe, chlorophyll would be greatly reduced or may disappear completely and carotenoids becomes the dominant pigment in the fruit surface.

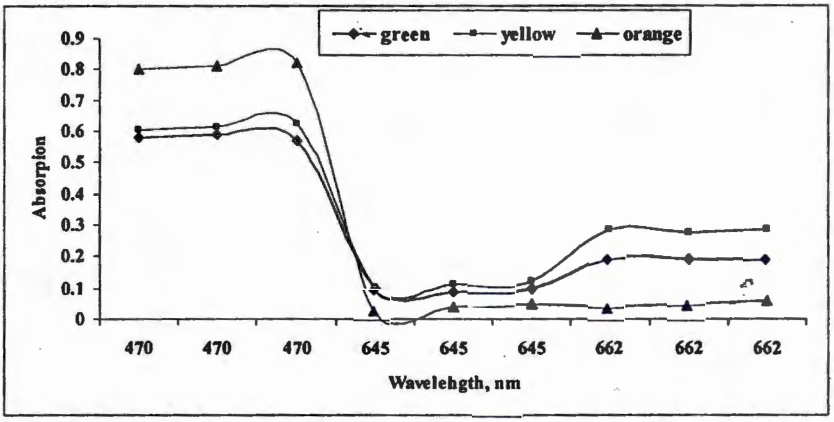

Fig. 3 Relationship between wavelength and absorption spectra of orange at different maturity stages (green, yellow and orange colors)

The computer vision and image analysis program was successful in differentiating orange maturity stages. The results showed strong relationships between different indices including R/G band ratio, average intensity of RGB, *VARI*, chlorophyll a and b and carotenoids at different maturity stages. The Results illustrated in Fig.4 show that with increasing maturity time the carotenoids increased from 4.80 to 15.77 mg/100g, while chlorophyll a and b decreased from 1.92 to 0.72 and from 3.01 to 1.18 mg/100g, respectively.

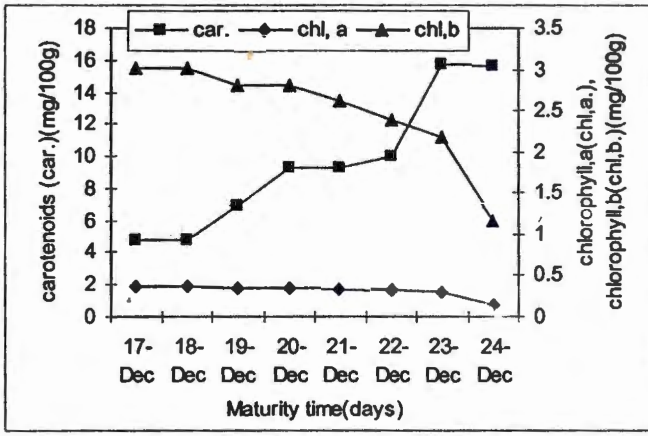

Fig. 4 Relationship between maturity time (days) and chlorophyll a and b and carotenoid concentration

Association between Red/Green ratio and various orange chemical properties

The relationships between the Red/Green band ratio and chlorophyll a and b concentration, carotenoids and also other chemical properties are shown in Fig. 5. When the Red/Green band ratio increased from 1.36 to 1.61, carotenoids increased from 4.80 to 15.77 mg/100g. In contrast, chlorophyll a and b decreased from 1.92 to 0.72 and from 3.01 to 1.18 mg/100g, respectively with increasing R/G band ratio. When Red/Green band increased from 1.36 to 1.61, acidity decreased from 1.25 to 1.07 % while percentage of liquid, pH, total soluble solid (tss), and Tss/acidity increased from 41.54 to 49.83 %, from 2.84 to 3.07, from 8.20 to 10.06 (Brix,%) , and from 6.78 to 9.00 mg/100g. When orange fruits maturity continues, there are some changes happen in the physiological composition of it as total soluble solid increases due to increase in sugar content and percentage of acidity decreases. Also green color on orange fruits skin gradually disappears and substituted by yellow color. The following equations were satisfied for predicting chlorophyll a and b and carotenoids by the Red/Green band ratio during maturity:

$y_{ch,a} = -23.352x^2 + 66.454x - 45.37 \quad R^2 = 0.74$

$y_{ch,b} = -32.044x^2 + 90.207x - 60.519 \quad R^2 = 0.81$

$y_{car} = 51.97x^2 - 111.19x + 59.24 \quad R^2 = 0.83$

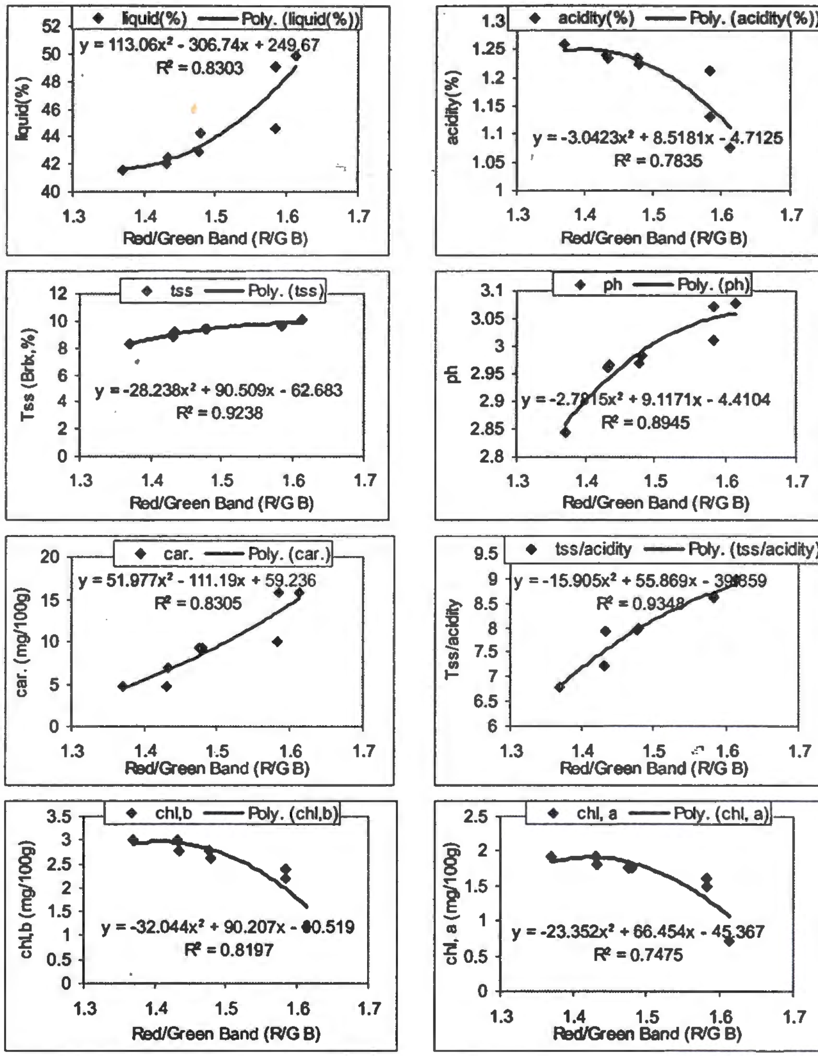

Fig. 5 Relationships between the Red/Green band ratio and chlorophyll a and b, carotenoids and other biochemical properties.

Association between average of RGB (intensity) and various orange biochemical properties

Fig.6 depicts the relationships between average intensity of RGB and chlorophyll a and b carotenoids concentrations, acidity, pH, tss, and tss/acidity. Increasing average intensity of RGB from 126.5 to 147.1 increased carotenoids from 4.80 to 15.77 mg/100g while chlorophyll a and b decreased from 1.92 to 0.72 and from 3.01, to 1.18 mg/100g, respectively. The results also demonstrated that acidity decreased from 1.25 to 1.07 %, when the average bands (intensity) increased from 126.46 to 147.06 while percentage of liquid, pH, total soluble solid (tss), and tss/acidity increased from 41.54 to 49.83 %, from 2.84 to 3.07, from 8.20 to 10.06 (Brix,%) , from 6.78 to 9.00 mg/100g with increasing average intensity of RGB. Increasing orange fruits maturity time associate with some changes. These changes happen in the physiological composition of fruits. For example, total soluble solids increased and sugar content increases and percentage of acidity decreased and green color gradually disappears on the orange fruits skin and yellow and orange colors start to appear. The results therefore demonstrated the sensitivity of the color intensity (average of RGB) to various biochemical properties of orange fruits and thus can be a reliable and sensitive index to fruit properties.

The following equations were derived for predicting chlorophyll, a and b and carotenoids (mg/100g) with the average of RGB (intensity):

$$Y_{ch,a} = -0.005x^2 + 1.3255x - 85.258 \quad R^2 = 0.93$$

$$Y_{ch,b} = -0.0073x^2 + 1.9022x - 121.52 \quad R^2 = 0.97$$

$$y_{car} = 0.0297x^2 - 7.5093x + 479.71 \quad R^2 = 0.82$$

Association between VARI index and different orange biochemical properties

The VARI index is one of the most indices commonly used in fruit grading and sorting since it is sensitive to fruit chemical changes. Fig. 7 shows the relationships between VARI index and chlorophyll a and b, carotenoids concentration and other orange properties including acidity, percentage of liquid, pH, total soluble solid (tss), tss/acidity. When VARI index increased from 0.155, to 0.234, carotenoids increased from 4.80 to 15.77 mg/100g. VARI also showed a sensitive index to the content of chlorophyll a and b since decreasing their values from 1.90 to 0.72 mg/100g and from 3.01 to 1.18 mg/100g, respectively were also recorded as VARI index increased from 0.155 to 0.234.

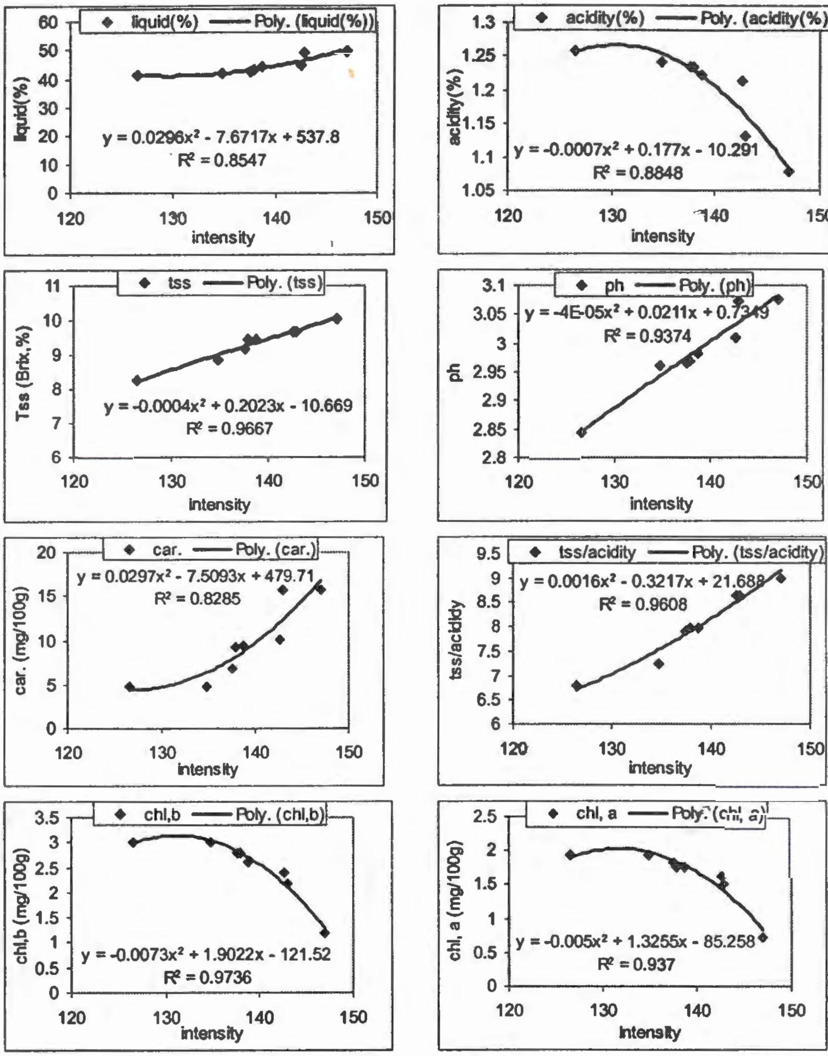

Fig. 6 Relationships between average of RGB bands and different orange biochemical properties.

The results further showed that acidity decreased from 1.25 to 1.07 % while percentage of liquid, pH, total soluble solid (tss), tss/acidity increased from 41.54 to 49.83 %, from 2.84 to 3.07, from 8.20 to 10.06 (Brix,%) , from 6.78 to 9.00 mg/100g. The results therefore demonstrated that VARI index can be a successful index in the determination of orange maturity and can give a better understanding about orange quality which is useful for increasing the total income for the Egyptian economy.

The following equations were satisfied for predicting chlorophyll, a and b and carotenoids (mg/100g) as a function of VARI index.

$Y_{ch,a} = -170.19\,x^2+57.338x - 2.8148$ $\qquad R^2 = 0.668$

$Y_{ch,b} = -244.87x^2+80.149x - 3.5684$ $\qquad R^2 = 0.759$

$y_{car} = 929.79x^2 - 232.91x + 18.368$ $\qquad R^2 = 0.859$

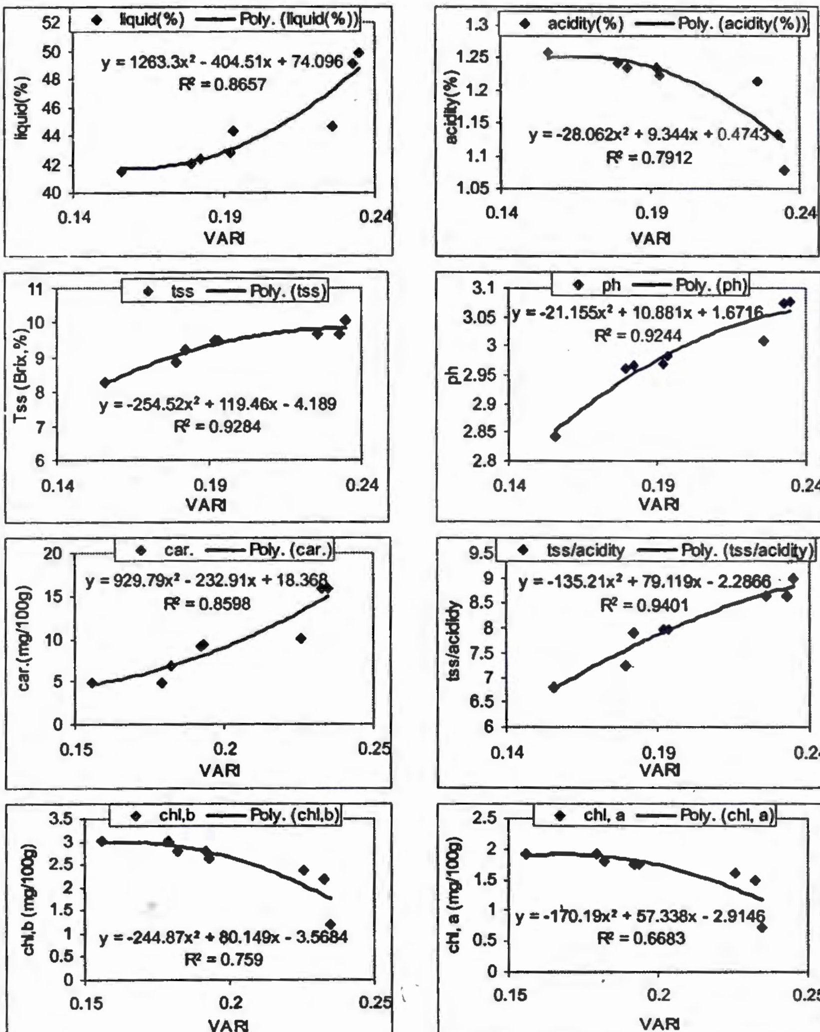

Fig. 7 Relationships between VARI index and various orange biochemical properties

CONCLUSION

An image analysis technique was found to serve as a suitable and accurate method for external orange fruit inspection. Relationships were determined between R/G band ratio, average of RGB bands and VARI index with chlorophyll a and b, carotenoids and other biochemical properties. Multiple regression analysis and correlation coefficient tested the association between chlorophyll a and b and carotenoids and different band ratios including R/G ratio and average of RGB bands to identify the optimum index sensitive to orange maturity. The results demonstrated that the average R/G band ratio, average RGB and VARI indices provide a better indication of chlorophyll a and b and carotenoids concentrations. The coefficient of determination for all properties of R/G band ratio and VARI indices were less than those with average of RGB. In conclusion, machine vision systems can give a step forward to increase grading and sorting of different fruits and also can be a cost effective technique in this area.

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الملخص العربى

تقنية تحليل الصور لتقدير نضج ثمار البرتقال

عادل هلال المتولى* شيماء صلاح **

تعتبر الموالح من أهم الحاصلات البستانية التى تقوم مصر بإنتاجها سنويا وتصديرها للخارج حيث بلغ إنتاج مصر فى عام ٢٠١٣ من ثمار البرتقال ٢,٥٧ مليون طن و تتأثر الجودة التصديرية لثمار البرتقال بشكل كبير بعمليات الحصاد والتداول والتخزين والتى إذا حدث بها أى خلل أدى ذلك الى تقليل جودتها لعدم صلاحيتها للتصدير وبالتالى يؤثر هذا على الدخل القومى بمصر، ولهذا تكمن أهمية الإهتمام بطور النضج للثمار و تحديد موعد الحصاد حتى يتم تصديرها بالمواصفات التصديرية الخاصة بها ونجد أن طرق تحديد طور النضج المناسب يتم بإستخدام الفحص اليدوى والخبرة بمشاهدة حجم ولون الثمار وشكلها الخارجى

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وهذا يحتاج إلى خبرة عالية ومن هنا تبرز أهمية إستخدام تقنيات حديثة لمعرفة درجات النضج مثل تقنية تحليل الصور. لذا كان الهدف من البحث دراسة إمكانية استخدام تحليل الصور فى تقدير نضج ثمار البرتقال.

تم تصوير الثمار خلال فترات النمو المختلفة و تقدير بعض الصفات الكيميائية معمليا والتى تضم رقم الحموضة ونسبة المواد الصلبة الذائبة الكلية ونسبة الحموضة والنسبة بين المواد الصلبة الذائبة الكلية إلى نسبة الحموضة ونسبة العصير وتركيز الكلوروفيل أ و ب وتركيز الكاروتين. تم حساب المؤشرات اللونية المختلفة مثل شدة وتركيز وكثافة الصورة ودليل مقاومة المناخ المرنى ونسبة اللون الأحمر إلى الأخضر. لقد تم عمل تحليل لونى للصور التى تم إلتقاطها بالكاميرا الرقمية بداخل صندوق مكعب طول ضلعه ٣٠ سم " ومغطى باللون الأسود من الخارج والداخل لتقليل إنعكاس الضوء. تم معالجة الصور بواسطة برنامج ACDSee وذلك حتى يتحول امتداد الصورة إلى TIFF وبعد ذلك استخدم برنامج ENVI لتحليل الصورة و الحصول على اللون الأحمر والأخضر والأزرق للصورة ثم اشتقاق المؤشرات اللونية المختلفة ويمكن تلخيص النتائج المتحصل عليها كالتالى:

وجدت علاقة إرتباط قوية بين الخواص الكيميائية للثمار وبين المؤشرات اللونية للصورة وكانت أعلى قيم مع دليل شدة الصورة ثم VARI بينما باقى المؤشرات أعطت قيم أقل لمعامل الإرتباط وذلك خلال فترات النضج.

وجد أن هناك علاقة بين كل من المؤشرات اللونية والصفات الكيميائية حيث أعطى دليل شدة الصورة أعلى قيمة لمعامل التقدير مع tss (0.97) تلاه الدليل VARI (0.94) بينما **المؤشر R/G** اعطى قيم أقل مع معظم الخواص الكيميائية.

التوصيات:

- يمكن إستخدام تقنية تحليل الصور كمؤشر لتمييز درجات النضج لثمار البرتقال.
- وجد أن دقة إستخدام مؤشرات القياس اللونية اختلفت طبقا للصفات الكيميائية واللونية ويمكن إستخدام المؤشر VARI للتنبؤ بالمراحل المختلفة لنضج ثمار البرتقال.
- يمكن التنبؤ بقيم بعض الصفات الكيميائية مثل نسبة tss إلى نسبة الحموضة وتركيز الكلوروفيل وتركيز الكاروتين من خلال معادلات تربط بن المؤشرات اللونية مثل دليل شدة الصورة ، VARI.