LEMON QUALITY EVALUATION DURING MATURITY USING COLOR ANALYSIS AND LASER TECHNOLOGY

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ABSTRACT

The main purpose of the present study is creation of optical standard scale and quality evaluation parameters when studying of lemon fruits (Citrus aurantifolia) at different maturity stages. The lemon fruits were classified into six stages of maturity according to their color graduation from green to yellow color. The physical, mechanical and chemical properties of lemon fruit were measured. A laser light source with wavelength 543.5 nm with power 4 mW was used, to measure the optical properties of lemon fruits. Each sample was imaged with CCD camera, these images were chromatically analyzed with RGB scale by software program. The results showed that: 1- The main dimensions, mass and volume of lemon fruits were gradually increased. Meanwhile, the peel thickness and the density were gradually decreased with lemon maturity stages, 2- The friction angle of lemon fruits was gradually increased, meanwhile the required force to penetrate the lemon fruits and the firmness were gradually decreased with lemon maturity stages, 3- The juice percentage, total soluble solids (TSS), total sugars and the percentage of acidity were gradually increased, meanwhile the pH value of the lemon fruits was gradually decreased, with lemon maturity stages, 4- The light reflectivity was decreased, meanwhile the light absorptivity intensity was increased as the fruit gradually matured from stage one to stage six., 5- By decreased density of light reflection from fruit surface, the juice, total soluble solid, total sugar and the acidity percentages were increased, pH value was decreased, On the other hand, in the case of density of light absorption percentage was increased and 6- The color analysis (RGB) of fruits color images showed that the red color component was gradually increased, meanwhile each of green and blue color components were gradually decreased as fruits matured from stage 1 to 6.

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Therefore, there is potential for use of laser light to determine the maturity stage of lemon fruits and color analysis of fruits images to distinguish the maturity stage of lemon fruits.

1. INTRODUCTION

Milind (2008), reported that lemons are used either as cut fruit or in juice form, based on the need and convenience. They are known to possess nutritive as well as medicinal values, mainly as rich source of vitamin C. Further, they contain other vitamins also such as vitamin B, riboflavin and minerals like calcium, phosphorous, magnesium besides proteins and carbohydrates. Lemons are known to reduce risk of heart diseases, cancer and also work as antiseptic, astringent, digestive stimulant etc.

Gonzalez-Molina et al. (2010), mentioned that citrus genus is the most important fruit tree crop in the world and lemon is the third most important Citrus species. Several studies highlighted lemon as an important health-promoting fruit rich in phenolic compounds as well as vitamins, minerals, dietary fiber, essential oils and carotenoids. Lemon fruit has a strong commercial value -the value of the product in respect of the quality factors- for the fresh products market and food industry.

Hardy and Sanderson (2010), showed that some markets require that citrus fruits meet specific maturity standards before being sold. These standards are most commonly described as a ratio of sugar, expressed as total soluble solids (TSS) to acid and sometimes percent juice. Maturity testing is undertaken on a sample of 10–20 pieces of fruit representative of the fruit ready to harvest. The more fruit tested the more accurate the test results. Juice content. This is the quantity of juice in the fruit, expressed as percent juice. The juice content of fruit increases as they mature. However when fruit are over-mature their juice content often decreases. TSS refers to the total amount of soluble constituents of the juice. These are mainly sugars, with smaller amounts of organic acids, vitamins, proteins, free amino acids, essential oils and glucosides. Approximately 85% of the total soluble solids of citrus fruit are sugars.

Khojastehnazhand et al. (2010), reported that the color and size are the most important features for accurate classification and/or sorting of citrus such as oranges, lemons and tangerines. The feasibility of using machine vision systems to improve product quality while freeing people from the traditional hand sorting of agricultural materials.

Narendra and Hareesh (2010), said that the lighting source type, location and color quality play an important role in bringing out a clear image of the object. Lighting arrangements are grouped into front- or back-lighting. Front lighting serve as illumination focusing on the object for better detection of external surface features of the product while back-lighting is used for enhancing the background of the object. Light sources used include incandescent lamps, fluorescent lamps, lasers, X-ray tubes and infra-red lamps.

Omid et al. (2010), mentioned that the signals from fruit samples were captured by the cameras, transferred to the PC through the video capture cards, digitized and stored on the PC into three user-defined buffers in red, green, and blue color coordinates (RGB) for further analysis. In the HSI system, hue value is comparatively stable and the color of citrus can be determined by calculating the average Hue value for the fruit.

Elmasry et al. (2012), concluded that some external quality criteria, such as color, texture, size, and shape, are actually automated on industrial graders, but grading of fruits and vegetables according to the other appearance criteria, such as bruises, rottenness, and some other unobvious defects which present the same color and texture to the sound peel, or defects which are always confused with the stem-end and calyxes, is not yet efficient and consequently remains a manual operation.

Pathare et al. (2013), concluded that colour is an important quality attribute in the food and bioprocess industries, and it influences consumer's choice and preferences. Food colour is governed by the chemical, biochemical, microbial and physical changes which occur during growth, maturation, postharvest handling and processing.

Jafari et al. (2014), said that the internal quality of the fruits can be evaluated if there is a correlation between the internal and visible external characteristics. It is normally seen that oranges with coarser surfaces have thicker skin and vice versa. A correlation was achieved between the coarseness factors and thickness of the oranges which showed a good agreement between these two factors. The experiments could be used for non-destructive grading of orange or other citrus fruits to evaluate skin ratio of the fruit.

Zhang et al. (2014), Said that appearance is a very important sensory quality attribute of fruits and vegetables, which can influence not only their market value, consumer's preferences and choice but also their internal quality to some extent. External quality of fruits and vegetables is generally evaluated by considering their color, texture, size, shape, as well as the visual defects.

The main purpose of the present investigation is creation of optical standard scale and quality evaluation parameters when studying of lemon fruits (*Citrus aurantifolia*) at different maturity stages.

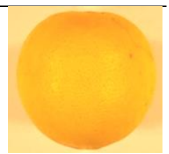
1. MATERIAL AND METHODS

The experiments were carried out at the Laboratory of Laser Application in the Agricultural Engineering at National Institute of Laser Enhanced Science (NILES), Cairo University and the Central Laboratory of Agricultural Engineering Research Institute, Agricultural Research Center, Dokki, Giza, Egypt. The experiments and measurements for the optical, mechanical, physical and chemical properties of lemons were carried out according to the following procedures:

2.1 Fruit Sample

This study was carried out during season 2013 on lemon fruits (*Citrus aurantifolia*), from one of farm at Qalubya Governorate. For each sampling, 600 of lemon fruits were selected to achieve these measurements. These fruits were classified visually into six stages of maturity according to the color of their skin as shown in Fig. (1).

Figure 1. Six maturity stages of lemon fruits

No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
					
Dark green	**Light green**	**Half green**	**Half yellow**	**Light yellow**	**Yellow**

2.2 Physical Properties

Fruit samples of each mature stage were collected, and to the following measurements, in order to determine the physical properties: 1) Fruit mass (g) was determined using a digital scale; its sensitivity was 0.01 g, 2) Fruit diameters (mm) were measured using Vernier caliber., 3) Fruit skin thickness (mm) was measured using Vernier caliber, 4) Fruit volume (cm^3) was measured by water displacement method in graduated flask, and 5) Fruit density (cm^3/g) was calculated by dividing the mass over the volume.

2.3 Mechanical Properties

The mechanical properties of lemon fruits at different maturity stages included fraction angle, requested penetration force and firmness of the lemon fruits. The measurements were as follow (1) the fraction angle was measured on wooden surface and measure the angle required to begin the fruit to start to rolling, (2) the requested penetration force and firmness (N) were measured by using the pentrometer by using different head tool (cone and flat). The 6.4 mm of diameter head tool was used to measure the requested penetration force, while the 15 mm diameter head tool of the pentrometer was used to measure the firmness.

2.4 Chemical Properties

Fruit juice samples were subjected to the following measurements in order to estimate the chemical properties of lemon fruits:

- Juice percentage was estimated by squeezing the fruit and weight the juice produced, then calculate the percentage of the juice.
- Juice preparation, freshly squeezed lemon fruit juice was made employing handle juice press. The following juice quality parameters were considered: total soluble solid percentage was measured using refract-meter, acidity was measured in lab, pH was measured by pH meter and juice percentage. The lemon juice percentage was determined using the following equation:
    - Lemon juice, % = [M1/ M2]X 100 ……….. (1)

  Where: M1 is the mass of lemon juice, g; and M2 mass of lemon fruits, g.

- pH value was measured by using a digital pH-meter.
- Determine ^{o}Brix using an analog refractometer.
- Total soluble solids (TSS) : TSS refers to the total amount of soluble contents of the juice. Approximately 85% of TSS of citrus juice are sugars.

Total soluble solids (TSS) = ^{o}Brix ……… (2)

- Fruits acidity was determined by a procedure known as titration. This test involves adding few drops of indicator solution (phenolphthalein) to 10 mL of juice and then measuring the volume of sodium hydroxide required to neutralize the solution.

% acidity = titrable acidity (mL) X 0.064 ……….(3)

- A total sugar was estimated according to **A.O.A.C. (2000).**

2.5 Optical Properties

2.5.1 Laser Setup

The experimental setup was adjusted at incident angle equal to reflected angle (45^{o}) to obtain high reflections and to establish criteria for identifying optical properties of lemon fruits. The experimental setup was shown in Fig. (2).

2.5.2 Laser Type

Helium-Neon (He-Ne) laser in the visible light with wavelength 543.5 nm with power 4 mW, and intensity of 4200 lux was used as a light source. Laser source was sitting on a holder. The specifications of laser were continuous beam and beam diameter of 0.75 mm.

2.5.3 Lens

Convex silica glass lens of 100 mm focal length with diameter 75 mm was used. The lens was put between the fruit sample and the luxmeter with angle of 45 degree to focus the reflected light and collect it on the luxmeter detector .

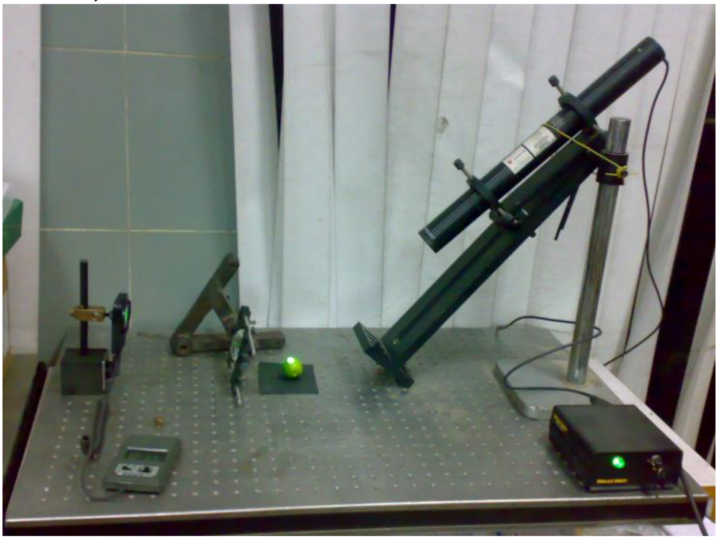
2.5.4 Digital luxmeter

A digital luxmeter with high accuracy and sensitivity was used. Digital luxmeter with ranges of 0-50,000 Lux to measure light intensity.

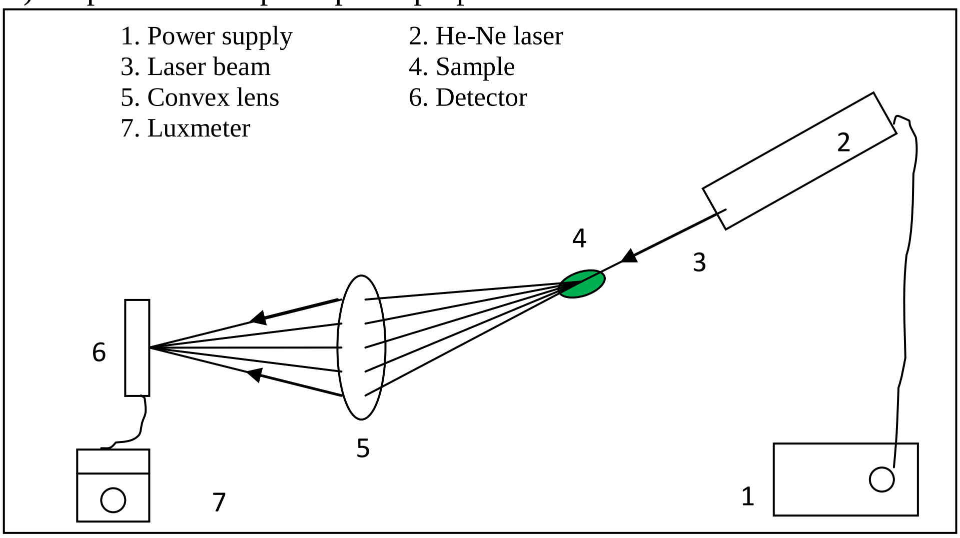
The laser beam was reflected from lemon surface and collected by concave lens to luxmeter detector. The absorption of lemon fruit was calculated from the following equation according to the energy conservation law:

$$I = R + A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where: I : The incident beam, lux; R - reflective beam, lux; and A- absorptive beam, lux.



a): Experiment setup of optical properties.

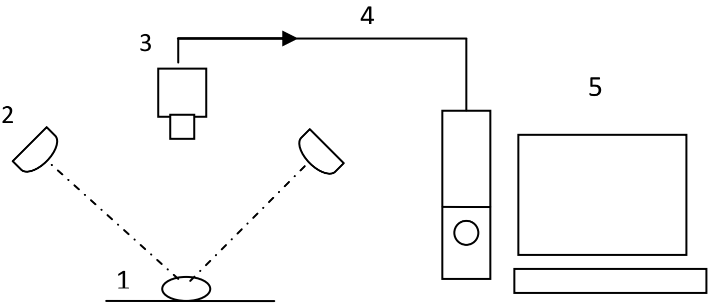


b) : Schematic diagram of optical properties.

Figure 2. Experiment schematic diagram of set up for measuring the optical properties of lemon fruits.

Illumination and color analysis systems :

a): Image of illumination system.



b): Vision and color analysis systems.

1- Sample, 2-light source, 3- Digital camera, 4- Electric wire, and 5- Personal computer

Figure 3. Vision, illumination and color analysis system.

1.6 Vision, illumination and color analysis system

Vision, illumination and color analysis system used to image the fruits with CCD camera. These imaged saved digitally in a PC and color analyzed with a specialist software, Fig. (3). Table (1) shows the specifications of illumination system.

Table 1. specifications of illumination system

Model	Hama Reporo
Source of manufacture	Germany
No. of lamps	4
Lamp type	Ordinary
Light color of lamp	White
Lamp Power, W	100
Power supply electricity, Volt	220
Area image (DIN)	A3, A4, and A5
Length of stand, cm	73
Light incident angle, rad (deg).	45

2. RESULTS AND DISCUSSIONS

Figure 4. shows the main dimensions, skin thickness, mass, volume and density of lemon fruits. It showed that the vertical and horizontal diameters of lemon fruits gradually increased, vertical diameter were 41.67, 43.59, 43.79, 43.87, 44.36 and 44.42 mm and of horizontal diameter were 35.65, 37.73, 39.62, 40.53, 42.44 and 44.23 mm for maturity stages from one to six of lemon fruits, respectively. Meanwhile, average values of skin thickness decreased from 1.91, 1.73, 1.72, 1.66, 1.42 to 1.10 mm for the same lemon fruits of maturity stages.

Figure 5. shows the volume, mass and density of lemon fruits. It showed that, the volume increased gradually with averages of 79.07, 102.50, 118.35, 138.36, 145.08 and 170.88 cm^3 and mass increased gradually with average values of 29.73, 36.08, 39.53, 41.23, 43.09 and 50.41g for maturity stages from one to six of lemon fruits, respectively. Meanwhile, the fruits density decreased gradually with average values of 0.376, 0.352, 0.334, 0.298, 0.297 and 0.295 g/cm^3 for the same lemon fruits.

Figure 6. shows the relationship between maturity stages of lemon fruits and some of mechanical indicators. These mechanical properties included the fraction angle required to start the fruit to roll, the required force to penetrate the lemon fruits and the firmness of them. It was noticed that the rolling angle increased as the fruit matured. The fraction angles were recorded with average values of 7.33, 8.00, 8.80, 9.53, 10.00 and 11.50 degrees for maturity stages from one to six of lemon fruits, respectively.

While each of the required force to penetrate the lemon fruits and the firmness decreased gradually as the fruits matured. The average values for the required force to penetrate the lemon fruits were 60.6, 55.5, 54.0, 53.4, 50.0 and 48.5N and for the firmness were 49.5, 40.3, 38.7, 36.0, 31.5 and 28.5 N for maturity stages from one to six of lemon fruits, respectively.

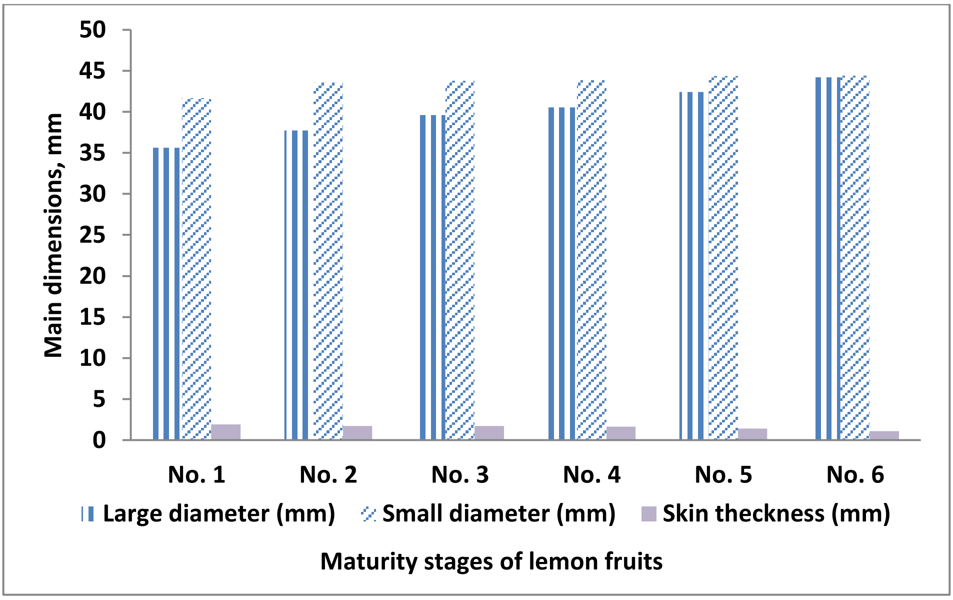


Figure 4. Main dimensions and skin thickness for maturity stages of lemon fruits.

Table 2. and Figure 7. show the relationship between maturity stages of lemon fruits and some chemical indicators of the lemon fruits. These chemical properties included the pH values, TSS, acidity and total sugars. The percentage of juice content for each lemon fruit was calculated. These percentages increased with average values of 35.89, 37.08, 38.19, 40.97, 41.69 and 46.96%for maturity stages from one to six of lemon fruits, respectively.

Also, the pH values and the acidity percentage increased as the fruit matured from stage to stage of maturity. The pH values were measured and the averages were calculated, these averages were 2.6, 2.5, 2.5, 2.3, 2.3 and 2.3 for maturity stages from one to six of lemon fruits, respectively. And, the averages of acidity were 1.23, 1.67, 2.03, 2.45, 2.57 and 2.61% for maturity stages from one to six of lemon fruits, respectively. While, the TSS (^{o}Brix) and the total sugars percentages decreased as the fruit matured from stage to stage of maturity. The TSS (^{o}Brix) averages were 7.5, 7.6, 7.7, 8.0, 8.3 and 8.7 degree, and the total sugars percentages averages were 5.86, 5.93, 6.05, 6.35, 6.38 and 6.66% for maturity stages from one to six of lemon fruits, respectively.

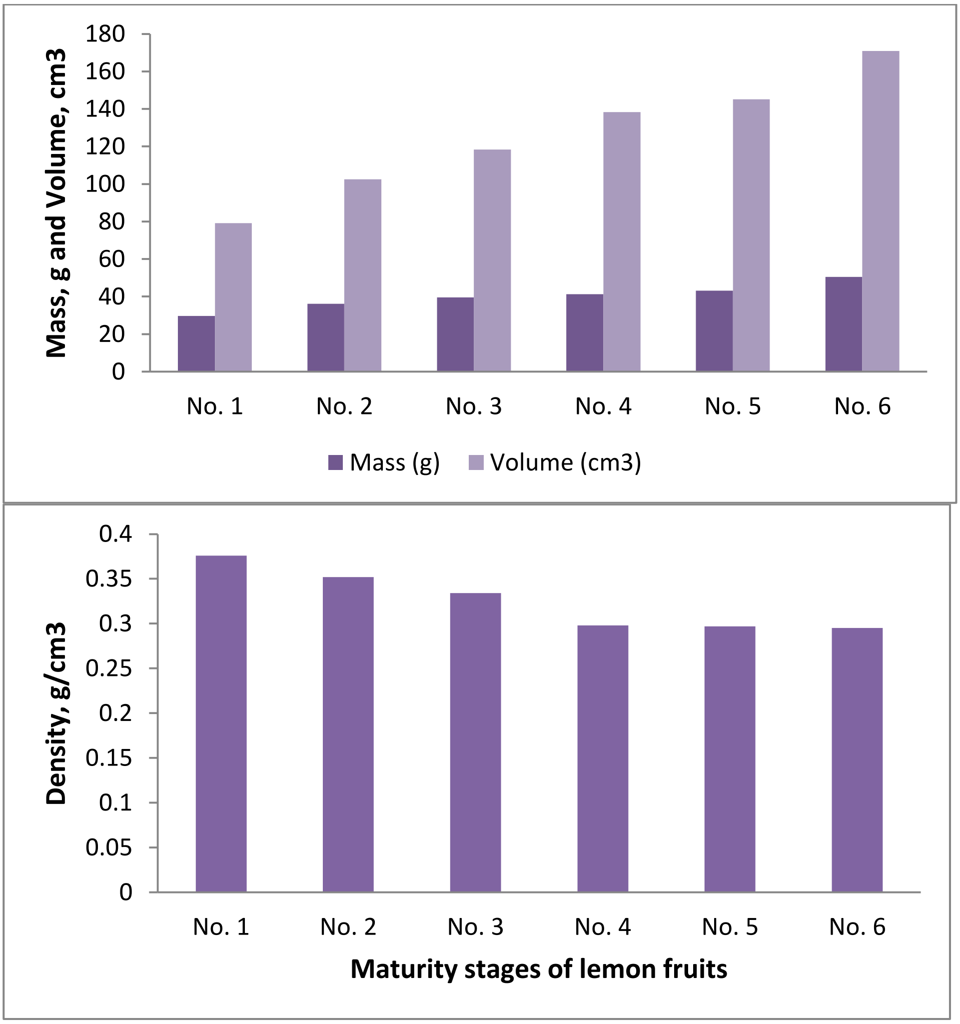


Fig. (5): Physical properties of lemon fruits at different maturity stages

Table 2. Some chemical properties of lemon fruits at different maturity stages.

Maturity stage	Juice, (%)	pH, Value	TSS (^{o}Brix)	Acidity (%)	Total sugars (%)
1	35.89	2.6	7.5	1.23	5.86
2	37.08	2.5	7.6	1.67	5.93
3	38.19	2.5	7.7	2.03	6.05
4	40.97	2.3	8.0	2.45	6.35
5	41.69	2.3	8.3	2.57	6.38
6	46.96	2.3	8.7	2.61	6.66

Fig. (8) shows the relationship between maturity stages of lemon fruits and some of optical indicators of the lemon fruits. These optical properties included the light intensities reflection and absorption percentages.

The total beam intensity was measured and recorded as 4200 lux and each fruit was exposure by the laser beam, then the reflection beam intensity was measured. Then, the percentages of reflection and absorption of laser light intensities for each lemon fruit was calculated. These percentages of light reflection intensity decreased with average values of 1.425, 1.260, 1.101, 0.954, 0.763 and 0.688% for maturity stages from one to six of lemon fruits, respectively. While, the percentages of light absorption intensity increased with average values of 98.575, 98.740, 98.899, 99.046, 99.237 and 99.312% for maturity stages from one to six of lemon fruits.

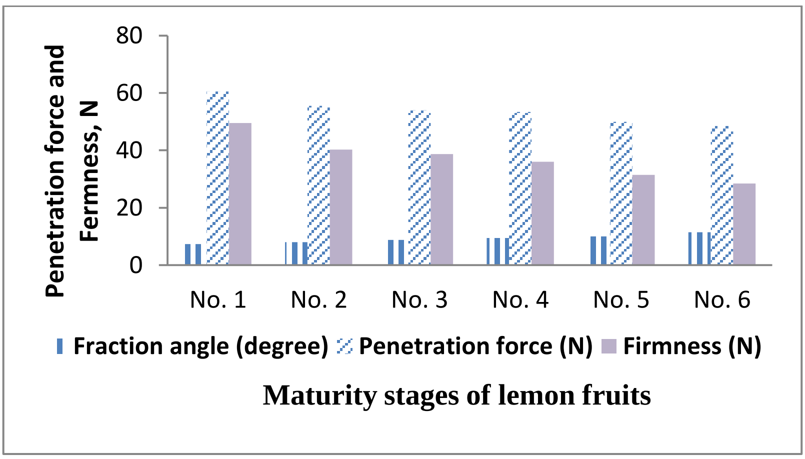


Figure 6. Mechanical properties of lemon fruits at different maturity stages

Table 3. and Figure 9. show the relationship between maturity stages of lemon fruits and its color analysis. The average values of the red, green and blue components measured for maturity stages of lemon fruits which can be used as a color scale. The average value of red component increased gradually from 142.8, 143.9, 145.1, 146.5, 173.1 and 175.1 for maturity stages of lemon fruits. Meanwhile, The average values of green and blue color components decreased gradually.The value of green color component was 128.5, 122.0, 116.9,115.2, 111.9 and 107.1, and the value of blue color component was 61.0, 53.2, 43.2, 42.1, 25.0 and 21.5 for maturity stages from 1 to 6 of lemon fruits, respectively.

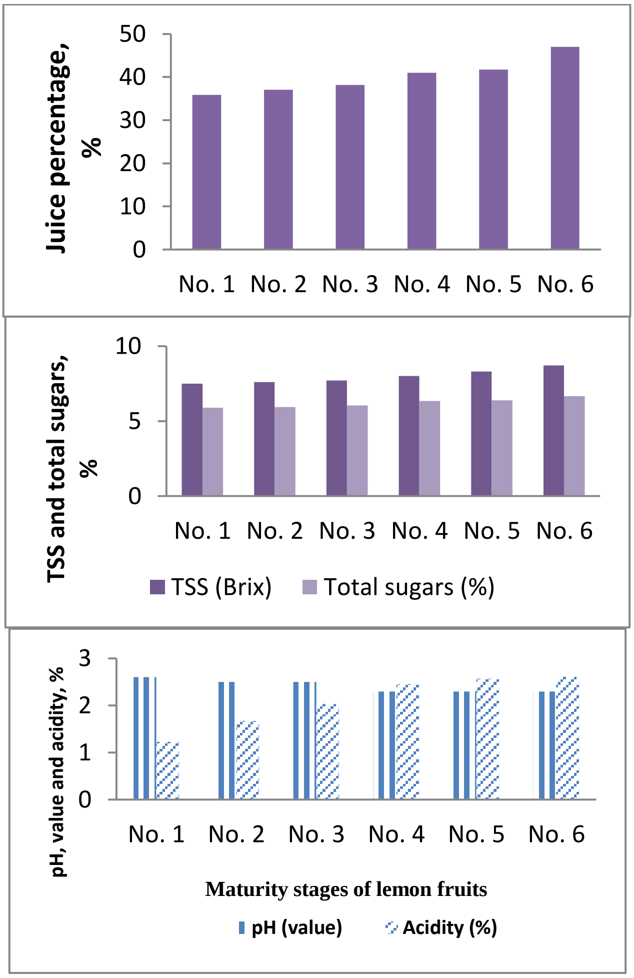


Figure 7. Chemical properties of lemon fruits at different maturity stages

Table 3. Color analysis of lemon fruits at different maturity.

Maturity stage	Red	Green	Blue
1	142.8	128.5	61.0
2	143.9	122.0	53.2
3	145.1	116.9	43.2
4	146.5	115.2	42.1
5	173.1	111.9	25.0
6	175.1	107.4	21.5

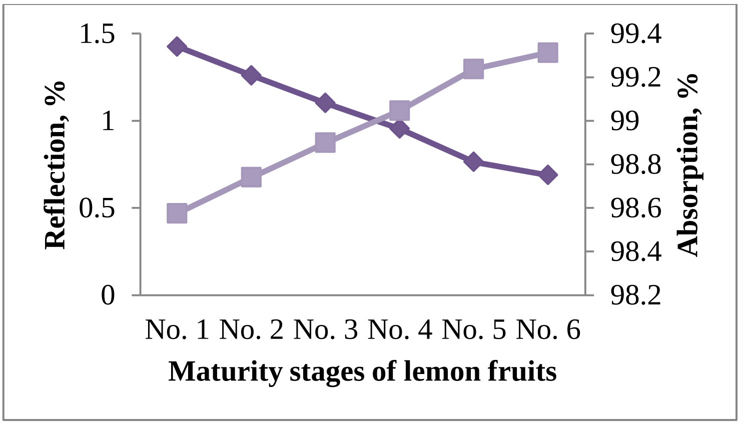


Figure 8. Optical properties of lemon fruits at different maturity stages.

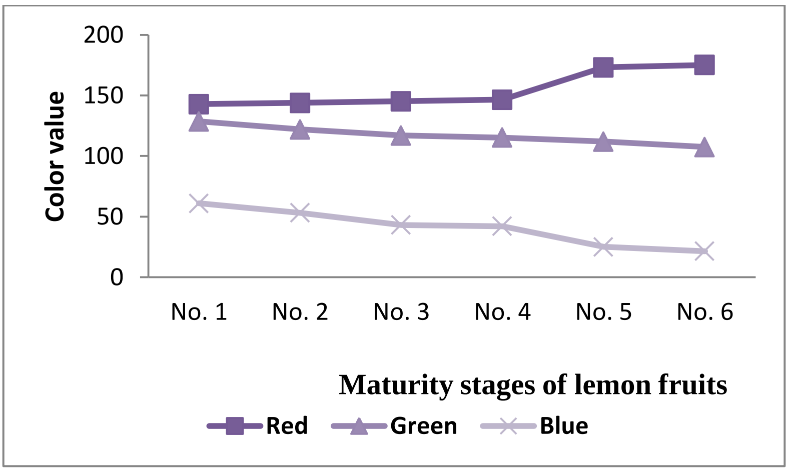


Figure 9. Color analysis of lemon fruits at different maturity stages.

Table 4. shows the optical scale of lemon fruits at different maturity stages. This scale can be used to define the maturity stage of each fruit.

Table (4-24): Optical scale of lemon fruits at different maturity stages.

Maturity stage		Green color (value)	Reflection intensity (Lux)	Absorption intensity (Lux)
1	Max	135	64	4143
	Avg	128.5	59.86	4140.14
	Min	125	57	4136
2	Max	125	57	4152
	Avg	122.0	52.93	4147.07
	Min	119	48	4143
3	Max	119	48	4157
	Avg	116.9	46.26	4153.74
	Min	116	43	4152
4	Max	116	43	4163
	Avg	115.2	40.06	4159.94
	Min	117	37	4157
5	Max	117	37	4169
	Avg	111.9	32.06	4167.94
	Min	109	31	4163
6	Max	109	31	4176
	Avg	107.4	28.89	4171.11
	Min	105	24	4169

3. CONCLUSION

The quality evaluation parameters under study for maturity stages for the lemon (*Citrus limonia*) fruits had the following trends as:

1- The main dimensions, mass and volume of lemon fruits were gradually increased. Meanwhile, the peel thickness and the density were gradually decreased with lemon maturity stages.

2- The fraction angle of lemon fruits was gradually increased, meanwhile the required force to penetrate the lemon fruits and the firmness were gradually decreased with lemon maturity stages.

3- The juice percentage, total soluble solids (TSS), total sugars and the percentage of acidity were gradually increased, meanwhile the pH value of the lemon fruits was gradually decreased, with lemon maturity stages.

4- The reflection light intensity was decreased, meanwhile the light absorption light intensity was increased as the fruit gradually matured from stage one to stage six.

5- By decreasing density of light reflection percentage from fruit surface, the juice, total soluble solid, total sugar and the acidity percentages increased, meanwhile, pH value was decreased, On the other hand, in the case of density of light absorption percentage was increased for maturity stages from 1 to 6 of lemon fruits.

6- The color analysis (RGB) showed that the red color component increased gradually, meanwhile each of green and blue color components decreased gradually as fruits matured from stage 1 to 6 which can be used as a color scale.

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الملخص العربي

تقييم جودة ثمار الليمون خلال مراحل النضج باستخدام تكنولوجيا الليزر والتحليل اللوني

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الهدف الرئيسي لهذه الدراسة هو إنشاء مقياس ضوئي قياسي ودراسة العوامل التقيمية لثمار الليمون صنف (*Citrus aurantifolia*) عند مراحل النضج المختلفة. تم تقسيم ثمار الليمون إلي ستة مراحل من النضج بناءا علي التدرج اللوني من اللون الأخضر وحتى الأصفر. تم قياس الخصائص الطبيعية والميكانيكية والكيمائية لثمار الليمون. تم استخدام مصدر ليزر ضوئي بطول موجي ٥٤٣,٥ نانوميتر بقدرة ٤ مللیوات وذلك لقياس الخصائص الضوئية لثمار الليمون. تم تصوير كل عينة بكاميرا ذات تقنية CCD ، هذه الصور تم تحليلها لونيا علي أساس مقياس RGB باستخدام برنامج مخصص.

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٢- رئيس بحوث بمعهد بحوث الهندسة الزراعية – مركز البحوث الزراعية - الدقى – مصر
٣- باحث مساعد بمعهد بحوث الهندسة الزراعية – مركز البحوث الزراعية - الدقى – مصر

وتم الحصول علي النتائج : ١- تزداد تدريجيا قيم الأبعاد الرئيسية والكتلة والحجم لثمار الليمون. في حين ، يتناقص تدريجيا قيم كل من سمك القشرة وكثافة الثمرة بتقدم مرحلة نضج ثمار الليمون ، ٢- تزايدت زاوية الاحتكاك لثمار الليمون ، في حين ، قوة إختراق ثمار الليمون وصلابة الثمرة تناقصت مع تقدم الثمرة في مراحل النضج ، ٣- تزايدت تدريجيا قيم كل من نسبة العصير والمواد الصلبة الذائبة والسكريات الكلية ونسبة الحموضة ، في حين ، تناقصت تدريجيا قيم الـ pH مع تقدم الثمرة في مراحل النضج ، ٤- تناقصت الانعكاسية الضوئية ، في حين تزايدت الامتصاصية الضوئية مع تقدم الثمرة في مراحل النضج من المرحلة الأولى إلي السادسة ، ٥- بتاقص الكثافة الضوئية المنعكسة من سطح الثمرة تزايدت قيم نسب كل من العصير والمواد الصلبة الذائبة والسكريات الكلية والحموضة بينما قيم pH تناقصت ، أما علي الجانب الآخر ، فقد تزايدت نسبة كثافة الضوء الممتص و ٦- أوضح التحليل اللوني (RGB) للصور الملونة للثمار أن مكون اللون الأحمر قد تزايد تدريجيا ، في حين يتناقص كل من مكون اللونين الأخضر والأزرق تدريجيا بتقدم الثمار في مراحل النضج من المرحلة الأولى إلي السادسة. وعليه يوجد إمكانية لاستخدام الليزر الضوئي والتحليل اللوني لصور الثمار لتمييز مرحلة نضج ثمار الليمون ومعرفة عوامل جودتها.