A laser reflection method to detect strawberry fruit defects

Abd El-Rahman Abd El-Raouf Ahmed [1], Helmy El-Sayed Hassan [2], and Hend Nabil Mohamed [3*]

(1 . Agricultural Engineering Research Institute, Agricultural Research Center, Egypt.
2. National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt;
3. Agricultural Economic Research Institute, Agricultural Research Center, Egypt.)

Abstract: This study aims to use the method of laser reflection from the surface of strawberry fruits to classify different strawberry defects to facilitate the process of sorting the fruits during the handling process. The study was conducted on exposing the strawberry fruits (festival variety) to laser radiation with wavelengths of 543.5 and 632.8 nm, after dividing the fruits into six groups according to strawberry defects, to measure the amounts of reflected radiation and generated electricity. The results obtained were follows: a) For the physical and chemical properties of strawberry fruits: It was found that there is no dispersion in height, width, length, volume, weight, total soluble solids (Brix) and the pH value of the fruits. Their variance values indicate that there is stability of the physical and chemical characteristics in this variety of strawberries., b) The results of the T-test showed that there was a significant difference between the light density reflected or the amount of generating electricity from the surface of standard strawberry fruits and the surface of defective strawberry fruits at every defect (mold, insects, green end, white shoulder, green), in the case of using different levels of the laser beam with a wavelength of 543.5 or 632.8 nm. Then, the amount of reflected radiation or the amount of electrical energy generated could be used to separate the affected fruits from the healthy ones, c) The results of the One Way Anova analysis showed that there was a statistically significant correlation between the light density reflected from strawberry fruits (as a result of using laser beams at 543.5 or 632.8 nm wavelengths) and the amount of electricity generated on the surface of the photovoltaic cells, d) It was possible to use laser reflection light or the amount of generating electricity to classify and sort strawberry fruits according to its defects.

Key words: quality valuation, strawberry fruit, visible laser, physical properties

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1 Introduction

The strawberry crop is one of the vegetable crops of great importance at the export level as it is exported fresh or prepared to many international markets, and the strawberry area reaches about 19 thousand acres, including 10 thousand acres of old land and about nine thousand acres of new lands, and on the production side, it was found that the total strawberry production is about 319 thousand tons, with a production value estimated at 1129 million Egyptian pounds. The amount of Egyptian exports of fresh strawberry crops is about 21385 tons in 2018 with export value estimated about 73896 thousand dollars. The most important markets for Egyptian strawberries, Belgium, Germany, Russia and England have a market share of about 22.3%, 19.4%, 9.7%, and 9.4% respectively. (Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, National Agricultural Income Bulletin, 2017).

Strawberries are the only species of fruit with the seed on the outside. The strawberry has 200 seeds on average. Eight strawberries contain more vitamin C than an orange. Also, strawberries are full of a special

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***Corresponding author: Hend, N. M.,** Senior of Researcher , Agricultural Economic Research Institute, Agricultural Research Center, Egypt. E-mail: dr.hend_nabil@hotmail.com.

substance called ellagic acid, which can help fight cancer. Strawberry (*Fragaria* × *ananassa* Duch.) belongs to the roseceae family and is a widely consumed fruit. Agricultural production forms one of the most important economic sectors (FAO, 2013). Kalt et al. (1999) reported that, although white strawberries became red during storage, they do not undergo sufficient changes in sugar and acid content to be suitable for fresh consumption. Minimal processing results in the physical alteration of a fruit due to the operations of selection, washing, classification, peeling, cutting or slicing, sanitization, rinsing, draining, wrapping and cooling to obtain a fresh product doesn't need further preparation (Puschmann et al., 2006). The most important strawberry quality indicators are content of sugars and total acids, which can be described as a sugar / acid ratio (Pineli et al., 2011).

Sugar / acid ratio characterizes the degree of sweetness, which depends on the cultivar, ripeness, and weather conditions. According to Sturm et al. (2003) and Pelayo et al. (2003). Fruit quality is defined as a measure of the characters or attributes that determine the suitability of the fruit to be eaten as fresh or stored in a reasonable period without deterioration. Fruit quality could be considered as a multiple concept encompassing the physical, physiological, nutritional, and pathological attributes that affect fruit shelf life. Quality of a fresh produce includes appearances (size, shape, colour, gloss, and freedom from defects and decay), texture (firmness, crispness, and toughness), flavor (sweetness,sourness, aroma, and off-flavors), and nutritive value (vitamins, minerals, nutrients and carbohydrates). (ElMasry et. al, 2007).

Strawberry (Fragaria sp.) is one of the economically important fruits which are more popularly eaten fresh, used for garnishing cakes and pastries, flavored juices and milk products, and processed into jams and others. Thus, together with the recent concern for food quality and safety, automatic technologies for judging the fresh quality of strawberry are being sought. Technologies that can sort fruit for appearance, texture, taste, flavor and/or nutritive value would assure fruit quality and consistency, increase consumer confidence and satisfaction, and enhance the competitiveness and profitability of the fruit industry (Lu and Ariana, 2002).

Strawberry is one of the non-climacteric fruits and in order to achieve the highest quality in terms of flavor, taste and color, it must be harvested at full maturity. The main changes in fruit composition only happen during maturation process and in contact with the mother plant (Cordenunsi et. al, 2005). Mechanical damage is considered as a type of stress that occurs during the harvest and post-harvest manipulation of fruits. This stress is accompanied by physiological and morphological changes that affect the fruit commodity. Apart from the mechanical stress, there environmental factors, which also cause quality reduction are other types of stress due to biological (Shewfelt, 1998). Giampieri et al. (2012) showed that the strawberry represented a relevant source of micronutrients, such as minerals, vitamin C, folate and phenolic substances, most of which were natural antioxidants and contributed to the high nutritional quality of the fruit.

All these compounds are essential for health and, in particular, strawberry phenolics are best known for their antioxidant and anti-inflammatory action, and possess directly and indirectly antimicrobial, anti-allergy and anti-hypertensive properties, as well as the capacity to inhibit the activities of some physiological enzymes and receptor properties. Shahin et al. (2002) compared between features obtained from optical measurements by Laser technique and the standard RGB images for classifying tomatoes in different ripeness classes. Laser features have been captured under different wavelengths. For comparison and classification, Fisher's linear discriminate analysis was used. This technique is very suitable for tomatoes classification in different ripeness classes.

Throop et al. (2003) designed two conveyors, one for capturing x-ray images for internal defects and the other for capturing images of surface defects on apples. A small wheel protruding 1.2 mm up through the center of a small ring contacted the apple surface rotating the apple until the concave stem or calyx moved over the wheel causing the wheel to lose contact. Hassan (2003) mentioned that, the electrical signals from sound tomato were consistently affected by the presence of various surface defects and discolor of tomatoes. This is the basis for Opto-electronic instrument for sorting and grading tomato.

Khojastehnazhand et al. (2010) concluded that the quality grading included outer parameters (size, color intensity, color homogeneity, bruises, shape, stems identification surface texture and mass), inner parameters (sweetness, acidity or inner diseases) and freshness. Alfatni et al. (2013) reported that the fruit quality was related to both internal (firmness, sugar content, acid content percentage and defects) and external (shape, size, defects and damage) variables. Fruit internal grading is one of the quality grading systems used in agricultural research. Internal characteristics such as moisture, sugar, acidity and the like to offer valuable information about fruit ripeness, which may not be easily detected by merely examining the fruit's external characteristics.

Crisosto et al. (2003) mentioned that consumers had a preferred color for a specific item. Colors that are not appropriate for the item, indicative of loss of freshness or suggestive of a lack of ripeness, can turn away willing consumers. For instance, good quality and ripe bananas are associated with yellow color without brown spots, tomatoes are associated with red instead of orange, cherries are associated with red instead of yellow and kiwi fruits are associated with green flesh instead of yellow. Ramos et al. (2004) mentioned that in case of the instrumental color methodology, there are three major considerations: what instrumental method to use (pigment extraction or reflectance), how to express the data and how to use the data.

Xu and Zhao (2010) showed that the strawberry automated grading system could utilize one, two or three characteristics to grade the strawberry into three or four grades. In order to solve the multi characteristic problems, the multi-attribute Decision Making Theory was adopted in this system. The system applied a conveyer belt, a camera, an image box, two photo-electrical sensors, a leading screw driven by a motor, a gripper, two limit switches and so on. The system was controlled by the single-chip-microcomputer (SCM) and a computer. The results show that the strawberry size detection error is not more than 5%, the colour grading accuracy is 88.8%, and the shape classification accuracy is above 90%.

Gao et al. (2010) demonstrated that the detection for fruits using optical properties was one of the most practical and the most successful technique in non-destructive measurement. It has the following characteristics: high-sensitivity detection, good adaptability, lightweight equipment, flexible usage, and no harm to humans. This technique has gradually been applied to the practical stage on abroad.

Fu et al. (2007) reported that one of the advantages of the reflectance mode was that measurements were easier to obtain and the light levels of the reflected radiation are much higher than that of transmitted radiation. However, variations in superficial and surface properties of the pear fruit might influence calibrations. The objectives of this study are: a) evaluation of some physical and chemical properties of strawberry fruits., b) classification of strawberry fruit defects, according to reflect the laser method., and c) statistical analysis of relation between reflection and electrical intensity using laser in the detection of various defects of strawberry fruits.

2 Materials and methods

The experiments were carried out at the Laboratory of Laser Application in the Agricultural Engineering Lab., at the National Institute of Laser Enhanced Science (NILES), Cairo University, Egypt. The experiments and measurements of the optical, electrical, physical and chemical properties of strawberry fruits were carried out in 2019 according to the following procedures.

2.1 Sample plant

Festival variety of strawberry fruit is a short-day cultivar selected to compete in Florida's winter and early spring fruit , the variety produces medium red, conical fruits. It is superior disease resistance and excellent pollination under cool, humid conditions result in a high percentage of marketable fruit, especially in the early part of the season. The fruit has excellent dessert and aromatic quality. The consistent internal red color makes Florida festival an excellent candidate for freezer market

2.2 Physical properties:

2.2.1 Main dimensions fruit samples

One hundred fruits in mature stage were collected. Fruit samples were subjected to the following measurements, in order to determine the physical properties of orange fruits: 1) Fruit mass (g) was determined using a digital scale; its sensitivity was 0.01 g, and 2) Fruit vertical, horizontal diameters and fruit skin thickness (mm) were measured using Vernier caliber.

2.2.2 Volume estimation of fruits

The volume of strawberry fruit was estimated by water displacement in graduated cylinder and flacks. Each fruit was submerged gently in a known volume of water (V_1) and estimate the volume of water and the volume of the fruit (V_2) in mm^3 dimension. The volume of the fruit was calculated from the following equation.

$$\text{The volume of the fruit, } mm^3 = V_2 - V_1 \quad (1)$$

Where: V1: a known volume of water (mm^3), and V2 : estimate the volume of water (mm^3).

2.2.3 Mass density or density Estimation of the strawberry fruits

The mass density or density of a material is defined as its mass per unit volume. The mass density of a material varies with temperature and pressure. The variance is typically small for solids and liquids. Whenever information on temperature or pressure was available in the literature, it was added to the reference.

$$\rho = M / V \quad (2)$$

Where: ρ: the density (g/mm^3), M: Mass (g), and V : the volume of fruit (mm^3)

2.3 Chemical properties:

Fruit juice samples were subjected to the following measurements in order to estimate the chemical properties of strawberry fruits. Strawberry fruits were squeezed and the chemical tests were achieved with 100 ml of juice.

2.3.1 pH value was measured by using a digital pH –meter:

The technical specifications of Testo 206-pH3 were as follows: measurement range, pH value ranging from 0 to 14 at 0 °C to 80°C, dimensions by 197 x 33 x 20mm, weight in 69g and display with LCD, 2 lines.

2.3.2 Determine °Brix using a digital hand –held refractometer:

The specifications of digital hand held refractmeter model (atago pal-1 3810 -e18) were as follows: measurement scale range in Brix from 0.0 to 53.0%, 9.0 ^{O} C to 99.9 ^{O} C, measurement accuracy by Brix (+ or -) 0.2%, sample measurement temperature in 10 to 100 degrees C (ATC), ambient temperature in 10 ^{O} C to 40 ^{O} C, sample volume in 0.3 ml, Measurement time in three seconds, dimensions in 10.9 x 5.5 x 3.1cm (H ×W × D), weight in 100g and display by Digital, LCD.

2.4 Laser setup

The experimental setup was adjusted to measure reflection intensity of strawberry fruits. The experimental setup was shown in Figure 1.

2.4.1 The He-Ne laser

The helium-neon (He-Ne) laser with wavelengths 543.5 and 632.8 nm was used as a light source in the present work. The specifications of He-Ne laser were shown as follows.

2.4.2 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 an angle of 45^{O} to focus the reflected light and collect it on the luxmeter detector.

2.4.3 Holders

Holders fabricated from copper were used to hold lens, sample, luxmeter detector. The holder also, which allowed the photovoltaic cell to move in any direction.

2.4.4 Digital avometer

Model CDA- 701 made in Japan was used to measure the electrical signal with volt which results from the converted reflection of light from the fruit surface by a photovoltaic cell. This avometer was with accuracy 0.1 mV (DC), measuring range from 1 mV to 1000 V (DC).

2.4.5 Digital luxmeter

A digital luxmeter with high accuracy and sensitivity was used to measure the intensity of light reflection from fruit surface and then reflection light was collected by a concave lens to luxmeter detector. Measurements of digital luxmeter were with ranges of 0-50,000 Lux. Digital luxmeter specifications.

2.4.6 Photovoltaic cell

The dimensions were 60 and 40 mm in length and width, respectively. It was mounted on a holder which allowed the cell to move in any direction. The intensity of reflected light was transformed to voltage by photovoltaic cell which was transferred to an avometer.

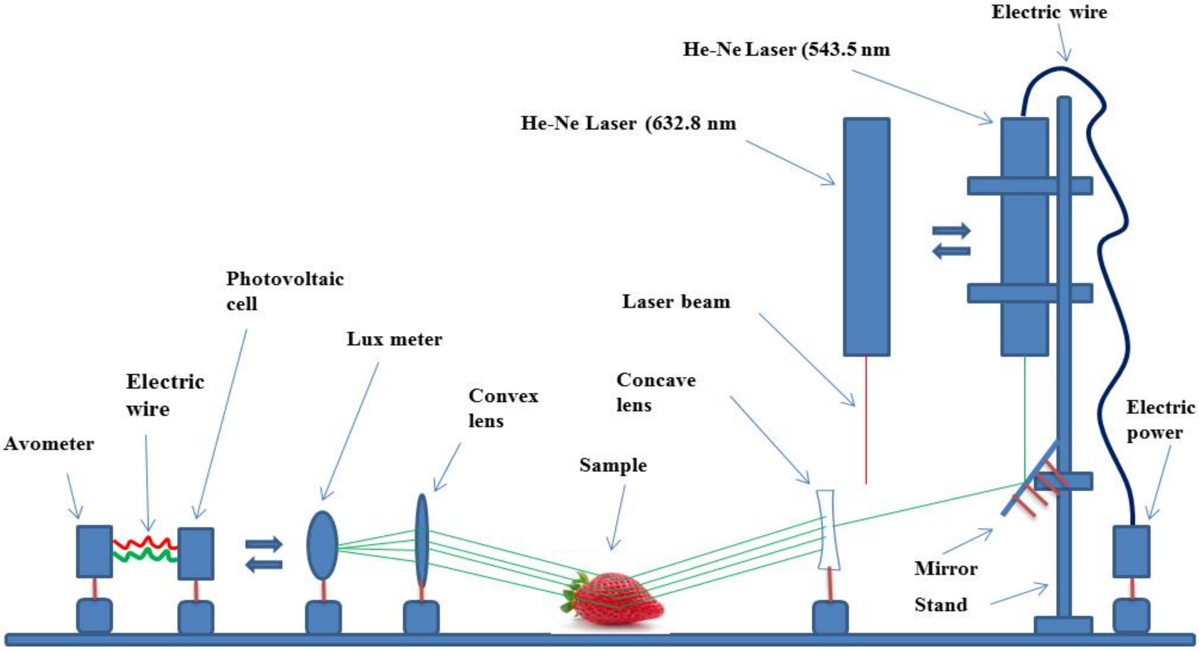

Figure 1 The experimental setup used measurements for the optical properties.

2.5 Statistical analysis methods

Descriptive analysis was used to measure the stability of the physical and chemical properties of strawberry fruits of (Festival variety), and also was used in Test (T) independent samples to measure the significant differences amount of reflected radiation or the amount of electrical energy generated between healthy strawberry fruits and defective strawberry fruits using visible laser rays with wavelengths of 543.5 and 632.8 nm. It was also used in One way Anova test to measure the direction and significance of the relationship between the light intensity reflected by strawberry fruits and the amount of electricity generated on the surface of the photovoltaic cells at different wavelengths.

3 Results and discussion

3.1 Descriptive analysis of physical and chemical characteristics of strawberry fruits

The following Table 1 shows the results of the descriptive analysis of the physical and chemical characteristics of the strawberry fruits (festival variety), by analyzing the results of about 50 samples of strawberry fruits, and the results of the statistical analysis were as follows:

Table 1 Descriptive analysis of physical and chemical characteristics of strawberry fruits

Properties	pH	Brix, %	Density, g/mm^3	Mass, g	Volume, mm^3	Long, mm	Width, mm	High, mm
Mean	3.558	7.51	1.124	12.992	11.628	24.833	26.547	32.117
Median	3.6	7.5	1.115	12.55	11.05	24.65	27	32.45
Std. Deviation	0.10515	0.2234	0.078	4.3864	3.9924	3.8561	4.7486	3.6335
Minimum	3.4	7	1	7.2	6.5	19.3	16.6	23.2
Maximum	3.7	7.9	1.3	29.2	24.1	38.4	36.8	40.6
Variance	0.011	0.05	0.006	19.241	15.939	14.87	22.549	13.203

For the physical properties, it was found that the characteristics of height, width and length of the fruits were as follows: the minimum values were about 23.2, 16.6, and 19.3 cm, while the maximum values were about 40.6, 36.8, and 38.4 cm, respectively. Mean values were about 32.117, 26.547, 24.833 cm, respectively, while median values were about 32.450, 27, and 24.65 cm, respectively, meaning that about 50% of the samples fall at this level, also mean and median values converging, which indicated that there were not many values of abnormalities that are outside these limits.

Standard deviation values were about 3.63, 4.7486, and 3.8561, respectively, which indicates that there is no dispersion in the data, as the values of variance were about 13.203, 22.549, 14.87, respectively, and this indicates the amount of space or dispersion between the data and the arithmetic mean for each attribute and these values indicate that there is stability for the height and width characteristics of the fruit length in this variety of strawberry.

Likewise, the characteristics of size, weight, and density of fruits were as follows: the minimum values were about 6.5 cm, 7.2 g, 1.0 g/cm^3, respectively, while the maximum values were about 24.1 cm, 29.2 g, 1.3 g/cm^3, respectively. Mean values were about 11.628 cm, 12.992 g, 1.124 g/cm^3, respectively. While median values were about 11.05 cm, 12.55 g, 1.115 g/cm^3, that meaning that about 50% of the samples fall at this level for each of the characteristics. The mean and median values were convergence, which indicated that there were no irregular values outside these limits. Standard deviation values were about 3.9924, 4.3864, and 0.078, respectively. Therefore, there is no dispersion in the data. Variance values were about 15.939, 19.241, 0.006,respectively, which indicates the amount of dispersion between the data and the mean, and these values indicates that there were constants for the size, weight and density properties of the fruits in this strawberry variety.

For the chemical properties, such as percentage of soluble solids (Brix) and pH value, minimum values were about 7.0% and 3.4 respectively, while maximum values were about 7.9% and 3.7, respectively. Mean values were about 7.51% and 3.558 respectively, while median values were about 7.5% and 3.6 respectively, meaning that about 50% of the samples were located at this level. A reference to the convergence of mean and median values indicates that there are no abnormal values outside the limits. Standard deviation values were about 0.2234, 0.10515 respectively, and this indicates that there is no dispersion in the data for these attributes. The values of variance were about 0.05, 0.011 respectively, and this indicates the amount of dispersion between the data and the arithmetic mean. There is a stability to the characteristics of Brix and pH value in this category of strawberry.

3.2 Reflection and electrical properties of Strawberry fruits defects by lasers

The results of analysis to measure the significance of the difference between the reflection intensity of the laser from the standard strawberry fruits were compared to the defective strawberry fruits (mold, insect, green end, white and green shoulder), In the case of using laser with wavelength of 543.5 nm, results in Table 2 indicated that the standard was about 36.42 lux. While, the defects were about 26.37, 20.00, 19.19, 17.83 and 12.2 lux, respectively, and there were significant differences between standard and defective fruits at 1%, and 5%, which means the possibility of using laser with wavelength of 543.5 nm in the sorting process of strawberry fruits.

Table 2 T-test to measure the significance of the difference between the amount of intensity reflected of the standard fruits

Defects of strawberry fruits	Means		df	T-test	Sig P.value
	Reflection of laser with wavelength, 543.5 nm	standard			
Mold	25.58	36.42	11	8.108	0.000
Insect	20.00	36.42	11	10.245	0.000
Green tip	18.67	36.42	11	9.192	0.000
Whit shoulder	17.67	36.42	11	10.041	0.000
Green	12.67	36.42	11	17.828	0.000

Table 3 T-test to measure the significance of the difference between the amount of intensity reflected of the standard fruits

Defects of strawberry fruits	Means		df	T-test	Sig P.value
	Reflection of laser with wavelength, 632.8 nm	standard			
Mold	23.12	40.42	26	0.000	16.075
Insect	20.44	40.42	26	0.000	20.299
Green tip	19.30	40.42	26	0.000	22.488
Whit shoulder	16.30	40.42	26	0.000	26.742
Green	10.30	40.42	26	0.000	27.849

In the case of using a laser with a wavelength of 632.8 nm, Table 3 shows the results indicated that the standard was about 40.42 lux while the defective were about 23.12, 20.40, 19.30, 16.30 and 10.30 lux, respectively. There were significant differences between standard and defective fruits at the level of 1%, and 5%, which means the possibility of using laser with wavelength of 632.8 nm in the strawberry sorting process.

The results of analysis to measure the significance of the difference between the amount of electrical energy generated from the standard strawberry fruits were compared to the defective strawberry fruits (mold, insect, green end, white and green shoulder). In the case of using a laser with a wavelength of 543.5 nm., the results in Table (4) indicated that the standard was about 19.31 mv. While, the defects were about 16.69, 12.85, 11.15, 10.0 and 7.85 mv, respectively. There were significant differences between standard and defective fruits at 1%, and 5%, which means the possibility of using laser 543.5 nm in the strawberry sorting process.

Table 4 T-test to measure the significance of the difference between the amount of electrical energy generated from standard strawberry

Defects of strawberry fruits	Means		df	T-test	Sig P.value
	Electrical of laser with wavelength, 543.5 nm	Standard			
Mold	16.69	19.31	12	4.180	0.001
Insect	12.85	19.31	12	14.000	0.000
Green tip	11.15	19.31	12	15.772	0.000
Whit shoulder	10.00	19.31	11	15.254	0.000
Green	7.85	19.31	12	18.294	0.000

In the case of using laser 632.8 µm, the results in Table 5 indicated that the standard was about 249.23 lux while the defects were about 166.46, 149.21, 137.58, 119.43 and 90.50 Lux, respectively. There were significant differences between standard and defective fruits at 1%, and 5% which means the possibility of using laser 632.8 µm in the strawberry sorting process.

Table 5 T-test to measure the significance of the difference between the amount of electrical energy generated from standard strawberry

Defects of strawberry fruits	Means		df	T-test	Sig P.value
	Electrical of laser with wavelength, 632.8 nm.	Standard			
Mold	166.46	249.23	12	21.261	0.001
Insect	149.21	246.21	13	18.404	0.000
Green tip	137.58	249.50	11	24.815	0.000
Whit shoulder	119.43	246.21	13	19.205	0.000
Green	90.50	246.21	13	25.064	0.000

3.5 Relationship between the light intensity reflected and the amount of electricity

The result of One Way Anova test was shown that, in the case of using a laser with the wavelength of 543.5 nm., Table 6 shows there is a statistically significant positive relationship between the intensity of the light radiation reflected from the surface of the fruits and the amount of electricity generated in the photovoltaic cells at 5%. In the case of using a laser with the wavelength of 632.8 µm, Table 7 shows there is a statistically significant positive relationship between the intensity of the light radiation reflected from the surface of the fruits and the amount of electricity generated in the photovoltaic cells at 1%, and 5%.

Table 6 One Way Anova of reflection intensity and electrical signals from strawberry fruits using laser radiation with wavelength of 543.5 nm

Reflection intensity and electrical signals	Sum of squares	df	Mean square	F-test	Sig. P.value
Between groups	237.630	1	237.630	5.473	0.041
Inside groups	434.150	10	43.415		
Total	671.780	11			

Table 7 One Way Anova of reflection intensity and electrical signals from strawberry fruits using laser radiation with wavelength of 632.8 nm

Reflection intensity and electrical signals	Sum of squares	df	Mean square	F-test	Sig. P.value
Between groups	50700.000	1	50700.000	32.829	0.000
Inside groups	15443.667	10	1544.367		
Total	66143.667	11			

4 Conclusions

The results obtained were concluded as follows:

(1) For the physical and chemical properties of strawberry fruits (festival variety): It was found that there is no dispersion in height, width, length, volume, weight, total soluble solids (Brix) and the pH value of the fruits. Their variance values indicate that there was stability of the physical and chemical characteristics in this variety of strawberries.

(2) The results of the T-test showed that there was a significant difference between the light density reflected or the amount of generating electricity from the surface of standard strawberry fruits and the surface of defective strawberry fruits at every defect (mold, insects, green end, white shoulder, green), in the case of using different

levels of the laser beam with the wavelengths of 543.5 or 632.8 nm. Then, the amount of reflected radiation or the amount of electrical energy generated could be used to separate the affected fruits from the healthy ones

(3) The results of the One Way Anova analysis showed that there was a statistically significant correlation between the light density reflected from strawberry fruits (as a result of using laser beams at 543.5 or 632.8 nm wavelengths) and the amount of electricity generated on the surface of the photovoltaic cells

(4) It's possible to use laser reflection light or the amount of generating electricity in order to classify and sort strawberry fruits according to its defects.

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