Investigation of Photo-Absorption and Current-Voltage Properties of Liquid Extracts from Fruits for Organic Solar Cells Application

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Abstract: In this research work, the optical absorption and photo-current characteristics of black grape, strawberry and orange solutions were investigated. The solutions were extracted from fresh fruits and UV-V is spectrophotometer was utilized to record the absorption spectra of the samples. Besides, the photo-current properties were investigated via current-voltage characteristics of the fruit solutions under illumination. The results showed that energy gaps of the fruits are located within the visible spectrum. Energy gap of 1.84eV was found for the black grape, 2.11eV for strawberry and 3.10eV for the orange solution. The broad absorption spectra for black grape and strawberry have proved the fruits capability to harvest solar energy. Additionally, the enhanced photo-current activity of the fruit solutions under light suggested their potential application for the organic and/or dyes solar cells

Keywords: Absorption, energy gap, black grape, strawberry, orange, dyes solar cells.

1. INTRODUCTION

Nanostructured organic solar cells (OSCs) [1, 2] and dye based solar cells [3] are important devices used to convert the sunlight directly into electricity. These devices have now received a very considerable attention due to their easy fabrication process, light weight and minimal material usage. The vast majority of researches in the field of organic solar cells are importantly focused on the optical absorption response of the active materials [4-6] used in the fabrication process. The optical absorption of the active material plays an essential role in defining the overall performance of the device [1], there by harvesting sufficient amount of solar energy to generate electricity. When light strikes a material several optical phenomena will take place; scattering, reflection, absorption, refraction, and transmission [7]. The light absorption is primarily related to the chemical constituents of the materials, whereas light scattering is influenced by structural/physical characteristics e.g. density, particle size, and cellular structures. One important criterion for materials to serve as active ingredient in the solar cell devices is that the energy gap (E_g) of the material is located within the energy of visible light spectrum. In a research study, the optical properties of apple skin was investigated in the wavelength range from 350 to 2200 nm [8]. Moreover, the response of absorption coefficient spectra governed by the pigments contents (e.g. chlorophylls and carotenoids) has been utilized as a tool to estimate the ripening stages of some fruits and vegetables [9, 10]. Nassif *et al*. studied light scattering through fruits during ripening aiming at monitoring fruits maturation [11]. More research works on optical properties of organic materials like trunk of trees [12], fruits [13, 14], and foods [15] have been also carried out. Extensive literature showed that previous research works have been limited within the investigation of fruits for the agricultural and quality control related issues. Little attention has been paid to study the optical absorption behaviors of fruits in terms of harvesting visible light energy for the application of organic solar cells, while that organic and natural dyes are under interesting investigation for their application in photovoltaic devices [16, 17]. Therefore, the current research work was devoted to investigate the optical absorption and photocurrent (current-voltage) response of fruit extracts, namely from black grape, strawberry, and orange. It was noticed that the optical absorption of the extracted dyes are within the interesting range of solar spectrum and the photoelectric properties showed considerable deviation upon the illumination of the materials, making them a viable candidate for the application of organic solar cells and/or dye based solar cells.

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2. MATERIALS AND METHODS

The fruits; strawberry, orange, and black grape were collected in fresh form and they were cleaned thoroughly to be ready for extracting their juices. The liquid extraction (juice solution) was performed by cutting and pressing process of the fruits. Then, filtration paper (20 µm pore size) was used to refine the extracts and to produce a smooth solution to be clear from grains and small particles. The liquid extracts have been further diluted with distilled water to obtain

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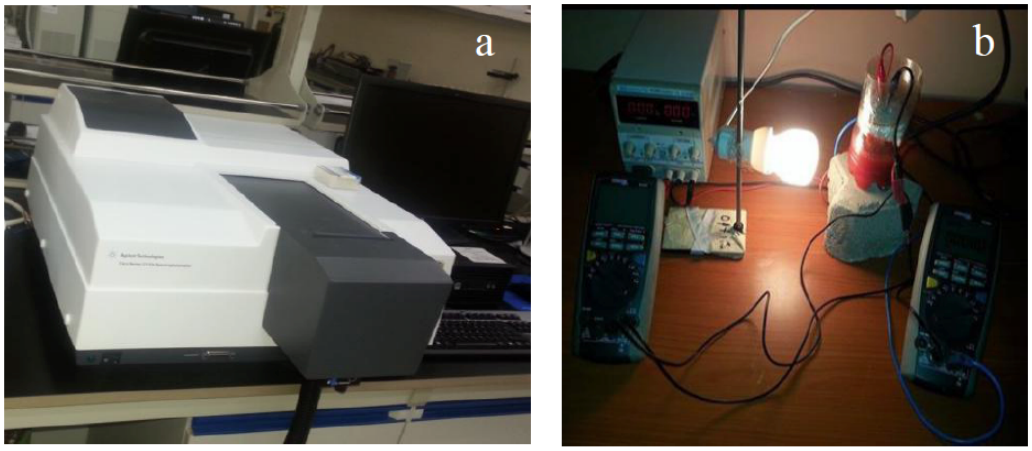

Figure 1: Experimental setup used to record (**a**) photo-absorption spectra and (**b**) current-voltage characteristic of the solution samples.

concentrations that does not produce saturated absorption curve in the absorbance spectra. To investigate the photo-absorption, Lambda 25 spectrophotometer (Figure **1a**) has been utilized and the optical absorption spectra of the solution samples were recorded in the wavelength range from 200 to 800 nm. The current-voltage investigation under dark and light conditions was recorded by means of digital multimeters. This is where the solution samples have been dropped into specific transparent plastic bottles, and two aluminum electrodes, with 1 cm apart, were inserted into the solution as shown in Figure **1b**. The current-voltage measurement was recorded in the range of ±4.4 V, while a light source with intensity of 11.4 μW/cm^2 was used for the illumination purpose. The distance between the light source and the solution samples was set to be about 10 cm, while the light was directed perpendicular to the area located between the two electrodes that was filled by the solution samples. All the records were carried out in ambient and under the room temperature of 23 ^{o}C. Figure **1** shows the experimental setup used for the investigation of the solution samples.

3. RESULTS AND DISCUSSION

Figure **2** shows the absorption spectra of the black grape solution from the ultraviolet (UV) to the visible (Vis) wavelength range. It is seen that the absorption curve has covered a wide range of absorption, extending to about 600 nm. This can be understood as the energy of ultraviolet radiation is readily absorbed by the solution sample to excite electrons from the ground state to the excited state. However, upon decrement of radiation energy i.e. increasing the wavelength, there will be a less probability to excite electrons from the low energy level (ground state) to the higher energy levels (excited states). A relatively abroad absorption peak was noticed at about 550 nm. This was ascribed to the presence of $\pi \rightarrow \pi^*$ electronic transitions [18], which is governed by carotenoid and chlorophyll compounds in the black grape juice [19]. Noteworthy, the oscillating absorption behavior in the UV region may refer to the scattering phenomena, which is more likely to occur in the liquids exposed to the high energy radiation.

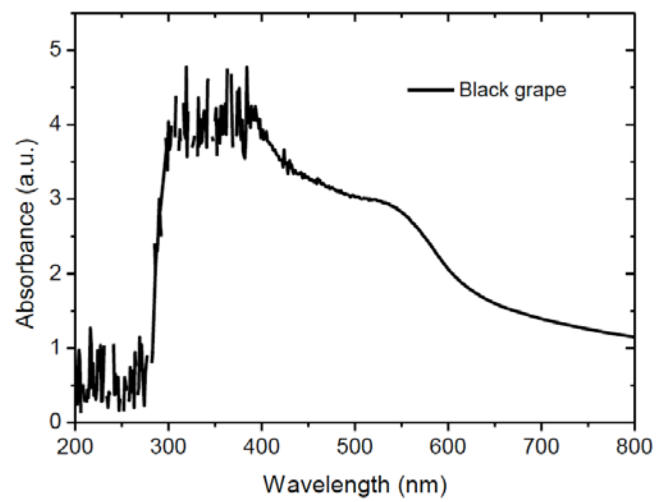

Figure 2: The absorbance spectra of black grape solution.

Figure **3** shows the dark and light current-voltage characteristics of black grape solution in the forward and reverse biased connection. It was noticed that the *I-V* characteristics showed a non-linear rectification behavior. The rectification ratio, which is defined as the ratio of forward biased current to the reverse biased current, can be calculated using the following equation [20]:

$$RR = \frac{I_F}{I_R} \quad (1)$$

Where, I_F and R_F are forward biased and reverse biased currents at a specific voltage, respectively. It was found that the rectification ratio at $V = \pm 2.8$V (at the voltage beyond the potential barrier; potential barrier voltage is obtained by the extrapolating linear part of I-*V,* where the x-axis intersection represents the barrier value) is almost equal to 0.55 and 1.62 for the dark and light conditions. The higher *RR* under light compared to that of under dark indicating the occurrence of photovoltaic effect. This is resulted from the interaction of light with the solution molecules to produce photocurrent [20]. It is worth mentioning that the potential barrier (V_b= 2.0V) under light was smaller than that of under dark (V_b= 3.1V) in the forward biased condition, which is another evidence for the presence of photovoltaic effect in the black grape solution.

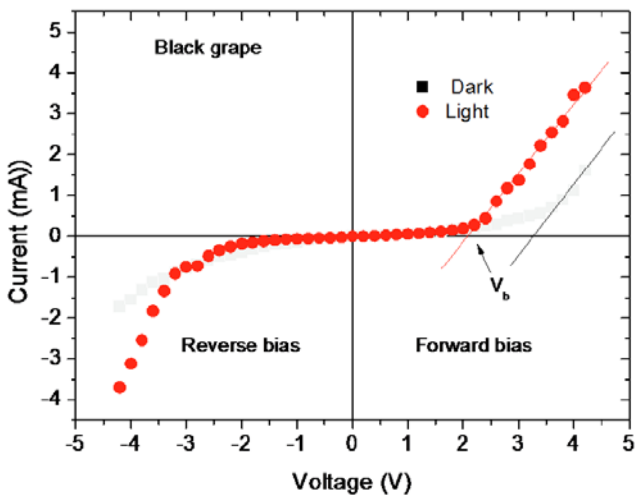

Figure 3: The *I-V* characteristic of black grape solution in the dark and light condition.

Figure **4** shows the absorption spectra of strawberry solution in the wavelength range from 200 to 800 nm. One can notice the presence of an intense peak at about 500 nm, which is at higher energy level compared to that of black grape at 550 nm. The occurrence of this absorption peak is referred to the presence of electronic transitions from bonding to anti-bonding molecular orbitals i.e. $\pi \rightarrow \pi^*$ electronic transitions. Noticeably, there is a shoulder absorption peak at about 420 nm for the strawberry solution, which can be attributed to the presence of intermolecular electronics transitions within the sub-energy levels. The differences in absorption energy peak between that of strawberry and that of black grape may refer to the various chlorophyll compounds existed in their juices [19, 21, 22].

Figure **5** shows the current-voltage characteristics of strawberry solution in the voltage range from 4 V to -

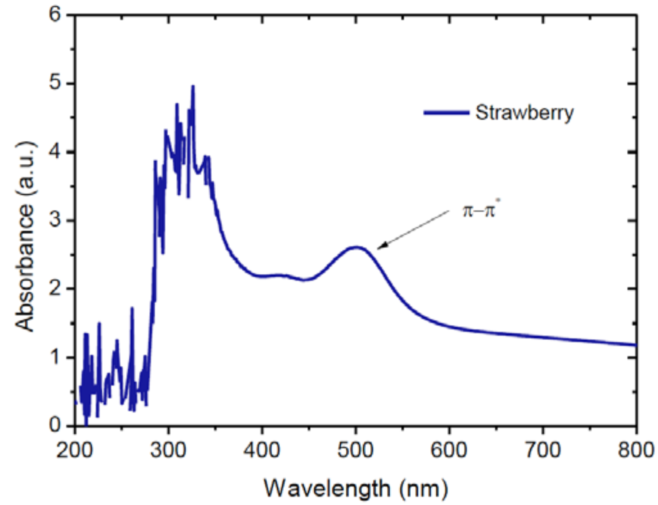

Figure 4: The absorbance spectra of strawberry solution.

4.2 V under light and dark. In the forward bias, the variation of potential barrier for the strawberry solution upon illumination, to be about 1.1 V, is almost the same as achieved in black grape solution. This property approved that the effect of light incident on the solution is to generate photocurrent, thereby increasing the current passing through the solution. Noticeably, in the reverse biased connection, the photo-current was decreased, meaning that the value of reverse potential barrier has been increased compared to that of the dark condition. This may be ascribed to the hysteric effect generating by the accumulated space charges, which in turn renders the flow of current in reverse direction.

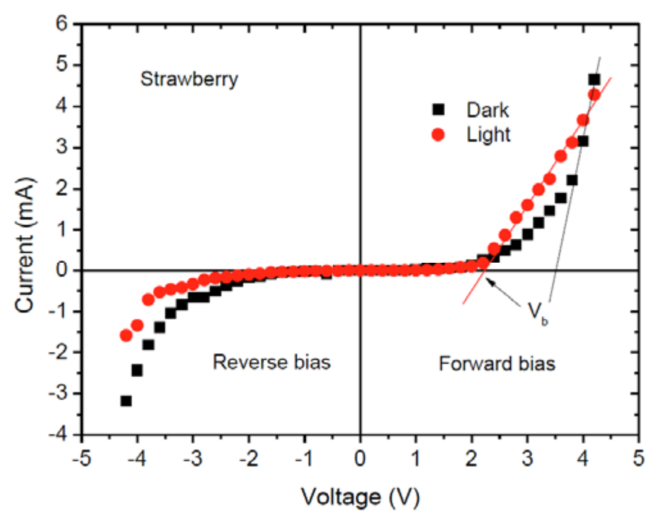

Figure 5: The *I-V* characteristic of strawberry solution in the dark and light condition.

Figure **6** shows the absorption spectra of the orange solution in the wavelength range from ultraviolet to visible spectrum. The rapid decrease in the absorbance from about 360 nm onward can be correlated to the orange color due to its carotenoid contents [23]. It was seen that the main absorption behavior appeared in the ultraviolet region, which reveals the high transparency of orange juice for the longer wavelengths of visible light spectrum. The absorption process is basically induced by the presence of electrons excitation from the valence band to the conduction band by means of high energy ultraviolet radiation. Worthwhile, the photo-current activity of the orange solution, as noticed through the curve deviation of under light from that of under dark beyond the potential barrier, was weaker than those of black grape and strawberry solutions (see Figure **7**). This is because of that the absorption response in the orange solution is mainly limited within the ultraviolet region of light, while the black grape and strawberry solutions are good absorbers of ultraviolet and visible light energies.

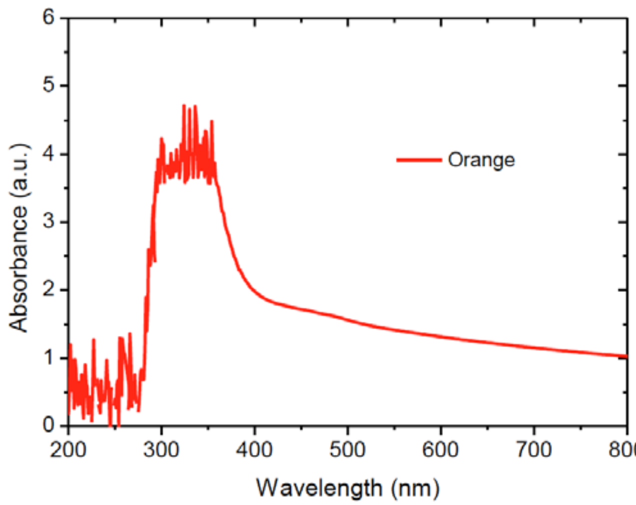

Figure 6: The absorbance spectra of orange solution.

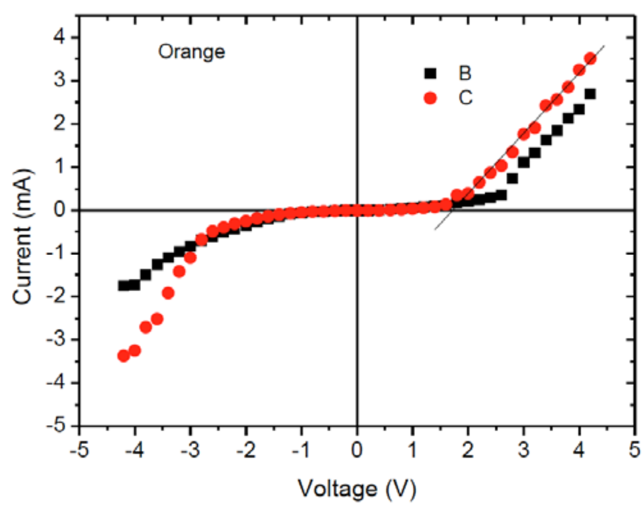

Figure 7: The *I-V* characteristic of orange solution in the dark and light condition.

Figure **8** shows the comparison of absorption spectra for black grape, strawberry, and orange solutions in the wavelength range from 200 to 800 nm. It was obvious from the figure that black grape showed broader absorption spectra in comparison to those of strawberry and orange solutions. However, upon the comparison of strawberry absorption to those of black grape and orange solutions, two absorption peaks for the strawberry solution was detected. This can be ascribed to the presence of sub-transitional energy bands in the molecules of strawberry. It is worthy to mention that there is a red-shifting absorption in the black grape juice compared to those of strawberry and orange juices. This can be referred to the carotenoid and chlorophyll compounds in the black grape solution, thereby absorbing lower energies spectrum [19].

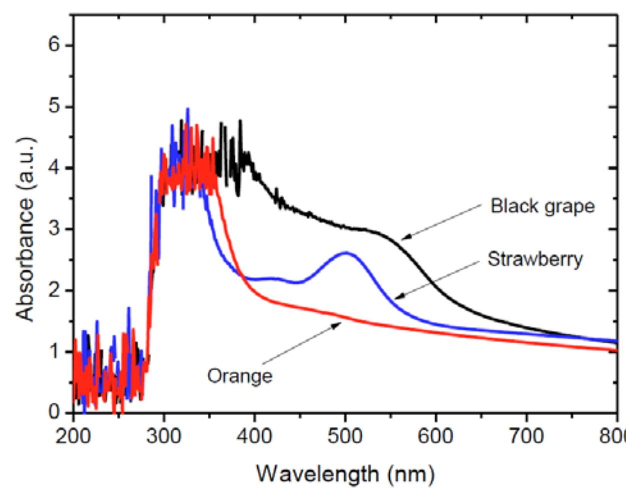

Figure 8: Comparison of the absorption spectra for the fruit solutions under investigation.

Figures **9a-c** show the absorption edge region for the black grape, strawberry and orange solutions, respectively, from which the energy gap (the difference between valence and conduction band) can be estimated. The data points regions, where the absorption spectra are decreased rapidly with the increase of wavelength can be utilized to determine energy gap (E_g). This is readily done by extrapolating a straight line to intersect the x-axis. The point of intersection gives the E_g. For the black grape solution, the wavelength (λ) of intersection was found to be 675nm, which is equivalent to the energy gap of 1.84eV. This calculation of E_g was performed as follows:

$E = h\nu = hc/\lambda$, where E is the energy of photon, h is the Planck's constant its value is 6.626×10−34 J.s, and c is the velocity of light (3×10^8m/s), ν is the frequency of radiation in Hz or s^{-1}. Hence;

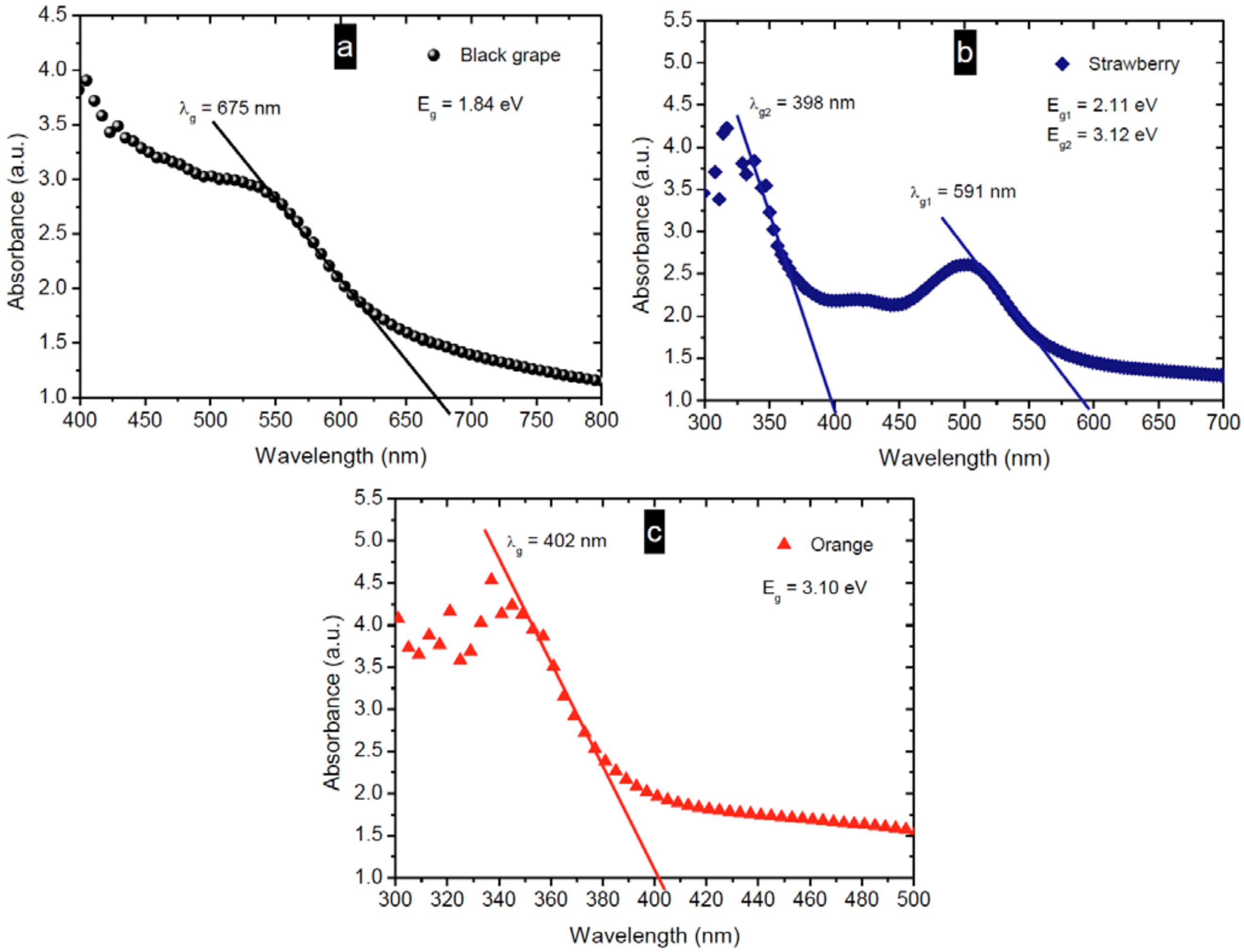

Figure 9: Energy gap estimation for the fruit solutions under investigation.

$E_g = (4.136\times10^{-15} \times 3\times10^{8})/ (675\times10^{-9}) = 1.84\text{eV}$

Similar calculation procedures were performed for the strawberry and orange samples, as shown in Figures **9b** and **9c**. For the strawberry solution, there were two straight regions of interest. The region of high energy gap (E_{g1}) and low energy gap (E_{g2}). Hence, the wavelengths (λ) of intersection were found to be 398 nm and 591 nm, respectively. These were equivalent to the energy gap of 3.12eV and 2.11 eV, respectively. Nevertheless, for the orange solution, the absorption edge was found to be 402 nm, which is equivalent to the energy gap of 3.10eV.

Table **1** shows the calculated absorption edge (λ_{edge}) and energy gap for the solution samples. It was seen that the black grape shows smaller energy gap of 1.84 eV compared to those of the strawberry and orange solutions with 2.11 eV and 3.10 eV, respectively. As such, the back grape possessed a higher absorption edge in comparison to those of strawberry and orange solutions. This was ultimately resulted in a broader absorption spectrum for the black grape. Worthwhile, the absorption properties of black grape and strawberry juices have been well behaved in the ultraviolet and visible regions, making them a strong candidate for the organic and/or dyes solar cells.

Table 1: The Absorption Edge and Energy Gap of Solution Samples

Solution Sample	Absorption Edge, λ_{edge} (nm)	Energy Gap, E_g (eV)
Black grape	675	1.84
Strawberry	591	2.11
Orange	402	3.10

4. CONCLUSIONS

Solutions of the black grape, strawberry and orange were extracted from fruits in fresh form and their photo-absorption and photovoltaic properties were successfully investigated, aiming at verifying their potential application for organic/dye solar cells. The results showed that the energy gap of the fruits were very well located within the visible light spectrum. The energy gap of the juices was determined to be 1.84eV for black grape, 2.11eV for strawberry and 3.10eVfor the orange. Besides, the results of black grape and strawberry solutions showed broad absorption spectra covering almost all the part of the visible light, indicating their viability to harvest solar energy. Nevertheless, the absorption of black grape showed a broader spectrum compared to those of other fruits. Moreover, the results of photovoltaic investigations for the fruit samples showed a considerable increase in the photocurrent generation as a result of illumination process. The black grape solution showed enhanced photo-current activity compared to those of other solutions, reflecting the broad photo-absorption response in the black grape sample. It was concluded that fruit extracts can be a viable candidate to be utilized in the fabrication of nanostructured organic and/or dyes solar cells.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this article.

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