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Synthesis of Carbon-Based Quantum Dots Using Lemon Juice under Hydrothermal Method

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ABSTRACT

In this research, pure lemon juice was used to synthesize carbon-based quantum dots (CQDs) using hydrothermal method. Heated at 120 ℃ for a period of 3 hours, CQDs were successfully synthesized. The properties of CQDs were investigated by both FTIR and fluorescence spectrophotometer. Successful results show satisfactory optical properties and good water solubility from the CQDs. To further increase the quantum yield percentage of CQDs, onion juice was added to pure lemon juice at lemon-onion ratio of 8:2. The CQDs synthesized showed improved results with unexpected optical properties, strong water solubility as well as higher quantum yield percentage of 1.349%. Further investigation was done to find the optimal lemon-onion ratio for best quantum yield percentage results with different lemon-onion ratio. Results proves lemon-onion ratio of 8:2 is the optimal ratio. The CQDs synthesized are non-toxic due to the use of natural resources as its main materials as well as zero addition of chemicals throughout the synthesis process. Its zero-toxicity could benefit consumers in terms of consumables, such as toiletries, and water quality monitoring industry, such as heavy metal sensing and free chlorine sensing, as well as in medical field, such as bio-imaging and nanomedicine. Moreover, the by-products after synthesis are degradable, thus it would not create any long-lasting wastes. This could benefit the zero waste direction the world is heading towards.

Keywords: Carbon quantum dots, hydrothermal method, lemon juice, photoluminescence, quantum yield percentage

1. INTRODUCTION

Quantum dots (QDs) are miniature, often smaller than 10 nanometers, man-made semiconductor particles, including Cadmium Selenide and Lead (II) Sulfide. Due to their extremely small size, they differ from bulk materials in terms of optical and electronic properties [1]. QDs are often applied in bio-imaging and nanomedicines due to their tuneable optical properties.

On the other hand, carbon-based quantum dots (CQDs) with sizes below 10nm are new form of nano-carbon materials [2]. They possess similar physical properties and chemical structure of graphene oxide. Materials used to extract CQDs are often from natural resources, such as lemons and oranges. Any carbohydrate can be used to prepare CQDs if and only if the ratio of C, H, and O is 1: 2: 1 [3]. By using natural resources, CQDs extracted would be non-toxic and user-friendly.

QDs, normally extracted from chemical-made semiconductors, such as Cadmium Selenide (CdSe) and Cadmium Telluride (CdTe), are known to be toxic and dangerous to humans. Scientists had found out that these submicroscopic dots when decomposes, would emit toxic metals into the environment [12]. Therefore, when used in applications such as bio-imaging and nanomedicine, it would be very dangerous to the human body. Due to this, CQDs might be the solution to solve

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this disadvantage. Using methods such as hydrothermal method or microwave pyrolysis, CQDs are often extracted from natural materials such as apples and oranges. Therefore, without any chemicals and being all natural, CQDs are non-toxic and safe to use in applications. However, CQDs obtained from natural resources have low emission and quantum yield in comparison to QDs. Thus, green precursors could be used to increase these aspects.

This study is to extract quantum yield from natural resources using hydrothermal method. Natural resources have less toxicity relative to chemicals.

In this study, via hydrothermal method, an effort to extract quantum yield from lemon juice would be done. An article by Adda [4] stated that lemon contains a small amount of fat (0.003%) and protein (1.1%) with its main composition being water (89%) and carbohydrates (9.3%). Carbohydrates in lemons mainly contain fibers and sugars including sucrose, fructose, and glucose. Therefore, lemon juice is a suitable candidate for CQD synthesis since it had achieved the CQD requirement stated by Tang et al. [3] where the ratio of carbohydrate contained in lemon juice is of 1: 2: 1. Moreover, Hoan et al. [5] had also investigated the function of citric acid in choosing a suitable candidate for CQD synthesis. Using three different citric acid containing fruit juice as precursors, including orange juice, fresh lemon juice, and ripe lemon juice, a strong photoluminescence (PL) emission peak was observed at a higher wavelength with the highest PL intensity. Due to the higher citric acid content, lemon juices showed higher PL in comparison. Fresh lemon juice was discovered to have the highest PL due to ripe lemon juice showing a significant decrease in the constituent grade as well as the destruction of surface structure, thus causing a drop in PL emission. Therefore, fresh lemon juice would be used in this study for CQD synthesis.

To enhance quantum yield percentage, onion juice would be added in different ratio into lemon juice to obtain higher quantum yield percentage. The addition of onion juice is due to its sulphur and nitrogen compound contents [6] which had been proven to be efficient in improving the fluorescent properties of CQDs. Undoped CQDs have varying surface states relative to the varying energy levels to create an excitation-dependent and broad emission spectra as well as a broad UV/Vis absorption band [7]. By doping with heteroatoms, including Nitrogen and Sulphur, fluorescent properties of CQDs had been improved, such as higher quantum yield, and tunable electronic and chemical properties. Sun et al. [8] had reported that due to the passivation by heteroatom, the surface detect would function as excitation energy traps and cause an effect on the photoluminescence of the CQDs. In this case, sulphur atom acts as a catalyst for oxidation reduction reaction, thus producing more passivated surface detect of CQDs, therefore further increasing the photoluminescence [9]. On the other hand, nitrogen atom creates a new kind of surface state (N-state) where electrons trapped by this new surface state could promote radiative recombination of high yield [10]. Examples include a study done by Duan et al. [11] where N-S-doped CQDs of 28% quantum yield were synthesized by using sulfamic acid as a surface passivation agent and ethylenediamine as the carbon source.

As a result of the success of this research, contributions could be made for aspects including society, and economy. The CQDs extracted from natural resources are non-toxic. This is because natural resources themselves, such as lemons and onions, are non-toxicity materials. Due to zero addition of chemicals, the CQDs extracted from them would also be non-toxic. Furthermore, the CQDs were extracted via hydrothermal method, where also would not need any addition of chemicals or toxic materials. Therefore, the CQDs extracted would be zero-toxicity. Moreover, the byproducts after extraction are degradable, thus it would not create any long-lasting wastes. Other than that, this success could also contribute to the economy. Due to it being user-friendly for sensitive skin users, it could be applied to toiletries, such as shampoo and soap, thus increase the economy. Moreover, when applied in medical field, such as bioimaging and nanomedicine, its non-toxicity would not create any side effects to the patients. Patients could feel safe to consume or use these applications knowing they would not do any harm to their bodies.

2. RESEARCH METHODOLOGY

For the synthesis of CQDs, yellow onions and lemons were purchased from a local supermarket in Kota Warisan, Sepang, Selangor. 0.22μm and 0.44μm syringe filters were bought for filtering purposes. The fluorescence measurements were carried out in a fluorescence pectrophotometer (Jasco, model FP8300, Japan) equipped with a quartz cuvette. FTIR spectra were measured by FTIR spectrophotometer. The synthesis of CQDs was done in a Polytetrafluoroethylene-equipped stainless steel autoclave placed into a scientific vacuum oven.

2.1 Sample Preparation

Table 1 Type of mixtures based on different ratios of lemon:onion

Type of Mixture	Volume of Pure Lemon Juice (mL)	Volume of Pure Onion Juice (mL)	Ratio of Lemon:Onion
Mixture 1	50	0	10:0
Mixture 2	47.5	2.5	9.5:0.5
Mixture 3	40	10	8:2
Mixture 4	32.5	17.5	6.5:3.5
Mixture 5	25	25	5:5

To prepare Mixture 1, lemons were squeezed into a 50mL beaker. By using a 5mL pipette, 50mL of lemon juice was transferred into another 50mL beaker, which is labelled M1. To prepare Mixture 2, apart from squeezing lemons into a 50mL beaker similar to the preparation of Mixture 1, onions were sliced and placed into a blender. The onion juice was the poured through a filter paper into a 50mL beaker. By using a 5mL pipette, 40mL of lemon juice and 10mL of onion juice were transferred into another 50mL beaker labelled M2. Further on, the preparation of juices is still similar but the only difference is the ratio of lemon juice to onion juice, which are prepared at ratios of 9.5:0.5, 6.5:3.5, and 5:5 for Mixtures 3, 4, and 5 respectively.

Figure 1 shows the sample preparation procedure for the synthesis of CQDs. The CQDs were synthesized using hydrothermal method. In a typical synthesis, the mixture prepared was transferred into an autoclave, where it was placed into the oven carefully. The autoclave was the heated at approximately 120^{o}C for 3 hours. After heating, the product was left to cool to room temperature. Using filter paper, 0.44μm and 0.22μm syringe filter, the CQDs were purified and transferred into a reagent bottle. The CQDs are then successfully synthesized and prepared to be analysed.

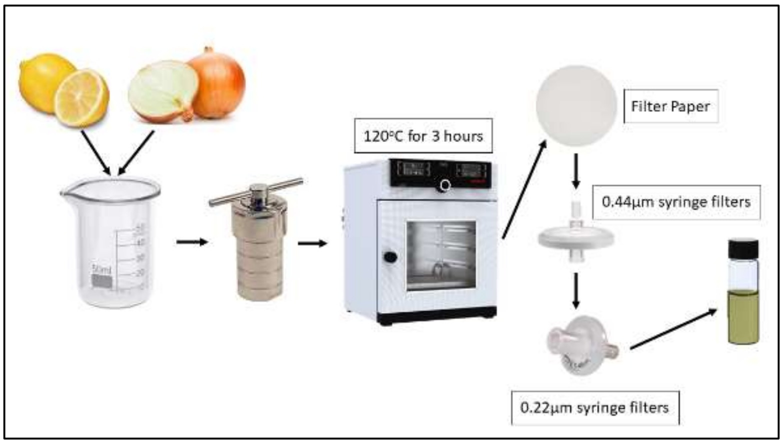
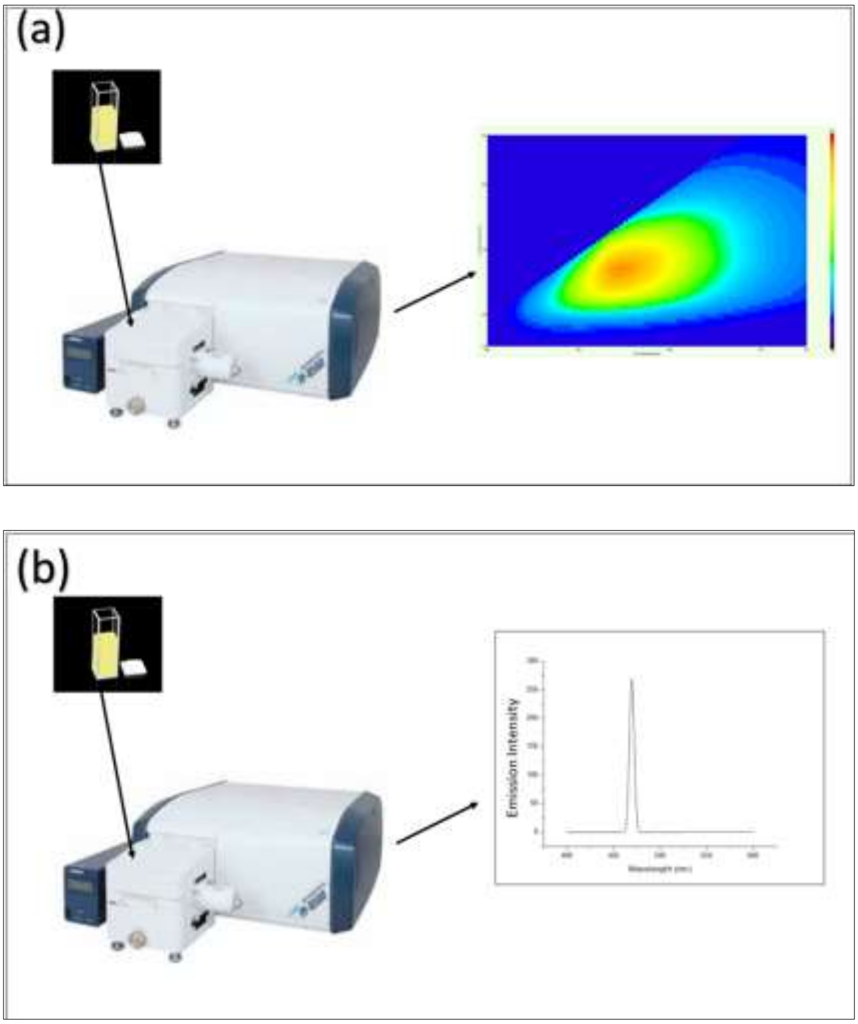


Figure 1. Sample preparation procedure.

2.2 Sample Performance Evaluation Method

In this section, 3-D peak measurement (Figure 2(a)) and emission spectra (Figure 2(b)) was carried out using a fluorescence spectrophotometer (Jasco, model Fp-8300, Japan) to find excitation wavelength, emission peak, and quantum yield. Moreover, infrared (IR) spectra were carried out using a FTIR spectrophotometer as shown in Figure 2(c). 3-D Measurement or in precise, 3-D fluorescence spectrum is an emission-excitation matrices (EEM). Using both excitation and emission monochromators successively, emission spectra for different excitation wavelengths could be measured. Therefore, at different excitation wavelengths, a collection of emission spectra is obtained at the same time. Therefore, the measurement obtained will include two dimensions: emission wavelength and excitation wavelength. The measurement also provides a fluorescence map of all the fluorophores in the mixture, thus enabling their concomitant characterization [13].

Using a dropper, 3mL of sample was inserted into a cuvette then placed carefully into the integrating sphere of the fluorescence spectrophotometer. The approximate wavelength of both excitation and emission peak was determined from the 3-D measurement. This was done by locating the highest fluorescence intensity in the spectrum based on the intensity level chart provided next to the spectrum.



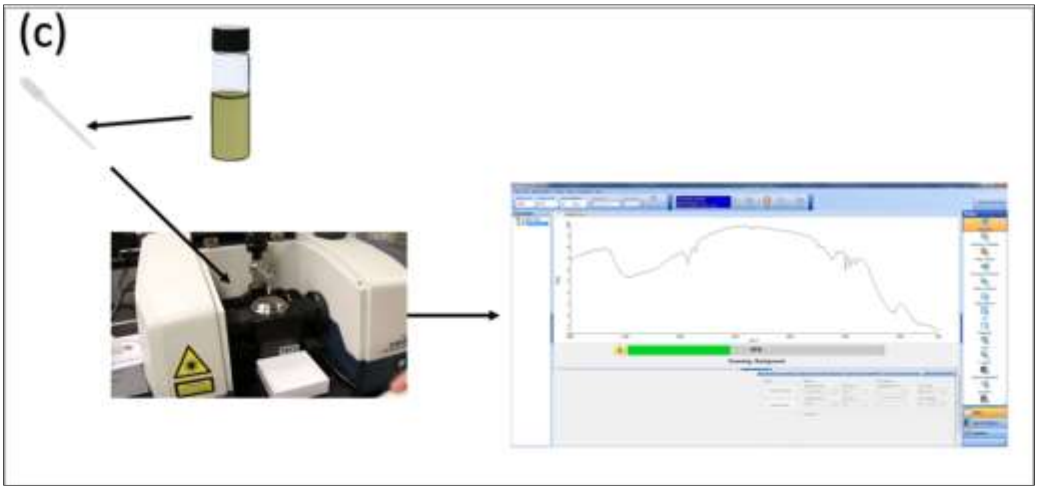


Figure 2. (a) 3-D Measurement procedure; (b) Spectrum analysis procedure; (c) IR spectra evaluation procedure.

Emission spectrum reflects the distribution of probability of various transitions from the lowest vibrational level, S_1 to the various vibrational levels, S_0. Therefore, it is almost similar to a variation of the luminescence light emission intensity as a function of constant excitation wavelength [13].

Using the excitation peak obtained from 3-D measurement, emission spectra were carried out using spectra analysis via fluorescence spectrophotometer. An empty cuvette was placed into the integrating sphere to carry out the analysis before inserting the cuvettes containing 3mL of sample. This is because air was used as reference for the analysis. Emission spectra was then plotted from the data recorded. Using the data, the external quantum efficiency or quantum yield percentage was determined using Equation 1 [14].

$$\text{External Quantum Efficiency (\%)} = \frac{\text{Absorptance (\%)}}{100\%} \times \text{Internal Quantum Efficiency(\%)} \quad (1)$$

Infrared (IR) Spectroscopy is the measurement of infrared light interacting with a molecule. It is normally used to find out the functional groups in the molecules. It measures the vibrations of atoms to determine the functional groups within the molecules. Light atoms and stronger bonds tend to vibrate at a high stretching wavenumber or frequency [15]. Fourier-transform infrared (FTIR) analysis measures the wavelength range in IR region absorbed by a material via applying IR radiation to the sample of the material. The absorbance of the sample is then used to determine the molecular structure and composition of the material [16].

For IR Spectra, using a FTIR spectroscopy, a background scan was performed beforehand. This was imperative to remove any surrounding noises, which if not removed, will cover up some functional groups during analysis. After background scan was done, using a dropper, one drop of sample was placed onto the diamond cell on the Attenuated Total Reflectance (ATR) plate. After the clamp was screwed down, IR spectra analysis was performed. It was suggested that after every analysis, ethanol and Kimwipes could be used to carefully clean the sensor. IR spectra was then plotted from the data recorded.

To determine the functional groups in the samples, IR spectrum table was referred. It lists out the IR spectroscopy frequency ranges, appearance of the vibration and absorptions for functional groups. The frequency was found in the first column of the table. Then, the corresponding absorption, appearance, group and compound class was determined [17].

3. RESULTS

CQDs produced by pure lemon juice were brought to undergo 3-D Measurement to obtain both excitation and emission wavelengths and peaks. Based on Figure 3(a), it was found out that the CQDs produced by pure lemon juice displays excitation peak at 470nm and emission peak centred between 535nm to 575nm, which shows the emission peak being in the green region. Therefore, CQDs produced by pure lemon juice emits green light when excited. Moreover, the results show that when light of 470nm hits the sample, the molecules of the sample will be excited and emits light with emission peak at wavelength between 535nm to 575nm. Using the excitation peak, emission spectrum could be carried out to calculate quantum yield.

Based on the emission spectrum in Figure 3(a), when pure lemon juice sample was excited by light of 470nm wavelength, emission peak was found at 550nm, which proves the previous finding of 3-D measurement where the emission peak was found between wavelengths of 535nm to 575nm. Hence, at 470nm, which is the excitation peak wavelength, the sample has the strongest absorption. When light of 470nm hits the sample, the molecules of the sample will be excited and emits light with emission peak at wavelength of 550nm.

To test for QY, air was used as reference. QY test was configured to analyse at excitation wavelength of 470nm and emission wavelength of 400nm to 600nm. Then, lemon juice sample was inserted for QY test. Calculations were then done using Equation 1 to find the external quantum efficiency, which results in 0.223%. This shows that when 10^5 photons are absorbed by the sample, only 223 photons are then emitted out by the sample. Therefore, by determining QY, it could determine the efficiency of the sample, which for this sample is 0.223%.

Then, replacing CQDs produced by pure lemon juice, CQDs produced by a mixture of pure lemon juice and onion juice at ratio of 8:2 was brought to test of 3-D measurement.

Based on Figure 3(b), it was seen that the CQDs display an emission peak centred between 550nm to 590nm, which illustrates that the emission peak is within the wavelength of both green light (495-570nm) to yellow light (570-590nm) region, thus further detailed analysis via emission spectra is to be done to find out the specific emission peak wavelength. It was also found out that the excitation peak was 485nm. Hence, when light of 485nm hits the sample, excitation of the molecules of the sample occurs, thus emitting light of wavelength between 550nm to 590nm. Emission spectrum could be then carried out using the excitation peak to calculate quantum yield.

Based on the emission spectrum in Figure 3(b), it was found that the emission peak was 566nm, which is within the wavelength of green light. Therefore, it proves that CQDs produced by lemon-onion mixture also emits green light when excited. Furthermore, when excited at 485nm, which is the excitation peak wavelength, the sample exhibits the strongest absorption.

After that, air was used as reference again for QY test. Differing from the previous test on the CQDs produced from pure lemon juice, the test was configured to analyse at excitation wavelength of 485nm and emission wavelength of 440nm to 700nm. This is due to the different excitation and emission peaks of both samples.

After analysis, using Equation 1, external quantum efficiency was calculated to be 1.349%. This proves that for every 10^5 photons absorbed by sample, 1349 photons are then emitted out. Hence, by calculating QY, the efficiency of the sample is found at 1.349%.

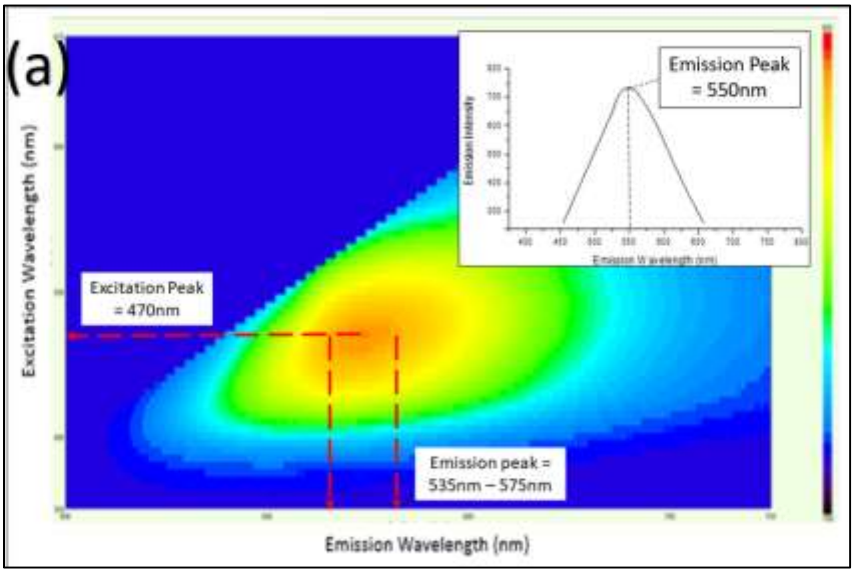
Next, to find the relationship between QY and lemon-onion ratio, different ratios were tested. Lemon-onion ratios of 9.5:0.5, 6.5:3.5 and 5:5 were used to produce CQD samples. Due to similar type of mixture, 3D measurement was not done. Similar emission and excitation peaks were used for QY measurement. The results were displayed in Figure 3(c).

Based on Figure 3(c), it was shown that at ratio of 8:2, the highest QY was exhibited from the lemon-onion mixture sample. As the ratio of onion increases or decreases from 8:2, QY decreases drastically, forming a bell-shaped curve. Therefore, it could be assumed that the ratio of 8:2 is the optimum ratio for CQDs of high QY.

Furthermore, surface functional groups of the CQDs from all samples were then sent for a Fourier-transform infrared (FTIR) analysis using a FTIR spectroscopy. FTIR analysis was done to find out the chemical substances or functional groups contained in the product, which in this case, the CQDs extracted. By identifying the functional groups, properties of CQDs synthesized could be identified, such as water solubility and polarity. Furthermore, chemical substances contained could also be identified. Thus, the CQDs could be confirmed if there is any toxicity.

FTIR analysis was done in a dry or moisture-controlled environment. This is due to the analysis being able to be affected by water vapour. If moisture level in the environment is not controlled, the absorption of water vapour will appear in the spectrum [18]. Before analysis of the samples, a background scan was done. Background scan is done to remove any noises produced by surrounding environment which will cover up some functional groups of the sample analysis if not properly removed [19].

After background analysis is done, the samples were tested for both lemon juice sample and optimum lemon-onion ratio mixture sample. Results of the analysis are shown in Figure 3(d). For both samples, as shown in Figure 3(d), the peak at 3367 cm^{-1} was attributed to stretching vibration of normal polymeric hydroxyl (O–H). Moreover, at 1638 cm^{-1}, the peak was attributed to stretching vibrations of Alkenyl C=C and bending vibrations of amide (N–H). Furthermore, weak peak located at 1222 cm^{-1} attributes to stretching vibrations of alkyl aryl ether (C–O) and fluoro compound (C–F). The FTIR spectra shows a successful unification of amino groups and hydroxyl as well as minor fluorides and ether on both CQD surfaces. Using these findings, the properties of the sample could be identified based on the strength of the peaks.



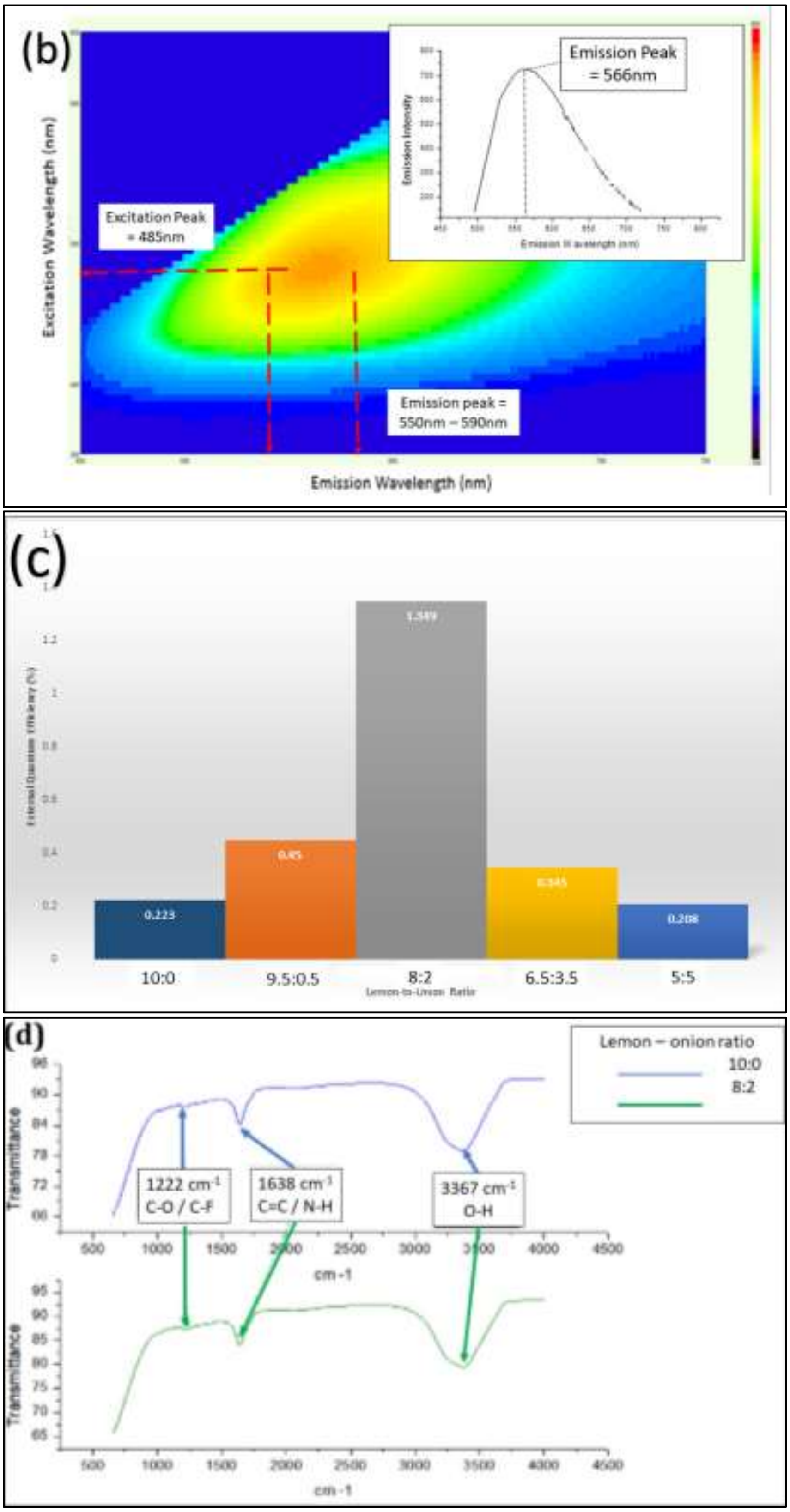


Figure 3. (a) 3-D Measurement of excitation wavelength over emission wavelength for CQDs produced from pure lemon juice with the corresponding Emission Spectra (top right); (b) 3-D Measurement of excitation wavelength over emission wavelength for CQDs produced from lemon-onion mixture of ratio 8:2 with the corresponding Emission Spectra (top right); (c) Bar chart of lemon-to-onion ratio versus external quantum efficiency; (d) Infrared (IR) Spectrum of CQDs produced from pure lemon juice and lemon-onion mixture of ratio 8:2.

4. DISCUSSION

Based on 3-D Measurements in Figure 3(a) and Figure 3(b), it was found out that there is an increase of wavelength when onion juice is added to lemon juice. This is due to the S-doping of the CQDs via the mixing of lemon juice with onion juice which contains sulphur. A study by Lu et al. [7] had proven that when adding S-dopants to CQDs, a red-shift of maximum emission wavelength will occur. Furthermore, based on the 3-D Measurements in Figure 3(a) and Figure 3(b), it was found out that the excitation wavelength is within visible wavelength range, which is between 400nm to 800nm [20]. This is crucial as it proves that the CQDs produced by both pure lemon juice and lemon-onion mixture are safe when applied on human body, especially during bioimaging. In comparison to Table 2, it was found out that other than CQDs produced from watermelon and lemon juice, the other CQDs have excitation wavelengths around UV region, which is between 10nm to 400nm [20]. This may constraint the practical usage especially in human body because UV region is more harmful than visible region.

Table 2. Summarized methods, conditions and results of synthesis of CQDs from natural resources [3], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30].

Precursors	Solvents	Temperature (°C)	Synthesis Time (hr)	Method	Results			Reference
					Excitation (nm)	Emission (nm)	Quantum Yield Percentage (%)	
Lemon	-	280	12	Hydrothermal	425	508	21.37	Hoan et al. (2019)
Lemon	Ethanol	120	3	Hydrothermal	410	482	16.7	He et al. (2018)
Lemon and Onion	Deionized water and Ammonium Hydroxide	370	0.1	Microwave Pyrolysis	340	425	23.6	Monte-Filho et al. (2019)
Apple	-	180	12	Hydrothermal	340	428	6.4	Xu et al. (2014)
Strawberry	-	180	12	Hydrothermal	344	427	6.3	Huang et al. (2013)
Pomelo Peel	Water	200	3	Hydrothermal	360	444	6.9	Lu et al. (2012)
Willow Bark	Water	200	3	Hydrothermal	360	437	6.9	Qin et al. (2013)
Watermelon	-	220	2	Combustion routes	488	530	7.1	Zhou et al. (2012)
Orange	-	120	2.5	Hydrothermal	390	455	26	Sahu et al. (2012)
Fungus	Ultrapure water	200	6	Hydrothermal	370	455	15.3	Yang et al. (2017)
Onion	Ethylenediamine (EDA)	120	2	Hydrothermal	380	464	28	Bandi et al. (2016)

According to 3(c), when compared with CQDs made from lemon juice, it was found out that CQDs produced from lemon-onion mixture exhibits higher QY. This may be due to the addition of onion juice increases the QY of lemon juice. This was further proven by a study by Monte-Filho et al., which also produced CQDs from lemon-onion mixture [18]. However, the study uses microwave pyrolysis instead. Nevertheless, compared to studies by Hoan et al. which produced CQDs from pure lemon juice, the QY was observed to be higher for CQDs produced from lemon-onion mixture [5]. This may be due to the higher polarity of the CQDs produced from lemon-onion mixture. According to Lakowicz, the higher the polarity, the lower the energy is required for emission, thus higher or more emission could be observed from the sample [31].

The presence of strong peak at hydroxyl group in FTIR spectrum proves that the samples produced have high solubility. However, in comparison, the sample produced from lemon-onion mixture has higher solubility due to the sample exhibiting stronger hydroxyl peak. Moreover, the presence of this strong peak also proves that the samples are high in polarity. This proves that the CQDs can easily bond with other polar molecules, such as water. Nevertheless, lemon-onion mixture sample has higher polarity compared to lemon juice sample. Therefore, other than having higher ease when bonding with other polar molecules, CQDs from lemon-onion mixture have higher melting and boiling points than CQDs from pure lemon juice.

Based on the FTIR analysis, the CQD sample produced is suitable to be applied to feasible products, such as soap. The reason to this statement is because the CQD sample has high solubility and high polarity, making it compatible to be a material to make soap. Moreover, due to it having high melting and boiling points, it would not melt or boil easily in normal earthen temperatures.

Comparing CQDs prepared in this study with those prepared in the previous study by Monte-Filho et al., in terms of QY percentage, it was found out that the ones in this study was lower [22]. Previous study produces lemon-onion mixture CQDs with QY percentage of 23.6% while in this study, 1.349% of QY percentage is resulted from the CQDs prepared. This difference of QY percentage may be due to the method of preparing CQDs and the solvents used. In the previous study, microwave pyrolysis was used to prepare the CQDs with ethanol as the solvent. On the other hand, in this study, hydrothermal method was used instead. No solvent was used in this study. According to a study by Lakowicz, solvent could aid in the increase of QY percentage as well as its polarity and viscosity could affect the length of increase.

Other than that, in comparison, the previous study uses less time to prepare the CQDs than this study. The CQDs synthesized in the previous study uses 6 minutes of heating while for this study, the sample was left in a vacuum oven for 3 hours for CQD synthesis. Furthermore, the temperature for CQD preparation in this study is much lower in comparison to the preparation done in the previous study. In this study, the vacuum oven was set to 120^{o}C rather than 370^{o}C in a microwave like the previous study.

Regardless of the low QY exhibited, the CQDs prepared in this study is consumer-friendly as the materials used to prepare the CQDs are all natural and non-toxic. Moreover, due to the excitation wavelength being in visible wavelength, the CQDs prepared are safe to be practically used on the human body, such as bioimaging and nanomedicines.

5. CONCLUSION AND RECOMMENDATION

By using hydrothermal method, carbon-based quantum dots were successfully synthesized from pure lemon juice at 120^{o}C for 3 hours. The results show a quantum yield percentage of 0.223% from the carbon-based quantum dots synthesized. Moreover, when mixed pure lemon juice with onion juice at lemon-onion ratio of 8:2, it was found out that the carbon-based quantum dots synthesized from said mixture produced 6 times the quantum yield percentage compared to the ones from pure lemon juice. Furthermore, an optimal lemon-onion ratio was found to be 8:2. Based on the research, the quantum yield percentage is the highest at this ratio, which is 1.349%. When ratio of lemon increases, the quantum yield percentage increases until the optimal ratio of 8:2 is reached. After exceeding optimal ratio, when ratio of lemon increases, the quantum yield percentage decreases. In comparison to previous studies, it was found out that most CQDs produced have excitation peak in ultraviolet region while the CQDs produced in this study have excitation peak in visible region. This is vital as it is proof that the CQDs produced could be used safely inside the human body.

For this research, lemons and onions will be used to extract quantum yield. One of the limitations would be type difference. There are a lot of types of onions, such as red, white and yellow. A study by Jurgiel-Malecka et al. [32] had discovered that different onions contain different percentages of sulphur and nitrogen content. It was discovered that yellow onion contained the highest sulphur content (3.79%) in comparison to the red (2.18%) and white (3.20%) onions. Furthermore, yellow onion also contained the highest nitrogen content (27.58%) in comparison to the red (18.76%) and white (23.31%) onions. So, the type difference may cause a difference in the quantum yield results due to the amount of N-S-doping of the CQDs. In this study, yellow onions were used. Therefore, for future studies, QY test comparing different types of onions could be done to ensure if there were any differences. Moreover, large quantity of natural resource is required to extract quantum yield. As an example, one litre (1L) of lemon juice is required to only get a little amount of quantum yield. If done at a large scale, it would not be efficient. Therefore, synthesis by microwave pyrolysis would be recommended if applied at large scale. Furthermore, this study was only done at lab scale. It could differ if applied at a larger scale, especially when brought to industry. Thus, as a recommendation, future studies could apply the results of the study into industrial scale instead of lab scale.

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