**How does the different types of citrus fruits (Key lime, Calamansi lime, Kaffir lime, Mandarin lime, pomelo, orange and lemon fruit) differ in their citric acid content by determining the volume needed to neutralize NaOH solution by acid-base titration?**

1. **RESEARCH QUESTION**

How does the different types of citrus fruits (Key lime, Calamansi lime, Kaffir lime, Mandarin lime, pomelo, orange and lemon fruit) differ in their citric acid content by determining the volume needed to neutralize NaOH solution by acid-base titration?

1. **TITLE**

A comparative study of the citric acid content between the citrus fruits of key lime, calamansi lime, kaffir lime, mandarin lime, pomelo, orange and lemon using acid-base titration method.

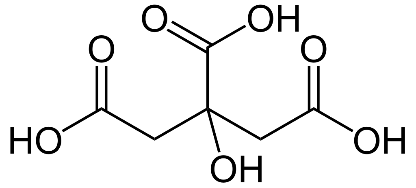
1. **INTRODUCTION**

The lime fruit is always considered as one of the most consumed citrus fruits in our daily lives, either in drinks or in cooking. In Malaysia and throughout Southeast Asia, some of the most consumed limes are namely the Key lime, Calamansi lime and the Kaffir lime. A question has been made about these citrus fruits when my grandmother wanted to cook fried noodles for her family, she always uses Calamansi lime in her cooking and refused to use Key lime and Kaffir lime. She said that amongst the three said lime fruits, the Calamansi lime is the most beneficial for our health. This is because my grandmother said that the citric acid content in the Calamansi lime is the highest amongst the three lime fruits.

To determine if this is true, I tried to find out the best way to discover the highest concentration of citric acid content within all citrus fruit extracts. I researched on the Internet and I discovered that there are three methods suitable to find the exact concentration of citric acid content in all the citrus fruits, which are the measurement of the pH for each citrus fruit[[1]](#footnote-1), the determination of electrical conductivity of the citrus fruits[[2]](#footnote-2) and the neutralization process via acid-base titration[[3]](#footnote-3). By researching more, I found out that of the acid-based titration is the best way to investigate my inquiries. This is due to the fact that acids and bases have complementary chemistry.[[4]](#footnote-4) Also, I also want to observe the colour change of the titration to find the equivalence point of the acid-base titration. Acid-base titrations use an equipment called a burette to determine the exact concentration of an acidic or base sample. From there, I decided to use acid-base titration to find out the how much citric acid content in 7 types of citrus fruits in fixed volume by determining the endpoint of the experiment.

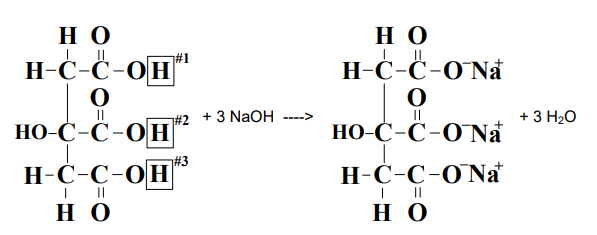
1. **BACKGROUND INFORMATION**

Citrus fruits significantly contain citric acid.[[5]](#footnote-5) Citric acid, which is systematically known by the International Union of Pure and Applied Chemistry (IUPAC) as 2-hydroxypropane-1,2,3-tricayboxylic acid is a type of tricarboxylic acid, in which the acid contains three carboxylic acids in terms of organic chemistry. It is also known by the IUPAC nomenclature as the -hyroxytricarballylic acid.[[6]](#footnote-6)



*Figure 1: Citric acid or 2-hydroxypropane-1,2,3-tricayboxylic acid*

The molecular formula of the citric acid is C6H8O7. It is considered a weak acid that is formed in the citric acid cycle.[[7]](#footnote-7) Citric acid is considered as a triprotic acid[[8]](#footnote-8), which means that each mole of citric acid release more than one acid or base equivalent. When dissolved in water, the acid is capable of donating 3 protons. Salt and water can be produced by adding a strong base to the acid. Each hydrogen ion in citric acid will react with one hydroxide ion (OH-) from the strong base, such as sodium hydroxide, NaOH, to produce water (H2O). The sodium ions from the sodium hydroxide, NaOH, is to be associated by taking the place of each hydrogen from citric acid.



*Figure 2: Chemical reaction of citric acid and sodium hydroxide*

From Figure 2, it is shown that one mole of citric acid, C6H8O7, reacted with three moles of sodium hydroxide, NaOH will produce a mole of a new type of salt and three moles of water, H2O.

In order to determine an unknown concentration of molarity of acid in a certain solution, the process of acid-base titration can be used. It is one of the means of quantitative analysis. The unknown substance needs to be reacted with another substance which is called as a titrant. When the reaction is considered complete, the reaction end is customarily marked with the appearance of colour from a pH indicator, such as the phenolphthalein indicator.[[9]](#footnote-9)

The concentration of the citric acid contained in lime fruit solutions can be determined by the methodology of acid-base titration. A recognized volume of the lime fruit extract is quantified, and it is added into an Erlenmeyer flask. In the flask, the phenolphthalein indicator solution is added. A strong base, such as sodium hydroxide, NaOH, is added into the Erlenmeyer flask until the acid has completely reacted. When it is completely reacted, the acidic solution will become basic, and it can be marked by the presence of a pinkish colour from the phenolphthalein indicator in the lime fruit extract. A burette is used in the acid-base titration process which allows the strong base to be added into the citric acid. From here, the exact volume of the basic solution added to the acidic solution can be determined during the acid-base titration process. The concentration of NaOH can then be calculated from the chemical stoichiometry of the reaction.

1. **HYPOTHESIS**

Among the citrus fruits of Key lime, Calamansi lime, Kaffir lime, Pomelo, Mandarin lime, Orange and Lemon, the Calamansi lime holds the highest concentration of citric acid.

1. **LIST OF VARIABLES**

*Table 1: List of Variables*

|  |  |  |
| --- | --- | --- |
| Variable | | Explanation |
| Independent Variable | Types of lime fruit | The experiment is conducted with 7 different types of lime fruit, which are the Key lime, Calamansi lime, Kaffir lime, Pomelo, Mandarin lime, Orange and Lemon. |
| Dependent Variable | The volume of NaOH in titration (cm3) | The volume of NaOH in titration is measured using the burette that is used to titrate against the citric fruit extract. By using this data, I can calculate and record the concentration of citric acid **by using the formula .** |
| Controlled Variable | Initial volume of lime extract, (cm3) | The initial volume of lime extract is maintained at 10 cm3. The volume is to be maintained because it will be used in the volumetric calculations and analysis. |
| Volume of distilled water, H2O, (cm3) | The volume of distilled water, H2O is maintained at 100 cm3. This volume will be added to the diluted citrus fruit extract. This is to be maintained since it will also be considered in the volumetric calculations and analysis of the titration experiment. |
| Molarity of sodium hydroxide, NaOH, (M) | The molarity of sodium hydroxide is fixed at 0.05 M. It is fixed because the fixed variable will be involved in the volumetric analysis. |
| Room temperature, (°C) | The room temperature where the experiment is conducted is fixed and is measured by using a mercury thermometer. It is maintained to prevent a change in the reaction rate of the acid-base titration. |
| Atmospheric pressure,  (mm Hg) | The atmospheric pressure of the room where the experiment is conducted is maintained and is measured by using a mercury barometer. It is to be maintained because altering it might cause a change of the rate of reaction of the experiment conducted. By using Google Science Journal app, the atmospheric pressure of the area of the conducted experimented is 1008.11 hPa which is approximately 756 mmHg. |
| Addition of phenolphthalein indicator | The phenolphthalein indicator is added into the flask containing the lime extract at 2 drops. This is to be fixed to ensure that the colour change of the phenolphthalein solution is at the same shades of colour. Adding more or less drops of the indicator may disturb the consistency of the judgement of the human eye when it comes to the colour change of the indicator. |
| Final volume of sodium hydroxide, NaOH, solution titrated against citrus fruit extract, | The final volume of sodium hydroxide, NaOH, solution titrated against citrus fruit extract is fixed at 50 cm3. It is to be maintained so that the calculation of the volume of NaOH solution required is easy since filling a 50 cm3 will result in the NaOH solution filling to the ‘0 cm3’ mark of the burette. |

1. **LIST OF APPARATUS AND MATERIALS**

*Table 2: List of Apparatus and its uncertainties*

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Apparatus | Uncertainty | Quantity |
| 1 | 10 cm3 pipette | (± 0.02 cm3) | 1 |
| 2 | 100 cm3 graduated cylinder | (± 1 cm3) | 1 |
| 3 | 250 cm3 beaker | - | 2 |
| 4 | 250 cm3 Erlenmeyer flask | - | 10 |
| 5 | 50 cm3 beaker | - | 1 |
| 6 | 50 cm3 burette | (± 0.05 cm3) | 1 |
| 7 | Dropper | N/A | 1 |
| 8 | Electronic balance | N/A | 1 |
| 9 | Filter paper | N/A | 7 |
| 10 | Google Science Journal application | N/A | 1 |
| 11 | Manual juicer | N/A | 1 |
| 12 | Magnetic stirrer and Magnetic stirring bar | N/A | 1 |
| 13 | Masking tape | N/A | 1 |
| 14 | Permanent marker | N/A | 1 |
| 15 | Pipette pump | N/A | 1 |
| 16 | Plastic funnel | N/A | 7 |
| 17 | Retort stand and clamp | N/A | 1 |

*Table 3: List of Materials*

|  |  |  |
| --- | --- | --- |
| No. | Material | Quantity |
| 1 | 0.05 M of sodium hydroxide, NaOH, solution | 500 cm3 |
| 2 | Calamansi lime extract | 100 cm3 |
| 3 | Distilled water, H2O | 1 litre |
| 4 | Kaffir lime extract | 100 cm3 |
| 5 | Key lime extract | 100 cm3 |
| 6 | Lemon extract | 100 cm3 |
| 7 | Mandarin lime extract | 100 cm3 |
| 8 | Orange extract | 100 cm3 |
| 9 | Phenolphthalein indicator | 20 cm3 |
| 10 | Pomelo extract | 100 cm3 |

1. **METHODOLOGY**

To begin my chemical experiment, I decided to adapt the methodology of Part II of the acid-base titration from the St. Ignatius College at Deakin University[[10]](#footnote-10) that has experimented on the acid base titration for the determination of citric acid from citrus fruits.

* 1. **PART I: FILTRATION OF CITRUS FRUIT EXTRACT**

1. The key lime fruit is pressed and juiced by using a manual juicer.
2. Then, the juice is poured into a bottle. This will be followed by all the other six citrus fruits.
3. Then, filtration of juice extract from pulp extract is done by filter all the extracts by using a 250 cm3 Erlenmeyer flask, a plastic funnel and a filter paper.
4. All the other six extracts from six other fruit are also filtered at the same time to save time.
5. The filtered products are the pure juice extracts of the citrus fruits.
6. All the filtered juice extracts are poured into a plastic container and is labelled by using a masking tape and a permanent marker.



*Figure 3: Filtration of Citrus Fruit Extract*

* 1. **PART II: ACID-BASE TITRATION**

1. 50 cm3 of sodium hydroxide, NaOH, solution is poured into a burette.
2. For key lime extract, firstly 10 cm3 of the filtered extract is poured into the beaker by using a 10 cm3 pipette and pipette pump.
3. 100 cm3 of distilled water, H2O is measured by using a 100 cm3 graduated cylinder.
4. The measured 100 cm3 of distilled water, H2O is then poured into a new 250 cm3 beaker.
5. Then the key lime juice extract is poured into the beaker containing 100 cm3 distilled water, H2O.
6. 2 drops of phenolphthalein indicator are added into the diluted solution by using a dropper.
7. The beaker containing the diluted filtered key lime extract is put onto a magnetic stirrer. A magnetic stirring bar is put into the beaker. From here, the magnetic stirrer is turned on and the solution begins to stir.
8. Step 1 until step 7 is repeated with other types of citrus fruits which are the Calamansi lime, the Kaffir lime, Pomelo, Mandarin lime, Orange and Lemon.

Graphical user interface

Description automatically generated

*Figure 4: Apparatus set up for acid-base titration*

* 1. **SAFETY CONSIDERATIONS ON METHODOLOGY**

The following are the safety considerations and precautions that has been taken during this chemistry exploration:

* Whenever dealing with acids and bases especially strong bases which are sodium hydroxide, NaOH, protective goggles are worn throughout the experiment.
* The pipette pump is used to pipette citrus fruit extracts containing citric acid.
* All the citrus fruit extracts, NaOH solution etc. are stored in glass containers.
* Distilled water, H2O is poured into the beaker filled with the juice lime extracts and not the other way around. This is to prevent spattering of acid even though citrus fruit extracts contain weak acids.
* Every single container containing different citrus fruit extracts, buffer solution, sodium hydroxide, NaOH solution, phenolphthalein indicator solution etc. are labelled using a masking tape and a permanent marker for easy identification of solutions.
* All used solutions are disposed in an approved manner in the chemistry laboratory.
* All power is turned off before leaving the laboratory.
* Some apparatuses such as the pipette, burette and graduated cylinder is rinsed by using distilled water, H2O to ensure other chemicals is present in these apparatuses.
* All experimental apparatuses are cleaned before and after use to prevent contamination.

1. **DATA COLLECTION**
   1. **RAW QUANTITATIVE DATA**

From Table 4, these readings will be used to identify the equivalence point for the acid-base titration.

*Table 4: Trial readings of the volume of NaOH needed to neutralize 110 cm3 diluted citrus fruit extract against type of citrus fruit extract*

|  |  |  |  |
| --- | --- | --- | --- |
| Citrus fruit extract | Volume of NaOH needed to neutralize 110 cm3 diluted citrus fruit extract (± 0.05 cm3) (Equivalence point) | | |
| Trial 1 reading | Trial 2 reading | Trial 3 reading |
| Key lime | 21.5 | 21.5 | 17.0 |
| Calamansi lime | 23.5 | 28.0 | 26.5 |
| Kaffir lime | 21.5 | 24.5 | 26.0 |
| Pomelo | 4.5 | 6.0 | 6.0 |
| Mandarin lime | 9.0 | 8.5 | 9.5 |
| Orange | 3.0 | 3.0 | 4.0 |
| Lemon | 3.5 | 3.5 | 3.0 |

* 1. **QUALITATIVE DATA**

The following are some of the qualitative data that has been observed during the experiment:

1. All pure citrus fruit extracts are colourless or slightly colourless after filtration of citrus fruit extracts.
2. Before experiment, sodium hydroxide, NaOH, solution is colourless.
3. When added phenolphthalein indicator into the diluted citrus fruit extracts, the solution is remained colourless, indicating that all the solutions are acidic.
4. Moments before the end titration product reaches equivalence point, the colour of indicator from some citrus fruit extract changed colour from colourless to cloudy yellow. This happens before the solution turned pink, indicating the equivalence point of the titration.
5. All solutions turn pale pink for a brief moment when equivalence point has been reached.
6. All solutions turn hot pink after equivalence point has been reached.
7. **DATA PROCESSING AND EVALUATION**

From the trial readings obtained from Table 4, the average reading for the volume of sodium hydroxide, NaOH solution is calculated.

*Table 5: Average volume of NaOH needed to neutralize 110 cm3 diluted citrus fruit extract against citrus fruit extract*

|  |  |
| --- | --- |
| Citrus fruit extract | Average volume of NaOH needed to neutralize 110 cm3 diluted citrus fruit extract (± 0.05 cm3) (Equivalence point) |
| Key lime | 20.0 |
| Calamansi lime | 26.0 |
| Kaffir lime | 24.0 |
| Pomelo | 5.5 |
| Mandarin lime | 9.0 |
| Orange | 3.5 |
| Lemon | 20.5 |

To calculate the molarity of citric acid contained in the Key lime extract, firstly the chemical equation of the chemical reaction of sodium hydroxide, NaOH, and citric acid, C6H8O7.

Next, the known values of the problem are listed.

* Molarity of NaOH, = 0.05 M
* Volume of NaOH, = 20.00 ± 0.05 cm3
* Volume of C6H8O7, = 110.00 ± 0.05 cm3

Since , we can now find out the unknown molarity of citric acid. From the chemical reaction above, it is known that the 3 mol of NaOH is needed to react with 1 mol of citric acid, C6H8O7. Thus, we can calculate that .

Its uncertainty, , is calculated using the following formula,

Therefore, the concentration of citric acid, C6H8O7, in diluted Key lime extract is .

*Table 6: Concentration of citric acid against type of citrus fruit (diluted)*

|  |  |  |
| --- | --- | --- |
| Type of Citrus Fruit | Concentration of citric acid, C6H8O7 (M) | Percentage uncertainty (%) |
| Key lime |  |  |
| Calamansi lime |  |  |
| Kaffir lime |  |  |
| Pomelo |  |  |
| Mandarin lime |  |  |
| Orange |  |  |
| Lemon |  |  |

Therefore, we can observe that the Calamansi lime holds the highest concentration of citric acid that is M. To find the concentration of citric acid in undiluted citrus fruit extract, the formula is used.

|  |  |
| --- | --- |
|  | = The concentration of citric acid in 110 cm3 diluted citrus fruit extract  (Information is obtained from Table 6) |
|  | = The volume of diluted citrus fruit extract = 110 cm3 |
|  | = The concentration of citric acid in 10 cm3 undiluted citrus fruit extract |
|  | = The volume of undiluted citrus fruit extract = 10 cm3 |

Its uncertainty, , is calculated using the following formula,

Therefore, the concentration of citric acid, C6H8O7, in undiluted Key lime extract is .

*Table 7: Concentration of citric acid against type of citrus fruit (undiluted)*

|  |  |
| --- | --- |
| Type of Citrus Fruit | Concentration of citric acid, C6H8O7 (M) |
| Key lime |  |
| Calamansi lime |  |
| Kaffir lime |  |
| Pomelo |  |
| Mandarin lime |  |
| Orange |  |
| Lemon |  |

Chart, bar chart

Description automatically generated

Type of citrus fruit

Concentration of citric acid,

Figure 5: The graph of the concentration of citric acid, against the type of citrus fruit

1. **EVALUATION**

Table 8: List of strengths identified in this experiment and its explanation

|  |  |
| --- | --- |
| Strengths | Explanation |
| All the experimented citrus fruit extracts are purely obtained from the citrus extract. | All the citrus fruit extracts are freshly produced from their respective fruits, instead of obtaining the extracts from commercially packaged juices. This has increased the reliability of the chemical analysis on the concentration of citric acid relative to the type of citrus fruit.[[11]](#footnote-11) |
| The experiments for each of the citrus fruit extracts involved are repeated three times. | After experimenting for three times, the results of all three experiments are averaged. This process aids in the elimination of the measurement errors.[[12]](#footnote-12) |
| Magnetic stirrer was used to swirl the titrated solution. | Instead of using human hands to swirl the final product of titration in the beaker, a magnetic stirrer is used to ensure a continuous stir of the titrated solution. This is to ensure that the colour change of the phenolphthalein indicator is consistent with the expected endpoint of the titration. |

Table 9: List of limitations identified in this experiment and methods to overcome the limitations

|  |  |
| --- | --- |
| Limitations | Methods to overcome limitation |
| The volume of sodium hydroxide, NaOH, solution in the burette and also the volume of distilled water, H2O, can be misread by experimenters due to human error. This has influenced the error of determining the equivalence point of this experiment. | The experiment is repeated three times and the result of all three trials are averaged. It was planned that the experiment is repeated more than three times. However, due to limited time, the experiment is only conducted as mentioned above. |
| When filling the burette with sodium hydroxide, NaOH solution, there is presence of air bubbles which can affect the liquid flow of the NaOH solution in the burette. | When finished filling the burette, I waited for a few minutes before I was sure that there are no air bubbles with the solution in the burette at all. |
| The colour change of the phenolphthalein indicator is not as accurate as the literature colour change which is from colourless to pink[[13]](#footnote-13) due to the experimenter’s interpretation of the colour change. This has led to the reduced reliability on the result of the equivalence point of titration. | The colour change of the indicator is rapid. In this case, by judgement of the human eye, I expected that the immediate change of the colour was an indication that the titration has reached its equivalence point. Also, I planned to use a pH meter to detect the of the indicator.[[14]](#footnote-14) However, due to limited resources of the pH meter in the laboratory, I did not proceed with this method. |
| During the first readings of the endpoint for the first dependent variable of the type citrus fruit, I washed the burette and pipette using tap water. This has contaminated the NaOH solution when it is poured after washing the said equipment. | Distilled water is used to wash the burette and pipette after each trials of the experiment. Distilled water aids in the significant removal of impurities from the used apparatus.[[15]](#footnote-15) |
| When filling the burette with sodium hydroxide, NaOH, solution, there is presence of air bubbles which can cause the volume readings to have errors.[[16]](#footnote-16) | When finished filling the burette, I waited for a few minutes before they are sure that there are no air bubbles in the solution in the burette at all. |

1. **CONCLUSION**

Table 10: The ranking of the concentration of citric acid, C6H8O7, according to its citrus fruit extract

|  |  |  |
| --- | --- | --- |
| Rank | Citrus fruit extract | Concentration of citric acid, C6H8O7 (M) |
| 1 | Calamansi lime |  |
| 2 | Kaffir lime |  |
| 3 | Lemon |  |
| 4 | Key lime |  |
| 5 | Mandarin lime |  |
| 6 | Pomelo |  |
| 7 | Orange |  |

In conclusion, this chemistry exploration has been achieved with the hypothesis of the experiment is accepted when it is proven by experimentation that the Calamansi lime holds the highest concentration of citric acid amongst the 7 citrus fruit that has been experimented on. This implies that my grandmother was right, in which she said that the Calamansi lime is the most acidic amongst all the limes that she has refused to use. Many problems have been encountered during the experimentation and analysation of the titration. For this exploration, the most major flaw is that I assumed that there would be 100% content of citric acid in all those citrus fruits. In fact, there are other acids composed in citrus fruits such as malic, succinic, malonic, lactic, oxalic and many more.[[17]](#footnote-17) Nevertheless, citric acid still accounts for the majority content of acids in citrus fruits.[[18]](#footnote-18)

As an extension to my chemistry exploration, it is possible that the concentration of citric acid can be determined by using UV-vis spectrometer from the observance of colour change in the citrate ions of aqueous solutions.[[19]](#footnote-19) Also, it is also expected that the use of pH meter can be another extension to my methodology. pH meter aids in the determination of the endpoint of the titration curves for all the citrus fruit extracts.[[20]](#footnote-20) To overcome the assumption of citric acid being the sole acid in the acid content in all the citrus fruits, it is expected that there would be a further research regarding the determination of any acid in the citrus fruits with further analysis according to the composition of the citrus fruits. All these extensions would allow more accurate and precise results in which we can analyse the benefits of it later in the future.

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