**Title: Investigating the acetic acid content in vinegar post the pickling process**

## I. Introduction

In the winter of 2015, a visit to the school bariatric physician revealed to me that I was excessively obese for my age. Being a foodie, I was devastated to realize of lack of taste-bud stimulating food in my redesigned diet. To make up for this deficiency, my dietician introduced me to house-hold treat: pickled vegetables. To complement my diet, I was allowed to eat vinegar pickled vegetables, rather than the traditional oil pickled vegetables. Because of this addition, I started eating more vegetables than ever before! The presence of this low calorie treat helped me stick to my diet and reduce my weight to an acceptable amount.

I partook in the process of making the vegetable pickle with my mother. Because the pickled vegetables took a lot of time to get prepared, my mother and I made several jars of pickled vegetables for the time being. However, we soon realized that the pickling process led to excessive wastage of vinegar after the pickles were consumed. It was unethical for us to waste vinegar in this manner and it also cost a lot of money to keep purchasing vinegar. To sort this out, my mother and I considered reusing the vinegar for further pickling. I immediately surfed the internet to know whether this was possible but were disappointed to realize that the vinegar is unable to preserve the vegetables after a certain fall in the acetic acid content(5%)[1]. This got me to further research into the change in acidic content of vinegar post the pickling of different vegetables for different brands. However, I was unable to find specific research on the same. Hence, the research question I designed is:

**To what extent does the acetic acid content, in different brands of vinegar, change after a process of pickling with cucumber, green chili, and carrot, for a period of 3 days so that the vinegar can be reused for the pickling process?**

While performing my research, I came across the overwhelming health benefits of vinegar. Besides being able to nullify pathogens in vegetables, vinegar has been proven to lower blood sugar levels, protect against type 2 diabetes, burn calories to aid weight loss, lower cholesterol level, and has also been hypothesized to have protective effects against cancer.[2] The excessive uses provoked my curiosity to find economical uses of this miracle chemical. I was captivated by the variety of applications and wished to contribute to the sustainable use of vinegar as a home remedy.

The three vegetables I have chosen for this investigation are cucumbers, carrots, and chilies. The reason I chose these vegetables is because they are most commonly pickled in the daily household. Moreover, these vegetables have short shelf lives so the preservation effects of vinegar in their case will be explicitly identified as they will have larger acetic acid absorption than other vegetables.

The brands that I have chosen are Sam's Vinegar (9% ethanoic acid), Healthkart Vinegar (5.0% ethanoic acid), Ching's chili vinegar (4.00% ethanoic acid), Kalvert Foods vinegar (5% ethanoic acid), Sarwar Foods vinegar (15% ethanoic acid). The reason for choosing the brands was they were readily available in my locale and were also marketed as being pickling friendly vinegar brands.

**Scope of research:**

[1] Erica, Erica, Erica, Angela, Lesa, Elizabeth, MaryAnn Coy, and Joycelyn. "Start Here." Northwest Edible Life, July 20, 2017. http://nwedible.com/is-reusing-pickling-brine-safe/. Accessed 26/01/20

[2] Gunnars, Kris. "6 Proven Benefits of Apple Cider Vinegar." Healthline. Healthline Media, March 15, 2018. https://www.healthline.com/nutrition/6-proven-health-benefits-of-apple-cider-vinegar#section6. Accessed 26/01/20

Post the pickling process, a drop occurs in the acidity levels of the vinegar. This drop renders the vinegar to be ineffective for preservation as the bacteria manage to thrive in lower acidity levels. By investigating the change in acidity content in vinegar post pickling, I hope to find the optimum vinegar which can lead to the least acidity content change for different vegetables so that it can be reused for the process multiple times.

## II. **Background Information**

Vinegar, a mild organic acid with a pungent odor, is an essential household product that is consumed in abundance throughout the world. It plays a vital role as a cooking agent in the modern kitchen and also has extensive application as a cleaning solvent. Vinegar  is used in several areas except pickling like weed killing, medical, window cleaning, cleaning stains on clothes, etc.[3]

Vinegar is prepared by a two-stage fermentation process. Initially, yeast convert sugars into ethanol anaerobically. Later, ethanol is oxidized to acetic acid aerobically by bacteria.[4] Vinegar may be produced from a variety of materials: apples or grapes (wine or cider vinegar); malted barley or oats (malt vinegar); and industrial alcohol (distilled white vinegar).

Vinegar is identified as a weak acid since it only partially dissociates in water. Due to the presence of acetic acid, vinegar manages to inhibit bacterial growth by lowering the pH of the vegetables. The high acidity content prohibits pathogen production and keeps the vegetable yeast, bacteria and  The spoilage of vegetables occurs due to the growth of microbes such as mold growth and scum on the surface. Vinegar, obstructs their production by drawing water out of the cells of the [5]vegetables through osmotic action, the process of movement of solvent through semi-permeable membrane into a solution that contains greater concentration of solute, resulting in an equilibrium concentration of solutes on either side of the membrane. After a brief period of 3-4 days, the acid levels between the pickled vegetable and the solvent stabilize and the vegetable remains bacteria-free. The change in acidic content is also responsible for the flavoring imparted on the vegetables by the vinegar post the pickling process.[6]

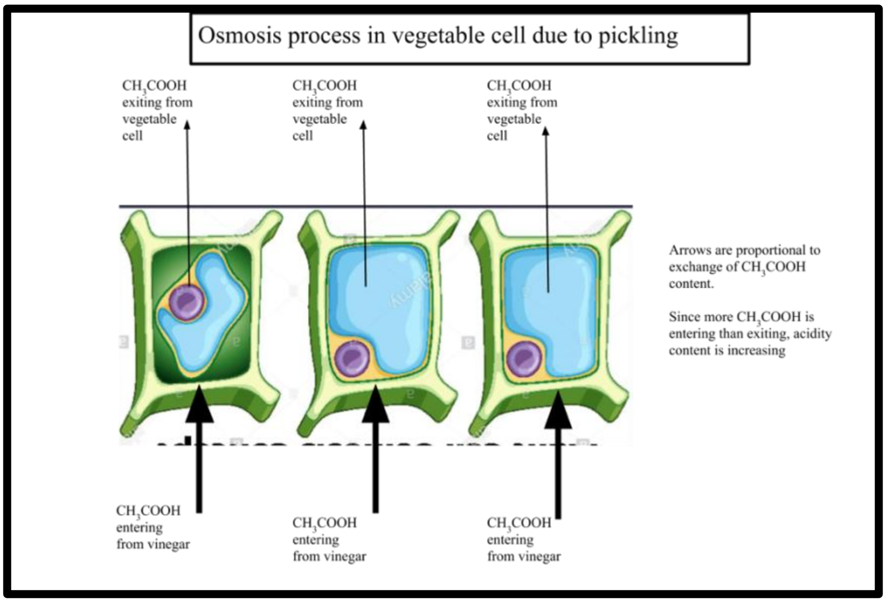


*Figure 1: Osmosis process in the vegetable cell*

3 The Editors of Encyclopaedia Britannica. “Vinegar.” Encyclopædia Britannica. Encyclopædia Britannica, inc., January 8, 2020. https://www.britannica.com/topic/vinegar. Accessed 26/01/20

4 Ebner, Heinrich, Enenkel, and Anton. “Two Stage Process for the Production of Vinegar with High Acetic Acid Concentration - Firma, Heinrich Frings.” FPO IP Research & Communities, February 28, 1978. http://www.freepatentsonline.com/4076844.html. Accessed 26/01/20

5 “Diagram Showing Osmosis in Plant Cell ...: Stock Vector.” Colourbox. Accessed January 26, 2020. https://www.colourbox.com/vector/diagram-showing-osmosis-in-plant-cell-vector-41551193. Accessed 26/01/20

6 Bonem, Max, and Max Bonem. “The Science of Vinegar Pickling, Explained.” Food & Wine. Accessed January 26, 2020. https://www.foodandwine.com/vegetables/pickled-vegetables/science-vinegar-pickles-explained. Accessed 26/01/20

The major component of vinegar is ethanoic acid. Ethanoic acid is an organic carboxylic acid with the functional group called the carboxyl group, COOH. Acetic acid has the chemical formula $CH_3COOH$ with a molar mass of 60.1g/mol. [7]

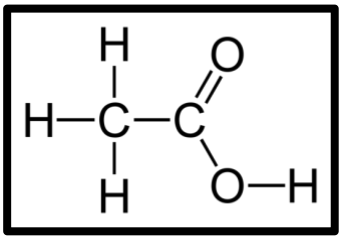

*Figure 2: Chemical structure of $CH_3COOH$*

Pickling is also recognised for enhancing nutritional value of the Vegetables. Pickling not only retains the vitamins and minerals in the vegetables, but also adds sodium and probiotics, live microorganisms that are good for your digestion, that enrich the vegetable's health benefits. In addition, beneficial bacteria in the intestines aids the immune system and prevents inflammation. Moreover, pickling preserves the natural antioxidants found in fruits and vegetables, which assist to eliminate free radicals. Free radicals are unstable chemicals that are formed naturally in the body, and can lead to cell damage and problems such as heart disease and cancer. [8]

Extensive research has taken place on investigating the enhancement in the nutritional value of carrots and green chilli due to pickling. The literature values obtained are as follows: research into pickling of carrots has shown that the process preserves moisture by 95%, enhances protein content by 194%, increases acidity by 600%, however reduces vitamin C content by 100%. Similarly, research into pickling of green chillies shows that the process preserves moisture by 92%, enhances protein content by 150%, increases acidity by 324%, and boosts vitamin C content to 117%.[9]

The analytical method for determining the percentage of acetic acid used in this research is Titration. Titration involves adding quantities of a base of known concentration (standard solution) to a known volume of the test solution until the neutralization reaction occurs.. The point at which the neutralization is complete is referred to as the endpoint and is observed by the colour change in the added indicator, phenolphthalein in this case.

## III. Methodology

By preparing a batch of pickles, where a single type of vegetables is dipped in samples of all types of vinegar brands, the change in acetic acid content of the vinegar brand samples is to be investigated. This is then done for all the types of vegetables. Using a titration process, where Sodium Hydroxide standard solution is used, the acidic content in the sample vinegar, post the pickling process is found out. This is compared to the percentage acetic acid value given by the company, and the change due to pickling is identified. The vinegar is optimum to use for the picking process is finally determined based on its final acetic acid content and whether it has enough acid to be reused for more batches greater periods of time.

## IV. Variables

### 1. Independent Variables

The 5 different brands of vinegar, namely Sam's Vinegar (9% ethanoic acid), Healthkart Vinegar (5.0% ethanoic acid), Ching's chili vinegar (4.00% ethanoic acid), Kalvert Foods vinegar (5% ethanoic acid), Sarwar Foods vinegar (15% ethanoic acid).

[7] Helmenstine, Anne Marie. "What Is the Chemical Composition of Vinegar?" ThoughtCo. ThoughtCo, June 4, 2019. https://www.thoughtco.com/chemical-composition-of-vinegar-604002. Accessed 26/01/20

[8] "Does Pickling Vegetables Take Away the Nutrition?" LIVESTRONG.COM. Leaf Group. Accessed January 26, 2020. https://www.livestrong.com/article/536144-does-pickling-vegetables-take-away-the-nutrition/. Accessed 27/01/20

[9] "Preservation of Carrot, Green Chilli and Brinjal by Fermentation and Pickling." International Food Research Journal . International Food Research Journal , April 23, 2014. http://ifrj.upm.edu.my/21 (06) 2014/49 IFRJ 21 (06) 2014 Iqba 098.pdf. Accessed 26/01/20

The **three different vegetables** that the pickle was prepared with, namely, cucumber, green chili, and carrot.

2. **Dependant Variable**
   Ethanoic acid content of the vinegar post the pickling process.
3. **Controlled variables**

*Table 1: Controlled variables*

| Variable | Method of control |
|---|---|
| Procedure for accessing the acetic acid content. Method of testing is kept constant. | The same titration process will be followed for every brand, and vegetable. The 3 trials for each case will be taken using the same method. |
| Amount of time devoted to pickling the vinegar. | The vegetables were pickled for exactly 72 hours, and the vegetables were removed and disposed of after the time interval. This was done so that the acid can be effectively absorbed and lead to a fall in the acidic content. |
| Volume of vinegar that was used in the pickling process. | 100 $cm^3$ of vinegar was used in the pickling process by pickling the vegetables in this volume of vinegar. |
| Equipment and apparatus | All the apparatus used in the titration process will be carefully washed and dried before each trial for the vegetable and the brand of vinegar. |
| Concentration of Sodium Hydroxide solution used as the titrant. | The concentration was calculated using a titration process with 0.1 mol $dm^{-3}$ Oxalic acid and found to be $0.082 \pm 0.015$ mol $dm^{-3}$. |
| Volume of vinegar used as the analyte. | 10 $cm^3$ of vinegar was measured every time, for the titration process, with a pipette. |
| Mass of vegetables used. | Each vegetable type had similar a similar mass for the vegetable used to pickle with the brands of vinegar. For example, the cucumbers were all nearly $30\pm 0.001g$ measured by Contech CAH-223 top pan balance. |

## V. Apparatus

- 1 Burette (Uncertainty $\pm 0.1 cm^3$)
- 1 Conical flask
- 1 Dropper
- 18 beakers, 1 1000$cm^3$ beaker (Uncertainty $\pm 100 cm^3$) and 17 200$cm^3$ beakers (Uncertainty $\pm 20 cm^3$)
- Clamp and stand
- 5 10 $cm^3$ pipettes
- Clamp and Stand
- Contech CAH- 223 top pan balance (± 0.001g)
- Clock

**Reagents**

1. Sodium Hydroxide solution ($0.082 \pm 0.015$ mol $dm^{-3}$ 1500$cm^3$)
2. Oxalic Acid (0.1 mol $dm^{-3}$ 200$cm^3$)
3. 5 brands of vinegar namely, Sam's Vinegar, Healthkart Vinegar, Ching's chili vinegar, Kalvert Foods vinegar, Sarwar Foods vinegar. Approximately 350$cm^3$ of vinegar from each brand.
4. Distilled water (Approximately 1500$cm^3$ used in the entire procedure)
5. 5 samples of carrot, 5 samples of green chili, and 5 samples of cucumber all of similar mass.
6. Phenolphthalein Indicator solution

**VI.**

## VII. Procedure

**PART 1: Preparing a batch vegetable pickles for the experiment**:
The process of making vinegar pickles was followed based on a traditional method. Each vegetable was pickled in a beaker of vinegar of each brand for a period of 3 days. No salt or additional preservative was added (These are typically added to enhance preservation and taste in traditional methods). Moreover, the pickles were not kept in synthetic conditions like refrigerator, which is traditionally done while preparing pickles. The steps for pickling were as follows:

1. The selection of vegetables is done based on their firmness so that equivalent mass of firm carrot, cucumber, and green chilli (Note: each vegetable had similar mass as the same vegetable sample used for another brand of vinegar, different vegetables had different mass) were taken and washed thoroughly.
2. Using 15 beakers, 100 $cm^3$ of vinegar is measured. The mass of the vinegar 100 $cm^3$ is then measured using the Contech CAH-223 top pan balance.
3. The vinegar is poured in the beakers. One vegetable of each type is placed in the beaker with each brand, namely Sam's Vinegar, Healthkart Vinegar, Ching's chili vinegar, Kalvert Foods vinegar, Sarwar Foods vinegar .
4. Appropriate markings are made on the beaker to identify the vinegar brand and the vegetable used. This is done to distinguish between different brands as all the beakers containing the pickled vegetables appear transparent. A lid is placed on the beaker to ensure outside weather is unable to interfere. *Figure 3 and Figure 4* show the prepared batches of green chilli, cucumber and carrot.
5. Each beaker is heated on a stove for 2 minutes.
6. The beakers are then stored away for 3 days (72 hours).
7. After 72 hours, remove the vegetables and store the vinegar in a refrigerated atmosphere to prevent changes in the content of the solution.

*Figure 3: Batch of pickled carrot and green chili*

*Figure 4: Batch of pickled cucumber*

**PART 2: Titrating the samples of vinegar with known concentration of Sodium Hydroxide solution:**
After the period of 3 days, samples of the vinegar solution were obtained from the batch of vegetables. Because vinegar is highly concentrated in acetic acid, the vinegar samples were diluted in order to have compatible results of concentration with the Sodium Hydroxide solution taken. The steps for preparing the analyte are as follow:

1. Using a pipette, 3 samples of 10 $cm^3$ vinegar are obtained from each beaker for each vegetable pickled in each brand.
2. The obtained vinegar is diluted to a ratio of 1:10. This is done by taking a 100$cm^3$ beaker and pipetting the 10$cm^3$ sample of vinegar and then filling the rest 90$cm^3$ up with distilled water.
3. A diluted 10 $cm^3$ sample of vinegar of is obtained from this mixture, leading to another 1:10 dilution to the diluted sample.
4. This sample is the analyte for the procedure.

The steps for the titration process are as follows:

1. Pipette 10 $cm^3$ of the vinegar in a conical flask and add 3 drops of phenolphthalein to it. The mixture will appear transparent.
2. Fill a 50 $cm^3$ burette with the Sodium Hydroxide solution and clamp the burette to a stand. Place the conical flask below the burette.
3. Add 3 drops of phenolphthalein to the conical flask.
4. Take the measurement of the initial volume of Sodium hydroxide solution in the burette.

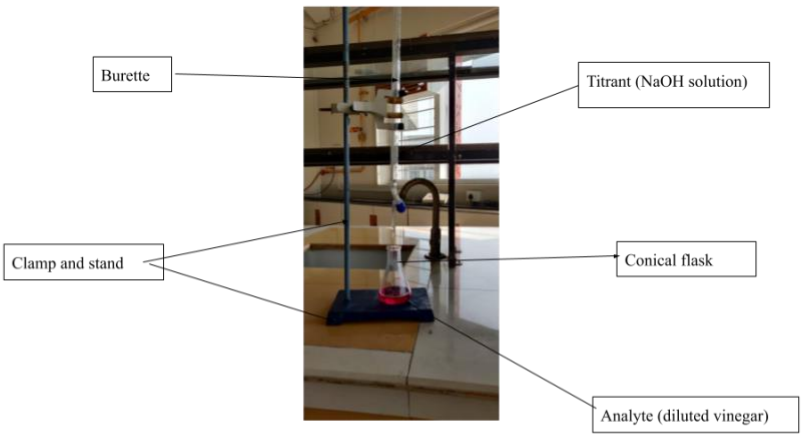


*Figure 5: The setup for the titration process*

5. Turn on the stopcock of the burette and add the NaOH drop by drop while swirling the conical flask vigorously. Turn the stopcock off at the instant when the solution turns completely pink, which indicates that the equivalence point has been reached.
6. Measure the volume of Sodium Hydroxide solution remaining in the burette.
7. Subtract the initial volume of Sodium Hydroxide solution from the final volume of Sodium hydroxide solution to find the volume of NaOH used in the titration process
8. Conduct 3 trials for each brand of vinegar chosen for each vegetable.
9. Repeat the titration process for each vinegar brand for 3 vegetables.

## VIII. <u>Ethical, Safety, and Environmental considerations</u>

a) This investigation does not have any environmental considerations.
b) Lab-coat must be worn at all times to safeguard against spillage of chemicals.
c) Gloves must be worn at all times during the titration process to avoid skin irritation from contact with phenolphthalein.
d) Preparation of NaOH solution from the NaOH crystals must be done with care to avoid burning sensation.
e) The vinegar pickle may leave a foul smell that may be considered unappetising or cause a puking sensation for some people. Facemask must be worn in that case.
f) Ethical consideration for the disposal of the vegetables after the pickling process is complete. Vegetables may be consumed if pickled properly.

## IX. <u>Raw Data Processing</u>

The objective of the data analysis is to identify the change in acetic acidic content of each brand of vinegar for each vegetable. The formula to do so is

$$Percentage\ of\ acetic\ acid = \frac{Mass\ of\ acetic\ acid\ in\ the\ vinegar}{Mass\ of\ vinegar} \times 100$$

The mass of vinegar is experimentally found using the Contech top pan balance, as described in the procedure. The mass of the acetic acid in vinegar and the concentration of the acetic acid are determined through the procedure by the following calculations:
(Note: All the following calculations are for trial 1 in *Table 5)*

*Table 2: Titration values for cucumber*

| Vegetable | Cucumber | | Volume of NaOH/$cm^3$ | | | |
|---|---|---|---|---|---|---|
| Brand Name | Mass of vinegar/g $\pm 0.001$ | Trial | Initial | Final | Change/$\pm 0.2 cm^3$ | Average |
| Sam's vinegar | 107.642 | 1 | 10.90 | 25.90 | 15.00 | 13.60 $\pm$ 1.4 |
| | | 2 | 1.60 | 13.80 | 12.20 | |
| | | 3 | 11.80 | 25.50 | 13.70 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Healthkart Vinegar | 102.095 | 1 | 25.40 | 30.50 | 5.10 | $6.00 \pm 1.1$ |
| | | 2 | 36.10 | 41.70 | 5.60 | |
| | | 3 | 0.00 | 7.20 | 7.20 | |
| Ching's chilli Vinegar | 104.765 | 1 | 24.00 | 31.10 | 6.10 | $5.90 \pm 1.4$ |
| | | 2 | 4.30 | 10.30 | 6.10 | |
| | | 3 | 11.50 | 15.90 | 4.40 | |
| Kalvert Foods Vinegar | 94.552 | 1 | 9.10 | 17.40 | 8.30 | $7.30 \pm 1.4$ |
| | | 2 | 23.40 | 29.00 | 5.60 | |
| | | 3 | 0.00 | 7.90 | 7.90 | |
| Sarwar Vinegar | 100.302 | 1 | 13.20 | 32.20 | 19.00 | $18.90 \pm 2.5$ |
| | | 2 | 2.50 | 23.90 | 21.40 | |
| | | 3 | 18.60 | 35.00 | 16.40 | |

*Table 3: Titration values for carrot*

| Vegetable | Carrot | | Volume of NaOH/$cm^3$ | | | |
|---|---|---|---|---|---|---|
| Brand Name | Mass of vinegar/g $\pm 0.001$ | Trial | Initial | Final | Change/$\pm 0.2 cm^3$ | Average |
| Sam's vinegar | 101.911 | 1 | 25.40 | 38.10 | 12.70 | $12.30 \pm 2.5$ |
| | | 2 | 38.10 | 25.40 | 9.70 | |
| | | 3 | 0.00 | 14.60 | 14.60 | |
| Healthkart Vinegar | 104.373 | 1 | 24.00 | 30.50 | 6.50 | $6.40 \pm 0.4$ |
| | | 2 | 30.50 | 36.40 | 5.90 | |
| | | 3 | 36.40 | 43.10 | 6.70 | |
| Ching's chilli Vinegar | 107.256 | 1 | 19.90 | 26.50 | 6.60 | $5.40 \pm 0.1$ |
| | | 2 | 26.50 | 31.20 | 4.70 | |
| | | 3 | 31.20 | 36.10 | 4.90 | |
| Kalvert Foods Vinegar | 93.273 | 1 | 0.00 | 7.20 | 7.20 | $6.20 \pm 0.8$ |
| | | 2 | 7.20 | 12.90 | 5.70 | |
| | | 3 | 12.90 | 18.60 | 5.70 | |
| Sarwar Vinegar | 99.241 | 1 | 0.00 | 19.70 | 10.70 | $16.60 \pm 3.6$ |
| | | 2 | 19.70 | 32.20 | 12.50 | |
| | | 3 | 0.80 | 18.30 | 17.50 | |

*Table 4: Titration values for Green chili*

| Vegetable | Green chilli | | Volume of NaOH/$cm^3$ | | | |
|---|---|---|---|---|---|---|
| Brand Name | Mass of vinegar/g $\pm 0.001$ | Trial | Initial | Final | Change/$\pm 0.1 cm^3$ | Average |
| Sam's vinegar | 104.774 | 1 | 0.40 | 13.60 | 13.20 | $13.90 \pm 0.1$ |
| | | 2 | 13.60 | 28.50 | 14.90 | |
| | | 3 | 28.50 | 42.00 | 13.50 | |
| Healthkart Vinegar | 105.430 | 1 | 0.00 | 10.40 | 10.40 | $8.50 \pm 1.7$ |
| | | 2 | 10.40 | 18.30 | 7.00 | |
| | | 3 | 18.30 | 27.40 | 9.10 | |
| Ching's chilli Vinegar | 103.350 | 1 | 0.00 | 5.80 | 5.80 | $6.40 \pm 1.4$ |
| | | 2 | 5.80 | 11.10 | 5.30 | |
| | | 3 | 11.10 | 19.20 | 8.10 | |
| Kalvert Foods Vinegar | 92.191 | 1 | 18.60 | 26.10 | 7.50 | $7.50 \pm 0.9$ |
| | | 2 | 26.10 | 34.50 | 8.40 | |
| | | 3 | 34.50 | 41.20 | 6.70 | |
| Sarwar Vinegar | 101.260 | 1 | 0.00 | 22.10 | 22.10 | $20.40 \pm 1.4$ |
| | | 2 | 22.10 | 41.90 | 19.80 | |
| | | 3 | 0.00 | 19.40 | 19.40 | |

**PART 1: Calculating the volume of Sodium Hydroxide used in the titration process:**

- The following segment of the table will be used to represent all the calculations, however, it is to be noted that these calculations apply to all the brands of vinegar used.

*Table 5: Titration values for trial*

| Vegetable | Green chilli | | Volume of NaOH/cm3 | | | |
|---|---|---|---|---|---|---|
| Brand Name | Mass of vinegar/g ±0.001 | Trial | Initial | Final | Change/±0.10cm3 | Average |
| Sam's vinegar | 104.774 | 1 | 0.40 | 13.60 | 13.20 | 13.90 ± 0.85 |
| | | 2 | 13.60 | 28.50 | 14.90 | |
| | | 3 | 28.50 | 42.00 | 13.50 | |

- The initial reading in the burette is denoted under the field 'Initial'. The final reading post the titration process is denoted by the column 'Final'. The change in the volume of the vinegar is given by the following formula:

$$Change\ in\ the\ volume\ of\ NaOH = Final\ reading - Initial\ reading$$
$$Change\ in\ the\ volume\ of\ NaOH = 13.60 - 0.40$$
$$Change\ in\ the\ volume\ of\ NaOH = 13.20\ cm^3$$

$$\Delta Change\ in\ the\ volume\ of\ NaOH = \Delta Final\ reading + \Delta Initial\ reading$$
$$\Delta Change\ in\ the\ volume\ of\ NaOH = 0.05 + 0.05$$
$$\Delta Change\ in\ the\ volume\ of\ NaOH = \pm 0.10$$

- This process is repeated for all the trials. The average change in volume Sodium Hydroxide solution is found using the following formula:

$$Average\ volume\ of\ NaOH\ Solution = \frac{Trial\ 1 + Trial\ 2 + Trial\ 3}{3}$$
$$Average\ change\ in\ volume\ of\ NaOH\ Solution = \frac{13.20 + 14.90 + 13.50}{3}$$
$$Average\ change\ in\ volume\ of\ NaOH\ Solution = 13.9cm^3$$
$$\Delta Average\ change\ in\ volume\ of\ NaOH\ Solution = \frac{Maximum - Minimum}{2}$$
$$\Delta Average\ change\ in\ volume\ of\ NaOH\ Solution = \frac{14.90 - 13.20}{2}$$
$$\Delta Average\ change\ in\ volume\ of\ NaOH\ Solution = \pm 0.85cm^3$$

**PART 2: Calculating the acidity content of acetic acid in the vinegar:**

- The reaction that occurs between NaOH and Acetic acid in the vinegar is as follows:

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

- The reactants, Sodium Hydroxide(aq) and Acetic acid, react to give the products of Sodium acetate and water. This is a neutralization reaction where Sodium Hydroxide is a standard solution. It can also be inferred that Acetic acid and Sodium Hydroxide are in a 1:1 ratio in the flask. Therefore the concentration can be followed by following the following method:

$$number\ of\ moles\ of\ NaOH(n_{Na}) = concentration\ of\ NaOH(c_{Na}) \times volume\ of\ NaOh\ consumed(v_{Na})$$
$$n_{Na} = 0.082 \times \frac{13.90}{1000}$$
$$n_{Na} = 1.139 \times 10^{-3} moles$$

- Since there is a 1:1 ratio between acetic acid and NaOH, they have equal number of moles

$$number\ of\ moles\ of\ Acetic\ acid(n_{AA}) = number\ of\ moles\ of\ NaOH(n_{Na})$$
$$n_{AA} = 1.139 \times 10^{-3} moles$$
$$\Delta n_{Na} = \left(\frac{\Delta c}{c} + \frac{\Delta v}{v}\right) \times n_{Na}$$

$$\Delta n_{Na} = \left(\frac{0.015}{0.082} + \frac{0.00085}{0.0139}\right) \times 1.139 \times 10^{-3}$$
$$\Delta n_{Na} = \pm 2.08 \times 10^{-4} moles$$

- In the procedure, the vinegar obtained from the beakers the pickling process was diluted by a 10 times factor. Moreover, this diluted vinegar was again diluted by a factor of 10 for obtaining the analyte for the titration process by taking 10 cm3 of the diluted solution. Hence the total amount of moles in the pickling beaker are

$$Total\ moles\ of\ acetic\ acid\ in\ the\ beaker\ (n_{AAf}) = n_{AA} \times 10 \times 10$$
$$n_{AAf} = 1.139 \times 10^{-3} moles \times 10 \times 10$$
$$n_{AAf} = 0.1139\ moles$$
$$\Delta n_{AAf} = \Delta n_{AA} \times 10 \times 10$$
$$\Delta n_{AAf} = \pm 0.0208\ moles$$

- In the formula, the first 10 multiplication accounts for the initial 1: 10 dilution and the other 10 multiplication is to account for the dilution that occurred due to the sample taken for titration.

- Now that the total moles of acetic acid in the beaker containing the pickled green chilli are known, the mass of the acetic acid can be found out. The following formula shows the method for doing so:

$$mass\ of\ acetic\ acid\ in\ the\ vinegar (m_{AA})$$
$$= \ Molar\ mass\ of\ acetic\ acid (60.05\ gmol^{-1}) \times n_{AAf}$$
$$m_{AA} = (12.01 \times 2 + 1.01 \times 4 + 15.99 \times 2) \times 0.1139$$
$$m_{AA} = 6.838g$$
$$\Delta m_{AA} = \Delta n_{AAf} \times 60.05$$
$$\Delta m_{AA} = \pm 1.249g$$

To calculate the percentage acidic content, the formula used earlier can be invoked:

$$Percentage\ of\ acetic\ acid = \frac{Mass\ of\ acetic\ acid\ in\ the\ vinegar}{Mass\ of\ vinegar} \times 100$$
$$Percentage\ of\ acetic\ acid = \frac{6.838}{104.774} \times 100$$
$$Percentage\ of\ acetic\ acid = 6.53\%$$
$$\Delta Percentage\ of\ acetic\ acid = \left(\frac{\Delta m_{AA}}{m_{AA}} + \frac{\Delta m_v}{m_v}\right) \times Percentage\ of\ acetic\ acid$$
$$\Delta Percentage\ of\ acetic\ acid = \left(\frac{1.249}{6.838} + \frac{0.001}{104.774}\right) \times 6.526$$
$$\Delta Percentage\ of\ acetic\ acid = \pm 1.19\%$$

  - (Note: this is not the percentage uncertainty in the acetic acid, rather, the uncertainty in the percentage itself).

*Table 6: Percentage of acetic acid in trials with cucumber calculations*

| Vegetable | Cucumber | | | |
|---|---|---|---|---|
| Brand Name | nAA/moles | nAAf /moles | mAA/g | Percentage/% |
| Sam's vinegar | $0.00112 \pm 2.05 \times 10^{-4}$ | $0.112 \pm 0.0204$ | $6.713 \pm 1.23$ | $6.23 \pm 1.14$ |
| Healthkart Vinegar | $0.000490 \pm 8.95 \times 10^{-4}$ | $0.0489 \pm 0.00895$ | $2.939 \pm 0.537$ | $2.72 \pm 0.44$ |
| Ching's chilli Vinegar | $0.00048 \pm 8.81 \times 10^{-4}$ | $0.0481 \pm 0.00881$ | $2.889 \pm 0.528$ | $2.68 \pm 0.49$ |
| Kalvert Foods Vinegar | $0.00060 \pm 1.90 \times 10^{-4}$ | $0.0595 \pm 0.0190$ | $3.578 \pm 0.654$ | $3.32 \pm 0.60$ |
| Sarwar Vinegar | $0.00155 \pm 2.84 \times 10^{-4}$ | $0.1553 \pm 0.0284$ | $9.323 \pm 1.71$ | $8.66 \pm 1.58$ |

*Table 7: Percentage of acetic acid in trials with carrot calculations*

| Vegetable Brand Name | Carrot $n_{AA}$/moles | $n_{AAf}$ /moles | $m_{AA}$/g | Percentage/% |
|---|---|---|---|---|
| Sam's vinegar | $0.00101 \pm 1.85 \times 10^{-4}$ | $0.101 \pm 0.0185$ | $6.073 \pm 1.119$ | $3.57 \pm 0.65$ |
| Healthkart Vinegar | $0.000520 \pm 9.5 \times 10^{-4}$ | $0.0521 \pm 0.0095$ | $3.135 \pm 0.573$ | $1.84 \pm 0.33$ |
| Ching's chilli Vinegar | $0.000445 \pm 8.1 \times 10^{-4}$ | $0.0442 \pm 0.00810$ | $2.659 \pm 0.486$ | $1.56 \pm 0.28$ |
| Kalvert Foods Vinegar | $0.000510 \pm 0.93 \times 10^{-4}$ | $0.0508 \pm 0.0930$ | $3.053 \pm 0.558$ | $1.79 \pm 0.32$ |
| Sarwar Vinegar | $0.00136 \pm 2.48 \times 10^{-4}$ | $0.135 \pm 0.0248$ | $8.158 \pm 1.496$ | $4.79 \pm 0.87$ |

*Table 8: Percentage of acetic acid in trials with green chili calculations*

| Vegetable Brand Name | Green chilli $n_{AA}$/moles | $n_{AAf}$ /moles | $m_{AA}$/g | Percentage/% |
|---|---|---|---|---|
| Sam's vinegar | $0.00114 \pm 2.08 \times 10^{-4}$ | $0.114 \pm 0.0208$ | $6.828 \pm 1.08$ | $6.52 \pm 1.19$ |
| Healthkart Vinegar | $0.000694 \pm 1.27 \times 10^{-4}$ | $0.0694 \pm 0.0127$ | $4.169 \pm 0.867$ | $3.98 \pm 0.57$ |
| Ching's chilli Vinegar | $0.000525 \pm 0.96 \times 10^{-4}$ | $0.0525 \pm 0.0960$ | $3.151 \pm 0.418$ | $3.01 \pm 0.79$ |
| Kalvert Foods Vinegar | $0.000618 \pm 1.13 \times 10^{-4}$ | $0.0618 \pm 0.0130$ | $3.708 \pm 0.244$ | $3.54 \pm 0.61$ |
| Sarwar Vinegar | $0.00167 \pm 3.06 \times 10^{-4}$ | $0.187 \pm 0.0306$ | $10.063 \pm 0.901$ | $9.60 \pm 1.67$ |

## X. Evaluation:

### PART 1: Graphical analysis

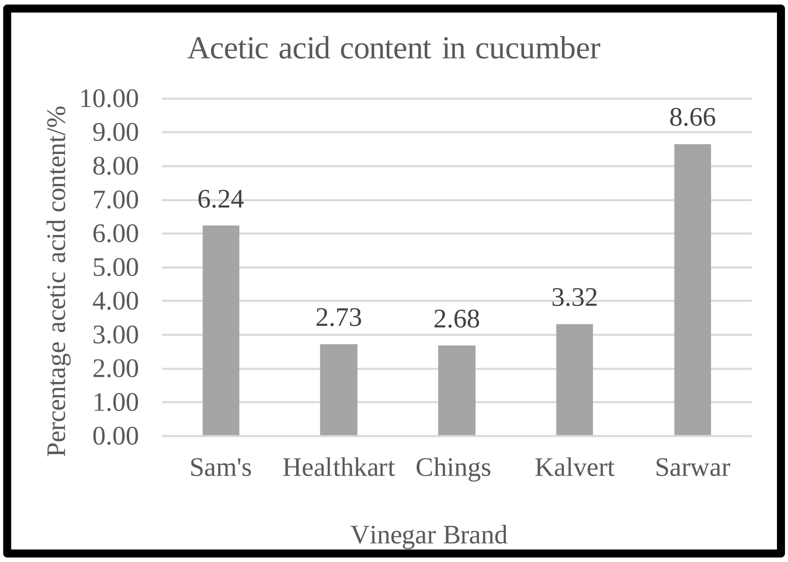


*Figure 6: Graph of acetic acid content in cucumber*

*Table 9: Percentage change in acetic acid content for cucumber*

| Vegetable Vinegar brand | Cucumber Percentage change in acetic acid content |
|---|---|
| Sam's | 30.70 |
| Healthkart | 45.40 |
| Ching's | 32.90 |
| Kalvert | 33.50 |
| Sarwar | 42.30 |

*Table 10: Percentage change in acetic acid content for carrot*

| Vegetable Vinegar brand | Carrot Percentage change in acetic acid content/% |
|---|---|
| Sam's | 60.30 |
| Healthkart | 63.10 |
| Ching's | 60.90 |
| Kalvert | 64.10 |
| Sarwar | 68.00 |

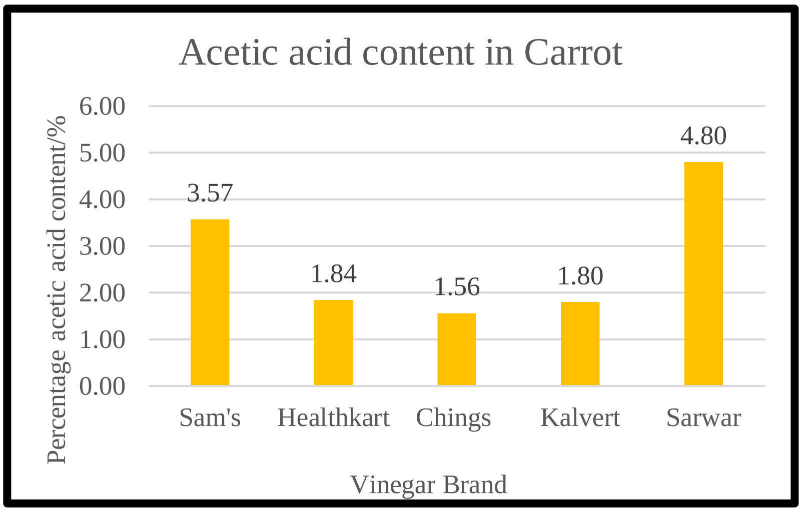


*Figure 7: Graph of acetic acid content in carrot*

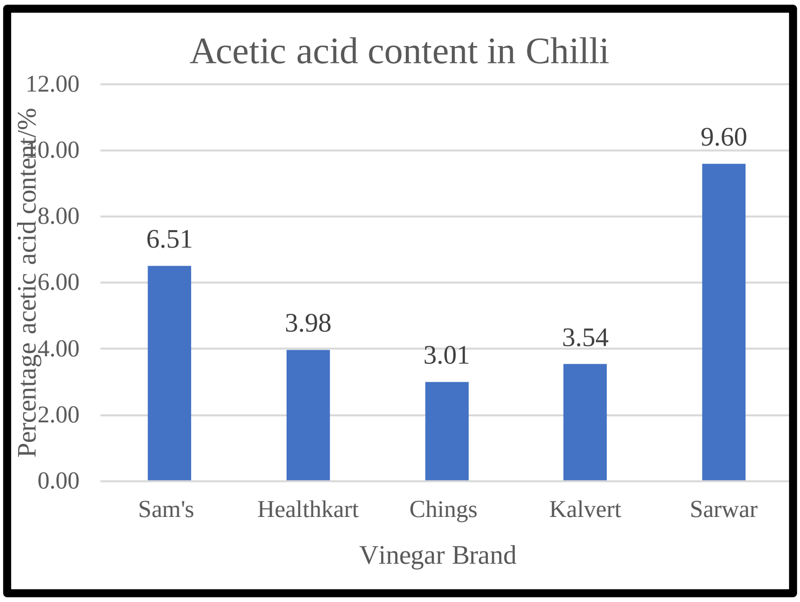


*Table 11: Percentage change in acetic acid content for green chili*

| Vegetable Vinegar brand | Green Chilli Percentage change in acetic acid content/% |
|---|---|
| Sam’s | 27.60 |
| Healthkart | 20.50 |
| Ching’s | 24.90 |
| Kalvert | 29.20 |
| Sarwar | 36.00 |

*Figure 8: Graph of acetic acid content in green chili*

Using *Figure 7, 8, 9*, and *Table 9, 10, 11*, the change in acetic acid for different brands of vinegar pickled with different vegetables can be identified.
It can be observed that Sarwar’s vinegar manages to retain the maximum acetic acid content post the 3-day pickling process for all three vegetables. This could be attributed to the fact that the brand started off with the maximum percentage vinegar content, 15%. This result shows that the vegetables are unable to absorb the acetic acid beyond a certain threshold in the amount of time they were pickled. It is also important to note that Sarwar vinegar showed the largest changes in percentage change in acetic acid content among the vegetables explored, shown in *Table 9, 10, 11*. The abundance of acetic acid in Sarwar’s vinegar in the pickling beakers led to Sarwar’s vinegar being absorbed the most proportionately.

Similarly, Sam’s vinegar was another brand of vinegar that managed to retain the acidic content to an amount that was significant enough, in some cases, to reconsider the vinegar for another pickling session, initial 9% acetic acid content. Another noteworthy aspect of this brand was that it consistently got the smallest percentage change in the acetic acid content for all the vegetables.

The other vinegar brands did not retain enough acetic acid content to be of use for the purpose of this investigation. Healthkart, Ching’s, and Kalvert foods vinegars‘ acetic acid content dropped below the 5% threshold value for safe reuse for pickling. However, it is important to note that these brands had the lowest initial value of acetic acid, nearly 5% for all 3 brands, and they experienced smaller acetic acid drop quantitively as compared to both Sarwar and Sam’s vinegar.

By referring to *Figure 6 and Table 9*, the results for cucumber can be analyzed. The change in the acetic acid content can be attributed to the presence of ascorbic acid and caffeic acid, which prevent water retention. The constant fluid exchange of the cucumber with the vinegar enables the cucumber to better absorb more acetic acid for a better preservation purpose to lower the content remaining in the vinegar.

It can be inferred from *Figure 7*, and *Table 10* that the percentage drop in acetic acid content was maximum for the carrot than any the vegetable. The reason for this is that in the procedure, the carrot was cut and placed in the beaker. Because the vinegar was exposed to the inside of the carrot, a greater proportion of acetic acid was absorbed by the carrot, which led a larger drop in the percentage content for all the brands tested. Moreover, carrots also contain caffeic acid, so this acid may serve the same function as it did for the cucumber.

*Figure 8* and *Table 11*, illustrate the results for the green chili. The green chili saw the smallest percentage change in acetic acid content compared to the other vegetables. The reason for this can be that green chili contains capsaicin acid, which may enter the vinegar over a period of 3 days and boost the acidic content, or lower the pH. This may lead to higher acidic content and influence the titration results as the acid content may not be of the acetic acid but the vegetable's own acid.

Based on the results obtained, it can be concluded that Sarwar's vinegar is the most useful for reusing for the pickling process, as this brand manages to retain the greatest acidity content among its competitors, however, it is important to note that it also has the largest acetic acid content initially. Therefore, the optimum vinegar brand can be Sam's vinegar, since, this brand experienced the smallest percentage change in the ethanoic acid content for all the vegetables. In some cases, Sam's vinegar managed to retain a higher percentage content of vinegar, then the threshold of reusability, 5%. Although, the rest of the brands managed to keep the vegetables in the investigation fresh, they may not be able to sustain this freshness in the long term.

**PART 2: Limitations, Improvements, errors**

⇒ In the titration process error could be developed if the burette is not viewed at a 90˚ angle while taking the measurement of the NaOH solution within. This will lead to an experimentally random error: parallax error. The readings from the burette are often difficult to judge based on the markings by human perceptions. Due to the readings obtained may be inaccurate. An improvement can be made by taking the reading on the lower meniscus.

⇒ While measuring the mass of the vinegar, care must be taken so that the top pan balance can been calibrated to 0g in order to avoid a systematic error, Zero error. Such an error will lead to an inaccurate result.

⇒ The vegetables used for the pickling process contain significant amounts of acid in them which may influence the titration process and exaggerate the acidic content of the vinegar brands due to the presence of multiple sources of acid. The acid present in cucumber and carrot is caffeic acid; the acid active in green chili is capsaicin acid. Because of the osmosis process, acid from the vegetable may get transferred to the vinegar and increase its acidity content to make the titration values inaccurate.

⇒ This presence of vegetable acidic content is ignored in the investigation and may be a relatively big source of error in the methodology.[10] [11] [12]

⇒ Although external environment conditions like, light intensity, temperature, moisture in the air were kept constant by shutting the windows and doors, some variation in them may influence the obtained titration values. Because the procedure demand longer time interval, 3 days for the pickling process, fluctuations in the mentioned factors may alter the contents of the vinegar and lead to inaccurate findings. This is particularly important as some of the indicators are light and temperature sensitive and only operate well under a certain range. To minimize the impact of this error, trials were taken at similar times in the day and 3 trials were taken to eliminate any such random error effect.

⇒ In the pickling process, the vegetables were partially dipped in the vinegar pickle. The extent of exposure of the vegetable to the vinegar will depend on the surface area of the vegetable that is in contact with the vinegar and will be likely in influencing the change in acidic content due to the osmosis process. The vegetables were strategically selected based on their shapes and sizes so that they were comparable, however, none of the vegetables were identical in terms of their surface area and volume so that perfect comparisons can be drawn. This leads to imprecise data within the measurements made for a vegetable and leads to a systematic error.

⇒ Each of the bottles of vinegar had different manufacturing dates, which could affect the results obtained. While some of the vinegar bottles were manufactured in 2020 itself, others were made in

10 Chillimaster, and Name *. "Are Chillies Acidic or Alkaline." Origin of Chilli. Accessed January 27, 2020. https://originofchilli.com/are-chillies-acidic-or-alkaline/. Accessed 27/01/20

11 "Cucumber Nutrition: Amazing Cucumber Nutritional Facts And Health Benefits." NDTV Food, June 4, 2018. https://food.ndtv.com/food-drinks/cucumber-nutrition-amazing-cucumber-nutritional-facts-and-health-benefits-1862266. Accessed 27/01/20

12 Sharma, Krishan Datt, Swati Karki, Narayan Singh Thakur, and Surekha Attri. "Chemical Composition, Functional Properties and Processing of Carrot-a Review." Journal of food science and technology. Springer-Verlag, February 2012. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3550877/. Accessed 27/01/20

latter part of 2019. The variation in the manufacturing dates can lead to the mentioned acetic acidic content on the ingredients of the vinegar bottles to be inaccurate and cause a systematic error, whereby, all the readings for the acid content for a brand to be changed.

⇒ There are several random and systematic errors that can be associated to the titration process. Because of human limitations, an error can be made in identifying the point equivalence during the titration process as the color may be misjudged near the endpoint. Because different people have different sensitivity to color, the endpoint may become subjective person to person. Improper rinsing of equipment, dirty glassware, air bubbles in the burette are all sources of random error that may disrupt accurate findings in the investigation. To resolve these errors, a titration curve may be plotted for every data point to enhance the methodology by calculating the endpoint accurately through the graphical representation. However, this was not done due to the large number of trials in the procedure.

⇒ There were no theoretical values that could be compared to for this investigation as there was no published literature that was based on investigating on similar lines. This leaves the data unvalidated and proper authentication for the values obtained remains unfulfilled

⇒ Limitations of the available resources in the laboratory has led to some assumptions such as constant acidic content in the vegetables, accurate acetic acid content as mentioned on the label of the vinegar bottle, constant atmospheric conditions, equivalent surface area exposure of the vegetables to all the vinegar brands in the pickling beaker. If any of these assumptions had a significant impact on the investigations, results would show awkward results. Since this variation was not witnessed, it can be inferred that the values obtained were at an acceptable degree.

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