# Investigation of the relationship between temperature and the degradation of Ascorbic acid in tomatoes using Redox Titration

## Introduction

Ascorbic acid, popularly known as Vitamin C[1], is a vital nutrient of various fruits and vegetables that we eat regularly in our daily lives. Its benefits to the human body are immense, ranging from preventing deficiency diseases like scurvy to stimulating our overall immune system. In more specific terms, ascorbic acid acts as an antioxidant that is particularly useful because it binds and neutralizes unstable free radicals produced in our body during metabolic reactions or acquired from the pollution in our environment. Additionally, it also boosts collagen synthesis, which is an essential protein that accelerates the growth and repair of gums, bones and tissues in our body.

During this year in lock-down, I spent a significant amount of my time assisting my parents in cooking our meals without the support of any domestic help or cook. I soon learned the detailed steps of preparing and cooking my favourite traditional Indian curries and lentil-based dishes. Interestingly, sliced tomatoes [2] were used extensively in the preparation of the spice blend. When heated through various cooking methods such as boiling, blanching and slow cooking, they added a degree of sourness (acidity) to the curry, which enhanced its taste and aroma. Seeing the large number of tomatoes being used during all 3 meals of the day (3-6 tomatoes for one dish), I was curious to investigate how the tomatoes' nutritional content was affected when subjected to heat.

The recommended daily intake of Vitamin C by Government health organizations (e.g., NIH) ranges from 75-90 mg. A revealing research study [3]on the PubMed database of the National Centre for Biotechnology Information (USA) concluded that the age, sex, and standardized season prevalence of vitamin C deficiency was 73.9% for ages 60 and over in India. Such a research investigation provided further impetus for me to **investigate how does the cooking temperature affects the thermal degradation of Ascorbic acid in freshly extracted tomato juice?** Hence, I also aim to figure out at what temperature the cooking process needs to be carried out to have maximum health benefits and Vitamin C retention.

## Background

Vitamin C refers to the chemical compound Ascorbic acid with the formula $\mathbf{C_8H_8O_6}$. Ascorbic acid is soluble in water because it has hydroxyl functional groups (OH) that readily form hydrogen bonds with the water molecules. This releases energy that pays back the requirement to break the intermolecular forces within the ascorbic acid and water molecules, resulting in dissolvement of ascorbic acid in water. For our investigation, another important property of ascorbic acid is its antioxidant behaviour, due to which it takes the role of reducing agent in reactions and it is itself easily oxidized in the presence of oxygen or free radicals (eg: hydroxyl radical) to form a more stable state of dehydroascorbic acid by the loss of 2 electrons.

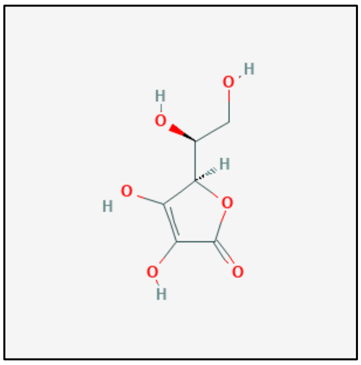


*Figure 1- Ascorbic Acid Structural Formula*

[1] https://pubchem.ncbi.nlm.nih.gov/compound/Ascorbic-acid
[2] https://economictimes.indiatimes.com/indias-affair-with-tomatoes/articleshow/6528342.cms?from=mdr
[3]https://pubmed.ncbi.nlm.nih.gov/22163038/#:~:text=Results%3A%20The%20age%2C%20sex%20and,the%20criteria%20for%20adequate%20levels.

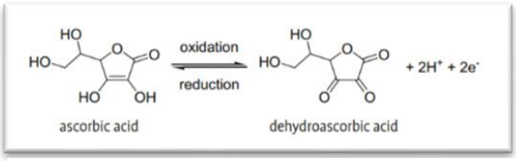



*Figure 2- ascorbic acid simplified reaction*

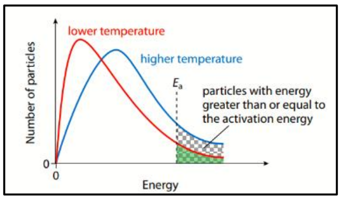



*Figure 3- Maxwell–Boltzmann distribution curve*

$C_8H_8O_6(aq) \rightleftharpoons C_6H_6O_6(aq) + 2H^+(aq) + 2e^-$ - **Reaction 1**

Evidently, at higher temperatures, the average kinetic energy of the ascorbic acid molecules will increase, allowing more successful collisions which rapidly increase the rate at which intermolecular forces within the ascorbic acid break to donate electrons (nucleophile). This makes ascorbic acid oxidation highly sensitive to heat which is why it is degraded at elevated temperatures.

Using this knowledge, we can devise redox titration with potassium iodate as the titrant for the determination of ascorbic acid concentration in our freshly extracted tomato solution with additional regents such as potassium iodide, HCl and starch indicator solution. This is an established titration method through which we can find the ascorbic acid concentration in our unknown analyte to a reasonable number of significant figures. Since ascorbic acid is readily oxidised and there are additional acidic compounds in tomatoes, an oxidation-reduction titration is more reliable compared with an acid-base-titration.

The individual ionic half oxidation and reduction reactions can be combined to get the full equation for the reaction.

1) Firstly, the Iodate ions from Potassium Iodate solution are reduced to form iodine

$2KIO_3^-(aq) + 12H^+(aq) + 10e^- \longrightarrow I_2(s) + 6H_2O\,(l)$

2) Meanwhile the Iodide ions from Potassium Iodide solution are oxidised to form iodine

$10I^-(aq) \longrightarrow 5I_2(aq) + 10e^-$

3) We can combine these Ionic Half-equations to form the complete Redox reaction

$2KIO_3^-(aq) + 10I^-(aq) + 12H^+(aq) \longrightarrow 6I_2(aq) + 6H_2O\,(l)$ **Reaction 2**

4) The iodine formed in this reaction oxidises the ascorbic acid in 1:1 molar ratio to its more stable form of dehydroascorbic acid and it is itself reduced to two iodide ions

$C_8H_8O_6(aq) + I_2\,(s) \longrightarrow C_6H_6O_6(aq) + 2I^-(aq) + 2H^+\,(aq)$ **Reaction 3**

1) Once all the iodine is reacted with ascorbic acid, the excess iodine will react with the starch solution indicator to form a dark blue starch iodine complex which will indicate the endpoint in the titration.

My dependant variable is the Vitamin C concentration. We can use the titre volume of $KIO_3$ to calculate the number of moles which we then use to calculate the number of moles of $I_2$ using the molar ratio of 1:3 in Reaction 2. Finally, we can use the molar ratio of 1:1 in Reaction 3 to find the ascorbic acid concentration

## Research Question

How does the cooking temperature affect the thermal degradation of Ascorbic Acid in freshly extracted tomato juice?

## Hypothesis

Since ascorbic acid is a water-soluble compound that is readily oxidised to form a dehydroascorbic acid, we can predict that as the temperature of the reaction increases, according to kinetic molecular theory, the rate of the reaction will increase. Hence as temperature is raised, the concentration of ascorbic acid will decrease linearly showing an inverse relationship. Due to this prediction, our average titre volume of potassium iodate required to reach the endpoint of titration should decrease with increase in temperature

## Variables

A) **Independent Variable:** Temperature ($℃ \pm 0.05$) Celsius - 20.00, 35.00, 45.00, 55.00, 65.00, 75.00. These temperatures mimic the range used during heating of spice blends. A water bath will be used to heat the tomato sample

B) **Dependant Variable** - Ascorbic acid (Vitamin C) concentration in tomato sample ($moldm^{-3}$) will finally be expressed in terms of standard food content units (mg per 100ml). Determined using Redox Titration outlined in the background. Consequently, stoichiometric calculations are executed according to redox reactions in the background.

**C. Control Variables**

| **Control Variables** | **Reason for Control** | **Method of Control** |
|---|---|---|
| Type and Condition of Tomato | Different types of tomato such as green and cherry tomatoes have different ripening and initial concentration of ascorbic acid resulting in an unfair and unreliable analysis | I bought a package of fully ripe red tomatoes freshly cultivated at a small farm close to my home. With the farmer, I ensured that they all had the same appearance, ripening stage and foliage. This was the best control measure I could implement. |
| Surrounding conditions (availability of oxygen, sunlight and room temperature) | External factors such as the change in the room temperature, change in sunlight exposure will accelerate the oxidation of ascorbic acid unpredictably, resulting in unreliable results as the initial ascorbic acid could fluctuate. | the experiment was conducted in the same room and temperature was measured to be between 20.00-21.00℃. The experiment was conducted in the same position from the window ensuring the light intensity was controlled. |
| Storage conditions before experiment is conducted | The oxidation of ascorbic acid is an ongoing process stimulated by the surrounding environmental factors | Experiment is conducted the same day that the tomatoes are bought to minimise the effects of degradation. All the tomatoes are stored in an empty container before experiment. |
| **Control Variables During Titration** | **Reason for Control** | **Method of Control** |
| Concentration of Potassium Iodate Solution ($KIO_3$) | In order to get comparable readings at each temperature, we can't change concentration because that affects the number of moles reacted during the titration calculations will be changed for each trial | 0.001 $moldm^{-3}$ solution is prepared. A preliminary standardization of potassium iodate solution is conducted with a known concentration of ascorbic acid powder to validate that concentration is within $\pm 0.00005$ of the intended concentration |

| Control Variables During Titration (continued) | Reason for Control | Method of Control |
|---|---|---|
| Concentration of Potassium Iodide Solution ($KI$) | Increasing the concentration of a reactant will increase the number of reactant particles so there will be more successful collision which increases the rate of the reaction. In this case, the number of iodide ions oxidised to iodine will be affected giving inaccurate results when calculating the final concentration of ascorbic acid left. | 0.3 $moldm^{-3}$ solution is prepared by the experimental procedure. Each trial uses $5cm^3$ of KI to contain the same number of moles. |
| Volume of Starch Indicator Solution | A larger volume will cause the starch molecules to interfere in the reaction uncontrollably with the iodine molecules and result in unreliable measure of the endpoint of the reaction as the colour change may happen earlier. | A 0.5 % solution is prepared. Each trial uses $2.5cm^3$. To maintain a fair comparison the persistence of the endpoint colour for 15 seconds is maintained for all trials |
| Volume of Hydrochloric Acid | The reduction of iodate ions to iodide requires a mild acidic environment. If the volume of HCl is changed this will result in unreliable calculation of the final ascorbic acid concentration | A 1 mol $dm^{-3}$ is prepared specified below. Each trial uses 5.0 $cm^3$ |
| Aliquot Volume of Tomato sample for each reading | The initial number of moles of ascorbic acid will vary at different volumes of the sample tomato solution giving inaccurate titre volumes | Once 100 $cm^3$ of tomatoes solution is prepared in a volumetric flask, it is separated into 25 $cm^3$ aliquot samples for more trials. |
| Volume of distilled water | If the volume of distilled water used is changed, the initial coloration of the sample will vary, making it difficult to interpret when the endpoint happens. Also, it will affect the dilution of the reagents in the sample giving unreliable results. | 25 $cm^3$ of distilled water will be added to each sample as measured from the measuring cylinder |

**Table 1: Control Variables**

## Apparatus and Materials

| Measurement Apparatus | Specifications | Quantity |
|---|---|---|
| Thermometer | Least count – 0.1℃, Uncertainty- $\pm$0.05℃ | 1 |
| 10 and 100 $cm^3$ Measuring Cylinders | Least count – $0.1cm^3$, Uncertainty- $\pm 0.05cm^3$ | 2 each |
| Burette | Least count – $0.1cm^3$, Uncertainty- $\pm 0.05cm^3$ | 1 |
| Digital Weighing Balance | Least count – 0.001g, Uncertainty- $\pm$0.001g | 1 |
| 100, 150 and 500$\text{cm}^3$ Volumetric Flasks | Least count –100, 150 and 500$\text{cm}^3$ graduated mark Uncertainty- $\pm 0.02cm^3$ | 2 each |
| Pipette (20$\text{cm}^3$) | - | 3 |
| Spatula | - | 1 |
| 250 $cm^3$ Conical Flask | - | 1 |

**Table 2: Apparatus and Specifications**

| Materials | Specifications |
|---|---|
| Potassium Iodate Solution ($KIO_3$) | 0.001 $moldm^{-3}$ prepared in 0.5 $dm^3$ of distilled water |
| Potassium Iodide Solation (KI) | 0.3 $moldm^{-3}$ prepared in 0.15 $dm^3$ of distilled water |
| Dilute Hydrochloric Acid | 1 $moldm^{-3}$ |
| Starch Indicator Solution | 0.5% concentration |
| Kitchen Knife | Serrated knife |
| Mortar and Pestle | Obtained from home kitchen |
| Cheesecloth | Obtained from home kitchen |

**Table 3: Materials and Specifications**

## Method of Experiment

*Preparation of Standard Solutions and tomato sample (University of Canterbury – methodology modified as per required concentrations) – molar masses of elements taken from NCERT (***Preliminary – Rinse all equipment with distilled water)**

A) **Potassium Iodate Solution ($KIO_3$) – 0.001 $moldm^{-3}$ prepared in 0.5 $dm^3$ of distilled water**

1. $M_r(KIO_3)$ = 39.10 + 126.90 + 3 (16.00) = 214.00 $gmol^{-1}$
2. $Number\ of\ moles(mol) = \frac{Mass\ of\ Sample(g)}{M_r(gmol^{-1})} = \frac{0.107g}{214.00\ gmol^{-1}} = 0.0005mol$
3. $Concentration\ (moldm^{-3}) = \frac{Number\ of\ moles\ (mol)}{Volume\ (dm^3)} = \frac{0.0005mol}{0.5\ dm^3} = 0.001\ moldm^{-3}$
4. Day Before – dry 1 gram of $KIO_3$ at 100℃ for several hours and then allow to cool (with the support of laboratory assistant at school)
5. Using a spatula measure 0.107g ($\pm 0.001g$) on the digital weighing scale using filter paper with correct calibration
6. Add measured quantity into 0.5 $dm^3$ volumetric flask and consequently add of distilled water
7. Simultaneously swirl the flask until the powder is completely dissolved and continue adding distilled water
8. Finish Pouring distilled water until the 0.5 $dm^3$ mark on the volumetric flask, ensuring you are reading from bottom of the curved meniscus.

B) **Potassium Iodide Solution ($KI$) – 0.3 $moldm^3$ prepared in 0.150 $dm^3$ of distilled water**

1. $M_r(KI)$ = 39.10 + 126.90 = 166.00 $gmol^{-1}$
2. $Number\ of\ moles(mol) = \frac{Mass\ of\ Sample(g)}{M_r(gmol^{-1})} = \frac{7.470\ g}{166.00\ gmol^{-1}} = 0.045mol$
3. $Concentration\ (moldm^{-3}) = \frac{Number\ of\ moles\ (mol)}{Volume\ (dm^3)} = \frac{0.045\ mol}{0.15\ dm^3} = 0.30\ moldm^{-3}$
4. Using a spatula measure 7.470g ($\pm 0.001g$) on the digital weighing scale using filter paper with correct calibration
5. Add measured quantity into 0.15 $dm^3$volumetric flask and consequently add of distilled water
6. Simultaneously swirl the flask until the powder is completely dissolved and continue adding distilled water
7. Finish Pouring distilled water until the 0.150 $dm^3$ mark on the volumetric flask, ensuring you are reading from bottom of the curved meniscus

**C) Starch Indicator Solution (0.5%)**

1. 0.250g of Soluble Starch measured using digital weighing scale and added to $50cm^3$ of distilled water near boiling temperature in $100cm^3$ Volumetric Flask
2. Volumetric flask filled to $100cm^3$ mark

**D) Hydrochloric Acid of concentration 1 $\mathbf{moldm^{-3}}$ obtained from laboratory**

## Preparation of Tomato Sample

In order to keep the measurements for different temperatures comparable, the same identical technique of washing, extracting and preparing the tomato solution will be executed. the individual steps are discussed in detail in the procedure section below

1. Tomato is washed and rinsed thoroughly in plenty of distilled water to remove any unwanted chemicals and contamination
2. Using a kitchen knife, the tomato is cut into small pieces and segregated until 100.000 grams quantity is measured on digital weighing balance
3. The 100.000 g sample is put inside the mortar obtained from home and using a pestle, the sample is slowly pressed and grinded.
4. During the grinding process, regularly add measurements of $10\text{cm}^3$ of distilled water followed by decanting of the sample using a cheesecloth to remove the pulp and seeds leaving only the filtrate to pass through into a volumetric flask
5. When all the filtrate has been collected from the tomatoes, add distilled water up to the mark in the $100\text{cm}^3$ volumetric flask
6. Proceed to execute the iodometric titration

## Method of Redox Iodometric Titration

1. Pour the prepared $\boldsymbol{KIO_3}$ solution from **A** into the cleansed burette, held on clamp stand, filling up to the 0 $\text{cm}^3$ mark.
2. Using a measuring cylinder, measure 25 $\text{cm}^3$ of the standard tomato solution from the volumetric flask and pour it into the 250 $\text{cm}^3$ conical flask
3. Using a measuring cylinder add $5\text{cm}^3$ of KI from **B**, $2\text{cm}^3$ of Starch Indicator Solution from **C**, 5 $\text{cm}^3$ of HCl from **D** and 25 $\text{cm}^3$ distilled water into the conical flask
4. Gently mix the solutions and place on top of white tile and beneath the burette
5. Titrate the sample against $\boldsymbol{KIO_3}$ drop by drop**,** qualitatively observing for the colour change
6. The initial light red-pink colour slowly shifts until it achieves a dark black colour representative of the endpoint for the redox reaction. (see figure 3,4 in qualitative observation section)
7. Note down the titre volume for the titration
8. Repeat Step A-G for trial 2,3,4,5 at 25℃ Celsius
9. For titrations trials 1-5 at 35, 45, 55, 65, 75 ℃, complete steps 1-2 and then heat the solution in the conical flask to the desired temperature using a water bath and a thermometer. Once the temperature is achieved, quickly complete steps 3-7. For every temperature 5 trials were conducted to reduce random error and the tomato sample was prepared when the previous batch was used.

## Risk Assessment – Safety and Environmental Precautions

| Safety and Environmental Precautions | Significance |
|---|---|
| Wearing protective lab coat, safety goggles and heat-resistant gloves, mask during the duration of the full experiment when handling all solutions and executing the titration. | Starch Indicator Solution may come in contact with skin or eyes to cause mild irritation and on inhalation can cause respiratory tract irritation. |
| | Potassium Iodide and Iodate dust may be harmful to respiratory tract if inhaled during handling the powder. (iodine compounds can stain both clothes and skin so proper care is advised) |
| | HCl is hazardous liquid that is corrosive to body tissues and moderately toxic when ingested. Must be handled with extreme scale |
| | Test tubes at high temperature can burn skin and pose a serious injury if dropped by accident |
| Using left over tomato residue for compost to be used later at home | Due to the large amount of tomato residue gathered, it's not ethical to dispose of it without consideration of its benefits as a compost to enrich soil. |
| Glassware is handled with extreme care and vigilance | Broken glass apparatus can cause serious pose a serious risk of injury or accident |
| Knife is used in the presence of teacher supervisor | Using the knife in an incorrect manner can be very dangerous to your skin and body and can result in accident if not operated carefully |

**Table 4: Risk Assessment for Experiment**

Using these molar ratios from the redox reaction equations we can calculate the final ascorbic acid concentration at the chosen temperatures using the standard formulas. The sample calculations are elaborated in detail underneath each table for the final ascorbic acid concentration at 20 Celsius.

*Figure 2- Initial Sample colour*

## Data Collection

## Qualitative Observations

**1.** Due to the initial pale red coloration of the tomato sample. It was difficult to identify the accurate endpoint of the redox titration. The colour changed from pale red to a darker red and then finally it to turned brown-black.  In order to familiarize with this change, I had conducted a rough titration at the beginning.

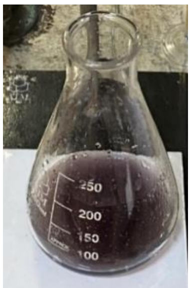



*Figure 3- Titration End point colour*

**2.** The room temperature fluctuated between 20-21℃ as the experiment was conducted in the winter months

**3.** When heating the tomato sample to a given temperature, final measurement at which it the sample was removed was not always accurate. For eg: it was 47.30 ℃ for 45.00℃ , 78.50℃  for 75.00 ℃. This can be attributed as systematic error in the experiment propagated by a human error (delay in removing sample from water bath)

4. The rate of stirring was manually done by hand so it was impossible to keep it controlled.

## Quantitative Data (Raw and Processed Data)

| Temperature $(T \pm 0.05)°Celcius$ | Volume of Potassium Iodate solution $(V \pm 0.05) cm^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | | Trial 2 | | Trial 3 | | Trial 4 | | Trail 5 | |
| | Start | End | Start | End | Start | End | Start | End | Start | End |
| 25.00 | 0.00 | 10.30 | 0.00 | 10.50 | 0.00 | 10.20 | 0.00 | 10.70 | 0.00 | 10.60 |
| 35.00 | 0.00 | 9.50 | 0.00 | 9.60 | 0.00 | 9.70 | 0.00 | 9.20 | 0.00 | 9.40 |
| 45.00 | 0.00 | 7.80 | 0.00 | 7.60 | 0.00 | 7.80 | 0.00 | 7.20 | 0.00 | 8.10 |
| 55.00 | 0.00 | 6.80 | 0.00 | 6.50 | 0.00 | 6.70 | 0.00 | 6.40 | 0.00 | 5.70 |
| 65.00 | 0.00 | 4.70 | 0.00 | 4.30 | 0.00 | 4.90 | 0.00 | 5.20 | 0.00 | 5.10 |
| 75.00 | 0.00 | 2.20 | 0.00 | 2.00 | 0.00 | 2.60 | 0.00 | 3.30 | 0.00 | 3.00 |

**Table 5: Raw Data- Start and End Volume of Potassium Iodate for each Temperature**

| Temperature $(T \pm 0.05)°Celcius$ | Average Titre Volume of Potassium Iodate used $(V \pm 0.0001) dm^3$ | Number of moles of Potassium Iodate (mol) | Number of moles of Iodine (mol) | Number of moles of Ascorbic acid (mol) |
|---|---|---|---|---|
| 20.00 | 0.0105 | $1.05 \times 10^{-5}$ | $3.15 \times 10^{-5}$ | $3.15 \times 10^{-5}$ |
| 35.00 | 0.0095 | $9.5 \times 10^{-6}$ | $2.85 \times 10^{-5}$ | $2.85 \times 10^{-5}$ |
| 45.00 | 0.0077 | $7.7 \times 10^{-6}$ | $2.31 \times 10^{-5}$ | $2.31 \times 10^{-5}$ |
| 55.00 | 0.0064 | $6.4 \times 10^{-6}$ | $1.92 \times 10^{-5}$ | $1.92 \times 10^{-5}$ |
| 65.00 | 0.0048 | $4.8 \times 10^{-6}$ | 1.44 x$10^{-5}$ | 1.44 x$10^{-5}$ |
| 75.00 | 0.0026 | $2.6 \times 10^{-6}$ | 7.80 x $10^{-6}$ | 7.80 x $10^{-6}$ |

**Table 6: Processed Data - Calculated values for number of moles of Potassium Iodate, Iodine and Ascorbic acid based on reaction 2 and 3 and average titre volume of Potassium Iodate**

## Stoichiometric Ratios and Formulas

**Molar Ratios**

$2KIO_3^-(aq) + 10I^-(aq) + 12H^+(aq) \longrightarrow 6I_2(s) + 6H_2O\ (l)$

$2KIO_3^- : 6I_2$

$2 : 6$

$1 : 3$

$C_8H_8O_6(aq) + I_2\ (s) \longrightarrow C_6H_6O_6(aq) + 2I^-(aq) + 2H^+\ (aq)$

$C_8H_8O_6 : I_2$

$1 : 1$

$No. of\ moles\ of\ \boldsymbol{KIO_3}(mol) = Conc.(moldm^{-3}) \times Volume\ (dm^3)$

$Number\ of\ moles\ of\ \mathbf{I_2}\ (mol) = Number\ of\ moles\ of\ \boldsymbol{KIO_3} \times 3(mol)$

$Number\ of\ moles\ of\ \mathbf{C_8H_8O_6}\ (mol) = Number\ of\ moles\ of\ \mathbf{I_2}(mol)$

### Sample Calculations for 20 °C

Average Volume of $\mathbf{KIO_3}$ used $(dm^3)$ = $\frac{(10.3+10.5+10.2+10.7+10.6)cm^3}{5} \times \frac{1}{1000} = 0.01046 \approx 0.0105\ dm^3$

No. of mol of $\mathbf{KIO_3}$ = Conc. $(moldm^{-3}) \times$ Volume $(dm^3)$ = $0.001 \times 0.0105 = 1.05 \times 10^{-5}$ mol

Number of moles of $\mathbf{I_2}$(mol) = Number of moles of $\mathbf{KIO_3} \times 3$ (mol) $= 1.05 \times 10^{-5} \times 3 = 3.15 \times 10^{-5}$ mol

Number of moles of $\mathbf{I_2}$ (mol) = Number of moles of $\mathbf{C_8H_8O_6}$(mol) $= 3.15 \times 10^{-5}$ mol

| Temperature<br><br>$(T\pm 0.05)°Celcius$ | Ascorbic Acid Concentration (M) | | Ascorbic Acid Concentration Uncertainty<br>$(M \pm \Delta M)$ mg/100 ml of solution | |
|---|---|---|---|---|
| | $moldm^{-3}$ | mg/100 ml of solution | Percentage Uncertainty | Absolute Uncertainty |
| 20.00 | $1.26 \times 10^{-4}$ | 22.19 | $\pm 5.69\%$ | $\pm 1.26$ |
| 35.00 | $1.14 \times 10^{-4}$ | 20.08 | $\pm 5.67\%$ | $\pm 1.14$ |
| 45.00 | $9.24 \times 10^{-5}$ | 16.27 | $\pm 6.52\%$ | $\pm 1.06$ |
| 55.00 | $7.68 \times 10^{-5}$ | 13.53 | $\pm 10.77\%$ | $\pm 1.46$ |
| 65.00 | $5.76 \times 10^{-5}$ | 10.14 | $\pm 9.52\%$ | $\pm 0.97$ |
| 75.00 | $3.12 \times 10^{-5}$ | 5.49 | $\pm 16.54\%$ | $\pm 0.91$ |

**Table 7: Ascorbic Acid Concentration and Uncertainties for each temperature**

$$\mathbf{C_8H_8O_6}\ Conc.(moldm^{-3}) = \frac{No.of\ mol.\mathbf{C_8H_8O_6}}{Volume\ of\ tomato\ sample} = \frac{No.of\ mol.\mathbf{C_8H_8O_6}}{0.025}$$

$$(In\ standard\ food\ units)\ \mathbf{C_8H_8O_6}\ Conc.\left(\frac{Mg}{100ml}\right) = No.of\ mol.\mathbf{C_8H_8O_6}\ \times molar\ mass \times 1000 \times 4 = No.of\ mol.\mathbf{C_8H_8O_6}\ \times 176.12\ (gmol^{-1}) \times 1000\ \times 4$$

(multiplied by 1000 to convert into mg and multiplied by 4 to express per 100ml of solution.

## Sample Calculations for 20 °C (significant figures maintained)

$$\mathbf{C_8H_8O_6}\ Conc.(moldm^{-3}) = \frac{No.of\ mol.\mathbf{C_8H_8O_6}\ (table\ 6)}{Volume\ of\ tomato\ sample(dm^3)} = \frac{3.15 \times 10^{-5}}{0.025} = 1.26\ \times 10^{-3} moldm^{-3}$$

$$(In\ standard\ food\ units)\ \mathbf{C_8H_8O_6}\ Conc.\left(\frac{mg}{100ml}\right) = No.of\ mol.\mathbf{C_8H_8O_6}\ \times molar\ mass \times 1000 \times 4$$
$$= 3.15 \times 10^{-5}(mol) \times 176.12\ (gmol^{-1}) \times 1000(mg)\ \times 4 = 22.19g$$

## Uncertainty Calculation for measurements of tomato sample at 20 °C (Random Error)

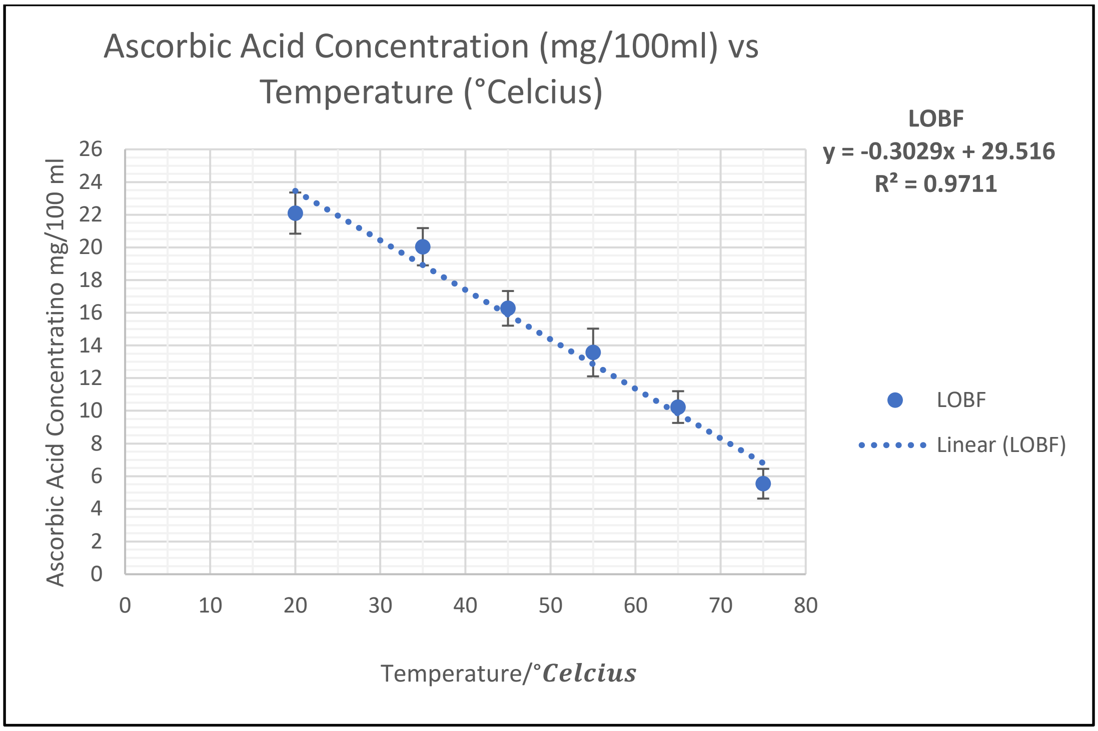
1. Individual Percentage error calculated for each apparatus

| Apparatus | Uncertainty | Calculation |
|---|---|---|
| Measuring Cylinder 100cm$^3$ | $\pm 0.05cm^3$ | $(0.05cm^3 \div 25.00cm^3) \times 100 = 0.200\%$ |
| Volumetric flask (100cm$^3$) | $\pm 0.02cm^3$ | $(0.02cm^3 \div 100.00cm^3) \times 100 = 0.020\%$ |
| Burette | $\pm 0.1cm^3$ | $(0.1cm^3 \div 10.5cm^3) \times 100 = 0.952\%$ |
| Digital weighing balance | $\pm 0.001grams$ | $(0.001g \div 100.000g) \times 100 = 0.001\%$ |
| Thermometer | $\pm 0.05°C$ | $(0.05°C \div 20.00°C) \times 100 = 0.250\%$ |

**Table 8: Sample Percentage Uncertainty Calculation**

2. All percentage Uncertainties added – 0.200%+0.020%+0.952% + 0.001%+0.250% = 1.423%
3. The calculated value of ascorbic acid concentration was multiplied by 4 so percentage uncertainty will be 4 times as much – $1.423\% \times 4 = 5.692\% \approx 5.69\%$
4. Percentage Uncertainty is 22.19mg $\pm$ 5.69%
5. Absolute Uncertainty- (22.19mg ×5.69) ÷100 = 1.26mg
6. 22.10mg $\pm$ 1.26mg
7. This process is repeated for uncertainty calculation at other temperatures (answers in table 7)

## Graphical Analysis




**Graph 1: Ascorbic Acid Concentration (mg/100ml) vs Temperature (°C) Graph**

## Conclusion

After collecting, processing and analysing the data collected in my experiment I have successfully proved my initial hypothesis that stated that as the temperature of the tomato solution was increase, the concentration ascorbic acid concentration would decrease giving an inverse relationship. This can be validated by looking at the average titre volume of Potassium Iodate needed to arrive at the endpoint of the titration which decreased as the temperature of the sample was increase because the number of moles of ascorbic acid in the sample was decreasing as well. Our graph 1 showcases an inverse relationship that can be modelled using a straight-line equation **y= -0.3029x + 29.516**. The $\boldsymbol{R^2}$ (Pearson Corelation Coefficient) value of my graph is **0.9711** which is in the range of 0.9-0.1. This indicates that the strength between both the variables is very strong and shows us that our results are accurate. However, it is important to acknowledge that we cannot confidently say that this relationship will hold before **20.00**°C if we begin to reach a cooler temperature the ascorbic acid concentration doesn't increase but the rate of degradation decreases so the value of **29.516 mg/100ml** at $\mathbf{0.00}$°C is not possible Again After $\mathbf{75.00}$°C the relationship can be reasonably accurate till the concentration of ascorbic acid reaches 0 mg/100ml but after exceeding the x-intercept, the graph will be inaccurate because it is practically impossible to say that the ascorbic acid concentration will be negative.

This relationship is in keeping with the wider scientific consensus that the degradation of vitamin c is inflected by heat, because as temperature increases the average kinetic energy of the particles increase and this accelerates the degradation process as highlighted in the background. Even though this relationship is widely established, the exact literature values vary depending on the experiment methodology and harvesting conditions of the tomato which can result in ascorbic acid content in the range of 18.3mg/100ml to 40mg/100ml and my calculated value at room temperature (22.10mg/100ml) falls within this range.

Throughout this experiment there were many random and systematic errors that affected the results. The main systematic error was the subjectivity present in identifying the end-point colour of the titration and the slight delay in identifying the endpoint after the exact equivalence point. The lack of 3-5 concordant results of titre volumes within 0.1-0.2$cm^3$and the presence of uncertainties in the measuring apparatus propagated the random error in the experiment. Overall, I was able to conclude successfully that my hypothesis is correct. This experiment was planned to mimic the cooking process of tomatoes in Indian spice-blends because they are also mixed in a certain amount of water. After conducting this experiment, I can now assess the extent of Vitamin C loss that we are incurring even when using large number of tomatoes in our dishes and my advice towards Indian households would be to conduct slow-cooking of the spice blend at lower temperatures (30-50℃**)** for relatively greater preservation of vitamin c compared with higher temperatures (50-100℃**).** Additionally, it would be best to include more tomatoes in salads so minimal health requirements are achieved**.**

## Evaluation

**Strengths of Experiment** – Due to initial coloration of the sample, the endpoint colour was not representative of the conventional blue-black colour of the starch indicator solution which is why conducting a preliminary investigation to familiarize myself with the colour change improved the accuracy of the experiment. Furthermore, being able to obtain high quality tomatoes from the same cultivar really helped ensure that the tomatoes were in the same ripening stage so the overall results were reliable which can be validated from my results and the final graph. Overall, I prepared the tomato samples using the identical preparation technique which enhanced the consistency in the methodology

**Weaknesses of Experiment**

| Source of Error | Effect on Results | Scope for Improvements |
|---|---|---|
| Determining the endpoint of the redox titration based on the colour change | **High Significance –** This is a systematic error in the experiment because identifying the colour change is subjective process and we always see the colour change after the equivalence point. Also, the fact that the solution had a strong initial coloration, it became difficult to define the end-point colour of the redox titration | In order to increase the accuracy of our results, we can use a device known as colorimeter that measures the absorbance of wavelength of light in the solution. We can use this to identify our exact colour change. Alternatively, we can use voltmeter which relates the changes in concentration in a redox reaction to the electric potential of the cell. |
| Lack of accuracy in heating tomato sample to required temperature | **Low-Significance** – As referred to in the qualitative observations, for some trials the measured temperate exceeded the required temperature. | A more sophisticated apparatus can be used to heat the sample such as thermostat or hot plate. |
| Manual Stirring of solutions | **Moderate-Significance** –The rate at which the analyte was swirled affected the kinetic energy of of the molecules which impacted the rate of the reaction unfairly | Make us of a magnetic stirrer to maintain a constant rate of stirring |
| Using a measuring cylinder to take measurements of the sample tomato solution. | **Moderate Significance -** the larger surface of the measuring cylinder causes a greater curvature in the meniscus affecting the accuracy of the measurement. | Make use of a volumetric pipette which that has a lower random error associated with it. |

| Source of Error (continued) | Effect on Results | Scope for Improvements |
|---|---|---|
| Lack of trials at each temperature affecting precision | **Moderate Significance – Random Error** Even after taking 5 trials at each temperature, there was a significant variance in the titre volumes. The percentage uncertainty in the readings ranged from $\pm 5.67\%$ to $\pm 16.54\ \%$. In each of the 5 trials, the lack of 3-5 concordant results of volume within $0.1cm^3$ also affected the precision of the results | Increase the number of trials in the experiment. This will help reduce the prevalence of random errors. As many trials should be conducted until we have enough concordant titre results |

**Table 9: Weaknesses of Experiment**

## Scientific Extension

An insightful extension to this experiment could be to delve deeper into specific cooking styles in Indian cooking instead of only the temperature variation. An interesting approach would be to see how the vitamin c content in tomatoes is affected by higher temperatures during poaching (82℃), simmering (85-93℃) and boiling (100℃). Due to limitation in my experimental procedure and apparatus I could not have done the experiment at boiling since the solution would be evaporated giving an unfair analysis.

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