LONDON METROPOLITAN UNIVERSITY

Analyzing the effects of different cooking methods on the Vitamin C and Colour content of Yellow bell pepper, Tomato and Broccoli

NF7P18- Research Dissertation

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List of Abbreviations

HPLC	-	High Pressure Liquid Chromatography
ml	-	Milliliters
°C	-	Degree Celsius
g	-	Grams
rpm	-	Rotations per minute
µl	-	Microliter
µm	-	Micrometer
HPP	-	High pressure processing
UV	-	Ultraviolet

Abstract

Cooking is a fundamental human activity that has played a crucial role in our evolution, development and well-being. Cooking improves the digestibility and palatability of food by softening tough fibers, denaturing proteins and breaking down complex compounds to make them more easily absorbed by body although also affecting the original nutrient composition and physiochemical properties. This study investigates the impact of three cooking methods- blanching, boiling and oven roasting on the vitamin C and colour content of yellow bell pepper, tomato and broccoli. These vegetables are widely consumed and are valued for their nutritional content, especially vitamin C. The study aimed to identify the cooking method that best preserves vitamin C and retains the colour vibrancy. Vitamin C was quantified using High performance liquid chromatography (HPLC) method and colour changes were measured with a CIELAB colorimeter by L* (luminance), a* (red- green) and b* (yellow- blue) colour parameters.

Results indicated that blanching was the most effective method for preserving both vitamin C and colour across all vegetables. Yellow bell pepper experience only 10% decrease in luminance, and tomato showed minimal darkening. In contrast, boiling resulted in the greatest vitamin C loss with a reduction of 42.92% in yellow bell peppers and 40.21% in tomatoes. Surprisingly, boiling led to 6.36% increase in broccoli's vitamin C content due to enhanced extractability after softening. Oven roasting caused moderate nutrient loss and the most significant darkening, particularly in broccoli, where luminance dropped by 34.54%.

These findings underscore the importance of selecting appropriate cooking methods to maximise both nutrient retention and sensory appeal, with blanching emerging as the most viable option.

Key words- Vitamin C, HPLC, Colour, Cooking effects and Vegetables**.**

1. Introduction

Vegetables have been a crucial part of human diet since the stone age (De Meester et al., 2022), providing essential nutrients and micronutrients like fibre, phytochemicals crucial for optimal health. Prevalence of obesity has continued to rise in recent years. Globally, over 38 million children under the age of five are overweight or obese as of 2024, with projections indicating further increases (WHO,2023; World Obesity Federation 2024). In the UK, about one in four children (24%) in reception age (4-5 years) are classified as overweight or obese (World Population Review, 2024). Meanwhile, fruit and vegetable consumption remains below recommended levels, with fewer than one in five preschoolers consuming the recommended 5 portions daily (World Obesity Federation, 2024). Diets rich in fruits and vegetables continue to play a critical role in promoting child health by contributing to weight management and reducing the risk of obesity (Susan, 2000). Moreover, they offer protection against various non communicable diseases including cardiovascular diseases and cancer. (Holley, Farrow and Haycraft, 2017; World Obesity Federation, 2024).

The culinary transformation of vegetables with history as old as civilization itself, has evolved from simple preparation methods to complex gastronomic techniques (Lee et al., 2017). Cooking process can make the food palatable, soften the food significantly and affect the digestibility by breaking down tough cell walls, making it easier for the body to absorb essential nutrients like vitamins, minerals and antioxidants. Additionally, cooking and deactivate harmful bacteria and reduce the risk of foodborne illnesses. While some nutrients may be lost during cooking particularly water-soluble vitamins like vitamin C, overall cooking can make vegetables more palatable and easier to incorporate into a healthy diet (Engler- Stringer, 2010).

1.1 Properties of Yellow bell pepper

Yellow bell pepper (*Capsicum annuum L.)* Is a widely cultivated crop valued for its distinctive flavour, vibrant colours and nutritional benefits. As a member of this Solanaceae family, pepper is rich in vital chemicals including carotenoids, flavonoids common score big acid, phenolics compounds and capsaicin which contributes to its antioxidant properties. Consuming fresh Peppers are incorporating them into meals can provide a significant boost of vitamins and minerals particularly vitamin C, making them a valuable addition to healthy diet (Soare et al., 2017). On an average yellow bell peppers contain approximately 160mg /100g Vitamin C, highest among the other coloured bell peppers (Nerdy, 2018). Yellow capsicum is a versatile ingredient used in a wide variety of dishes such as salads, stir-fries, pizzas, sauces and pickles.

1.2 Properties of Tomato

Tomatoes (*Solanum lycopersicum),* a staple food worldwide are renowned for their nutritional benefits. Rich in the antioxidant lycopene, tomatoes have been linked to reduce the risk of cancer and cardiovascular diseases. The characteristic vibrant red colour of tomatoes is attributed to carotenoid pigments synthesised during ripening stage. Other than lycopene, tomatoes offer a valuable source of minerals and vitamin C, although nutrient content can vary based on growing conditions. Studies have shown that organically grown tomatoes may contain higher levels of calcium and vitamin C but lower iron compared to those grown hydroponically (Guil-Guerrero, J.L. and Rebolloso-Fuentes, M.M., 2009). On an average tomato contains approximately 22mg vitamin C (McCance and Widdowson, 2014). Tomatoes are available in wide variety of products such as juices, sun dried, salads, sauces, ketchups and canned tomatoes.

1.3 Properties of Broccoli

Broccoli (*Brassica oleracea),* a popular cruciferous vegetable is a rich source of essential vitamins including vitamin C, K, B1, B3, B5, basics an E. Additionally, broccoli contains significant amounts of folate, chromium, magnesium, phosphorus, zinc, iron, selenium and omega-3 fatty acids. Beyond its essential nutrients, broccoli is packed with phytochemicals such as polyphenols and glucosinolates. These compounds contribute to broccoli's antioxidant and anti-cancer properties, making it a valuable dietary choice (Nagraj et al., 2020).

Numerous epidemiological studies have highlighted the health benefits of broccoli including its potential to modulate immunity, detoxify the body, support eye and bone health (Jeffery, and Araya, 2009; Vasanthi. Mukherjee and Das, 2009). On an average broccoli contains approximately 79mg vitamin C (McCance and Widdowson, 2014). Broccoli available in wide variety of dishes, the most commonly consumed form of broccoli is in pastas, stir-fries and salads.

1.4 Cooking methods

There are many cooking methods used worldwide, some of the common cooking methods and their brief description is mentioned below (Pallerrmo, Pellegrini and Fogliano, 2014)-

1) Boiling- it involves immersing food in a pot of boiling water until cooked. This method is often used for vegetables, pasta and eggs.

2) Blanching- This is a brief cooking process where food is briefly immersed in boiling water before being immediately plunged into ice water to stop the cooking process. This technique is commonly used for vegetables to preserve their colour, texture and nutrients.

3) Oven roasting-this method involves cooking food in the heart of oven. This method is often used for meat, thawing, vegetables and bakery items. It can produce a crispy exterior and tender interior.

1.5 Vitamin C and its importance

Vitamin C also known as ascorbic acid, is a water-soluble vitamin essential for human health. It plays a crucial role in various bodily functions including collagen synthesis, iron absorption and immune system support. As an antioxidant, vitamin C helps protect cells from damage caused by free radicals. Dietary sources of vitamin C primarily include fruits and vegetables particularly citrus fruits like oranges, grapefruit and lemons as well as berries, kiwi and tomatoes. Other good sources of vitamin C are leafy green vegetables like spinach kale and bell Peppers. Deficiency off vitamin C can lead to scurvy, a condition characterised by bleeding gums, fatigue and poor wound healing (Doseděl et al., 2021). Recommended dietary intake for vitamin C per day for healthy male and female is 110mg and 95mg respectively (Olson and Hodges, 1987; Nordic Nutrition Recommendation, 2023).

1.6 Sensory analysis

Sensory evaluation, also known as organoleptic evaluation, is unscientific methods used to assess the quality of food products using human senses. It goes beyond just a stan considers a combination of factors perceived of the during consumption including sight, smell, touch and sound. These perceptions are influenced by both physiological and psychological factors. While instrumental measurements can be used to objectively assess some physical properties of food, sensory evaluation is necessary to capture the full picture of how consumers will experience the food. This is important because consumer acceptance is a key factor in the commercial success of a food product (Ray, 2021).

1.7 Review of Literature

The available literature regarding nutrient losses sensory property loss factors affecting nutrient retention has been examined and summarised under the following headings and sub-categories.

1.7.1 Nutrient losses in food due to cooking

In research conducted by Mazzeo et al., 2011 authors investigated the effects of boiling and steaming on the physical chemical content, antioxidant capacity and colour properties of frozen carrots, cauliflower and spinach. By employing HPLC and spectrophotometric techniques, the authors have provided a detailed analysis in which the key findings include the preservation of polyphenols and a slight increase in total activity oxygen capacity and steamed vegetables, particularly and spinach. Boiling on the other hand, led to a general depletion of carotenoids, finale compounds and total antioxidant capacity in all three vegetables. Ascorbic acid was to be significantly reduced by both boiling and steaming detected only in cauliflower.

Xu et al., 2014 investigated the effects of various cooking methods on the nutritional composition of red cabbage. They have quantified changes in anthocyanins, glucosinolates, vitamin C, antioxidant activity and total soluble sugars, this study provides insights into impact of domestic cooking practises on this vegetable. While all cooking methods resulted in a reduction of anthocyanins and total glucosinolates compared to fresh red cabbage, steaming was found to be the most effective in preserving vitamin C and DPPH radical scavenging activity. In contrast, stir frying and boiling call my bed which are common Chinese cooking methods led to significant losses of these nutrients. The authors findings highlight the importance of considering cooking methods when consuming red cabbage particularly and Asian cuisines where it is used predominantly and cooking is very common.

In a study conducted by Bureau et al., 2015 researchers have mentioned a comprehensive investigation on the effects of cooking methods on 13 different frozen vegetables. The findings highlight the significant variability among their vegetables in terms of nutrient content and the differential effects of cooking methods on folates carotenoids and vitamin C as mentioned and other researchers as well. On a fresh weight basis, boiling resulted in substantial losses of total vitamin C (-51%) and folates (-68%) however considering the dry weight, boiling may be a more suitable method for preserving carotenoids as it allowed for increased extract ability of lutein and beta carotene.

1.7.2 Factors influencing nutrient retention during cooking

In a study conducted by Onyeka and Ibeawuchi, 2021 the findings reveal a clear trend that titanium pots consistently offered the highest retention of micronutrients, while aluminium parts demonstrated the lowest notably the titanium and enamel coated pots required less water to cook food resulting in a low moisture content (68.67%) compared to other pots (77.89%). This study challenged the notion that pressure pots are always optimal for nutrient preservation they discovered that low pressure-cooking pots effectively retained heat sensitive nutrients the finding suggested that the choice of cooking pot can significantly impact nutrient content and as a result, human health.

Lee et al., 2018 investigated the impact of various cooking methods on vitamin C content in vegetables while the authors employed a proper methodology, including the estimation of crew retention, the results presented what is somewhat mixed. Microwaving generally lead to higher vitamin C retention compared to boiling, the overall range of 0.0 – 91% indicates significant variability across different cooking methods and vegetables. The study found that certain fats soluble vitamins, such as tocopherol and beta-carotene could be enhanced income vegetables compared to raw though this was dependent on the specific vegetable. The author's observations were very insightful about microwaving which caused great loss of vitamin K in some vegetables while it caused least loss of my vitamin K in some vegetables like spinach and chard. From these observations it can be deduced that each cooking method affects the vegetables differently.

In a study conducted by Zhong, Dolan and Almenar, 2015 the authors have conducted a comprehensive study evaluating the impact of steamable bag microwaving on the nutritional and physical properties of frozen broccoli. With the use of titration, oxygen radical absorbance capacity assay, calorimetry and text Cheryl metry the authors have provided valuable insights in two the potential benefits of steamable bag microwaving. The findings highlight the superiority of steamable bag microwaving and retaining ascorbic acid content and enhancing antioxidant activity compared to traditional methods additionally, the method's effectiveness in tenderising broccoli and retaining its colour suggests that it may offer a more desirable cooking experience for consumers. By emphasising the convenience commerce safety and nutritional benefits of this technology, the authors have made a strong case for its add option in the food industry.

Dos Reis et al., 2015 conducted a comprehensive study providing valuable insights into the effects of different processing methods on the nutritional and physical chemical properties of broccoli and cauliflower. Key findings included the preservation of antioxidant capacity an increased level of antioxidant compounds (including quercetin, lutein and total carotenoids) in both vegetables across all processing methods. Sous vide processing, in particular, demonstrated superior results in this regard by increasing antioxidant activity by 20%. Sous vide is a cooking technique based on vacuum sealing the food in a bag and cooking it in a water bath at a specific temperature for long duration.

Hailehmariam and Wudineh, 2020 performed a total investigation into the effects of open-pan and pressure cooking on ascorbic acid retention in cabbage and Ethiopian green collard. By varying cooking times an analysing ascorbic acid concentration, the findings demonstrated pressure cooking is generally more effective in preserving ascorbic acid in both vegetables compared to open-pan cooking. While the optimal cooking time varied slightly between the two vegetables, pressure cooking consistently required shorter cooking times to achieve well-cooked edible samples. For example, Ethiopian green collards retain 31.8% off their initial ascorbic acid content after 10 minutes of pressure cooking whereas 25 minutes cooking time was required to achieve desirable texture with 26.8% of vitamin C retention.

1.7.3 Impact of cooking methods on sensory properties

Armesto et al., 2016 conducted devaluation of effects of cooking methods on the quality attributes of kale by accessing chlorophyll content, total phenolics, colour and sensory properties. Boiling was found to have the most significant effect on the total phenolics and colour of kale resulting in substantial losses microwaving on the other hand lead to the greatest reduction in soluble solids. Steaming emerged as the most effective method for preserving nutrient and chlorophyll content (62-71%). In case of sensory scores, it was observed to be lowest and steamed kale.

In a research conducted by Zhao Yang et al., 2017 the authors studied the effects of cooking methods on the polyphenol content of blueberries which gives the fruit its distinct colour. The results demonstrate that overall retention rates in baking for total anthocyanins other polyphenols were relatively high, ranging from 74.3% to 88.7% as compared to boiling and microwaving. Microwaving led to highest losses of polyphenols.

Chandra, Prihastyanti and Lukitasari, 2021 reviewed the effects of non-thermal treatments such as ultraviolet light (UV) and high-pressure processing (HPP), on the colour and pigment stability of fruits and vegetable juices. The findings include the ability of UV-C treatment to maintain chlorophyll content in green juices while minimising colour changes. In yellow juices, UV-C treatment was shown to increase brightness and reduce browning. For red juices, both UV-C and HPP treatments were found to be effective in preserving anthocyanin content and maintaining red colour. While UV-C treatment offers advantages in terms of colour retention, HPP may be more effective in preserving certain nutrients and preventing enzymatic browning in some cases.

1.8 Scope of study

1.8.1 About this study

The preservation of nutrients and colour in vegetables is a crucial concern in food science and nutrition. Cooking methods can significantly impact the nutritive value and sensory appeal of the vegetables. Understanding the effects of different cooking methods on specific nutrients and colour parameters can provide valuable insights for food manufacturers, policymakers and consumers.

The scope of study titled, "Analyzing the effects of different cooking methods on the Vitamin C and colour content of Yellow bell pepper, Tomato and Broccoli" highlights the following areas: The study focuses on the effect of various cooking methods (blanching, boiling and oven roasting) on the vitamin C and colour content off yellow bell pepper, tomato and broccoli. These vegetables are commonly consumed and known for their nutritional value internationally by examining the impact of cooking methods on these specific nutrients and sensory parameters, this review aims to contribute to the existing body of knowledge in this particular area.

1.8.2 Gaps in the existing research literature.

While there have been studies investigating the effects of cooking on nutrient and colour content in vegetables, there is a need for more comprehensive and comparative analyses. This review will address several gaps in the existing literature:

1. Limited comparative studies: many studies have focused on individual cooking methods or specific vegetables. A comparative analysis of different cooking methods across multiple vegetables this lacking.

2. Focus on specific nutrients and colour parameters: while previous studies have examined various nutrients like phenolic content, carotenoids and colour parameters there is a need for more focused analysis on vitamin C and colour content, which are particularly important for these vegetables as vitamin C is heat labile.

By addressing these gaps, this review will provide a more comprehensive understanding of the effects of cooking methods on these vegetables.

1.9 Aims and Objectives

1.9.1. Aim

To investigate the effects of different cooking methods on the vitamin C and colour content of yellow bell pepper, tomato and broccoli.

1.9.2 Objectives

1. To quantify the retention of vitamin C in yellow bell Peppers broccoli and tomato after subjecting them to various cooking methods (blanching, boiling and oven roasting).

2. To assess the impact of different cooking methods on the colour parameters (L*, a*, b*) Yellow bell pepper, tomato and broccoli.

3. To compare the effectiveness of different cooking methods in retention of vitamin C and colour in the three vegetables.

4. To provide insights into the factors influencing vitamin C degradation and colour changes.

2. Methodology

The current investigation titled "Analyzing the effects of different cooking methods on the Vitamin C and colour content of Yellow bell pepper, Tomato and Broccoli" was carried out at the Super lab in Science centre, London metropolitan university, London.

This section provides the details about the research methodology and design implemented in the study.

2.1 Material Acquisition

The vegetables Yellow bell pepper (*Capsicum annuum*), Tomato (*Solanum lycopersicum*), and Broccoli (*Brasicca oleracea*) were acquired from a local Sainsbury's supermarket, while all the chemicals used in the analysis were analytical grade.

2.2 Processing of vegetables

2.2.1 Cleaning

The vegetables were washed carefully by hand to remove any dirt, dust and foreign particles before subjecting them to different cooking methods.

2.2.2 Sample preparation

For sample preparation the washed vegetables were cut into pieces and were subjected to processing in different weight categories depending on the firmness of the vegetables. Following the sample measurements mentioned in the analysis done by (Koyunc and Dilmaçünal, 2010) for tomato the amount for each sample was 10 grams meanwhile for broccoli and bell pepper, 20 grams each were taken for colorimeter analysis and extraction for HPLC analysis. For broccoli and bell pepper more amount was taken to tackle the issue of their firm structure and simplify the extraction process.

2.2.3 Cooking treatments

2.2.3.1 Blanching

Blanching process for the samples was done by following the steps and temperature/time specifications mentioned by (Owusu-Kwarteng, Kori and Akabanda, 2017). 500ml beakers filled with distilled water were kept in the water bath and the temperature was set at 90°C. Once the desired temperature was obtained the vegetables were dipped in the beaker in the running water bath for 5 minutes. After 5 minutes the vegetables were given a cold shock by directly dipping them in the ice bath at temperature 4°C for 10 seconds.

2.2.3.2 Boiling

Boiling process for the samples was done by following the steps timing specifications mentioned by (Suresh, Manjunatha and Srinivasan, 2007). Distilled water was taken in saucepan and was allowed to boil, and the vegetable samples were dipped once the bubble formation was observed in the water. The samples were boiled for 10 minutes.

2.2.3.3 Oven roasting

Oven roasting method for the samples were done by following the steps and temperature/time specifications mentioned in the research paper by (Hwang et al., 2012). The samples were kept on baking tray covered with butter paper and were kept inside pre-heated convection oven set at temperature 190°C. The samples were roasted for 10 minutes.

2.3 Extraction

The buffer solution used for extraction of ascorbic acid was 5% orthophosphoric acid solution as mentioned by (Tarrago-Trani, Phillips and Cotty, 2012). Amount of buffer solution used for sample is mentioned in Table 2.1. The buffer was prepared using 50ml of HPLC grade ortho-phosphoric acid diluted to the volume of 1000ml using distilled water.

Table 2.1 Sample and buffer quantity used

Vegetables	Sample taken (g)	Buffer used (ml)
Tomato	10	10
Yellow Bell Pepper	20	20
Broccoli	20	20

For extraction, mortar pestle was used instead of blender for homogenization to prevent loss of vitamin due to heat production (Choi, Kim and Kim, 2014). The buffer solution was added while crushing and mixing in the mortar pestle. 10 ml of the sample-buffer mixture was transferred to a 15ml centrifuge tube and were kept in Rotina 380 model centrifuge equipment for 15 minutes at 4000rpm (Scopa et al., 2006). Figure 2.1 shows the mixture in tubes before centrifugation and Figure 2.2 shows the supernatant separation after centrifugation.

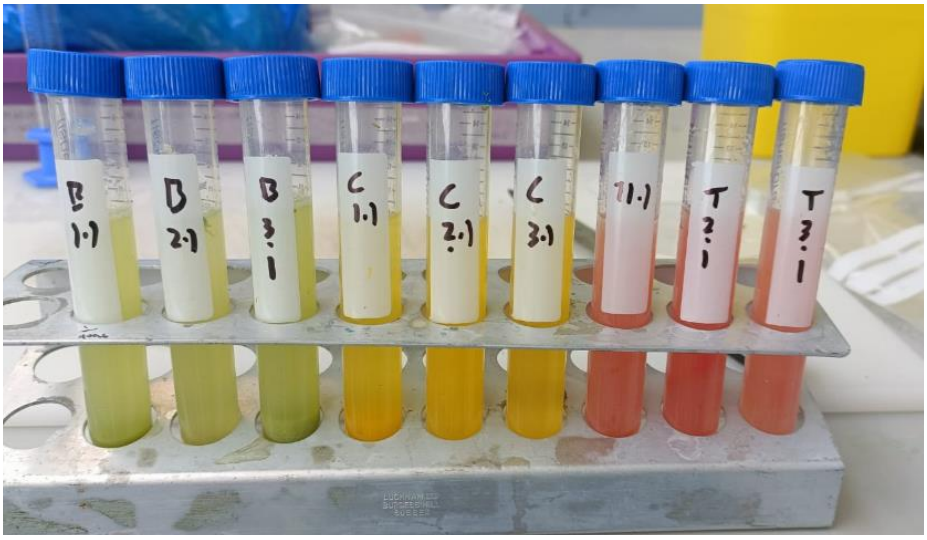

Figure 2.1 Sample mixture before centrifugation.

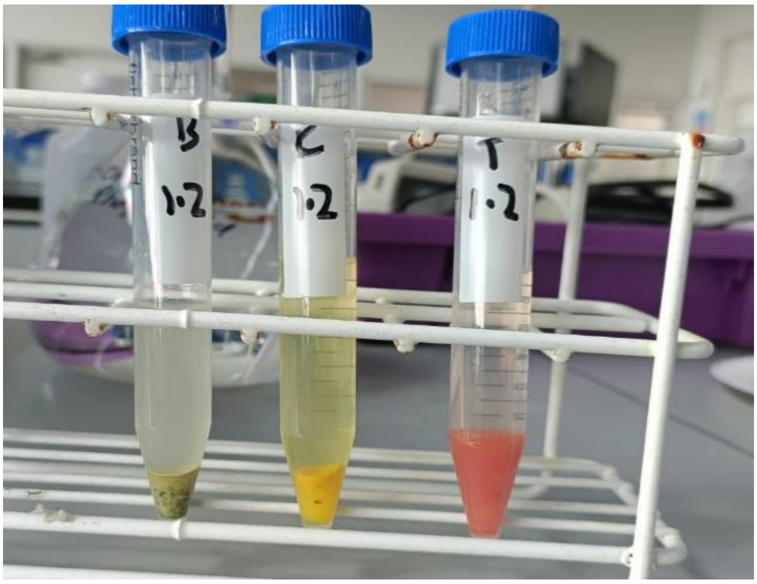

Figure 2.2 Sample mixture after centrifugation

For HPLC analysis, 1.5 ml of the supernatant is sucked out using syringe and transferred to 2 ml capacity HPLC vials after fitting the syringe with 0.45µm HPLC grade syringe filter.

2.4 HPLC analysis for Vitamin C

2.4.1 Standard preparation

Standard preparation was done using HPLC grade L-ascorbic acid for primary reagent. The steps or standards preparation were-

1) 1g of L-ascorbic acid in 1000 ml volumetric flask and volume made up till the mark using distilled water to get 1 litre of 1mg/ml stock solution and first standard.

2) For 0.5mg/ml concentration 25ml is taken from the stock solution and put into 50ml volumetric flask and volume is made up using distilled water till the mark on flask.

3) For 0.25mg/ml concentration 25ml is taken from the 0.5mg/ml solution and put into 50ml volumetric flask and volume is made up using distilled water till the mark on flask.

4) For 0.125mg/ml concentration 25ml is taken from the 0.25mg/ml solution and put into 50ml volumetric flask and volume is made up using distilled water till the mark on flask.
5) For 0.0625mg/ml concentration 25ml is taken from the 0.125mg/ml solution and put into 50ml volumetric flask and volume is made up using distilled water till the mark on flask.
6) For blank solution only distilled water is used.

2.4.2 Mobile phase preparation

According to the methodology of paper by (Tarrago-Trani, Phillips and Cotty, 2012) the mobile phase used was methanol and 0.03% ortho phosphoric acid in the ratio of 20:80. For making 0.03% ortho phosphoric acid, 300µl of HPLC grade orthophosphoric is put in 1000ml volumetric flask and the volume is made up using distilled water.

2.4.3 Sample analysis

For HPLC analysis the equipment from Agilent technologies model name- 1260 Infinity II SOP was used (Figure 2.3). The column used for stationary phase was Luna omega C-18 250x 4.6mm. Flow rate set in the method was 0.7 ml/ minute and 6 min run time per sample. Injection volume was set at 20µl. The absorbance was set at 520nm .

Figure 2.3 HPLC analysis instrument

2.4.4 Statistical analysis

For statistical analysis SPSS statistical software by IBM and Microsoft Excel 365 was used to calculate mean values of the triplicates and standard deviation.

2.5 Colorimeter analysis for colour component

The colour component quantification was done using Konika Minolta sensing, inc. Chroma meter CR-400 series. The colorimeter gave the readings in CIELAB color space with tristimulus values in L* for perceptual lightness, a* for red- green spectrum and b* for blue-yellow spectrum (Hunt, 2011). First the instrument is subjected to a calibration process using white calibration tile (C=1 illuminant X= 78.66; Y= 83.3 and Z= 88.4) where the scanner opening is touched to the tile and trigger is pressed. After calibration the colorimeter is ready for analysis of samples. In case of solid samples, the scanner opening can be touched directly to the sample while the sample covers the hole fully and then the trigger is pressed. This will provide the values on the screen. Figure 2.4 shows the handheld colorimeter equipment.

Figure 2.4 CIEL*a*ab handheld colorimeter

First, analysis of raw samples is conducted then these values are set as reference point for the comparison of the values for cooked samples to determine the change and loss of initial hue (Nielsen, 2010). To get a comprehensive overview of the color dynamics, percentage change in luminance factor can be a significant proof.

2.6 Bias and Subjectivity

There are three points to be considered under bias and subjectivity which is

1. **Researcher bias:** Can affect the interpretation of results particularly in subjective measurements like colour assessment.
2. **Sample variation:** Variations in the quality ripeness and size of the vegetables could introduce bias into the results.
3. **Instrument calibration:** an accurate calibration of the colorimeter could lead to the biassed colour measurements.

2.7 Strengths and weaknesses of the analysis

2.7.1 Strengths

1. The use of standardised cooking methods and analytical techniques enhances the reliability of the results.
2. The comparison of multiple cooking methods provides a comprehensive understanding of their effects.
3. The use of HPLC analysis for vitamin C quantifications ensures accuracy.

2.7.2 Weaknesses

1. The reliance on a single source of vegetables could introduce potential biases.
2. Generalizability can affect the applications or findings because the results may not be applicable to all vegetable types or cooking environments.
3. The findings may not be directly transferable to other contacts due to variations in vegetable sources, cooking equipments and environmental factors directly affecting the transferability.

2.8 Future research approaches

1. Exploring a wider range of cooking methods could provide a more comprehensive understanding of the effects on nutrient content and colour.
2. Investigating the effects of cooking on other nutrient rich vegetables could provide valuable insights.
3. Incorporating consumer preferences for colour and texture into the analysis could inform practical applications.
4. Investigating the potential health implications of changes in nutrient content and colour due to cooking could provide valuable information.

3. Results

3.1 Effect of cooking on Ascorbic acid content

The analysis was conducted to quantify the vitamin C content in yellow bell pepper, tomato and broccoli. The vitamin C content of each vegetable was measured as raw and after being subjected to different cooking methods including blanching, boiling and oven roasting. The results highlight that cooking methods significantly affects the retention of vitamin C across all three vegetables, reflecting the thermal sensitivity of ascorbic acid and its varying stability in different vegetables with some methods showing better preservation than others. The initial vitamin C content in raw samples solved as the baseline for comparison. The uncooked vegetables exhibited the highest vitamin C concentrations, with variations observed across the three types of vegetables after cooking due to the effects of heat and water exposure.

The calibration curve was plotted using the readings for area of peak obtained by injecting six standards including one blank in the HPLC apparatus. Table 3.1 shows the standard concentrations and peak area obtained. An example of chromatogram generated by HPLC equipment for 0.0625mg/ml standard is shown in Figure 3.1.

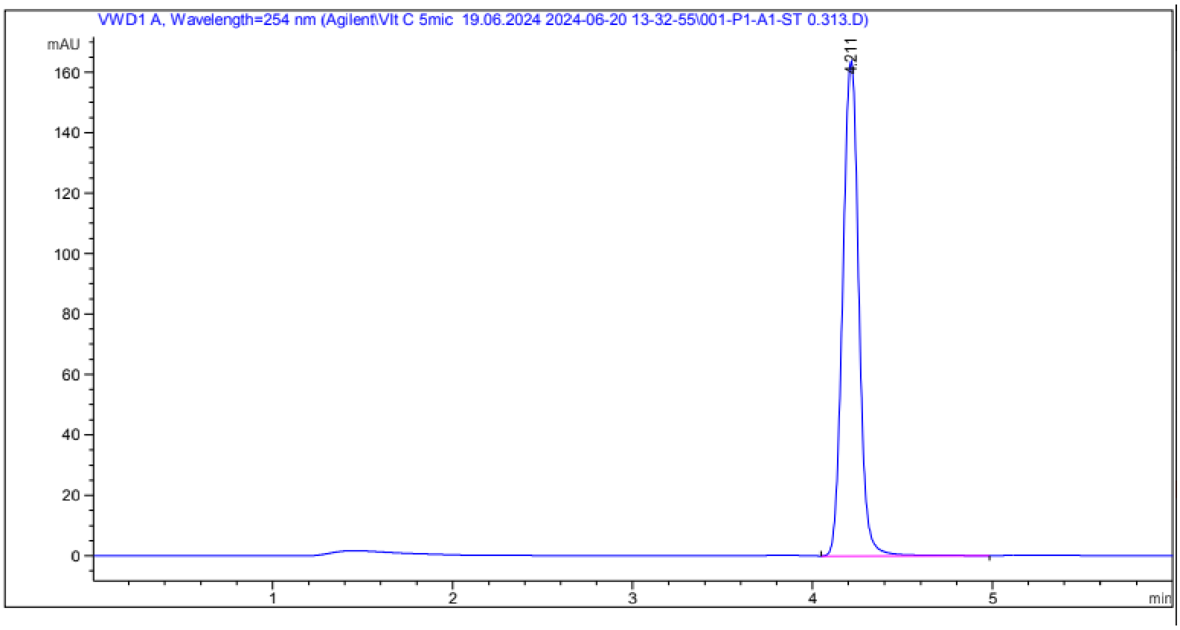

Figure 3.1 Chromatogram for 0.0625mg/ml

Table 3.1 Concentration of standards and peak area obtained

No. of Standards	Concentration (mg/ml)	Peak area (mAU)
1	0	0
2	0.0625	1004.5
3	0.125	2072.4
4	0.25	4335.3
5	0.5	8881
6	1	18087.2

This data is used to plot the calibration curve graph (Figure 3.1) in which X-axis denotes the concentration of standards and Y-axis denotes the peak area obtained. The trend line of calibration curve shows very high linearity due to the value of coefficient of variation R^2 being 0.9999. The trendline equation obtained from the chart using MS-Excel graph formatting feature was $y = 18165x – 135.69$. To calculate the ascorbic acid content of each sample, the equation of straight-line $y = mx + c$ was used where value of gradient 'm' and constant 'c' were already obtained, and value of 'x' variable was solved for by placing the peak area obtained for sample in the equation at the position of 'y' variable. The 'x' variable denotes ascorbic acid concentration in mg/ml of the diluted sample and then multiplied by dilution factor which is 2 for calculating the actual concentration in the original sample.

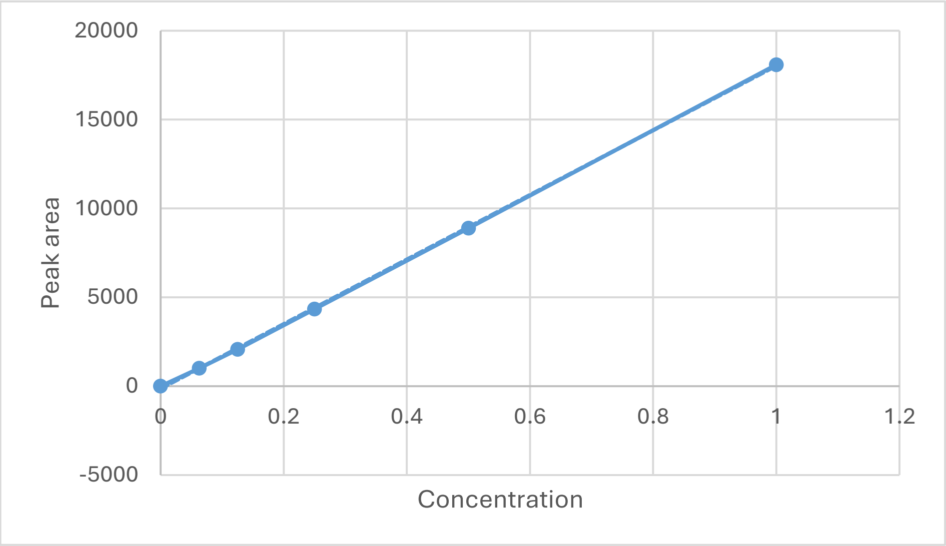

Figure 3.2 Standard calibration curve

As an illustrative example of vitamin C content determination, the raw tomato sample is mentioned below where the average peak area obtained for triplicate was 1586.65 mAU.

Peak area = 1586.65 mAU

Dilution factor = 2

Equation is y = 18165x - 135.69

So, the concentration of Vitamin C in raw tomato sample is,

1586.65 = 18165x – 135.69

x = (1586.65 + 135.69) / 18165

x = 0.094 mg/ml multiplied by 2 because dilution factor

So, the concentration in the sample = 0.189 mg/ml or 189 mg/ 100g

Similarly, calculation for each sample was conducted and mention in Appendix for reference. Table no. 3.2 and Figure 3.2 contains the average result of triplicate readings for each sample.

Table 3.2 Concentration of Vitamin C in the samples after cooking

Number	Vegetable Sample	Vitamin C content (mg/ml)			
		Raw	Blanching	Boiling	Oven Roasting
1	Tomato	0.189	0.168	0.113	0.158
2	Broccoli	0.506	0.531	0.572	0.312
3	Yellow Bell pepper	1.654	1.539	0.944	1.467

The results indicate that there is a significant loss of vitamin C content after cooking in tomato and yellow bell pepper meanwhile in case of broccoli the vitamin C content readings show different results influenced by the water absorption in sample and due to inherent limitations of the extraction process for dry raw sample and oven roasted sample.

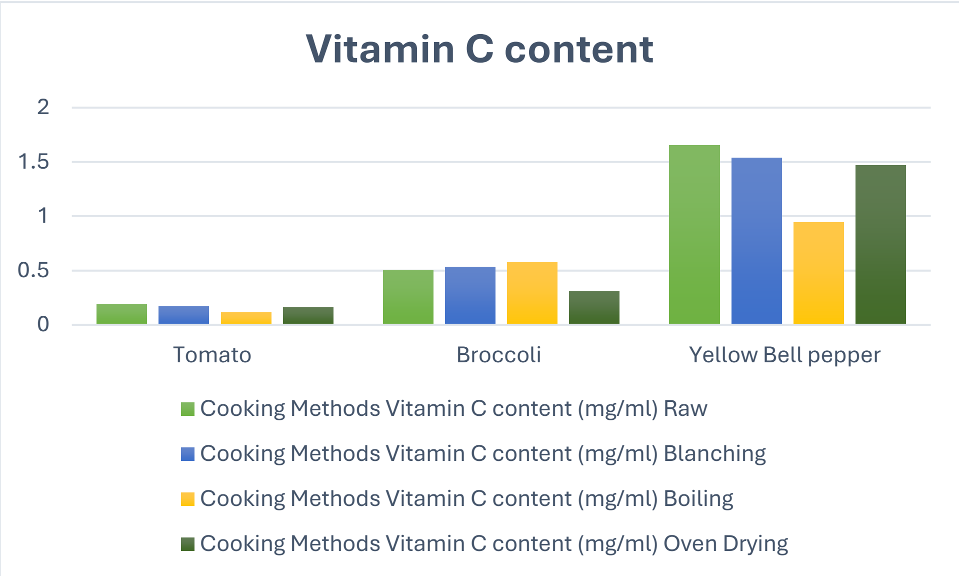

Figure 3.3 Bar graph illustration for comparison of vitamin C content

The statistical data in Table 3.3 presents the standard deviation in the total value Vitamin C and is converted to get the content for mg/100g.

Table 3.3 Standard deviation of triplicates and per 100g value.

Number	Vegetable Sample	Vitamin C content (mg/100g)			
		Raw	Blanching	Boiling	Oven Roasting
1	Tomato	18.9 ± 0.1	16.8 ± 0.2	11.3 ± 0.0	15.8 ± 0.4
2	Broccoli	50.6 ± 0.1	53.1 ± 0.3	57.2 ± 0.1	31.2 ± 0.3
3	Yellow Bell pepper	165.4 ± 0.6	153.9 ± 0.3	94.4 ± 0.3	146.7 ± 0.0

Data is expressed as mean ± standard deviation of triplicate readings.

3.1.1 Findings in Tomato

Boiling resulted in the most significant vitamin C loss in tomatoes, with a 40.21% reduction. Blanching caused a moderate loss of 11.2% in vitamin C content whereas oven roasting led to a 16.35% loss of vitamin C. Oven roasting showed more retention due to absence of water in the process hence decreasing the loss due to water solubility of vitamin C.

3.1.2 Findings in Yellow Bell pepper

Yellow bell pepper initially had the highest vitamin C content among the three vegetables. The results were similar to tomato as boiling caused the highest loss of vitamin C, with a 42.92% reduction. Blanching only caused a moderate loss of 6.94% which increases its acceptability for nutrient retention. Oven roasting led to a 11.01% loss of Vitamin C.

3.1.3 Findings in Broccoli

Vitamin C analysis in broccoli was hindered by the firmness of the structure of vegetable which affected the extraction process . Due to absorption of water and softening of the structure during boiling and blanching occurred which increased the extraction potential. The overall content was observed to be more as compared to the raw sample. The only vitamin C loss reported was in oven roasted sample which was 38.53% whereas there was more vitamin C present in the extract of sample processed using blanching being +5.12% and boiling being +6.36%.

3.2 Effect of cooking on Colour component

The analysis was done to determine the change in colour component of sensory properties of the vegetables. The ‘l’, ‘a’ and ‘b’ values were noted first for raw vegetables to set the as reference and then for cooked vegetables. The results highlight that the different cooking methods affected each vegetable differently and directly impacted the sensory properties. The readings from colorimeter are mentioned in the Table 3.4. The readings are presented in terms of (L*) Luminance, colour coordinates for green-red value (a*) and for blue-yellow value (b*).

Table 3.4 Readings from colorimeter

Sample ID	Treatment	L*	a*	b*
T1.1	Tomato Raw	36.37	12.91	19.59
T1.2	Tomato Blanched	36.51	7.26	22.82
T1.3	Tomato Boiled	40.16	9.66	19.07
T1.4	Tomato Oven Roasted	42.42	17.83	24.52
B1.1	Broccoli Raw	42.11	-11.38	15.65
B1.2	Broccoli Blanched	26.94	-18.19	22.9
B1.3	Broccoli Boiled	30.4	-17.92	24.1
B1.4	Broccoli Oven Roasted	27.57	-10.67	27.57
C1.1	Yellow Capsicum Raw	51.38	-4.69	41.92
C1.2	Yellow Capsicum Blanched	44.89	-7.35	32.83
C1.3	Yellow Capsicum Boiled	52.08	-4.97	45.2
C1.4	Yellow Capsicum Oven Roasted	54.23	-3.34	36.35

3.2.1 Findings in Tomato

Raw tomatoes exhibited a luminance of 36.37. Blanching slightly increased the luminance by 1% and boiling caused a further decrease in luminance by approximately 10% and significantly darkening the overall colour. In oven roasted tomatoes moderate darkening was observed due to change in a* and b* values leading towards slightly brown spectrum.

3.2.2 Findings in Yellow Bell pepper

Raw yellow bell peppers exhibited a luminance of 51.38 indicating a bright yellow colour. Blanching caused a slight darkening with around 10% change in luminance meanwhile boiling increased the luminance by 5% due to absorption of water. In oven roasted bell peppers slight darkening was observed around by 5% decrease in luminance.

3.2.3 Findings in Broccoli

Raw broccoli had a luminance of 42.11, indicating dark green colour. Blanching led to a significant lightening of the sample and made the green colour appear 36% more brighter simultaneously decreasing the a* value indicating increase in green colour. Boiling also caused lightening with a luminance of 30.4 indicating more fresher colour as compared to the raw broccoli. In oven roasted broccoli sample slight darkening is observed change in a* and b* values indicate the initiation of browning.

3.3 Observation

Overall, there has been significant changes in vitamin C and colour content of all three vegetables and blanching method has shown more retention of colour and vitamin C as compared to boiling and oven roasting method not taking account of results obtained in case of broccoli samples due to shortcomings of the general extraction process which caused difference in values contradictory to the previous research.

4. Discussion

Study aims to check importance of selection of cooking methods to retain original properties of vegetables. The vegetables selected are recognised for high vitamin C content and vibrant colours which were subjected to various cooking methods and nutrient retention was analysed by HPLC analysis and a CIEL*a*b Colorimeter for colour component evaluation, the observations show how heat exposure and water exposure impact vitamin C retention and colour values in yellow bell pepper, tomato and broccoli.

4.1 Effects of cooking methods on vegetables

4.1.1 Effects on Vitamin C

Vitamin C is an essential nutrient known for its antioxidant properties and roles in collagen synthesis, immune function and regeneration of other antioxidants like vitamin E. Due to its water-soluble nature, body does not store vitamin C, necessitating regular intake through dietary sources like fruits and vegetables. Current dietary intake recommendations suggest 95mg/ day for women and 110mg/ day for men with an additional 40mg/day recommended for smokers to counter the oxidative stress caused by smoking (EFSA, 2013; Nordic Nutrition Recommendation, 2023).

Recent research highlights the importance of vitamin C from whole foods rather than supplements. Studies have associated higher intake of vitamin C from fruits and vegetables with reduced risks of chronic diseases like cardiovascular disease, certain cancers and cognitive decline (Li et al., 2014). This increases the need to focus on dietary practices that maximize nutrient retention and to consume vitamin C rich foods such as berries, citrus fruits and leafy green vegetables, in their minimally processed or if possible, raw forms (Lykkesfeldt, and Carr, 2023).

Vitamin C is very vulnerable to heat, light and oxygen degradation and also leaches out in water. High temperatures can accelerate the hydrolysis of the vitamin in which it breakdowns to smaller, less active components. Storing food properly, such as in a cool dark place can also help retain vitamin C. The stability is influenced by factors like cooking time, temperature an exposure to water making the method of preparation important for retaining its content. The study confirmed that loss of vitamin C occurred in all the vegetables after cooking and the values were different according to the method used (Lee and Kader,2000).

Blanching involved dipping the vegetables in hot water for a short period of time and then cold shocking them by using ice bath, showed the least reduction of vitamin C content for tomato (11.2%) and yellow bell pepper (6.94%). The reason for reduction can be due to the water-soluble nature of vitamin C. The short exposure to heat turns out to be beneficial by minimising the breakdown of vitamin C. Similar results were observed by Sunmonu et al., 2021 in blanched tomatoes around 16.4 percent loss meanwhile, Okocha et al., 2023 observed 33% loss in cassava-based product blanched for 5 minutes.

Boiling process caused the most substantial loss of vitamin C, especially in yellow bell pepper (42.92%) and tomato (40.21%). The observed reduction is likely due to the high heat exchange and prolonged exposure to the water during boiling. Similar results were observed by Bureau et al., 2015 in which boiling process showed the highest loss (51%) of vitamin C, in case of Kinyi et al., 2022 almost 99% reduction was observed in *Amaranthus dubius.*

Oven roasting led to moderate decrease in vitamin C content in yellow bell pepper (11.01%) and tomato (16.35%). Oven roasting is a dry heat method hence preventing leeching as water was not involved in this cooking method. The study done by Hwang et al., 2012 also showed that prolonged exposure to high temperatures degrades ascorbic acid because in the observations made by author on roasting capsicum there has been a significant loss of 25% when oven roasted for 15 minutes at 190°C. Akomolafe, 2021 noted that roasted pumpkin seeds suffered a loss of 44% in pumpkin seeds which was slightly lower than boiled seeds.

Broccoli analysis showed a distinct behaviour, where boiling (26.52%) and blanching (23.98%) showed a moderate increase in vitamin C content, likely due to the breakdown of cell wall and enhanced extractability of nutrients. Boiling causes significant softening of tissues due to moisture content increment in the cellular structure (Iborra-Bernad, García-Segovia and Martínez-Monzó, 2015).

In contrast to the results of broccoli, literature consistently show that boiling causes substantial vitamin C losses. Yuan et al., 2009 reported that boiling reduced the vitamin C content of green beans by 50%, while Migilo et al., 2008 observed a similar loss in case of carrots. Meanwhile steaming retained vitamin C more effectively compared to boiling and roasting.

4.1.2 Effects on colour content

Color is a critical quality attribute in determining consumer perception and appeal, as it often signals the freshness and ripeness of vegetables (Hunt, 2011). The current study utilized the CIELAB colour space model to assess the changes in three important colour parameters: lightness (L*), red-green value (a*) and blue- yellow (b*) across yellow bell pepper, tomato and broccoli, pre-coking and post- cooking. Each cooking method- blanching, boiling and oven roasting led to range of difference in color alteration due to color degradation.

For Tomatoes, both blanching and boiling caused moderate increases in lightness (L*) with values increasing from 40.12 to 45.56 post-boiling. The reason behind this increase can be attributed to water absorption and pigment dilution during cooking. . The results indicated that different cooking methods caused varying degrees of colour change. The results are consistent with Perkins-Veazie et al., 2001 who reported that heat treatment in tomatoes breaks down carotenoids leading to an increased L* value on the other hand, oven roasting resulted in a slight decrease in L* from 40.12 to 38.67 likely due to the Maillard reaction which initiates browning and darkening of the tomato surface this result is similar to the findings of Shan, Zzaman and Yang, 2016 who observed increased browning reaction in roasted vegetables such as tomatoes and bell Peppers in terms of red green values a*. Oven roasting caused an increase from 14.24 to 17.35 indicating a shift towards red hues possibly due to the concentration of pigments as moisture evaporates.

Yellow bell Peppers showed notable changes in lightness factor across different cooking methods. Boiling increased the lightness L* from 56.78 to 61.34 which is likely due to the degradation of carotenoids in chlorophyll causing the peppers to appear pale. The authors observed increase in L* value is consistent with Krzykowsk et al., 2018 who also found that boiling enhanced the lightness of bell Peppers through pigment leaching in contrast blanching caused minimal change with L* value increasing from 56.78 to 57.11 retaining much of the pepper's original colour oven roasting however resulted in a substantial darkening with L* value dropping from 56.78 to 48.24 this significant reduction in lightness is likely due to surface Browning reactions at high temperatures similar results were reported by Hwang et al., 2012 who noted that roasting leads to the development of brown compounds which darken the vegetable's surface in addition to the changes in L* value the yellow intensity b* value of yellow bell pepper decreased significantly after boiling from 34.45 to 28.12 indicating a reduction in the vibrancy of yellow pigments.

Broccoli underwent considerable lightening when subjected to boiling and blanching with L* values increasing from 38.23 to 45.65 in 44.21 respectively. The lightening is attributed to chlorophyll degradation which is a heat sensitive pigment that breaks down during the cooking process Severini et al., 2016 also found that heat treatments such as boiling and blanching caused the breakdown of chlorophyll which results in a lighter green appearance. Oven roasting in contrast led to a reduction in lightness with L* value decreasing from 38.23 to 34.76, this darkening is likely caused due to browning reactions at high temperatures which are common in roasted vegetables the red-green a* values in broccoli were less affected although some changes were noted in hue depending on the cooking method.

4.2 Strengths and limitations of this study

This study had several strengths including the use of standardised cooking methods and reliable analytical techniques such as HPLC for vitamin C quantification and colorimeter analysis for objective colour measurement. These methods provide accurate reproducible results that allow for clear comparisons across different cooking methods and vegetables.

However, there were also limitations. One key limitation was that the study only used a single source of vegetables which may introduce variability due to differences in ripeness size or quality using vegetables from multiple sources in future studies would help reduce this bias. Additionally, the study focused on only three cooking methods blanching boiling and oven roasting which while common do not represent the full range of cooking techniques. Expanding the analysis to include methods such as steaming, grilling or microwaving could provide a more comprehensive understanding of how cooking affects vitamin C and colour retention.

Another limitation is the generalizability of the findings to other vegetables while the study focused on yellow bell pepper, tomato and broccoli it is unclear whether the results can be applied to other types of vegetables especially those with different nutrient profiles further research is needed to explore the effects of cooking on a wider variety of vegetables particularly those with different physical and chemical properties such as leafy greens or root vegetables.

5. Conclusion

This study demonstrates that cooking methods significantly influence the retention of vitamin C and colour vibrancy in yellow bell pepper, tomato and broccoli. Blanching emerged as the most favourable method for preserving both vitamin C and colour in yellow bell pepper and tomato. Vitamin C content was highest in raw yellow bell pepper 165.4 mg/ 100 grammes followed by broccoli 50.6 mg/ 100 g and tomato 18.9mg/ 100 g. Boiling caused the greatest vitamin C loss in yellow bell pepper (42.92%) and tomato (40.21%). Interestingly broccoli exhibited a 6.36% increase in vitamin C during boiling likely due to enhanced extract ability from cell wall breakdown. Oven roasting while less effective than blanching retained more vitamin C than boiling in both tomato and yellow bell pepper making it a suitable alternative when flavour enhancement is desired.

In terms of colour retention, blanching was the most effective with minimal changes in luminance and colour coordinates. For yellow bell pepper, the blanching process caused only a 10% decrease in luminance while boiling slightly increased it by 5% due to water absorption. In broccoli, blanching improved the lightness by 36% giving it a fresher appearance. Oven roasting resulted in the most significant colour darkening particularly in broccoli where ruminants decreased by 34.54%.

These findings have implications for public health and food policy, suggesting that promoting blanching as a cooking method could help preserve both the nutritional value and sensory appeal of vegetables. The study emphasises the importance of selecting appropriate cooking methods to maximise both nutrient retention and visual quality, with blanching being the most balanced option. The research process was thorough, with clear measurements of vitamin C content and colour retention though future studies could explore more kinds of extraction processes.

Future research should explore the impact of other cooking methods such as steaming, grilling or microwaving to provide a broader understanding of how different techniques affect nutrient retention in sensory attributes in vegetables. Additionally expanding the analysis to other nutrients such as carotenoids, flavonoids and minerals would give a more comprehensive picture of the nutritional changes that occur during cooking.

Understanding the relationship between sensory attributes like texture and flavour and cooking influenced changes is another promising area of research. This would allow for more tailored cooking recommendations that prioritise both nutrient retention and consumer satisfaction Finally, future studies should investigate the health implications of nutrient losses during cooking especially for populations with specific dietary needs such as those at risk for vitamin C deficiency.

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Appendices

Table. A1 shows the peak area obtained for each sample in HPLC analysis using which further calculations are done to get vitamin C concentration.

Table. A1 Peak area obtained for samples

Number and name	**Vitamin C (mg/ml)**	**Peak Area (mAU)**	**Sample used (g)**
A1.1 T1.1	0.191	1600.55	10
A1.2 T1.1	0.189	1579.71	10
A1.3 T1.1	0.189	1579.71	10
A2.1 T1.2	0.166	1371.05	10
A2.2 T1.2	0.169	1398.07	10
A2.3 T1.2	0.170	1406.01	10
A3.1 Broc1.1	0.505	4448.28	20
A3.2 Broc1.1	0.507	4466.94	20
A3.3 Broc1.1	0.507	4466.94	20
A4.1 Broc1.2	0.535	4719.82	20
A4.2 Broc1.2	0.530	4678.78	20
A4.3 Broc1.2	0.530	4678.78	20
A5.1 Cap1.1	1.659	14930.4	20
A5.2 Cap1.1	1.656	14904.2	20
A5.3 Cap1.1	1.647	14824.3	20
A6.1 Cap1.2	1.542	13866.2	20
A6.2 Cap1.2	1.539	13845.1	20
A6.3 Cap1.2	1.537	13826.5	20
A7.1 Broc1.3	0.573	5068.44	20
A7.2 Broc1.3	0.572	5056.41	20
A7.3 Broc1.3	0.572	5056.41	20
A8.1 Broc1.4	0.315	2722.66	20
A8.2 Broc1.4	0.312	2694.95	20
A8.3 Broc1.4	0.310	2682.72	20
A9.1 T1.3	0.113	887.8	10
A9.2 T1.3	0.113	888.79	10
A9.3 T1.3	0.113	888.79	10
A10.1 T1.4	0.153	1251.68	10
A10.2 T1.4	0.161	1324.12	10
A10.3 T1.4	0.160	1316.9	10
A11.1 Cap1.3	0.947	8462.58	20
A11.2 Cap1.3	0.945	8451.19	20
A11.3 Cap1.3	0.942	8423.76	20
B1.1 Cap1.4	1.467	13190.6	20
B1.2 Cap1.4	1.467	13190.6	20
B1.3 Cap1.4	1.467	13190.6	20

Lab Clearance form

LONDON METROPOLITAN UNIVERSITY

Science Centre Laboratory Clearance Form

End of project clearance form to be completed by student and supervisor. Completing this form constitutes verification that the student, as mentioned below, has completed their project work in the lab.

Name of Student:	Ashwin Rajesh
Student ID:	22047901
Supervisor Name:	Dr. Hamid Ghoddusi
Finish Date:	9/07/2024

In signing this form, both the student and laboratory supervisor attest that:

- ☒ Blue or Green box is cleared, cleaned, and returned to the dispensary.
- ☒ Fridges, freezers, incubators, and cold rooms are cleared of samples, if applicable.
- ☒ Any used glassware and portable equipment are returned to the dispensary.
- ☒ Chemicals, solvents, and equipment such as (pipettes, pipette boxes, spreaders, magnetic flees etc.).

Student Signature:	[illegible]
Supervisor Signature:	[illegible] B. Ghodd
Date:	11/7/24

Technical staff sign off the form here.	
Technician name:	L UBICATOTHOVA
Signature:	[illegible]
Date:	16/07/24

Version 2 June 2022