

STUDY THE IMPACT OF THERMAL TREATMENT ON THE QUALITY ATTRIBUTES OF COCONUT WATER

A THESIS

BY

EYASIN AHMED CHOWDHURY

Student Id: 1707061

Session: 2023-2024

Semester: Jan-June, 2024

MASTER OF SCIENCE

IN

FOOD PROCESSING AND PRESERVATION



DEPARTMENT OF FOOD PROCESSING AND PRESERVATION

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY

UNIVERSITY, DINAJPUR-5200

JUNE, 2024

STUDY THE IMPACT OF THERMAL TREATMENT ON THE QUALITY ATTRIBUTES OF COCONUT WATER

A THESIS

BY

EYASIN AHMED CHOWDHURY

Student Id: 1707061

Session: 2023-2024

Semester: Jan-June, 2024

Submitted to the

*Department of Food Processing and Preservation, Hajee Mohammad Danesh Science and
Technology University, Dinajpur in partial fulfilment of the requirements of the degree of*

MASTER OF SCIENCE

IN

FOOD PROCESSING AND PRESERVATION



DEPARTMENT OF FOOD PROCESSING AND PRESERVATION

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY

UNIVERSITY, DINAJPUR-5200

JUNE, 2024

STUDY THE IMPACT OF THERMAL TREATMENT ON THE QUALITY ATTRIBUTES OF COCONUT WATER

A THESIS

BY

EYASIN AHMED CHOWDHURY

Student Id: 1707061

Session: 2023-2024

Semester: Jan-June, 2024

Approved By

.....
Supervisor
Dr. S. M. Kamrul Hasan
Professor,
Department of Food Processing and
Preservation (FPP)

.....
Co-Supervisor
Md. Mojaffor Hosain
Associate Professor,
Department of Food Processing and
Preservation (FPP)

.....
Prof. Dr. S.M. Kamrul Hasan
Department of Food Processing and Preservation
Chairman of the Examination Committee

DEPARTMENT OF FOOD PROCESSING AND PRESERVATION
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY
UNIVERSITY, DINAJPUR-5200

JUNE, 2024

ACKNOWLEDGEMENT

I express my deepest sense of gratitude to almighty God who has given scope to me to carry out the present research work and complete to the thesis.

*It is a great privilege to me to express my deepest gratitude and profound regard to research Supervisor **Dr. S. M. Kamrul Hasan**, Professor, Department of Food Processing & Preservation (FPP), for his constant supervision, proper guidance, encouraging suggestions and enthusiastic support throughout this study.*

*I would like to express sense of appreciation, gratitude and indebtedness in respected Co-Supervisor **Md. Mojaffor Hosain**, Associate Professor, Department of Food Processing & Preservation (FPP) for her help, suggestions, assistance and criticism throughout the entire period of research work, as well as in the preparation of project report.*

*I would like to express my heartfelt gratitude to my friends, **Md Asaduzzaman** and **Sabur Khan**, for their invaluable support, immense help, and unwavering cooperation.*

Finally, I wish to acknowledge my heartfelt indebtedness to my beloved parents for patience, inspirations, sacrifices, blessing and encouragement for completing the research work successfully.

EYASIN AHMED CHOWDHURY

ABSTRACT

Coconut water, obtained from the fruit of the coconut palm (*Cocos nucifera*), is renowned for its refreshing taste and a variety of health benefits, including hydration, electrolyte balance, and antioxidant properties. As a natural beverage, it is rich in potassium, sodium, and magnesium, making it popular among athletes and health-conscious individuals. . This study examines the impact of microwave and autoclave treatment on the essential quality properties of coconut water, including physicochemical properties, microbial safety, enzymatic activity, and sensory characteristics. Microwave processing involves exposing the product to electromagnetic radiation, which heats it through the rapid vibration of water molecules. In contrast, autoclave processing, or steam sterilization, is a more traditional thermal treatment that uses pressurized steam to heat the product to high temperatures. Fresh coconut water was used as a control to compare the effects of each thermal process on key parameters such as color, flavor, taste, and overall acceptability. The results indicate that both treatments effectively inactivated microbial loads immediately after processing, with no bacterial growth detecting at day first. Moreover, microwave treatment led to a slower recovery of PPO and POD enzyme activity compare to autoclave treatment and also contributing to improved color retention and antioxidant stability. Physicochemical tests indicated minimal changes in pH and TSS for microwave and autoclave treated samples. Even though both thermal treatments ensured microbial safety, microwave treatment proved to be more effective in preserving the natural qualities of coconut water, particularly in terms of color, flavor, and overall sensory acceptability.

CONTENTS

CHAPTER	TITLE	PAGE NO.
	ACKNOWLEDGEMENTS	i
	ABSTRACT	ii
	CONTENTS	iii-iv
	LIST OF TABLES	v
	LIST OF FIGURES	vi
CHAPTER I	INTRODUCTION	1-2
CHAPTER II	REVIEW OF LITERATURE	3-9
2.1	Introduction	3
2.2	Nutritional Composition and Health Benefits of Coconut Water	4
2.3	Coconut Water Composition and Characteristics	4
2.4	Thermal Treatments for Food Preservation	6
2.4.1	Impact of Thermal Treatments on Quality Attributes	6
2.5	Perishability and Preservation Challenges	7
2.6	Enzyme Inactivation in Coconut Water	7
2.7	Thermal preservation methods of coconut water	8
CHAPTER III	MATERIALS AND METHODS	10-15
3.1	Chemicals and reagents	10
3.2	Sample preparation	10
3.3	Thermal treatment	10
3.3.1	Microwave treatment	11
3.4	Measurements of color parameters	12
3.5	Determinations of pH, total soluble solids (TSS) and titratable acidity (TA)	12
3.6	Determination of bioactive compounds	12
3.6.1	Total Phenol Content (TPC)	12
3.6.2	Total flavonoids content (TFC)	12
3.7	Analysis of antioxidant capacity	13

CONTENTS (Contd.)

CHAPTER	TITLE	PAGE NO.
3.7.1	Antioxidant capacity measured with DPPH assay	13
3.8	Enzyme Activity measurement	13
3.8.1	Polyphenol oxidase activity	13
3.8.2	Peroxidase activity	14
3.9	Shelf-life evaluation	14
3.10	Total Plate Count	14
3.11	Sensory Evaluation	15
3.12	Statistical analysis	15
CHAPTER IV	RESULTS AND DISCUSSION	16-25
4.1	Effect of thermal treatment on pH, TSS, and TA	16
4.2	Effect of thermal treatment on color	17
4.3	Mineral Composition in Coconut Water	18
4.4	Effect of thermal treatment on total phenolic content (TPC)	19
4.5	Effect of thermal treatment on total flavonoid content (TFC)	20
4.6	Effect of thermal treatment on antioxidant capacity	21
4.7	Effects of microwave treatment on microbial growth (TPC) during storage	22
4.8	Effects of microwave treatment on PPO and POD on enzyme activity during storage	23
4.9	Sensory evaluation of coconut drinks	25
CHAPTER V	CONCLUSIONS	26
	REFERENCES	27-31

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
1	Nutritional Composition of Coconut Water (DebMandal and Mandal, 2011)	4
2	Antioxidant Activity of Coconut Water (Yong et al., 2009)	4
3	Comparative Impact of Preservation Methods on Coconut Water (Raghubeer et al., 2017)	7
4	Changes in Physicochemical Properties During Storage (Chia et al., 2012)	7
5	Thermal preservation methods of coconut water	8
6	Changes of pH, and TSS, in terms of thermal treatment	16
7	Changes of color parameters (L, a*, b*) in terms of thermal treatment	17
8	Coconut Water Mineral Composition.	18
9	Heavy Metal Composition in Coconut water.	18
10	Changes in total plate count (TPC) in thermal treatment	23
11	Changes in PPO, POD enzymes of microwave-treated juice during storage	24

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1	Steps of coconut water preparation	11
2	Variations in total phenolic content (TPC) due to thermal treatments	19
3	Variations in total flavonoid content (TFC) due to thermal treatments	20
4	Changes of antioxidant capacity in terms of thermal treatment	21
5	Microbial load count during storage	23
6	Radar chart comparing the sensory attributes	25

CHAPTER I

INTRODUCTION

Coconut water, the clear, nutritious liquid found inside young, green coconuts, has emerged as a popular beverage worldwide.

In recent years, researchers have shown interest in the health and medicinal advantages of tender coconut products. It contains biologically important components such as sugars, proteins, free amino acids, vitamins, minerals, and growth-promoting factors (Tuyekar et al., 2021). Often dubbed "nature's sports drink," it is celebrated for its refreshing taste and numerous health benefits. Its low-calorie content, combined with a rich array of essential nutrients, positions coconut water as a superior alternative to artificial sports drinks and sugary beverages (Campbell-Falck et al., 2000). It has been effectively utilized for oral rehydration and the treatment of childhood symptoms, intestinal flu, and cholera in various regions around the world. (Tuyekar et al., 2021)

Nutritionally, coconut water is a treasure trove of vital components. It is rich in electrolytes such as potassium, sodium, and magnesium, which are crucial for maintaining proper hydration and muscle function (Yong et al., 2009).

Additionally, it contains vitamins like vitamin C and B-complex vitamins, amino acids, and antioxidants, all of which contribute to its health-promoting properties (DebMandal & Mandal, 2011). The presence of cytokinins, which have anti-aging and anti-carcinogenic effects, further enhances its nutritional profile (Ge et al., 2016). However, despite its numerous benefits, coconut water is highly perishable, making it susceptible to microbial spoilage and enzymatic degradation, which can significantly affect its quality and safety (González-Aguilar et al., 2003).

To address the perishability issue, various preservation methods have been explored, with thermal treatment being one of the most effective. (Aghajanzadeh et al., 2021)

Thermal treatments, such as microwave and autoclave treatments, are widely used in the food industry to ensure microbial safety and extend the shelf life of perishable products (Guzik et al., 2021). Microwave heating enhances energy efficiency and shortens heating times, potentially producing products with better sensory and nutritional quality compared to those processed through traditional pasteurization. (Martins et al., 2019).

Microwave treatment, characterized by its rapid and uniform heating, has the advantage of minimal nutrient loss and better retention of sensory qualities. (Saikia et al., 2015). Microwave radiation can heat materials with dielectric properties by absorbing the energy and converting it into heat. This ability makes microwaves useful across various industries and agricultural sciences. (Guzik et al., 2021)

This method uses electromagnetic waves to generate heat, which inactivates microorganisms and enzymes, thereby preserving the nutritional and sensory attributes of the product (Vadivambal & Jayas, 2010).

On the other hand, autoclave treatment involves high-pressure steam sterilization, which is highly effective in achieving complete microbial inactivation but may have a more pronounced impact on the quality attributes of the treated product (Stumbo, 1973).

The aim of this study is to investigate and compare the effects of microwave and autoclave treatments on the quality attributes of coconut water and evaluate the effectiveness of microwave and autoclave treatment in preserving coconut water during storage.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Coconut water, derived from the endosperm of young, green coconuts (*Cocos nucifera* L.), has gained significant popularity in recent years due to its refreshing taste, nutritional benefits, and potential health-promoting properties.

It is rich in essential electrolytes such as potassium, sodium, calcium, and magnesium, which are vital for hydration and electrolyte balance (Campbell-Falck et al., 2000). Additionally, coconut water contains bioactive compounds like cytokinins, which have anti-aging and anti-carcinogenic properties, and antioxidants that help combat oxidative stress (Yong et al., 2009).

Several studies have examined the nutritional composition of coconut water. For instance, DebMandal and Mandal (2011) analyzed the nutrient profile of coconut water and reported significant amounts of sugars, vitamins (such as vitamin C and B-complex vitamins), amino acids, and minerals. Important amino acids like arginine, alanine, and cysteine contribute to its nutritional value.

The physicochemical properties of coconut water, including pH, total soluble solids (TSS), and color, are critical indicators of its quality. Research by Prades et al. (2012) indicated that the pH of fresh coconut water typically ranges from 4.5 to 5.5, while the TSS content is around 5-6°Brix. These parameters are influenced by factors such as the maturity of the coconut and storage conditions.

Storage studies have shown that the quality attributes of coconut water change over time. Chia et al. (2012) investigated the effects of storage on the physicochemical properties of coconut water and found that the pH decreased during storage due to the production of organic acids by microbial activity. Additionally, the TSS content decreased, which was attributed to the utilization of sugars by microorganisms. The color of coconut water also changed, with a noticeable browning effect primarily due to the Maillard reaction and enzymatic browning influenced by the presence of sugars and amino acids.

2.2 Nutritional Composition and Health Benefits of Coconut Water

Coconut water is a nutrient-rich beverage containing essential electrolytes, vitamins, amino acids, and antioxidants. According to Yong et al. (2009), coconut water is particularly high in potassium, magnesium, and sodium, which are vital for maintaining electrolyte balance and proper hydration. It also contains cytokinins, which exhibit anti-aging and anti-carcinogenic properties (Ge et al., 2016). Additionally, coconut water is low in calories and rich in vitamins such as vitamin C and B-complex vitamins, enhancing its nutritional profile and making it a valuable beverage for health-conscious consumers (DebMandal & Mandal, 2011).

Table 1: Nutritional Composition of Coconut Water (DebMandal and Mandal, 2011)

Nutrient	Amount (per 100 ml)
Potassium	250-300 mg
Sodium	10-25 mg
Calcium	20-25 mg
Magnesium	10-15 mg
Vitamin C	2-4 mg
Sugars	2.6-5.0 g
Amino Acids	0.1-0.5 g

Table 2: Antioxidant Activity of Coconut Water (Yong et al., 2009)

Antioxidant Activity	Value
DPPH Radical Scavenging Activity	150-180 μ mol TE/100 ml
Reducing Power	0.2-0.4 Absorbance
Total Phenolic Content	20-25 mg GAE/100 ml

2.3 Coconut Water Composition and Characteristics

Coconut water is a nutritious, fat-free beverage that is low in sugars and calories while being high in essential nutrients. However, once a coconut is opened, the water inside begins to gradually lose its nutrients and flavors. This degradation is partly due to enzymes found in coconut water, such as peroxidase (POD) and polyphenol oxidase (PPO), which react with oxygen, leading to the loss of nutritional value and flavor (Evans and Halliwell, 2001). Young coconut water tends to contain more sugar and total phenolics compared to mature

coconut water. It is naturally sterile within its shell and contains a mixture of organic and inorganic compounds that support the body's antioxidant system (Evans and Halliwell, 2001)

Inorganic ions play a crucial role in various cellular functions, including enzymatic activation, bone formation, hemoglobin function, gene expression, and the metabolism of amino acids, lipids, and carbohydrates (Institute of Medicine, 2000) . Coconut water is rich in these inorganic ions, contributing to its therapeutic properties. The basic ionic composition of coconut water helps replenish essential electrolytes, such as sodium, potassium, magnesium, and calcium, which are lost through sweat. This makes coconut water an effective rehydration beverage, as its electrolyte balance closely resembles that of the human body, promoting homeostasis without disruption (Vigliar et al., 2006).

Tender coconut water (TCW) consists of approximately 95.5% water, 4% fats, 0.1% protein, 0.02% calcium, 0.01% phosphorus, 0.5% iron, along with significant amounts of amino acids, mineral salts, vitamins (including B-complex), cytokines, sugars, alcohol sugars, lipids, nitrogenous compounds, organic acids, and enzymes (Santoso et al., 1996) . Delta-lactones contribute to the unique taste of tender coconut water. TCW is also rich in amino acids such as arginine, alanine, cysteine, and serine, containing higher levels of these amino acids compared to cow's milk (Markose and Poduval, 2009). Potassium is one of the most prominent minerals in TCW, playing a significant role in its flavor.

Interestingly, after four months of exclusive breastfeeding, the calcium content in colostrum begins to decline. Regular consumption of coconut water by nursing mothers can help meet their babies' calcium needs (Vigliar et al., 2006). Tender coconut water also contains ascorbic acid (vitamin C) and B-complex vitamins, with ascorbic acid concentrations ranging from 2.2% to 3.7% per 100ml. As the coconut matures and the surrounding kernel hardens, the ascorbic acid content decreases. Additionally, coconut water contains folate (vitamin B9), which was discovered in the late 1930s and is essential for preventing anemia during pregnancy and reducing mitochondrial toxicity caused by methanol metabolites (Jackson et al., 2004) .

Because of its rich mineral composition and low total sugar content, coconut water is a natural isotonic liquid, making it an ideal rehydrating and refreshing beverage after physical activity (Reddy and Lakshmi, 2003).

2.4 Thermal Treatments for Food Preservation

Several studies have compared the effects of microwave and autoclave treatments on various food products. Ahmed et al. (2016) investigated the impact of these treatments on the nutritional and sensory qualities of fruit juices. Their findings indicated that microwave treatment resulted in better retention of vitamins and antioxidants compared to autoclave treatment. Similarly, Al-Hilphy et al. (2012) compared the effects of microwave and autoclave treatments on the quality attributes of milk. The study concluded that microwave treatment preserved the nutritional and sensory qualities of milk more effectively than autoclave treatment.

In the context of coconut water, limited research has been conducted to compare the effects of microwave and autoclave treatments. Prades et al. (2012) explored the impact of thermal treatments on the quality attributes of coconut water and found that microwave treatment was more effective in preserving the nutritional and sensory qualities compared to conventional pasteurization methods. However, comprehensive studies comparing microwave and autoclave treatments specifically on coconut water are lacking, highlighting the need for further research in this area.

In a study, sugarcane juice samples were heated in a microwave, ELBA EMO-A271 oven (Fiamma Sdn. Bhd., Malaysia) at three different heating levels; 120 W (ML), 400 W (MM), and 700 W (MH) for 5 min. (Songchai Adulvitayakorn et al., 2019)

2.4.1 Impact of Thermal Treatments on Quality Attributes

The quality attributes of coconut water, including its physicochemical properties, nutritional composition, and sensory characteristics, are critical for consumer acceptance. Thermal treatments can significantly influence these attributes. According to Ge et al. (2016), the application of microwave treatment can preserve the natural flavor, color, and nutritional content of coconut water more effectively than traditional thermal methods. In contrast, autoclave treatment, while effective in microbial inactivation, may lead to nutrient degradation and alterations in taste and appearance (Stumbo, 1973).

Table 3: Comparative Impact of Preservation Methods on Coconut Water (Raghubeer et al., 2017)

Preservation Method	Microbial Load (CFU/ml)	Sensory Quality (1-10 scale)	Vitamin C (mg/100 ml)
Fresh	10 ⁴	9	3.8
Pasteurization	<10	8	3.5
Autoclaving	<10	6	2.0
Microwave	<10	8	3.2

2.5 Perishability and Preservation Challenges

Despite its numerous benefits, coconut water is highly perishable due to its susceptibility to microbial spoilage and enzymatic degradation. González-Aguilar et al. (2003) emphasized that the high water content and nutrient-rich composition of coconut water create an ideal environment for microbial growth, leading to rapid spoilage. Traditional preservation methods, such as refrigeration and pasteurization, have been employed to extend the shelf life of coconut water. However, these methods often result in changes to its sensory and nutritional qualities (Prades et al., 2012).

Table : 4 Changes in Physicochemical Properties During Storage (Chia et al., 2012)

Storage Time (Days)	pH	TSS (°Brix)	Color (L* value)
0	5.4	5.8	68
7	5.1	5.4	65
14	4.8	5.0	62
21	4.5	4.6	58

2.6 Enzyme Inactivation in Coconut Water

Polyphenol oxidase (PPO) and peroxidase (POD) are the primary enzymes responsible for browning and off-flavor development in coconut water (Matsui et al., 2008). These enzymes catalyze oxidation reactions that lead to the formation of brown pigments and undesirable flavor compounds. Thermal inactivation of these enzymes has been a focus of numerous

studies. Murasaki-Aliberti et al. (2009) reported that a combination of temperature and time (90°C for 180 seconds) was effective in inactivating both PPO and POD in coconut water, but resulted in noticeable changes in flavor. Augusto et al. (2012) further investigated the kinetics of PPO and POD inactivation in coconut water, finding that POD was more heat-resistant than PPO and required higher temperatures or longer treatment times for complete inactivation. Understanding the thermal stability and inactivation kinetics of these enzymes is crucial for optimizing thermal treatments that effectively extend shelf life while minimizing quality losses.

Table : 5 Thermal preservation methods of coconut water (Naik et al., 2020)

Treatments	Treatment Conditions	Observations/Results
Conventional Thermal Heating	Temperature 5°C to 80°C	Density and Newtonian viscosity were affected negatively; Thermal diffusivity affected positively
	Temperature 100°C; Time 10 min	Can preserve the coconut water up to a six-month period; Slight decrease in acidity during storage
	Temperature 80–95°C; Time 2.5–15 min	The thermal resistance of enzymes varies with the maturity stage; Enzymes in over-matured coconut water have lower thermal resistance
	Temperature 110°C and 136°C	Prevent pink discoloration and loss of organic compounds
	Temperature 90°C; Time 5 min; Temperature 80°C; Time 15 min	Reduction in microbes, sensory, and nutritional value
	Temperature 80–95°C; Time 2.5–10 min	Thermal inactivation of peroxidase achieved at 95°C for 5 min
	Pressure 400 Mpa; Temperature 90°C; Time 300 s	Effectively inactivates the enzymes
	Temperature 110°C; Time 8 s	Develop undesirable pink color; Decrease in sugars, organic acids, and ethanol
	Temperature 85°C; Time 10 min	Microbiologically safe for consumption till the fifth week of storage; Loss of the desirable sweet-sour flavor and development of astringent quality
	Temperature 93°C; Time 16 s; Power level 2450 MHz	Temperatures above 90°C, enzymes activity was not detected

Microwave Processing	Temperature 84.45°C; Time 20 s; Power level 2450 MHz	Inactivate the polyphenol oxidase and peroxidase faster than conventional thermal heating
	Temperatures between 0°C and 90°C; Frequencies between 500 and 3000 MHz	Compared to salts, sugars had weak polarization or loss during processing
	Temperature 100–140°C; Time 0–600 s	Formation of 3-pentane-2-one and ethylactonoate volatile compounds are good indicators of ohmic heating treatment
	Voltage gradient 50–20 V/cm; Temperature 80°C, 90°C and 100°C; Time 0, 1.5 and 3 min	By increasing voltage gradient and heating time, the activity of polyphenol oxidase was gradually decreased
Ohmic Heating	Voltage 100–300 V; Frequency 50 Hz; Temperature 74°C; Time 15 s	Retains 97% tyrosol compared to conventionally heated samples (90%)
	Coconut water spray dried with 15% maltodextrin; Inlet temperatures 165°C; Outlet temperatures 65°C	Produces 55% amorphous coconut powder; Good physico-chemical, antioxidant, and storage stability characteristics
Spray Drying	Coconut water spray dried with the addition of maltodextrin (20% w/v); Inlet temperature 150°C; Outlet temperature 67°C; Airflow 50 mm; Feed rate 3 ml/min	Good physico-chemical, antioxidant, and storage stability characteristics
	Using Moringaoleifera gum (1.5%), maltodextrin (30%); Inlet temperature 120°C	Yields a better quality of spray-dried coconut water powder

CHAPTER III

MATERIALS & METHODS

3.1 Chemicals and reagents

Folin–Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), p-Nitrophenyl- α -D-glucopyranoside (pNPG), α -glucosidase, sodium bicarbonate, gallic acid, quercetin, acarbose, sodium nitrite, and aluminum chloride hexahydrate ($\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$), and methanol (99.9%), pyrocatechol, guaiacol, PVP were of analytical grade (Sigma Aldrich, Germany). Analytical grade hydrochloric acid, and sodium hydroxide, mono-sodium phosphate, disodium phosphate, potassium hydrogen phosphate (K_2HPO_4), potassium dihydrogen phosphate (KH_2PO_4), and hydrogen peroxide (H_2O_2) were also purchased from Merck, Germany.

3.2 Sample preparation

Coconut water samples were collected from the local market in Dinajpur. Each coconut was carefully cut and open using a clean knife to avoid contamination. The coconut water was then poured directly into sterile beakers for further analysis. Total soluble solid (TSS) and pH value of the coconut water were determined in the ranges of 5.2–5.3° Brix and 4.6–4.70, respectively.

3.3 Thermal treatment

The coconut water was processed using both a microwave oven and an autoclave. To treat it in the microwave, 300 ml of fresh coconut water in a 1000 ml beaker was microwaved for 6 minutes. Similarly, for autoclave treatment, the same amount of coconut water in a 1000 ml beaker was placed in an autoclave at 121°C and 15 psi for 4 minutes. After both treatments, the coconut water was immediately cooled to room temperature in a biosafety cabinet and preserved in sterilized bottle for analysis.

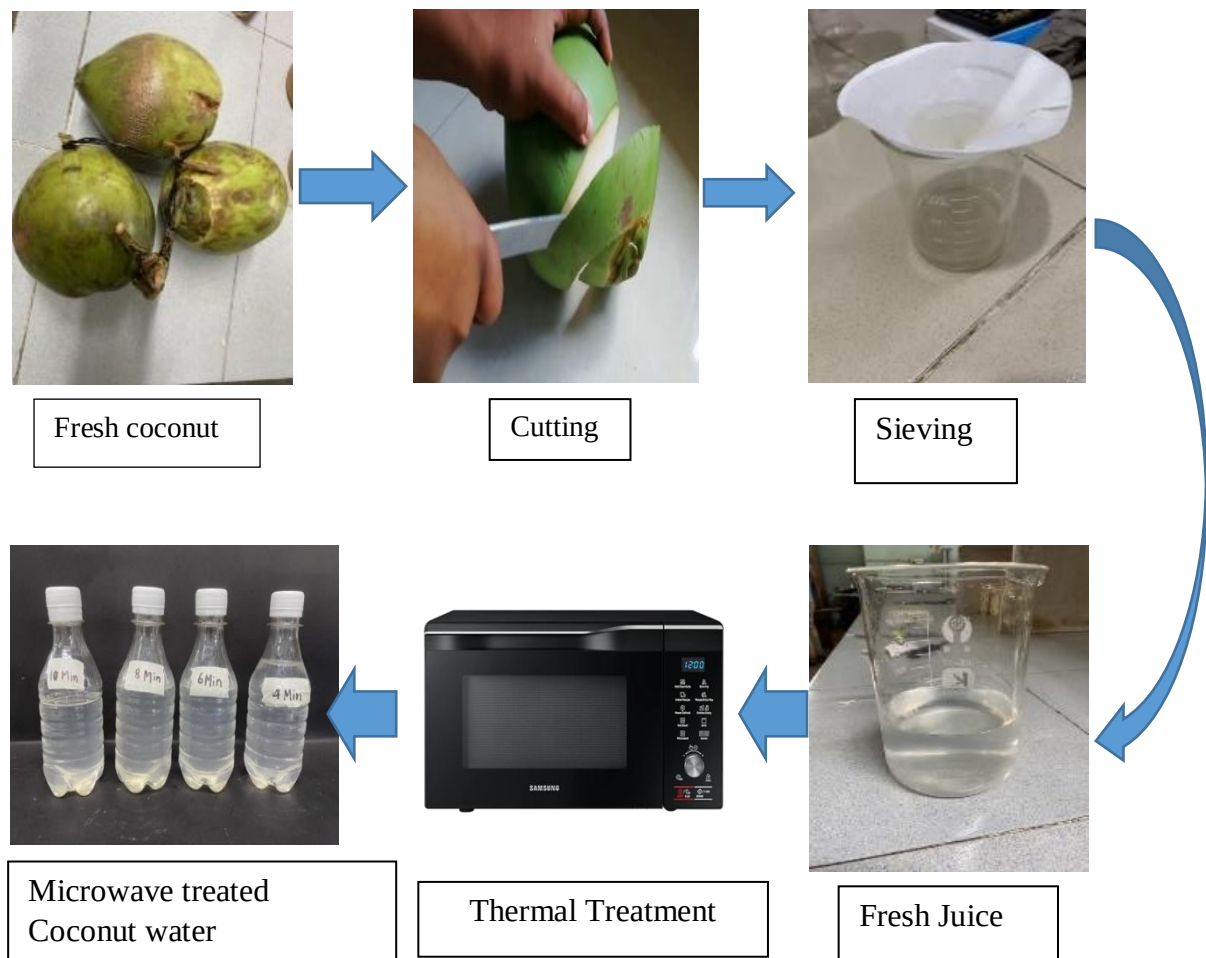


Figure 1: Steps of coconut water preparation

3.3.1 Microwave treatment

Microwave treatment utilizes electromagnetic radiation, typically at a frequency of 2450 MHz, to efficiently heat substances such as coconut water. This method relies on the agitation of water molecules within the liquid, induced by microwave energy. As the microwaves penetrate the juice, they cause the water molecules to oscillate. This oscillation generates internal friction, leading to heat production directly within the liquid, unlike traditional methods that heat from the outside. This mechanism allows for rapid and even heating throughout the liquid. Such a process proves effective for microbial inactivation, as demonstrated in a study where *Escherichia coli* levels in apple juice were reduced by 2–4 log cycles with microwave power settings ranging from 270W to 900W. The primarily thermal nature of microbial inactivation was evidenced by D-values, which varied from 0.42 minutes at 900W to 3.88 minutes at 270W, indicating quicker microbial reduction at higher power levels (Cañumir et al., 2002).

3.4 Measurements of color parameters

A colorimeter was used to analyze color at room temperature (25°C). A white color reference was used to calibrate the chromometer. L stood for lightness, a* for redness, and b* for yellowness in the color expression system. Three measurements were taken, and the average of the data was calculated. Additionally, the following equations were used to get the overall color difference (ΔE):

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}$$

Where L_0 , a_0 , and b_0 represented the control values for coconut water.

3.5 Determinations of pH, and total soluble solids (TSS)

The pH values of coconut water samples were measured at room temperature by a pH meter. The TSS of coconut water was measured using a digital refractometer at an ambient temperature and expressed as °Brix.

3. 6 Determination of bioactive compounds

3.6.1 Total Phenol Content (TPC)

The total amount of phenolic compounds was measured using the Folin-Ciocalteu method, which was reported by Islam et al. (2023). Initially, 0.5 mL of the sample extract and 0.5 mL of the Folin-Ciocalteu reagent were mixed. 1 mL of 7.5% Na_2HCO_3 solution was transferred to the mixture, which was then diluted with distilled water to make the volume 10 mL. The mixture was vortexed for 30 seconds and then kept in a dark place for 35 minutes before it was centrifuged at 4000 rpm for 10 minutes. The absorbance was taken at 750 nm by a UV-Vis spectrophotometer (UV-1800, Shimadzu Corporation, Japan). The total amount of TPC (mg GAE/ml coconut water) was determined based on the gallic acid (0-200 μM) standard curve ($R^2 = 0.9976$).

3.6.2 Total flavonoids content (TFC)

The total flavonoid content (TFC) was determined following the method described by Islam et al. (2023). In brief, 1 mL of the coconut water was placed in a falcon tube along with 4 mL of distilled water and 0.3 mL of 5% NaNO_2 solution. After allowing the mixture to rest for five minutes, 0.3 mL of 10% AlCl_3 was added, and the solution was left to stand for one minute. Furthermore, 2.4 mL of distilled water and 2 mL of 1 M NaOH were then added and thoroughly mixed. After centrifuging the mixture for 10 minutes at 4000 rpm, it was placed

in a dark area for 15 minutes. After that, a UV-vis spectrophotometer (UV-1800, Shimadzu Corporation, Kyoto, Japan) was used to measure the absorbance at 510 nm. The TFC (mg QE/ml coconut water) was then calculated using the quercetin (0–100 μ M) calibration curve ($R^2 = 0.993$).

3.7 Analysis of antioxidant capacity

3.7.1 Antioxidant capacity measured with DPPH assay

The DPPH free radical scavenging activity was determined using the method presented by Islam et al. (2020). In brief, a vigorous mix of 50 μ L coconut water and 1.950 mL of DPPH methanolic solution was used, and the mixture was allowed to rest in a dark place at room temperature. After that, a UV-vis spectrophotometer (UV-1800, Shimadzu Corporation, Japan) was used to measure the absorbance at 515 nm. The Trolox standard curve was used to determine the results, which were represented as μ M Trolox equivalents per milliliter of coconut water (μ M Trolox/ml coconut water).

3.8 Enzyme Activity measurement

3.8.1 Polyphenol oxidase (PPO) activity

Polyphenol oxidase activity of coconut water was measured using the method described by Sarkar et al. (2024) with slight modification. To optimize the polyphenol oxidase assay, an enzyme extraction solution was prepared first by mixing 1% PVP with 100 ml 0.02 M sodium phosphate buffer of pH 7. After that, the enzyme was extracted by adding a 10 ml coconut water sample to a 20 ml enzyme extraction solution and vortexed for 1 to 2 minutes. The mixture was centrifuged at 1000 rpm for 20 minutes, and the resulting supernatant was used to measure the absorbance. The final PPO assay solution comprised 2 ml of 0.1 M pyrocatechol and 0.5 ml of distilled water. The reaction was initiated by adding 500 μ L of enzyme extract to the assay solution, which was vortexed and immediately absorbance was read in a spectrophotometer at 420 nm for 15 min at 30 sec or 1-minute intervals. The polyphenol oxidase activity was calculated based on the following equation.

$$\text{Polyphenol oxidase activity} = \Delta A \times \frac{\text{Total volume}}{\text{Enzyme extract}} \times \text{Dilution factor}$$

$$\text{Dilution factor} = \frac{\text{Total volume of extraction}}{\text{Sample weight}}$$

Where, ΔA = Absorbance difference per minutes; Total volume = Cuvette reagent volume; Enzyme extract = amount of enzyme extract taken.

3.8.2 Peroxidase (POD) activity

Peroxidase enzyme activity of coconut water was measured using the method described by MacAdam et al. (1992) with slight modification. To optimize the peroxidase assay, enzyme extraction solution was prepared first by mixing 1% PVP with 100 ml 0.05 M potassium phosphate buffer of 6.5 pH. After that, the enzyme was extracted by adding a 10 ml coconut water sample to 20 ml enzyme extraction solution and vortexed for 1 to 2 minutes. The mixture was then centrifuged at 1000 rpm for 20 minutes, and the resulting supernatant was used to measure the absorbance. The final peroxidase assay solution was composed of 1 ml of 0.05 M potassium phosphate buffer (pH 6.5), 250 μ L of 0.2 M guaiacol, and 500 μ L of 0.1 M hydrogen peroxide. The reaction was initiated by adding 500 μ L of enzyme extract to the assay solution, which was vortexed and immediately absorbance was read in a spectrophotometer at 470 nm for 15 min at 30 sec or 1 minute interval. The peroxidase activity was calculated based on the following equation.

$$\text{Peroxidase activity} = \Delta A \times \frac{\text{Total volume}}{\text{Enzyme extract}} \times \text{Dilution factor}$$

$$\text{Dilution factor} = \frac{\text{Total volume of extraction}}{\text{Sample weight}}$$

Where, ΔA = Absorbance difference per minutes; Total volume = Cuvette reagent volume; Enzyme extract = amount of enzyme extract taken.

3.9 Shelf-life evaluation

After treatment, all samples were stored at room temperature for 30 days. Samples were carried out at 0, 15, 30 days to determine quality and enzyme activity changes during storage.

3.10 Total Plate Count

The total plate count technique reported by Ma et al. (2019) was followed to detect live cells in coconut water, with some modifications. 0.89% sterile saline solution was used to serially dilute each sample, and one milliliter of each dilution was transferred onto triplicate plates using the nutrient agar. The total aerobic bacteria (TAB) were counted after 48 hours of incubation at 37 °C.

3.11 Sensory Evaluation

Fresh coconut water served as the control sample. At zero days of storage, a panel of 10 judges assessed the sensory qualities of fresh, microwave-treated, and autoclave treated coconut water. The panelists evaluated each sample based on key attributes such as color, flavor, cloudiness, and overall acceptability. Using a 9-point Hedonic scale, where 1 represented strong dislike and 9 indicated strong liking, the judges provided their ratings.

3.12 Statistical analysis

All results were presented as average value $\pm$ standard deviation (SD). Data was analyzed by One-way analysis of variance (ANOVA) of the SPSS 22 software (Chicago, IL, USA). Mean separations were performed by Duncan's multiple-range test. Differences were considered significant at $p < 0.05$.

CHAPTER IV

RESULT & DISCUSSION

4.1 Effect of thermal treatment on pH and TSS of coconut water

As indicated in Table 6, there was no statistically significant difference ($p > 0.05$) in the pH and total soluble solids (TSS) of coconut water subjected to microwave, autoclave, and untreated conditions. The pH values ranged from 4.61 to 4.69, while the TSS ranged from 5.10 to 5.23 °Brix, indicating that the thermal treatments had a minimal effect on these parameters. This suggests that both microwave and autoclave treatments did not adversely affect the acidity or sweetness of coconut water, and the values remain within acceptable quality standards for fresh coconut water.

These findings are consistent with prior studies on the thermal treatment of fruit-based beverages. For example, Prades et al. (2012) observed that pasteurization of coconut water at 70°C for 15 minutes did not significantly affect the pH or °Brix values, maintaining its natural taste and sensory attributes. Similarly, Marta et al. (2014) reported that both pasteurization and microwave treatments had negligible effects on the °Brix and pH levels of orange juice, highlighting that moderate thermal processes are capable of preserving the key physicochemical qualities of coconut water without substantial alterations.

Therefore the results demonstrate that coconut water retains its core attributes, such as pH and TSS, even after thermal processing, making these treatments suitable for extending shelf life while preserving the natural characteristics of the beverage.

Table 6: Changes of pH, and TSS, in terms of thermal treatment

Sample	pH	TSS (°Brix)
Fresh juice	4.68 ± 0.02^a	5.10 ± 0.10^a
Microwaved	4.69 ± 0.01^a	5.20 ± 0.0^a
Autoclaved	4.61 ± 0.01^a	5.23 ± 0.06^a

Data are presented as means $\pm$ standard deviation ($n = 3$);

4.2 Effect of thermal treatment on color

Thermal treatments, such as microwave and autoclaving, have profound effects on the color properties of coconut water, which is reflected in the data presented in Table 7. It highlights the variations in these parameters for microwave- and autoclave-treated coconut water. A significant shift ($p < 0.05$) was observed in all treatments compared to fresh coconut water. Both microwave and autoclave processing caused a reduction in the L^* value (lightness), while the a^* value (redness) increased. However, the b^* value (yellowness) remained relatively constant. For example, coconut water had the highest L^* value, which declined after microwave treatment and dropped further post-autoclaving. This darkening, indicated by a lower L^* value, may be linked to an increase in redness (a^*) and the breakdown of specific pigments, a phenomenon also noted in studies on other fruit juices (Rattanathanalerk et al., 2005).

Our results align with earlier research on the thermal treatment of coconut water, which exhibited a similar pattern. Increased thermal intensity led to a visible darkening of the juice, shown by a reduction in L^* value and an elevation in a^* value (Genovese et al., 1997; Ibarz et al., 1999). These color changes are largely due to non-enzymatic browning reactions, such as the Maillard reaction, as well as pigment degradation, which commonly cause color deterioration during thermal processing (Garza et al., 1999; Bhattacharjee et al., 2011).

The ΔE value, representing the total color difference, is a critical measure for assessing color change. In this study, ΔE was greater for autoclave-treated juice compared to microwave-treated juice, reflecting a larger overall color change with more intense thermal treatment. Previous studies have made similar observations, showing that thermally treated coconut water displayed higher ΔE values, suggesting noticeable visual differences from fresh samples (Aguilo-Aguayo et al., 2009; Wibowo et al., 2015). These findings imply that thermal processing, especially autoclaving, causes considerable color alterations.

Table 7: Changes of color parameters (L , a^* , b^*) in terms of thermal treatment

Sample	L	a^*	b^*	ΔE
Fresh juice	32.28 ± 0.50^a	1.56 ± 0.08^a	4.71 ± 0.07^a	
Microwaved	30.94 ± 0.19^b	1.77 ± 0.02^b	4.67 ± 0.04^a	1.36 ± 0.01^b
Autoclaved	30.73 ± 0.22^b	1.86 ± 0.09^c	4.66 ± 0.03^a	1.58 ± 0.02^a

Data are presented as means $\pm$ standard deviation ($n = 3$); Means followed by different superscript letters (a-c) in the same column differed significantly at $p < 0.05$.

4.3 Mineral Composition in Coconut Water

Table 8: Coconut Water Mineral Composition.

Minerals	Concentration (mg/L)
Zinc	0.607 ± 0.020a
Copper	0.025 ± 0.002b
Iron	0.0173 ± 0.001c
Manganese	0.8903 ± 0.015a
Potassium	2310 ± 50a
Sodium	80.5 ± 1.5b
Calcium	449.92 ± 10.1a
Magnesium	39.44 ± 0.9b
Phosphorus	20.28 ± 0.8a

Table 9: Heavy Metal Composition in Coconut water.

Heavy Metals	Concentration (mg/L)
Chromium	0.001 ± 0.0001b
Cadmium	0.0048 ± 0.0003b
Nickel	0.1467 ± 0.005a
Lead	0.0325 ± 0.001a

“(Means ± Standard Deviation, n = 3). Means followed by different superscript letters (a-c) in the same column show statistical differences among minerals.”

Coconut water is widely recognized for its rich mineral content, offering a variety of essential nutrients beneficial for human health. Potassium, found in high concentrations of 2310 mg/L, is the most abundant mineral, essential for maintaining electrolyte balance, heart function, and muscle contractions, making coconut water an excellent natural rehydration beverage, as supported by research from Campos et al. (2015). In addition to potassium, significant levels of calcium (449.92 mg/L) and magnesium (39.44 mg/L) contribute to bone health and muscle function, consistent with findings by Yong et al. (2009) and Amalraj & Pius (2015), highlighting their roles in preventing osteoporosis and supporting cardiovascular health. Coconut water also contains trace minerals such as zinc (0.607 mg/L), copper (0.025 mg/L), iron (0.006 mg/L), and manganese (0.8903 mg/L), all of which are crucial for various metabolic processes. Zinc supports immune function, copper aids in iron metabolism, and manganese contributes to bone development and antioxidant defenses, as demonstrated in studies by Hunt et al. (2013). However, alongside these beneficial minerals, trace amounts of cadmium (0.0048 mg/L) and lead (0.0325 mg/L) were also detected, which, although below the safety limits set by health authorities such as the World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA), pose potential health risks with long-term exposure, as they can accumulate in the body. Previous research, including studies by

Prohaska (2011) and Zimmermann & Hurrell (2007), emphasizes the importance of monitoring environmental contaminants in natural products like coconut water, particularly in regions prone to soil and water pollution. Therefore, while coconut water remains a valuable source of hydration and nutrients, it is essential to ensure its safety through regular quality assessments.

4.4 Effects of thermal treatment on total phenolic content (TPC) of coconut water

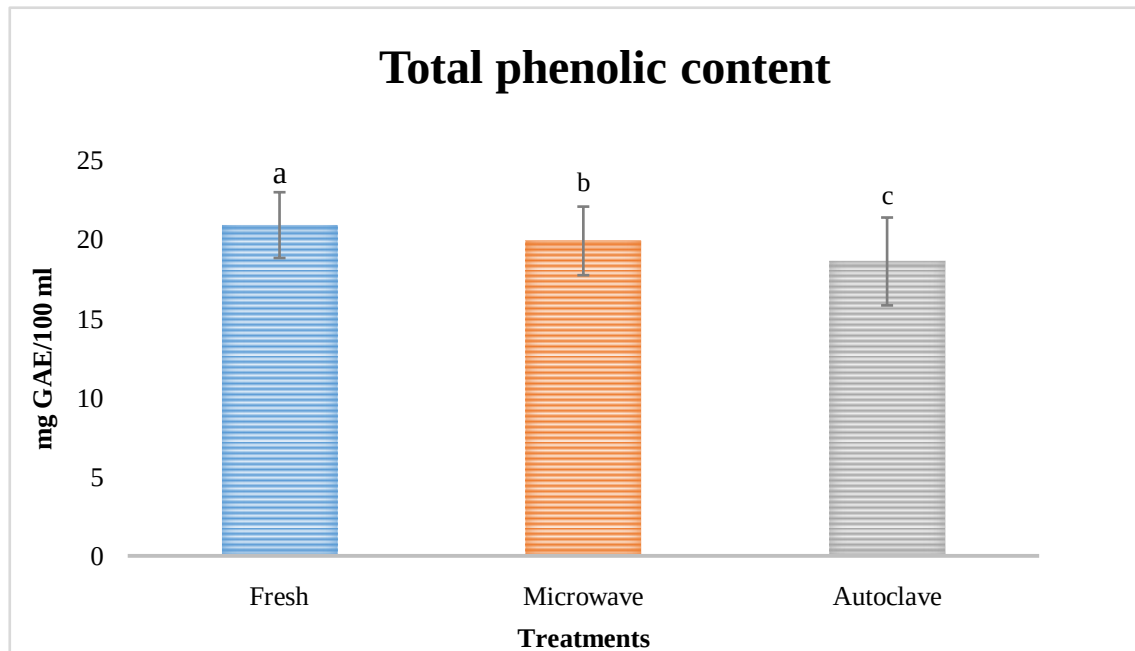


Figure 2: Variations in total phenolic content (TPC) due to thermal treatments are displayed. The mean values, differentiated by lowercase letters (a–c), indicate statistically significant differences between the treatments.

Phenolic compounds are recognized for their antioxidant capabilities, which are crucial for combating oxidative stress and associated degenerative diseases (Patel et al., 2022). The graph depicted illustrates the impact of different treatment methods on the phenolic content in coconut water, highlighting significant variations among the treatment types as indicated by figure 2. Specifically, the phenolic content in fresh coconut water was notably higher at 20.9 mg GAE/100 mL compared to those subjected to microwave and autoclave treatments, which recorded 19.9 mg GAE/100 mL and 18.6 mg GAE/100 mL respectively.

The study revealed that the TPC values decreased post-treatment, with autoclave treatment showing the most significant reduction, aligning with findings by Lee and Kim (2018) that

thermal processing can detrimentally affect phenolic compounds due to their heat-labile nature. These results were statistically significant ($p < 0.05$), emphasizing the decrease in phenolic content due to thermal degradation processes. Such findings support the theory posited by Gupta et al. (2017) that thermal treatments can induce oxidative degradation of phenolic substances, further corroborated by evidence from Zhang et al. (2019) who reported similar impacts in their study on thermally processed beverages.

4.5 Effects of thermal treatment on total flavonoid content (TFC) of coconut water

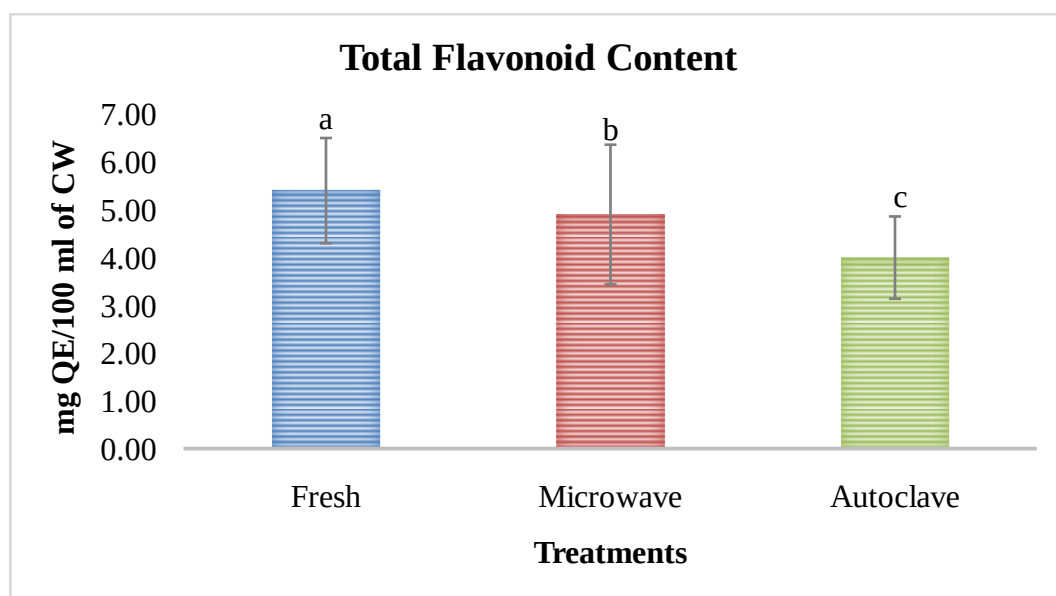


Figure 3: Variations in total flavonoid content (TFC) due to thermal treatments are displayed. The mean values, differentiated by lowercase letters (a–c), indicate statistically significant differences between the treatments.

The data presented in the figure 3 shows the Total Flavonoid Content (TFC) in coconut water under different processing conditions. The fresh coconut water sample had the highest TFC at 5.40 ± 1.10 mg/100 ml, followed by microwave-treated coconut water at 4.90 ± 1.46 mg/100 ml, and autoclave-treated coconut water at 4.00 ± 0.86 mg/100 ml. This indicates a decreasing trend in TFC as the processing intensity increases.

Coconut water is known for its nutritional properties and bioactive compounds, including flavonoids. The observed decrease in TFC with thermal processing aligns with findings in the scientific literature related to coconut water. For instance, Tan et al. (2014) reported that thermal processing of coconut water led to significant reductions in bioactive compounds, including flavonoids.

The microwave treatment resulted in a relatively smaller decrease in TFC compared to autoclave treatment. This is consistent with research by Reddy et al. (2005), who found that microwave processing can sometimes better preserve bioactive compounds in coconut water compared to conventional thermal treatments due to shorter processing times and more uniform heating.

The more substantial decrease in TFC observed with autoclave treatment may be attributed to the higher temperatures and longer processing times typically associated with this method. This is supported by studies such as that of Chowdhury et al. (2009), who observed significant reductions in antioxidant activity and bioactive compounds in coconut water subjected to thermal processing.

4.6 Effect of thermal treatment on antioxidant capacity

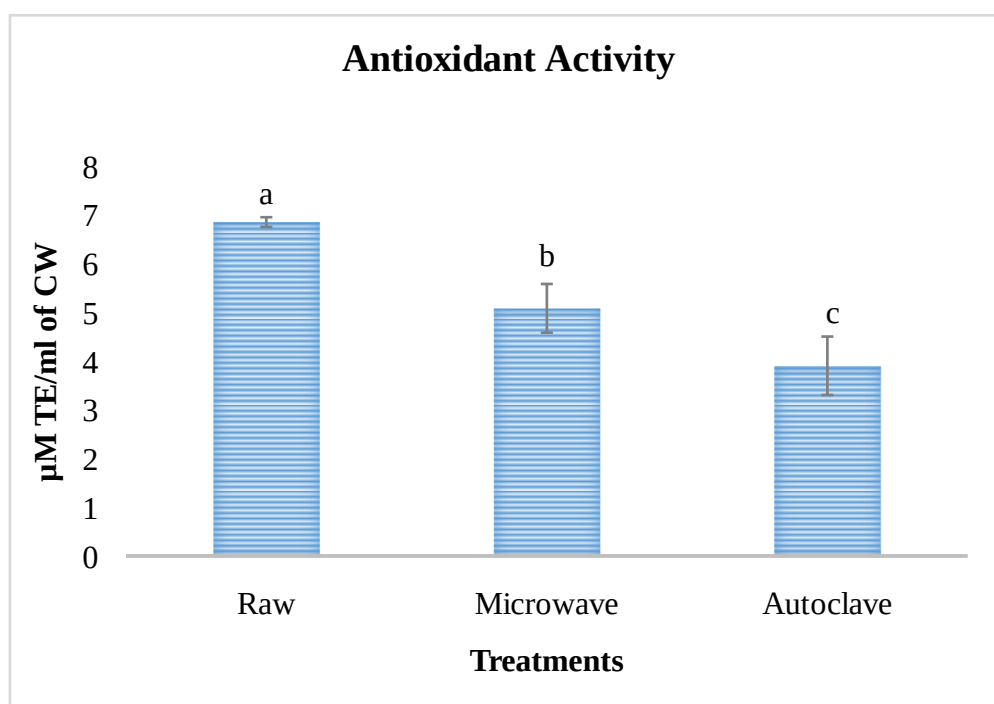


Figure 4: Changes of antioxidant capacity in terms of thermal treatment. Means followed by different lowercase letters (a–c) show significant differences among treatments.

The data presented in the graph shows the antioxidant activity (measured by DPPH assay) of coconut water under different processing conditions. The fresh coconut water sample exhibited the highest antioxidant activity (6.86 ± 0.1 µM TE/ml), followed by microwave-treated coconut water (5.09 ± 0.5 µM TE/ml), and autoclave-treated coconut water ($3.91 \pm$

0.6 μM TE/ml). This trend indicates a decrease in antioxidant activity as the intensity of thermal processing increases.

Antioxidants play a crucial role in neutralizing free radicals and preventing oxidative stress, which is linked to various chronic diseases. The DPPH assay results demonstrate that both microwave and autoclave treatments significantly ($p < 0.05$) reduced the antioxidant capacity of coconut water compared to the fresh sample. The observed reduction in antioxidant activity with thermal processing is consistent with findings in the literature. For instance, Tan et al. (2014) reported that thermal processing of coconut water leads to significant reductions in antioxidant compounds, including phenolics and flavonoids, which contribute to the overall antioxidant activity.

Specifically, microwave treatment resulted in a retention of approximately 74.2% of the original antioxidant activity, while autoclave treatment preserved only about 57.0%. This aligns with research by Reddy et al. (2005), who found that microwave processing can better preserve bioactive compounds, including antioxidants, due to shorter exposure times and more uniform heating.

The more substantial decrease in antioxidant activity observed with autoclave treatment can be attributed to the higher temperatures and longer processing times typically associated with this method. This is supported by studies such as that of Chowdhury et al. (2009), who observed significant reductions in antioxidant activity in coconut water subjected to autoclave treatment.

4.7 Effects of thermal treatment on microbial growth during storage of coconut water

The microbiological quality of coconut water was evaluated by measuring the total plate count (TPC) in samples treated with microwave and autoclave over a 30-day storage period. The results are presented in the table above.

Immediately after treatment (day 0), both microwave and autoclave processing completely inactivated the microbial population in coconut water, with total plate counts below the detection limit. This initial complete inactivation is consistent with previous studies on thermal processing of fruit juices and coconut water (Rawson et al., 2011; Cappelletti et al., 2015).

During the storage period, both treatments showed a gradual increase in microbial counts. In Table 9, for the microwave-treated samples the TPC reached 3.6 log₁₀ CFU/mL at day 15 and slightly increased to 3.9 log₁₀ CFU/mL by day 30. The autoclave-treated samples showed a similar trend, with 3.48 log₁₀ CFU/mL at day 15, increasing to 3.9 log₁₀ CFU/mL by day 30 (table 10).

The observed microbial recovery and growth during storage could be attributed to the survival and subsequent multiplication of heat-resistant spores or the recovery of sub-lethally injured cells (Silva and Gibbs, 2001) (figure5).

Table 10: Changes in total plate count (TPC) in thermal treatment

Treatments	Days of storage	Total plate count (log ₁₀ CFU/mL)
Microwave	0	Not detected
	15	3.6 ^b
	30	3.9 ^a
Autoclave	0	Not detected
	15	3.48 ^b
	30	3.9 ^a

Data are presented as means ± standard deviation (n = 3); N.D. not detected indicates (detection limit < 1 CFU/mL); Different superscript letters (a-b) indicates significantly different means P<0.05 in the same column.

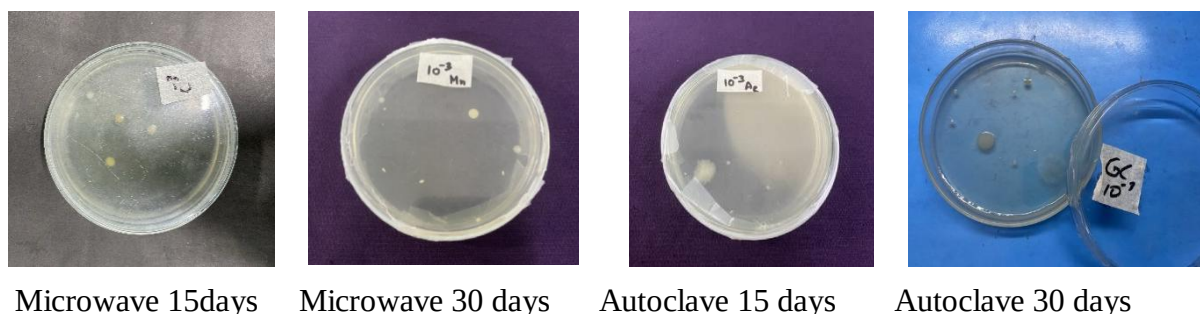


Figure 5: Microbial load count during storage

4.8 Effects of thermal treatment on PPO and POD enzyme activity during storage

The data presented shows the activity of polyphenol oxidase (PPO) and peroxidase (POD) enzymes in coconut water subjected to microwave and autoclave treatments over a 30-day

storage period. Both treatments demonstrated an initial reduction in enzyme activity compared to untreated samples, consistent with findings by Matsui et al. (2008) who reported thermal inactivation of these enzymes in coconut water.

For microwave-treated samples, PPO activity decreased from 0.022 U/ml at day 0 to 0.018 U/ml by day 30, while POD was completely inactivated initially but showed slight recovery (0.00675 U/ml) by day 30 (Table 10). This partial inactivation and potential reactivation of enzymes align with observations by Augusto et al. (2015), who noted that microwave processing could result in incomplete enzyme inactivation in coconut water.

Autoclave treatment initially showed higher PPO activity (0.036 U/ml) compared to microwave treatment, possibly due to the release of bound enzymes as suggested by Murasaki-Aliberti et al. (2009) in their study on pineapple juice. However, PPO activity in autoclaved samples decreased to 0.018 U/ml by day 30, matching the level in microwave-treated samples. POD activity in autoclaved samples remained constant at 0.00675 U/ml throughout the storage period.

These results indicate that both treatments partially inactivated PPO and POD, with microwave treatment showing more immediate effects on POD. The gradual decrease in PPO activity during storage in autoclaved samples suggests potential delayed effects of heat treatment or enzyme instability over time, as observed by Campos et al. (1996) in coconut water. The persistent low levels of enzyme activity highlight the challenges in completely inactivating these quality-deteriorating enzymes in coconut water, emphasizing the need for optimized processing conditions or combination treatments to enhance stability and extend shelf life

Table 11: Changes in PPO, POD enzymes of coconut water during storage

Treatments	Days of storage	PPO (U/ml)	POD (U/ml)
Microwave	0	0.022	0.0135
	15	0.018	0
	30	0.018	0.00675
Autoclave	0	0.036	0.00675
	15	0.03	0.00675
	30	0.018	0.00675

4.9 Sensory evaluation of coconut drinks

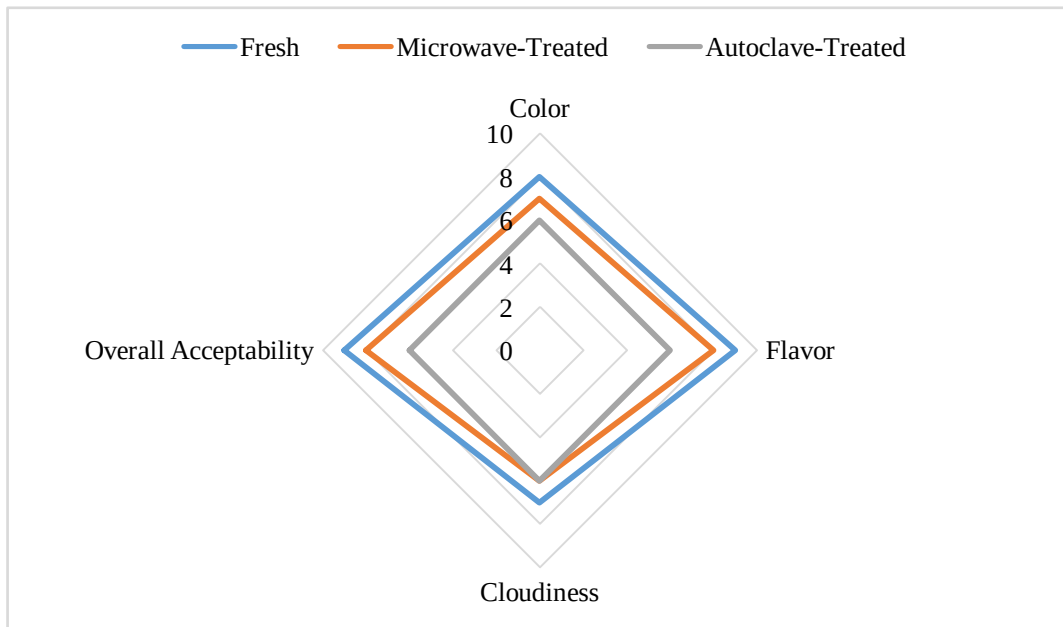


Figure 6: Radar chart comparing the sensory attributes (color, flavor, cloudiness, and overall acceptability) of fresh, microwave-treated, and autoclave-treated coconut water.

The comparison of sensory attributes based on the radar chart (Fig. 6) highlights the performance of fresh, microwave-treated, and autoclave-treated coconut water samples across four key parameters: color, flavor, cloudiness, and overall acceptability. Fresh coconut water consistently scored the highest in all categories, with a near-perfect score of 9 for flavor and overall acceptability. It also performed well in color (8) and cloudiness (7), reinforcing its superior sensory qualities.

Microwave-treated samples closely followed the fresh sample, scoring 8 for both flavor and overall acceptability, indicating that this treatment retains much of the original coconut water's appeal. However, it registered slightly lower in color (7) and cloudiness (6), showing a minor but noticeable degradation in these areas compared to the fresh sample.

On the other hand, autoclave-treated coconut water scored the lowest across all attributes, particularly in color, flavor, and overall acceptability (each scoring 6), reflecting the adverse effects of high-temperature processing. The cloudiness attribute also remained stagnant at 6, similar to the microwave-treated sample. These results indicate that while microwave treatment preserves much of the coconut water's sensory characteristics, autoclaving significantly compromises its overall quality.

CHAPTER V

CONCLUSION

This study aimed to evaluate the effects of microwave heating and autoclaving on the quality attributes of coconut water, as well as to investigate the efficacy of these treatments in ensuring microbial safety, enzyme inactivation, and sensory quality preservation during storage at room temperature. The research findings revealed that while both microwave and autoclave treatments led to some reduction in bioactive compounds and antioxidant activity compared to fresh coconut water, these losses were significantly lower in microwave-treated samples than in autoclaved ones.

Key physicochemical parameters such as pH and Total Soluble Solids (TSS) of coconut water remained largely unaffected by both thermal treatments. However, color analysis demonstrated a notable total color difference (ΔE) in microwave-treated samples compared to autoclaved ones, indicating better color retention with microwave heating.

Both microwave treatment and autoclaving proved highly effective in reducing the total microbial count to below detectable limits. Although some microbial growth was observed during the storage period for both treatments, it remained within acceptable limits, suggesting an extended shelf life for the thermally processed coconut water.

Enzyme activity analysis showed that both microwave heating and autoclaving successfully inactivated polyphenol oxidase (PPO) and peroxidase (POD), two key enzymes responsible for quality deterioration in coconut water.

In conclusion, this study demonstrates that while both microwave treatment and autoclaving are effective methods for inactivating enzymes and spoilage microorganisms in coconut water, microwave heating offers superior results in terms of quality preservation. The better retention of bioactive compounds, antioxidant activity, color, and sensory characteristics in microwave-treated samples, compared to autoclaved ones, suggests that microwave technology offers a promising alternative for coconut water preservation. This method effectively extends shelf life while minimally impacting the product's quality attributes, making it a more advantageous option than autoclaving for coconut water processing.

REFERENCES

- AC Kannangara, VGG Chandrajith and KKDS Ranaweera. Comparative analysis of coconut water in four different maturity stages. *J Pharmacogn Phytochem* 2018;7(3):1814-1817.
- Aghajanzadeh, S., Ziaifar, A. M., & Verkerk, R. (2021). Effect of thermal and non-thermal treatments on the color of citrus juice: A review. *Food Reviews International*, 39(6), 3555–3577.
- Aguilo-Aguayo, I., Soliva-Fortuny, R., & Martin-Belloso, O. (2009). Avoiding non-enzymatic browning by high-intensity pulsed electric fields in strawberry, tomato and watermelon juices. *Journal of Food Engineering*, 92(1), 37-43.
- Awua, A. K., Doe, E. D., & Agyare, R. (2011). Exploring the influence of sterilisation and storage on some physicochemical properties of coconut (*Cocos nucifera* L.) water. *BMC Research Notes*, 4(1), 451.
- Bhattacharjee, A. K., Tandon, D. K., Dikshit, A., & Kumar, S. (2011). Effect of pasteurization temperature on quality of aonla juice during storage. *Journal of Food Science and Technology*, 48(3), 269-273.
- Campbell-Falck, D., Thomas, T., Falck, T. M., Tutuo, N., & Clem, K. (2000). The intravenous use of coconut water. *The American Journal of Emergency Medicine*, 18*(1), 108-111.
- Campbell-Falck, D., Thomas, T., Falck, T. M., Tutuo, N., & Clem, K. (2000). The intravenous use of coconut water. *American Journal of Emergency Medicine*, 18*(1), 108-111.
- Cañumir, J. A., Celis, J. E., de Bruijn, J., & Vidal, L. V. (2002). Pasteurisation of Apple Juice by Using Microwaves. *Lebensmittel-Wissenschaft und Technologie*, 35, 389-392.
- Chandrasekaran, S., Ramanathan, S., & Basak, T. (2013). Microwave food processing—A review. *Food Research International*, 52(1), 243-261.
- Chia, C. L., Rosnah, S., Noranizan, M. A., & Wan Ramli, W. D. (2012). The effect of storage on the quality attributes of ultraviolet-irradiated and thermally pasteurized fresh young coconut water. *International Food Research Journal*, 19*(2), 657-664.

- Chowdhury, M. M., Aziz, M. G., & Uddin, M. B. (2009). Development of shelf-stable ready-to-serve green coconut water. *Biotechnology*, 8(1), 44-51.
- DebMandal, M., & Mandal, S. (2011). Coconut (*Cocos nucifera* L.: Arecaceae): In health promotion and disease prevention. **Asian Pacific Journal of Tropical Medicine*, 4*(3), 241-247.
- Garza, S., Ibarz, A., Pagán, J., & Giner, J. (1999). Non-enzymatic browning in peach puree during heating. *Food Research International*, 32(5), 335-343.
- Ge, L., Yong, J. W. H., Goh, N. K., Chia, L. S., Tan, S. N., & Ong, E. S. (2016). Identification of kinetin and kinetin riboside in coconut water using a combined approach of liquid chromatography–tandem mass spectrometry, high performance liquid chromatography and capillary electrophoresis. **Journal of Chromatography B*, 829*(1-2), 26-34.
- Genovese, D. B., Elustondo, M. P., & Lozano, J. E. (1997). Color and cloud stabilization in cloudy apple juice by steam heating during crushing. *Journal of Food Science*, 62(6), 1171-1175.
- González-Aguilar, G. A., Ayala-Zavala, J. F., & De La Rosa, L. A. (2003). Preserving quality of fresh-cut products using safe technologies. **Journal of Food Science and Technology*, 40*(5), 341-350.
- Guzik, P., Kulawik, P., Zając, M., & Migdał, W. (2021). Microwave applications in the food industry: an overview of recent developments. *Critical Reviews in Food Science and Nutrition*, 62(29), 7989–8008.
- Ibarz, A., Pagán, J., & Garza, S. (1999). Kinetic models for colour changes in pear puree during heating at relatively high temperatures. *Journal of Food Engineering*, 39(4), 415-422.
- Igual, Marta & Contreras, Catalina & Camacho, M. & Martínez-Navarrete, N.. (2014). Effect of Thermal Treatment and Storage Conditions on the Physical and Sensory Properties of Grapefruit Juice. *Food and Bioprocess Technology*. 7. 10.1007/s11947-013-1088-6.

- Institute of Medicine (IOM), Dietary Reference Intakes for Calcium, Phosphorous, Magnesium, Vitamin, and Fluoride, National Academy Press; Washington DC, USA, 2000. doi: 10.17226/5776; PMID: 23115811.
- Jackson, J.C, Gordon A, Wizard, G, McCook K, Rolle R, Changes in Chemical Composition of Coconut (*Cocos nucifera* L) Water During Maturation of the Fruit, *J. Sci Food Agric*; 2004; 54:1049–1052. <https://doi.org/10.1002/jsfa.1783>.
- Kannangara, A. C., Chandrajith, V. G. G., & Ranaweera, K. K. D. S. (2018). Comparative analysis of coconut water in four different maturity stages. *Journal of Pharmacognosy and Phytochemistry*, 7(3), 1814-1817.
- Markose V.T, Sree Kumar Poduval, Processing and Value Addition of Coconut, Coconut Development Board, India, 2009; 3.
- Martins, Carolina & Cavalcanti, Rodrigo & Cardozo, Tatiana & Couto, Sílvia & Guimarães, Jonas & Fasura Balthazar, Celso & Rocha, Ramon & Pimentel, Tatiana & Freitas, Mônica & Raices, Renata & Silva, Marcia & Esmerino, Erick & Granato, Daniel. (2021). Effects of microwave heating on the chemical composition and bioactivity of orange juice-milk beverages. *Food Chemistry*. 345. 128746.
- Matsui, K. N., Gut, J. A. W., de Oliveira, P. V., & Tadini, C. C. (2008). Inactivation kinetics of polyphenol oxidase and peroxidase in green coconut water by microwave processing. *Journal of Food Engineering*, 88(2), 169-176.
- Murasaki Aliberti, Nathalia & Silva, Rodrigo & Gut, Jorge & Tadini, Carmen. (2009). Thermal inactivation of polyphenoloxidase and peroxidase in green coconut (*Cocos nucifera*) water. *International Journal of Food Science & Technology*. 44. 2662 - 2668. 10.1111/j.1365-2621.2009.02100.x.
- Naik, M., C. K., S., Rawson, A., & N, V. (2020). Tender Coconut Water: A Review on Recent Advances in Processing and Preservation. *Food Reviews International*, 38(6), 1215–1236.
- P. Evans, B. Halliwell, Micronutrients: Oxidant/antioxidant Status. *Br. J. Nutr.* 2001; 85:67–74. PMID: 11509092.
- Prades, A., Dornier, M., Diop, N., & Pain, J. P. (2012). Coconut water preservation and processing: a review. *Fruits*, 67(3), 157-171.

- Raghubeer, E. V., Campbell, N. A., & Rajasingham, S. (2017). Comparative evaluation of pasteurization, autoclaving, and microwave treatments on the microbial and sensory qualities of coconut water. *Journal of Food Processing and Preservation*, 41*(6), e13235.
- Rattanathanalerk, M., Chiewchan, N., & Srichumpoung, W. (2005). Effect of thermal processing on the quality loss of pineapple juice. *Journal of Food Engineering*, 66(2), 259-265.
- Rawson, A., Patras, A., Tiwari, B. K., Noci, F., Koutchma, T., & Brunton, N. (2011). Effect of thermal and nonthermal processing technologies on the bioactive content of exotic fruits and their products: Review of recent advances. *Food Research International*, 44(7), 1875-1887.
- Reddy, P., Lakshmi M, Coconut Water Properties, Uses, and Nutritional Benefits in Health and Disease Review, *Journal of Current Clinical Medicine and Laboratory Biochemistry*, 2003; 10(2):11-21.
- Saikia, S., Mahnot, N. K., & Mahanta, C. L. (2015). A comparative study on the effect of conventional thermal pasteurisation, microwave and ultrasound treatments on the antioxidant activity of five fruit juices. *Food Science and Technology International*, 22(4), 288–301.
- Santoso U, Kubo, K, Ota T, Tadokoro T, Maekawa A, Nutrient Composition of Kopyor Coconuts (*Cocos nucifera* L.), *Food Chem*, 1996; 57:299–304. doi: [https://doi.org/10.1016/0308-8146\(95\)00237-5](https://doi.org/10.1016/0308-8146(95)00237-5).
- Tan, T. C., Cheng, L. H., Bhat, R., Rusul, G., & Easa, A. M. (2014). Composition, physicochemical properties and thermal inactivation kinetics of polyphenol oxidase and peroxidase from coconut (*Cocos nucifera*) water obtained from immature, mature and overly-mature coconut. *Food Chemistry*, 142, 121-128.
- Tuyekar, S. N., Tawade, B. S., Singh, K. S., Wagh, V. S., Vidhate, P. K., Yevale, R. P., ... & Kale, M. (2021). An overview on coconut water: As a multipurpose nutrition. *Int. J. Pharm. Sci. Rev. Res*, 68(2), 63-70.

- Vadivambal, R., & Jayas, D. S. (2010). Non-uniform temperature distribution during microwave heating of food materials—A review. **Food and Bioprocess Technology*, 3*(2), 161-171.
- Vigliar R, Sdepanian V.L, Fagundes Neto U, Biochemical Profile of Coconut Water from Coconut Palms Planted in an Inland Region, *J Pediatr (Rio J)*, 2006; 82:308–312. DOI: 10.2223/JPED.1508; PMID: 1691283.
- Wibowo, S., Vervoort, L., Tomic, J., Santiago, J. S., Lemmens, L., Panozzo, A., Grauwet, T., Hendrickx, M., & Van Loey, A. (2015). Colour and carotenoid changes of pasteurised orange juice during storage. *Food Chemistry*, 171, 330-340.
- Yong, J. W. H., Ge, L., Ng, Y. F., & Tan, S. N. (2009). The chemical composition and biological properties of coconut (*Cocos nucifera* L.) water. **Molecules*, 14*(12), 5144-5164.