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RESEARCH ARTICLE

Assessing the Effects of Blanching and Pickling on the Microbiological Quality and Nutritional Retention of Cabbage: A Comparative Study

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Abstract

Background: Cabbage is a widely consumed vegetable that is highly perishable and prone to microbial contamination. Processing techniques such as blanching and pickling can improve its safety and extend shelf life, but their effects on microbial quality and nutrient composition require systematic evaluation.
Objective: This study investigated the impact of blanching at varying time–temperature conditions and pickling on the microbial safety and nutritional composition of cabbage.
Materials and Methods: Fresh cabbage samples were blanched at 80°C for 1 min, 85°C for 2 min, 90°C for 3 min, 95°C for 5 min, and 100°C for 7 min, or processed by pickling. A control sample was left untreated. Microbial quality was assessed using standard microbiological techniques, including enumeration of total heterotrophic bacterial counts (THBC), staphylococci (TSC), fungi (TFC), and coliforms. Proximate composition (moisture, ash, protein, fiber, and carbohydrate) was determined using standard analytical methods.
Results: THBC progressively declined with increasing blanching temperature and duration, with the lowest counts observed at 95–100°C, where bacterial growth was nearly inhibited after week 3. Pickled samples showed a steady decline (4.6×10^3 to 1.2×10^3 CFU/g), while controls retained high counts ($>10^5$ CFU/g). TSC was effectively inhibited from week 2 at ≥90°C, whereas pickling reduced counts by week 2. Fungal growth declined substantially at 90–95°C (as low as 4.4×10^2 CFU/g), while coliforms were absent in all treated samples. Nutritional analysis indicated that blanching enhanced crude protein and fiber retention, while pickling increased moisture but reduced ash content. Carbohydrates remained relatively constant across treatments.
Conclusion: Blanching, particularly at ≥90°C, and pickling significantly improved microbial safety of cabbage while maintaining key nutrients. These findings underscore the potential of both techniques as practical preservation methods for producing safe, nutritious, and shelf-stable cabbage products.

1. Introduction

According to Poti *et al.* [1], food processing is any technique used to turn fresh ingredients into food products. This can involve one or a combination of diverse processes, including washing, chopping, pasteurizing freezing, fermenting, blanching, pickling, packaging, cooking, and many more. It also consists of adding ingredients to food to extend shelf life. Food processing can affect the dietary quality of food by improving it, for instance, by adding components that are not present, such as vitamin D (through fortification), or by lowering fat, salt, or sugar. It can also cause loss of some fibers, vitamins, and minerals, for example, through excessive refining, heating, or freezing. [2]. The goal of processing is to reduce microbial spoilage and natural physiological deterioration of plant cells. Generally, the methods include blanching, dehydrating, canning, freezing, fermenting, pickling, and irradiating [3]. Blanching is a food

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processing method, also a cooking term, that describes a preparatory process wherein the food, usually a vegetable or fruit, is heated in steam or hot water for a short time, and cooled by plunging into iced water or water spray to stop the cooking process. It reduces the number of microorganisms, removes some air from the tissues, makes them more compact, and enhances the color of vegetable or fruit.

Pickling is defined as the technique of preserving a food either by anaerobic fermentation in brine or by immersing in vinegar [4]. The resulting food is called pickle. Vegetable consumption is widely accepted as an imperative factor of a healthy diet. Green veggies play a vital role in the development of the body, given their high nutritional value [5]. They are a great source to keep the body healthy and help to prevent diseases, such as eye diseases, cancer, and cardiovascular diseases [4].

Food insecurity, malnutrition, and lifestyle diseases, such as obesity, high blood pressure, carcinoma, and diabetes are among the most important global issues that have increased the demand for healthy foods, especially fruits and vegetables [6]. It is a common misconception that fresh vegetables are always superior in nutritional value, compared to processed vegetables. Several studies have proven that frozen, blanched, canned, or pickled vegetables actually have higher nutritional value than fresh products [7–9]. Fresh vegetables are subjected to quality and loss of vitamins during transportation and storage, whereas processing before these losses can yield a nutritionally superior product. Studies have shown that a major cause of nutrient loss in vegetables is due to the draining of cooking or processing liquids [10].

Foods that are not cooked or peeled are considered as important carriers of human pathogens. The consumption of vegetables is increasing, as they are associated with the prevention of some cancers, eye diseases, and cardiovascular diseases. As a result, 86% of the total global market share is related to vegetables [4,11]. It is estimated that up to one-third of the population of developed countries is affected by food-borne diseases annually, and this is likely to be wider in developing countries. Increasing interest in healthy diets as well as work-related activities have led to a change in lifestyle and increased consumption of salads and prepared vegetables, resulting in increased infections in humans associated with raw vegetables [4,12]. Sometimes, fresh vegetables are associated with bacteria and harmful viruses called pathogens.

Cabbage (*Brassica oleracea*) is a cruciferous vegetable. It is a leafy green or purple biennial plant, grown as an annual vegetable crop for its dense-leaved heads. Cabbage is a wholesome vegetable consumed globally [13,14]. It is normally known as an underappreciated vegetable, eaten fresh, and frequently processed as a pickle [15,16]. It is one of the most regularly grown and popular winter crops and comprises numerous minerals and vitamins such as vitamins A, B1, B2, and C as well as dietary fiber [17]. It is one of the most popular Brassica vegetables found in human diet because of its availability and a range of health benefits. It forms a huge part of global cuisines and diets. It is commonly used by boiling, stir-frying, in salads, or consumed as a fermented product. The most acquainted product of white cabbage is sauerkraut. It results from spontaneous fermentation of shredded and salted white cabbage by lactic acid bacteria (LAB) [15,18]. Blanching is used to eliminate enzymatic activity in vegetables and some fruits prior to other processing actions, such as freezing, dehydration, canning, or thermal processing. Other effects of blanching on vegetables include discharge of air and gases from the product, and reduction in product volume. The factors that affect the blanching time are type of fruits or vegetables, size of food pieces, blanching temperature, and heating method [19]. Similarly, blanching, combined with peeling or cleaning of food, helps to save energy consumption, space, and equipment cost. It also helps to remove pesticides and reduce microbial load. Blanching is widely used in different foods to reform the preservation process and contribute to enzymatic inactivation and microbiological control [19].

Blanching reduces the number of contaminating microorganisms from food surfaces and hence aids in successive preservation activities. Pickling is the process of bathing a food in a solution containing salt, acid, or alcohol [20]. It can be used with most foods, including fruits, vegetables, meats, seafoods, and eggs. Pickling is often combined with another method, such as fermenting, canning, or just refrigerating. Pickling includes chemical pickling and fermentation pickling. In chemical pickling, the food is placed in an edible liquid that inhibits or kills bacteria and other microorganisms. Typical pickling agents include brine, which is high in salt, vinegar, alcohol, and vegetable oil, especially olive oil; however, other oils can be used as well [21]. Fresh fruits and vegetables soften in a watery solution after 24 h because of slow, mixed fermentation – putrefaction [2]. Addition of salt interrupts undesirable activity, creating a favorable environment for desired fermentation [21]. Therefore, this study aims to fill this gap by providing a comprehensive explanation on the impact of blanching and pickling on microbial safety, nutritional value, and sensory quality of cabbage.

2. Materials and Methods

2.1. Collection and processing of samples

Fresh cabbages were purchased from local markets in Port Harcourt, Rivers State, Nigeria and transported to Food Microbiology Research Laboratory, where the research work was accomplished. Cabbages were washed with distilled water, ensuring the samples were free from soils, debris, and extraneous materials. The vegetable was then peeled and cut into desired uniform sizes.

2.2. Blanching treatment

Cabbage samples were blanched using different time–temperature combinations.

2.2.1. Preparation

A large pot was filled with water and citric acid (0.1%), the blanching agent, was added to it. The required blanching time and temperature were measured for each combination (i.e., 1 min for 80°C, 2 min for 85°C, 3 min for 90°C, 5 min for 95°C, and 7 min for 100°C). Ice-cold water was prepared in a separate container for rapid post-blanching cooling.

2.2.2. Blanching process

The water in the pot was boiled up to the desired temperature. The cabbage pieces were placed in the boiling water in batches, maintaining time and temperature combination.

2.2.3. Temperature control

Water must be boiled vigorously in order to maintain procedure temperature close to 100°C. Added cabbage pieces caused the water temperature to drop. To control this, a large volume of water in proportion to the amount of cabbage was used to minimize drop in water temperature by continuous heating of water. After each batch is added, boiling of water is continued using a powerful heating source).

2.2.4. Time control

After adding the cabbage, the water was boiled to the required temperature to ensure the actual blanching temperature. Once boiling was resumed, the blanching time was set using a timer.

The blanched pieces of the vegetable were removed using a strainer and immediately transferred to ice-cold water to ensure the cooling process. After cooling, the blanched pieces were dried dry with clean towels. The process was repeated for all blanching combinations. The blanched vegetable samples were then stored in airtight containers or plastic bags at 20°C [22].

Plate (1): Blanched Cabbage Samples.

Plate (2): Pickled Cabbage Samples.

2.3. Pickling of Cabbage

2.3.1. Preparation

The pickling solution was prepared in a container by mixing vinegar (5%), salt (2%), and water.

2.3.2. Pickling process

The cabbage pieces were placed in a sterilized jar. The pickling solution was poured on the vegetable, ensuring they were completely submerged in the solution. The jar was closed with a tight-fitting lid and stored in a refrigerator. Pickling was allowed to occur for the desired periods (1 week, 2 weeks 3 weeks, and 4 weeks). After pickling, the samples were removed from refrigerator for analysis as described by Rahman *et al.* [23] with slight modifications.

2.4. Microbiological Analysis of Blanched Cabbage (BC) and Pickled Cabbage (PC)

2.4.1. Preparation of stock from samples

In all, 25 g of BC and PC samples was transferred into 225-mL peptone water and homogenized using a stomacher for 1–2 min to ensure that microorganisms were properly released from food matrix into the solution. This process results into a stock solution. Then, 1 mL of stock solution was transferred into dilution bottles containing 9 mL of normal saline. After this, 0.1 mL from the last dilution was poured into petri dishes containing different media (plate count agar, potato dextrose agar (PDA), MacConkey agar, and mannitol salt agar) for analysis. Analysis was done before and after blanching and pickling treatments [24].

2.4.2. Total heterotrophic bacteria count (THBC)

In all, 1 mL of dilutions 10^{-1} and 10^{-2} of diluted samples of PC and BC in duplicates were spread onto agar media and incubated for 24 h at 37°C before enumeration.

2.4.3. Total fungi count (TFC)

In all, 1 mL of dilutions 10^{-1} and 10^{-2} of diluted samples were dispersed on already prepared PDA, incubated at 25°C for 5 days and observed for growth.

2.4.4. Total staphylococcus count (TSC)

In all, 1 mL of dilutions 10^{-1} and 10^{-2} were spread on mannitol salt agar, incubated at 37°C for 24 h, and observed for growth of yellow colony.

2.4.5. Total coliform count (TCC)

In all, 1 mL of dilutions 10^{-1} and 10^{-2} of diluted PC and BC samples in duplicates were spread on agar media and incubated for 24 h at 37°C before enumeration.

2.5. Isolation and preparation of pure colony

Colony from each culture was picked using sterile wire loop and sub-cultured on freshly prepared and sterile nutrient agar, and incubated for 24 h for bacteria, while PDA was used for isolation of fungi at 25°C for 5 days. Suspected bacterial colonies were identified and characterized on the basis of simple staining and gram staining [25,26] and a set of biochemical characterization, that is, indole test, methyl-red test, Vogues–Proskauer test, citrate utilization test, catalase test, coagulase test, and oxidase test, by standard methods as shown by Sherman [25] and Holt *et al.* [26].

2.6. Identification of fungi

This was done by staining fungi isolates in lactophenol, and viewed under the microscope. The cultural characteristics of each of the fungi isolates were identified based on their shape and color, whereas the cell morphology was done based on mycelia, hyphae, septate, and spore formation using lactophenol blue. The pure isolated fungi were identified using cultural and morphological (microscopic) features according to the most documented keys in fungal identification [27].

2.7. Sensory evaluation

A panel of trained assessors evaluated sensory attributes (appearance, texture, taste, and smell) of fresh, BC, and PC samples to determine the acceptability of these preservation methods. Fresh, PC, and BC samples were presented to a panel of judges for sensory evaluation for color, taste, flavor, and the overall acceptability using hedonic scale in accordance with the method described by Larmond [28]. The panel members were selected on the basis of their ability to discriminate and scale a broad range of different attributes of fresh, BC and PC. An orientation program was organized for panel members to brief them on the objective of the study. The performance results were as follows: 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; and 1 = dislike extremely.

2.8. Physiochemical analysis

Proximate analysis was done on fresh cabbage, BC, and PC as described by the American Association of Cereal Chemists (AACC) [29].

3. Results

3.1. Total heterotrophic bacteria count

The THBC results for different samples are shown in Table 1 and graphically presented in Figure 1. The table shows the growth of heterotrophic bacteria of BC and unblanched cabbage samples at different temperatures and different period of monitoring. The THBC in BC at 80°C ranged from 6.8×10^4 colony-forming unit (CFU)/g at week 1 to 2.2×10^3 at week 4. The THBC in BC at 95°C and 100°C decreased from 4.4×10^3 CFU/g at week 1 to 1.4×10^3 CFU/g at week 3 and 4.0×10^3 CFU/g at week 1 to 1.0×10^3 CFU/g at week 3, respectively. THBC for unblanched cabbage ranged from 1.7×10^5 CFU/g at week 1 to 1.8×10^5 CFU/g at week 4. It was observed from the results that the THBC for BC decreased from week 1 to week 4 for temperatures of 80°C, 85°C, and 90°C. THBC for BC at 95°C and at 100°C decreased from week 1 to week 3, and there were no growth in week 4. THBC for unblanched cabbage increased from week 1 to week 4.

3.2. Total heterotrophic bacteria count for pickled cabbage

The THBC for different cabbage samples is shown in Table 2 and Figure 2. The THBC for PC samples had decreased from 4.6×10^3 CFU/g in week 1 to 1.2×10^3 CFU/g in week 4. The unpickled cabbage (control cabbage [CC]) showed increased counts through the subsequent weeks.

3.3. Total Staphylococcus counts for blanched cabbage

The TSC for BC at different temperatures in relation to the weeks of monitoring is shown in Table 3, and graphically presented in Figure 3. The TSC of the sample decreased

Table (1): Total heterotrophic bacteria count for blanched cabbage.

	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
BC 80°C	6.8×10^4	4.83	4.4×10^3	3.64	3.2×10^3	3.50	2.2×10^3	3.34
BC 85°C	6.0×10^4	4.78	4.0×10^3	3.60	3.0×10^3	3.47	1.6×10^3	3.20
BC 90°C	5.1×10^3	3.70	2.6×10^3	3.41	1.6×10^3	3.20	1.4×10^3	3.14
BC 95°C	4.4×10^3	3.64	1.8×10^3	3.25	1.4×10^3	3.14	–	–
BC 100°C	4.0×10^3	3.60	1.2×10^3	3.07	1.0×10^3	3	–	–
CC	1.7×10^5	5.23	2.10×10^5	5.32	2.18×10^5	5.33	1.81×10^5	5.25

Notes. BC: blanched cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

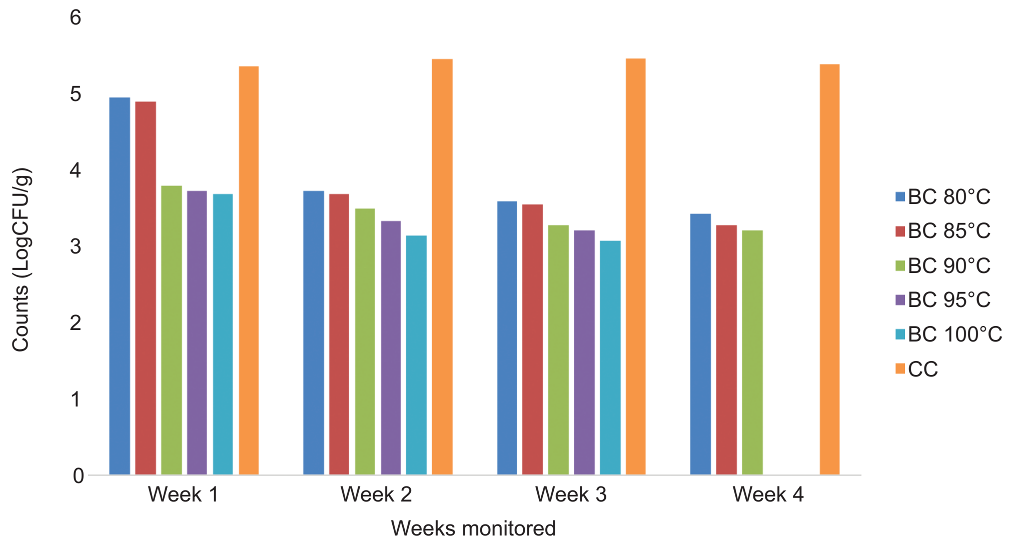

Figure (1): Total heterotrophic bacteria count for blanched cabbage. BC: blanched cabbage at different temperatures, CC: control cabbage.

Table (2): Total heterotrophic bacteria count for pickled cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
PC	4.6×10^3	3.66	1.2×10^3	3.07	1.2×10^3	3.07	1.2×10^3	3.07
CC	1.7×10^5	5.23	2.1×10^5	5.32	1.2×10^3	5.33	1.81×10^5	5.07

Notes. PC: pickled cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

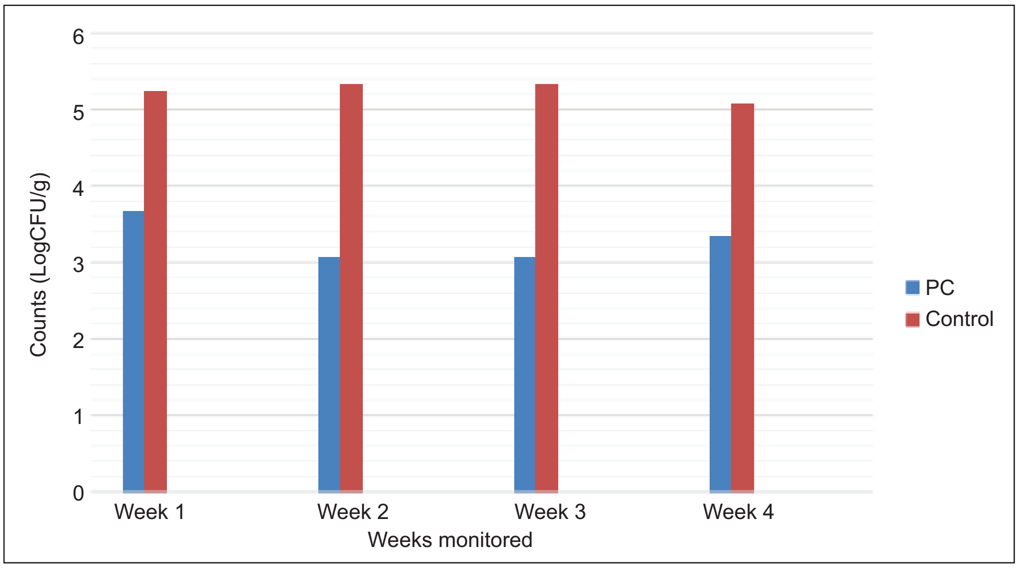

Figure (2): Total heterotrophic bacteria count for pickled cabbage. PC: pickled cabbage; CC: control cabbage; CFU: colony-forming unit

with increasing temperature. The TSC for unblanched cabbage increased from week 1 to 3.

3.4. Total Staphylococcus count for pickled cabbage

The TSC for PC is shown in Table 4 and Figure 4. The TSC decreased from week 1 to 2 with counts ranging from 3.6×10^3 CFU/g to 1.2×10^3 CFU/g. Pickling completely inhibited staphylococcal growth from week 3 to 4. The TSC for unpickled cabbage increased in subsequent weeks.

3.5. Total coliform count for blanched cabbage

The TCC results for BC samples are shown in Table 5 and Figure 5. No detectable coliform count was observed

Table (3): Total staphylococcus counts for blanched cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
BC 80°C	1.2×10^3	3.83	–	–	–	–	–	–
BC 85°C	1.0×10^3	3.77	–	–	–	–	–	–
BC 90°C	–	–	–	–	–	–	–	–
BC 95°C	–	–	–	–	–	–	–	–
BC 100°C	–	–	–	–	–	–	–	–
CC	5.4×10^4	4.73	7.7×10^4	4.88	7.9×10^4	4.89	2.5×10^3	3.39

Notes. BC: blanched cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

Figure (3): Total staphylococcus count for blanched cabbage. BC: blanched cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

Table (4): Total Staphylococcus counts for pickled cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
PC	3.6×10^3	3.55	1.2×10^3	3.07	–	–	–	–
CC	5.4×10^4	4.73	7.7×10^4	4.89	7.9×10^4	4.90	2.5×10^4	4.40

Notes. PC: pickled cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

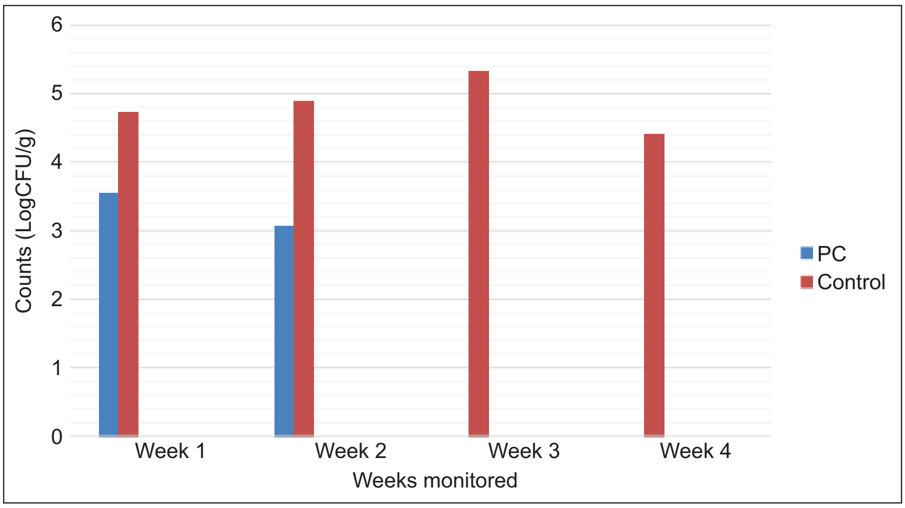

Figure (4): Total staphylococcus count for pickled cabbage. PC: pickled cabbage; CC: control cabbage; CFU: colony-forming unit.

throughout the 4 weeks of monitoring. However, only unblanched cabbage sample showed high TCC, ranging from 9.9×10^4 CFU/g to 8.8×10^5 CFU/g.

3.6. Total coliform count For pickled cabbage

The TCC results of PC are shown in Table 6 and Figure 6. PC samples showed no TCC throughout the period of 4 weeks. The TCC of CC sample ranged from 9.9×10^4 CFU/g to 8.8×10^5 CFU/g.

3.7. Total fungi count for blanched cabbage

The TFC results for BC samples are shown in Table 7 and Figure 7. The TFC for BC samples at temperatures of 80°C and 85°C ranged from 6.8×10^3 to 1.2×10^3 CFU/g from week 1 to 3 and 6.0×10^3 to 1.0×10^3 CFU/g from week 1 to 3. The TFC at 90°C decreased from week to 2. The TFC for unblanched cabbage ranged from 2.2×10^3 to 3.1×10^3 CFU/g for week 1–4.

3.8. Total fungi count for pickled cabbage

The TFC results for PC samples are shown in Table 8 and Figure 8. PC showed a consistent TFC of 2.0×10^3 CFU/g from week 1 to 4.

4. Discussion

Although eating veggies may have health benefits, there are questions about their nutritional retention and microbiological safety[30].The effects of pickling and blanching on the nutritional retention and microbiological quality of cabbage were assessed in this study. The results of the bacteria count showed reduction in THBC in BC samples across all temperatures over 4-week period. The initial THBC range (6.0×10^4–6.8×10^4 CFU/g) decreased to 1.2×10^3–3.2×10^3 CFU/g by week 4 as shown in Figure 1. Notably, BC 80°C and BC 85°C showed higher THBC compared to BC

Table (5): Total coliform count for blanched cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
BC 80°C	–	–	–	–	–	–	–	–
BC 85°C	–	–	–	–	–	–	–	–
BC 90°C	–	–	–	–	–	–	–	–
BC 95°C	–	–	–	–	–	–	–	–
BC 100°C	–	–	–	–	–	–	–	–
CC	9.9×10^4	4.99	1.16×10^5	5.06	8.8×10^5	5.94	8.8×10^5	5.06

Notes. BC: blanched cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

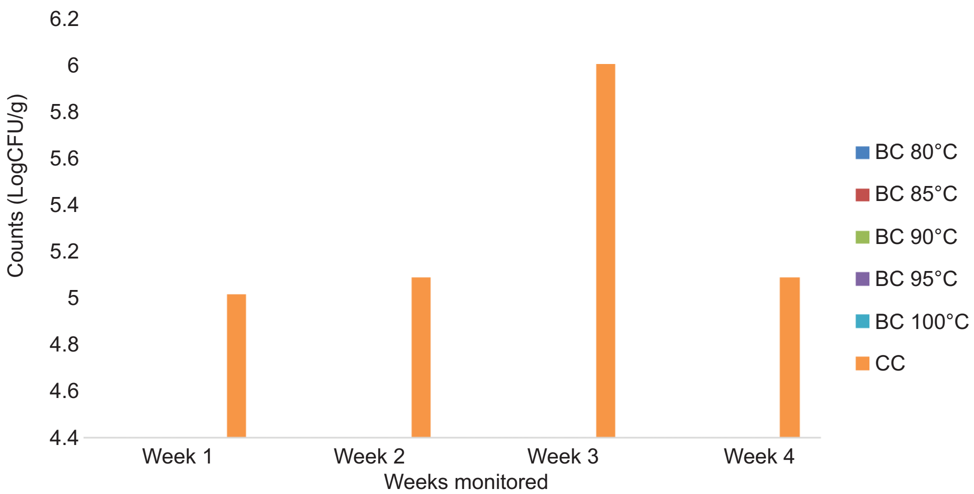

Figure (5): Total coliform count for blanched cabbage. BC: blanched cabbage; CC: control cabbage; CFU: Colony forming unit.

Table (6): Total coliform count for pickled cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
PC	–	–	–	–	–	–	–	–
CC	9.9×10^4	4.99	1.16×10^4	4.06	1.16×10^4	4.06	8.8×10^4	4.94

Notes. PC: pickled cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

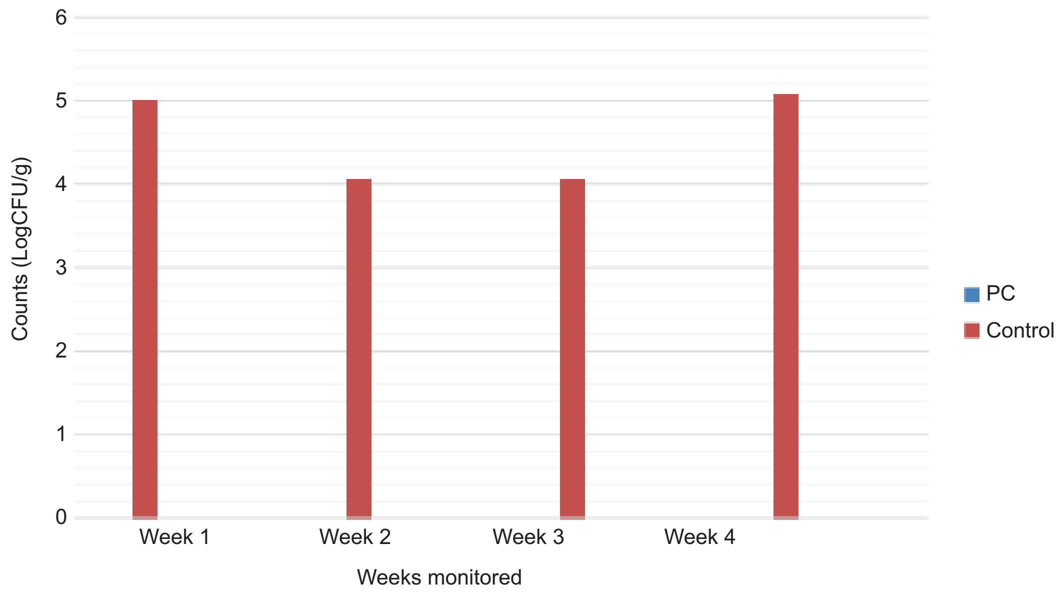

Figure (6): Total coliform count for pickled cabbage. PC: pickled cabbage at different temperatures; CFU: colony-forming unit.

Table (7): Total heterotrophic fungi count (THFC) for blanched cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
BC 80°C	6.8×10^3	3.83	1.2×10^3	3.07	1.2×10^3	3.50	–	–
BC 85°C	6.0×10^3	3.77	1.0×10^3	3.00	4.0×10^3	3.47	–	–
BC 90°C	5.1×10^2	2.70	1.0×10^3	3.00	–	–	–	–
BC 95°C	4.4×10^2	2.64	–	–	–	–	–	–
BC 100 °C	–	–	–	–	–	–	–	–
CC	2.2×10^3	3.34	3.6×10^3	3.55	3.8×10^3	3.57	3.1×10^3	3.49

Notes. BC: Blanched cabbage at different temperature; CC: control cabbage; CFU: colony forming unit.

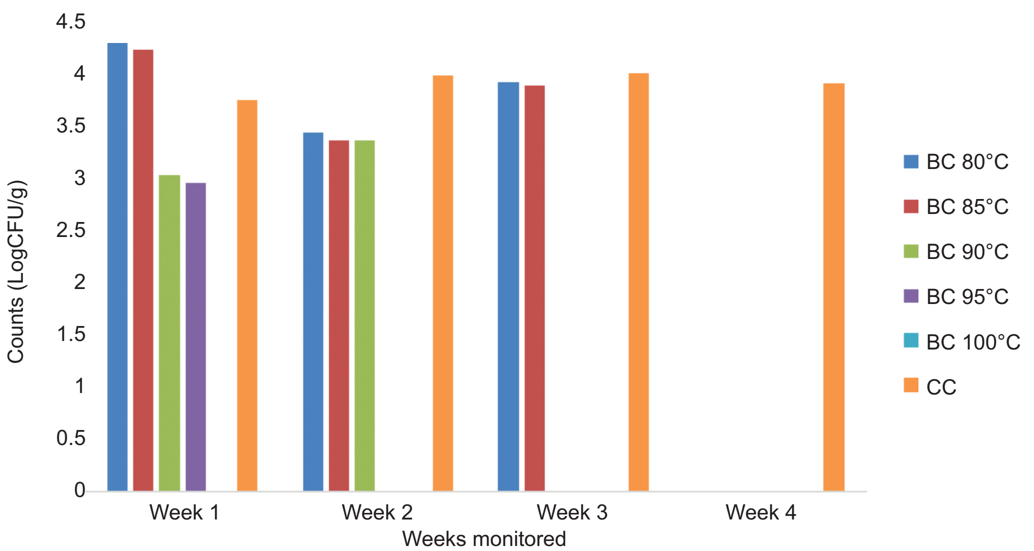

Figure (7): Total heterotrophic fungi count (THFC) for blanched cabbage. BC: blanched cabbage at different temperatures; CC: control cabbage; CFU: colony-forming unit.

Table (8): Total fungi count for pickled cabbage.

Sample	Week 1		Week 2		Week 3		Week 4	
	CFU/g	Log	CFU/g	Log	CFU/g	Log	CFU/g	Log
PC	2.0×10^{3}	3.30	2.0×10^{3}	3.30	2.0×10^{3}	3.30	2.0×10^{3}	3.30
CC	2.2×10^{3}	3.34	3.6×10^{3}	3.55	3.8×10^{3}	3 57	3.1×10^{3}	3.49

Notes: PC: pickled cabbage; CC: control cabbage; CFU: colony forming unit.

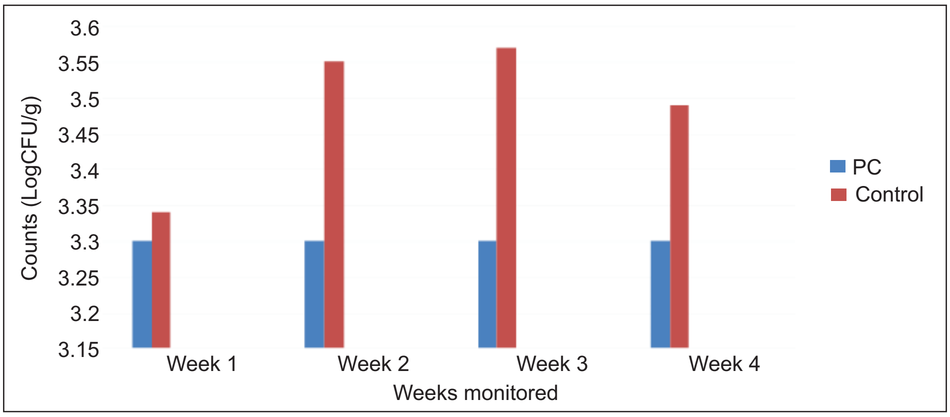

Figure 8: Total fungi count for pickled cabbage. PC: pickled cabbage; CC: control cabbage.

Table (9): Frequency of occurrence of bacteria isolates in blanched cabbage sample.

S. No.	Bacteria isolates	Frequency of occurrence (%)
1.	*Lactobacillus sp*	20.00
2.	*Leuconostocsp*	6.25
3.	*Staphylococcus sp*	5.00
4.	*Bacillus sp*	52.25
5.	*Pseudomonas sp*	12.50
6.	*Escherichia coli*	4.00
	Total	**100**

Table (10): Frequency of occurrence of fungi isolates in blanched cabbage samples

S. No.	Fungi identified	Frequency of occurrence (%)
1.	*Saccharomyces cerevisiae*	42.86
2.	*Fusarium sp*	57.14
	Total	**100**

Table (11): Frequency of occurrence of fungi isolates from pickled cabbage and control cabbage samples.

S. No.	Fungi identified	Frequency of occurrence (%)
1.	*Saccharomyces cerevisiae*	28.57
2.	*Penicillium sp*	28.57
3.	*Aspergillus sp*	28.57
4.	*Fusarium sp*	14.29
	Total	**100**

90°C, BC 95°C, and BC 100°C, indicating temperature-dependent bacterial inactivation. The CC sample had consistently high THBC (1.7×10^5–2.18×10^5 CFU/g), exceeding the recommended microbiological limit of THBC for vegetables (<10^4 CFU/g) [31]. The findings demonstrate the effectiveness of blanching in reducing microbial loads on vegetables [24,32]. Specifically, the results are comparable to the results of Aljahani [33], which reported a 2–3-log reduction in THBC after blanching of cabbage at 90°C for 2 min. Overall, the study suggests that blanching of cabbage at temperatures ≥90°C can achieve THBC levels within recommended microbiology limits. The microbiological analysis of PC revealed reduction in THBC, from 4.6×10^3 CFU/g in week 1 to 1.2×10^3 CFU/g in weeks 2–4, satisfying the recommended limit of <10^4 CFU/g [31], as illustrated in Figure 2. In contrast, CC had consistently high THBC (1.7×10^5–2.18×10^5 CFU/g). The findings demonstrate pickling's effectiveness in reducing microbial loads on vegetables [34], highlighting pickling as a reliable method for ensuring food safety and quality.

The TSC in BC samples decreased, as observed in Figure 3, exceeding recommended microbiology limit for vegetables. Initially, TSC ranged from 1.0×10^3 to 1.2×10^3 CFU/g at BC 80°C and BC 85°C, but were undetectable (NG) by week 2. In contrast, CC had consistently high TSC (5.4×10^4–7.9×10^4 CFU/g), exceeding the US Food and Drug Administration (FDA) [31] standards for TSC (<10^2 CFU/g). These findings demonstrate blanching's effectiveness in reducing staphylococcus in cabbage, and a reported 2–3-log reduction in TSC after blanching at 90°C for 2 min. The results also compared favorably with that of Aljahani [33], Alexandre *et al.* [34], and Scheinberg *et al.* [35],

Table (12): Sensory evaluation of blanched and control cabbage samples

Week	Sample	Appearance	Texture	Flavor	Overall acceptability
1	CC	7	7	7	7
	CB 80°C	8	8	7	8
	BC 85°C	8	8	7	8
	BC 90°C	8	7	7	7
	BC 95°C	7	6	6	6
	BC 100°C	6	5	5	5
2	CC	6	6	6	6
	BC 80°C	7	7	6	7
	BC 85°C	7	7	6	7
	BC 90°C	7	6	6	6
	BC 95°C	6	5	5	5
	BC 100°C	5	4	4	4
3	CC	5	5	5	5
	BC 80°C	6	6	5	6
	BC 85°C	6	6	5	6
	BC 90°C	6	5	5	5
	BC 95°C	5	4	4	4
	BC 100°C	4	3	3	3
4	CC	4	4	4	4
	BC 80°C	5	5	4	5
	BC 85°C	5	5	4	5
	BC 90°C	5	4	4	4
	BC 95°C	4	3	3	3
	BC 100°C	3	2	2	2

Notes. CC: control cabbage; PC: pickled cabbage.
Performance results: 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

Table (13): Sensory evaluation of pickled cabbage and control cabbage samples.

Week	Sample	Appearance	Texture	Flavor	Overall acceptability
1	CC	7	7	7	7
	PC	8	8	9	8
2	CC	6	6	6	6
	PC	8	8	9	8
3	CC	5	4	4	4
	PC	8	8	8	8
4	CC	4	4	4	4
	PC	8	7	8	8

Notes. CC: control cabbage; PC: pickled cabbage.
Performance results: 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

which achieved undetectable TSC levels after blanching of cabbage at 95°C for 3 min. Studies [2,34,35] demonstrated a significant reduction in TSC in BC. Specifically, blanching at 90°C for 2 min led to a decrease in TSC, with levels decreasing to below the detectable limits by week 2.

The current study indicates that blanching at temperatures ≥80°C is effective in reducing TSC to meet recommended microbiology limits, highlighting blanching as a reliable method for food processing and reducing microbial load on cabbage. Overall, the study suggests that blanching of

Table (14): Nutritional composition of pickled cabbage and blanched cabbage samples.

Parameter (%)	Pickled cabbage	Blanched cabbage 80°c	Blanched cabbage 90°c	Blanched cabbage 100°c	Raw cabbage (control)
Moisture content	18.27	6.90	7.21	7.51	6.55
Total ash	4.20	6.62	6.00	5.40	7.10
Lipid	0.63	0.54	0.60	0.63	0.52
Crude protein	5.60	4.96	5.10	5.71	4.88
Carbohydrate	45.28	45.36	46.20	46.55	45.31
Total fiber	**26.84**	**34.91**	**34.90**	**34.88**	**34.90**

cabbage at temperatures ≥80°C effectively reduces TSC, meeting the recommended microbiological limits.

The results of TSC for PC demonstrate the effectiveness of pickling in reducing staphylococcus counts in cabbage. The PC sample showed a decrease in staphylococcus counts from 3.6×10^3 CFU/g in week 1 to undetectable levels (NG) by weeks 3 and 4 as observed in Figure 4. In contrast, CC maintained consistently high staphylococcus counts, ranging from 5.4×10^4 to 7.9×10^4 CFU/g, with a mean value of 2.5×10^4 CFU/g. This exceeds the recommended microbiological limit of staphylococcus counts in pickled vegetables ($<10^2$ CFU/g) [31]. The findings demonstrate pickling's antibacterial effects [21,34,35], highlighting pickling as an effective method for controlling staphylococcus growth and ensuring food safety and quality.

The TCC for BC samples showed undetectable levels (across all temperatures [BC 80°C–100°C) throughout the 4-week period, as shown in Figure 5, meeting the recommended microbiological limit of <10 CFU/g [31]. In contrast, the CC sample had consistently high TCC (9.9×10^4–8.8×10^5 CFU/g), exceeding the stated limit. These results show that blanching of cabbage effectively lowers the amount of coliform bacteria present [35]. According to the findings, blanching of cabbage at temperatures ≥80°C successfully decreases coliform bacteria, guaranteeing the safety and quality of food. The present study's results are consistent with that of Breidt *et al.* [36], which examined the effects of different heat treatments on the microbial load of different vegetables and discovered that thermal treatments decreased the loads, including coliforms, on treated vegetables. The study specifically showed that temperatures between 85°C and 100°C were especially useful for obtaining notable decreases in microbial populations, including TCC.

This stark difference highlights pickling's efficacy in inactivating coliform bacteria, aligning with the studies demonstrating pickling's antibacterial effects [33,36]. The findings of the current study also aligned with other studies [33,37]. Aljahani [33] showed that the acidic conditions, such as those discovered in pickled vegetables, were effective at inhibiting the growth of coliform bacteria. The cited study emphasized that many coliform species, including *Escherichia coli*, *Salmonella*, and other food-borne pathogens, were unable to thrive in highly acidic environments (pH < 4.0). The findings of the current study demonstrates that pickling of cabbage led to undetectable TCC over the 4-week period, probably because of the acidic environment created during the pickling process. Overall, pickling emerges as a reliable method for ensuring food safety and quality by effectively eliminating total coliform bacteria from cabbage.

Figure 9 shows the frequency of bacterial genera *Bacillus sp.*, the most prevalent species in blanched samples, and *Lactobacillus sp*, the most prevalent species in pickled samples, with *Leuconostoc* accounting for 6.25% and *Pseudomonas* 12.50% of isolates. Both blanched and PC, however, had notably reduced frequencies, indicating the effectiveness in curbing bacterial presence. This study contributes to our understanding of the microbial diversity in PC and raw cabbage (CB) and provides valuable insights into their potential roles in food fermentation and preservation.

The results revealed the diversity of bacterial isolates in PC, BC, and raw cabbage. The Gram-positive isolates from PC (PC 1–5) and BC were predominantly identified as LAB, specifically *Lactobacillus* (PC 1, 2, 3, and 5), and *Leuconostoc* (PC 4) species. This finding is consistent with previous studies, which reported LAB as dominant microflora in fermented vegetables [38].

The presence of LAB in PC demonstrated their role in fermentation and preservation. In contrast, raw cabbage isolates (CB 1 and 2) were identified as *Pseudomonas* species, while isolates CB 3–5 were identified as *Bacillu*s species. This finding was in agreement with previous studies, which reported *Pseudomonas* and *Bacillus* species as common contaminants of raw vegetables [39,40].

The results established for THFC showed a significant reduction in BC samples across all temperatures over 4 weeks. The initial THFC range (1.2×10^3–1.8×10^3 CFU/g) decreased substantially, with most samples showing undetectable fungal growth (NG) by week 4, as observed in Figure 7. Notably, BC 80°C and BC 85°C showed higher THFC, compared to BC 90°C, 95°C, and 100°C, indicating temperature-dependent fungal inactivation. The CC sample had consistently high THFC (2.2×10^3–3.8×10^3 CFU/g), exceeding the recommended microbiological limit for THFC ($<10^2$ CFU/g) in vegetables [31].

These results were consistent with a study that showed how blanching of vegetables can effectively lower fungal loads [41]. In particular, the findings were the same as those of Natalino de Sá *et al.* [42], which discovered that blanching of cabbage for 2 min at 90°C reduced THFC by 1–2 logs. The results of this study were consistent with those of Lago and Norena [43]. The significant decrease in fungal counts observed in the current study was comparable to the observation made by Lago and Norena [43] those blanching treatments successfully decreased the populations of different microorganisms, such as yeasts and molds. Higher blanching temperatures, such as >90°C, were established to be more successful in lowering the microbial load [43]. The results of the current study, which showed that fungal counts were slightly higher at lower temperatures (80–85°C) and that fungal growth was undetectable at week 4 and this shows that blanching is an efficient techniques to manage fungal growth and guarantee the microbiological safety of vegetables, particularly when higher temperatures are used. Overall, the study suggests that blanching of cabbage at temperatures ≥90°C can achieve THFC levels within recommended microbiological limits.

The results of THFC showed that pickling of cabbage effectively maintained a stable and relatively low heterotrophic fungi count (HFC), with consistency of 2.0×10^3 CFU/g across all 4 weeks, as shown Figure 8. In contrast, the CC sample had higher HFC, ranging from 2.2×10^3 to 3.8×10^3 CFU/g. Notably, the pickled sample's HFC satisfied the recommended microbiological limit ($<10^4$ CFU/g) [31]. These findings suggest that pickling inhibits fungal growth in cabbage, aligning with [44], demonstrating pickling's antifungal effects. Overall, pickling of cabbage appears to be an effective method for controlling fungal growth and maintaining food safety and quality, similar to the study done by Breidt *et al.* [44].

The most common fungal genera in blanched samples are *Saccharomyces cerevisiae*, with Fusarium sp. making up 42–86% of the total count, as shown in Figure 10. According to the current study, aligning with [2], *S. cerevisiae* is a common yeast found in fermented foods. It is essential for fermentation because it can ferment sugars into ethanol and CO_2, which enhance flavor and preserve food. Singh [2] observed that because of its health benefits, yeast is a common ingredient in traditional fermented foods such as *miso* and *kimchi*. Singh observed Fusarium in food and agricultural environments, frequently resulting in deterioration and toxin production [2]. In this study, its occurrence was consistent with that of Valentino *et al.* [45] regarding fungal contamination and spoiling in food chains, especially in less regulated fermentation environments.

Comparing PC and BC to raw samples, the microbiological analysis showed that both processes considerably decreased the microbial load. Bacterial, yeast, and mold vegetative cells were successfully rendered inactive by blanching, which involved a brief exposure to high temperatures. This was consistent with earlier research showing that heat treatment causes microbial death by denatured proteins and disrupting microbial cell membranes. In contrast, the combined effects of salinity and acidity (usually from vinegar) in pickling dramatically reduced microbial growth. Pickling produces an acidic environment (typically pH < 4–6), known to be unfavorable to the majority of pathogenic and spoiling organisms, particularly Gram-negative bacteria. Acidified vegetables have a longer microbial shelf life and a lower risk of foodborne illnesses, according to this present study. According to this present study, the method of preservation should be chosen based on the intended use of cabbage.

4.1. Proximate Composition of pickled and blanched cabbage

The nutritional composition analysis of PC and BC presented in Table 13 reveals notable differences in ash, moisture content, protein, and fiber depending on the processing method. Interestingly, PC has a higher moisture content (18.27%) than that of BC (6.90–7.1%) and raw (6.55%), which agreed with earlier studies showing that pickling increases moisture retention. [46,47] but in contrast to other researches [48,49], which discovered that pickling tends to provide vegetables a higher moisture content because the brine used helps to hold on to water. This aligned with the study's conclusions that the highest moisture content is found in PC (18.27%). Osmosis causes water to flow in and out of cabbage tissues during pickling, particularly in mildly acidic or low-salt environments, until equilibrium is achieved. Unlike blanching (which uses high heat and causes more rapid water movement and loss), the pickling process is slower and more controlled, which can help retain some intracellular water, especially if pickling is done at lower temperatures or under controlled fermentation.

However, as demonstrated in this study, blanching of cabbage (at 80°C and 90°C) results in a significantly lower moisture content than PC or CC, particularly at higher temperatures. Blanching decreases moisture content, which may be advantageous for extending shelf life, but it also causes the loss of water-soluble nutrients, according to researchers [48,49]. However, compared to PC (4.20%), BC has a higher ash content (5.40–6.62%), which is consistent with the studies showing that heat treatment improves retention of minerals [50]. It was discovered that blanching of cabbage could increase its mineral content because it breaks down the cell walls, increasing the bioavailability of minerals. BC has a higher ash content than that of CC. PC has the lowest ash content, which could be due to minerals leach into the brine, as was demonstrated in a study [50], where pickling lowers vegetable mineral content. It is expected that PC may have higher ash content because of added salt, whereas BC may show higher ash content if blanching is short, moisture loss is significant, and minerals are retained within the tissue. Conversely, leaching during pickling, brine disposal, or post-pickling rinsing can lead to apparently lower the ash content in PC samples.

Compared to PC (5.60%) and raw cabbage (4.88%), BC at 100°C has a slightly higher protein content (5.71%), indicating that higher temperatures are best for retaining protein. Protein levels are decreased during the blanching process because of denaturation, especially when high temperatures are used, as demonstrated in literature [38,50]. PC, on the other hand, exhibits protein levels comparable to raw cabbage, which may be because the preservation method has little effect on protein content.

The present study found that BC, particularly at 80°C and 90°C, had slightly lower protein levels.

Carbohydrate content was almost constant across all temperature treatments of cabbage samples (45.28–46.55%). Blanching was found to have no effect on vegetable carbohydrate content, which was consistent with the current study's findings that the carbohydrate content is essentially constant across all treatments. However, the structure of cabbage cells changes during pickling, which could be the reason for slightly lower carbohydrate content in PC.

Compared to PC (26.84%), BC has higher fiber content (34.88–34.91%). These results showed improved fiber retention while blanching [13]. Both blanching and pickling, however, usually preserve fiber content. The study found that pickling slightly decreased the fiber content because it broke down vegetable's cell walls, while blanching had little effect on the fiber content. This study's results demonstrated that pickling increased the moisture content but could cause a slight loss in fiber and minerals, while blanching has a little effect on carbohydrate and lipid content but could slightly decrease protein levels and improve mineral bioavailability (higher ash content). According to the current study, blanching preserves minerals, fiber, and carbohydrates better than pickling, which results in little loss of ash and fiber. Overall, the present study highlights the impact of processing conditions on cabbage's nutritional profile, underscoring the importance of optimizing processing parameters to preserve nutrient content [51].

4.2. Sensory evaluation of prickled and blanched cabbage

Sensory evaluation is a critical component in assessing consumer acceptability and the overall quality of food products. In this study, the sensory properties of PC and BC were compared based on key parameters, such as appearance, color, texture, aroma, taste, and the overall acceptability. The evaluation showed notable differences in appearance, texture, flavor, and the overall acceptability. There was variation in appearance in CC and BC. The appearance of CC deteriorated steadily over the 4 weeks while BC maintained better appearance, compared to CC. BC at lower temperatures (80°C and 85°C) had better appearance than CC at higher temperatures that declined in appearance.

The sensory quality (texture and flavor) of CC declined from 7 to 4 (9-point hedonic scale) over 4 weeks, indicating a loss of crispness and freshness. Blanching at lower temperature retained texture and flavor.

The overall acceptability of CC decreased from 7 to 4 (9-point hedonic scale) while the BC had higher initial acceptability (7–8), which declined to 5–6 (9-point hedonic scale) by week 4. Blanching at lower temperature showed better overall retention of acceptability.

The sensory evaluation of BC aligned with the findings of Holzapfel *et al.* [38] Blanching, particularly at lower temperature, effectively preserved the sensory qualities of cabbage. However, blanching at higher temperature can lead to faster degradation of sensory qualities.

The sensory evaluation of CC and PC showed notable differences both samples. The appearance of CC deteriorated steadily over 4 weeks, starting at a score of 7 and dropping to 4 by week 4, while that of PC maintained a higher appearance score of 8 throughout the 4-week period. The pickling process helps to preserve color and visual appearance of the cabbage.

The flavor of CC declined from 7 to 4(9-point hedonic scale), which potentially be due to microbial activity and enzymatic changes, while that of PC was consistently high, starting at 9 and remaining at 8 by week 4. Vinegar used in pickling enhanced and preserved the flavor.

The texture of CC declined from 7 to 4(9-point hedonic scale), and loss of crispness and freshness was observed, while texture of PC remained relatively stable, starting from 8 in the first three weeks and slightly dropping to 7 by week 4. The pickling process, which includes vinegar, helps to maintain the firmness of cabbage.

The overall acceptability of CC decreased from 7 to 4(9-point hedonic scale, reflecting a decline in appearance, texture, and flavor. The overall acceptability of PC remained high. The sensory attributes of PC were well preserved because of pickling process.

The sensory evaluation of PC aligned well with the findings of Uthpala *et al.* [52]. Pickling effectively preserves the sensory qualities of cabbage. The acidic environment of pickling process inhibits microbial growth and enzymatic degradation, contributing to the prolonged preservation of desirable sensory attributes. Thus, pickling is a reliable method for extending the shelf life and maintaining sensory qualities of cabbage. The sensory evaluation indicates that pickling enhances the sensory appeal of cabbage, particularly in terms of flavor, texture, and appearance. While BC is acceptable, especially in cooked applications, it tends to be milder and softer, which may reduce its sensory impact in raw or cold servings. Optimizing blanching conditions (e.g., time and temperature) or combining both treatments (e.g., blanching before pickling) may help in balanced texture and flavor for improved consumer acceptance.

5. Conclusion

This study showed that improving both pickling and blanching processes could lower microbial load while maintaining the nutritional value of cabbage. The findings demonstrated that while pickling completely inhibited the growth of total coliform and significantly reduced the growth of THBC, blanching at temperatures >90°C decreased bacterial growth. Furthermore, after blanching and pickling, the study found that the nutritional makeup of cabbage changed, emphasizing the significance of preserving nutrient retention through optimal processing conditions. Overall, this study contributes to better food safety and quality by offering insightful information about how to create efficient blanching and pickling methods for cabbage.

Recommendations

Application of ideal pickling and blanching conditions on an industrial scale to guarantee constant nutrient preservation and microbial load reduction. More investigation is required into how different pickling agents and concentrations affect nutrient retention and microbial load. Creation of recommendations to help small-scale cabbage processors implement the best pickling and blanching techniques.

Author Contributions

All authors contributed equally to the design, execution, and interpretation of the research, as well as to the drafting and revision of the manuscript. All authors approved the final version of the manuscript and are responsible for its content.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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