A Comparative Study of Biochemical Changes in Cabbage

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Abstract

Fermentation has long been used and shared as a method of food preservation across many cultures, but recent research suggests that it also enhances nutritional value in food and contributes positively to metabolic health. This study will investigate how fermentation compares to steaming and frying in affecting vitamin C retention, glucose concentration, and pH levels in napa cabbage. Using at-home extraction methods, liquid samples were obtained from fermented, fried, and steamed cabbages, with three replicates prepared for each condition. Test strips were used to measure the vitamin C, glucose, and pH levels for all samples. Results indicate that fermentation preserves more vitamin C, reducing the glucose concentration significantly through microbial metabolism, and lowering pH levels due to its organic acid formation. These biochemical changes are relevant because the reduction in glucose and increased acidity help preserve antioxidants and promote better metabolic stability compared to thermal-based cooking methods.

Introduction

Cabbage is widely consumed in raw, cooked, and fermented forms across many cultures. However, different preparation methods can significantly alter its nutritional and biochemical properties. These changes occur because heat-based cooking and fermentation affect cellular structure, enzyme activity, and nutrient stability in fundamentally different ways. Fermentation has also been associated with improvement of gut health, increased nutrient bioavailability, and other beneficial metabolic effects due to the activity of lactic acid bacteria (LAB). During fermentation, LAB breaks down complex plant compounds and cell walls, which makes nutrients easier to absorb and utilize. These bacteria metabolize the sugars in cabbage and produce organic acids, which can lower pH levels and enhance food safety while also influencing how the food interacts with metabolism. Understanding how these preparation methods chemically alter cabbage can help consumers make more informed, health-conscious dietary choices. Therefore, it is expected that fermented cabbage will result in a greater nutrient bioavailability and higher retention of beneficial bioactive compounds compared to cooked cabbage.

Literature Review

Origins of Kimchi

Kimchi is a traditional Korean fermented food that originated as a method of preserving vegetables during the winter months, when fresh produce was scarce. Its history dates back to over a thousand years, where Korea's agricultural practices and climate led to the beginning of various traditions, specifically kimjang, the seasonal practice of preparing and sharing kimchi.[1] Over time, kimchi evolved from a simple salted vegetable dish into a complex food flavored with garlic, ginger, chili peppers, and seafood-based seasonings, using available resources to create a complex flavor. Today, kimchi is a cultural staple consumed daily in almost every Korean household.

Preservation & Biochemical Process

Since fermentation is an ancient method of food preservation, it heavily relies on microbial metabolism rather than thermal processing. During the fermentation of cabbage LAB, including *Lactobacillus plantarum*, *Leuconostoc mesenteroides*, and *Pediococcus pentosaceus*, metabolize sugars and convert them into lactic acid through anaerobic glycolysis. This process occurs best at temperatures between approximately 18-22°C (~64-72°F), which supports LAB growth while limiting unwanted microbes. As the lactic acid accumulates over time, the pH of the cabbage decreases to 3.5-4.0, creating an acidic environment that inhibits the growth of many spoilage and pathogenic bacteria.[2] The acidic environment helps preserve vitamin C because it is an acid, which is more chemically stable at lower pH levels and less likely to be at risk of oxidative degradation.[3] The acidic environment formed during fermentation further stabilizes certain vitamins and bioactive compounds, making fermentation a beneficial method for preserving a high level of nutritional quality while extending shelf life. For example, vitamin C and polyphenols (plant-based antioxidants) are better preserved under low pH conditions because the acidic environment slows down the oxidative reactions that would normally break them down. These compounds are important for human health since vitamin C supports immune function and collagen production, while polyphenols help reduce oxidative stress in the body by neutralizing harmful free radicals.[4]

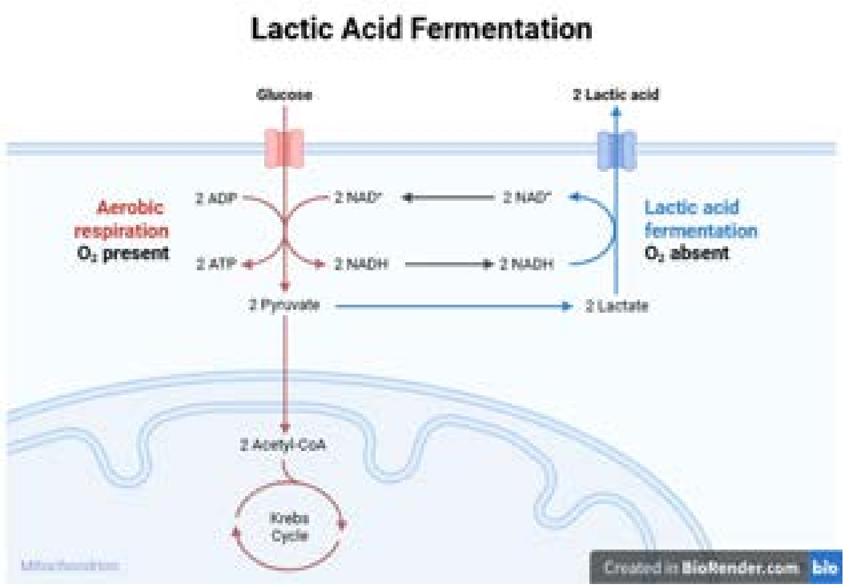

Fig. 1. Lactic acid fermentation pathway showing the conversion of glucose to lactate.

Lactic acid supports continued ATP production through glycolysis when oxygen levels are unable to sustain aerobic respiration. As shown in Fig. 1, the process begins with glycolysis, where glucose is converted into pyruvate, generating two ATP and reducing NAD^+ to NADH.

While aerobic conditions allow pyruvate to enter the mitochondrion for the Krebs Cycle, the anaerobic pathway allows the pyruvate to be reduced to lactate. This conversion is important because it regenerates NAD^+ by oxidizing NADH, allowing glycolysis to continue producing minimal ATP with the absence of oxygen.

Cultural & Dietary Significance

Kimchi originated as a survival-based preservation strategy to survive winters where food scarcity was a risk. The frequent consumption pattern shows kimchi as a staple fermented food in regular diets, making it different from other foods that are consumed less often. Research suggests that consuming kimchi in moderate portions approximately three to five times per week can be an excellent way to receive the health benefits of fermented foods without excessive intake.[5] In contrast, consuming it only once a month is unlikely to provide consistent probiotic or metabolic benefits, as regular intake produces a more stable gut microbiome.[6] However, preparation style and moderation remain important factors, as excessive consumption of highly salted or over-fermented kimchi may increase sodium intake or histamine exposure, potentially cancelling some benefits. These findings indicate that while fermented cabbage is culturally significant and nutritionally beneficial, its health effects are majorly influenced by its frequency of intake, portion size, and fermentation stage.

Glucose Metabolism & Glycemic Control

One major metabolic change caused by fermentation is the reduction of available carbohydrates prior to consumption, which lowers the glycemic index (GI)–a measure of how quickly a food raises blood glucose levels–when fermented cabbage is compared to fresh or cooked forms. During the fermentation process, lactic acid bacteria (LAB) metabolize simple sugars such as glucose and fructose through glycolysis (the Embden-Meyerhof-Parnas pathway), converting them into lactic acid, while some heterofermentative species also utilize the phosphoketolase pathway to produce lactic acid along with small amounts of acetic acid and carbon dioxide. The organic acids produced during fermentation delay gastric emptying and carbohydrate digestion, reducing the rate at which glucose is absorbed into the bloodstream and thereby decreasing postprandial glycemia. Research supports these mechanisms, showing that individuals who regularly consume fermented kimchi experience improvements in blood glucose regulation, insulin sensitivity, and other metabolic markers.[7] Reduced post-meal glucose spikes and decreased insulin demand suggest that fermentation pre-processes carbohydrates in a way that benefits human metabolism, and fermented foods may also promote beneficial gut microbiota that interacts with glucose-regulating hormones such as incretins, improving glucose uptake and stabilizing blood sugar levels.

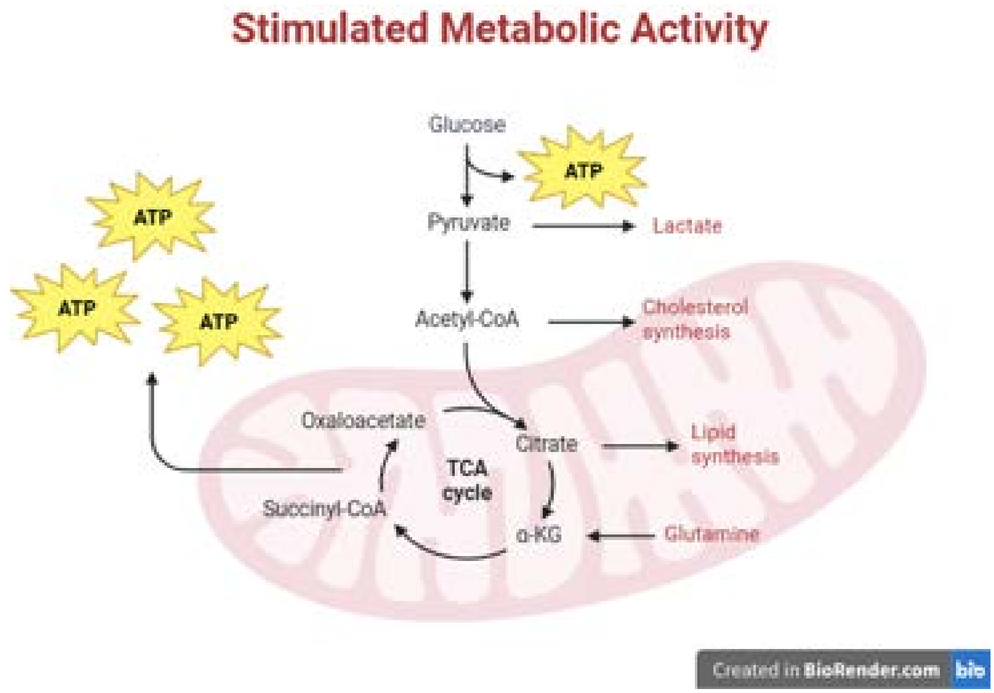

Fig. 2. Glucose metabolism pathway showing how glucose is used for energy production and biosynthesis.

As shown in Fig. 2, stimulated metabolic activity allows a cell to simultaneously increase the energy production and provide building blocks for growth. Glucose is first broken down through glycolysis, producing ATP and pyruvate. Pyruvate can either convert to lactate or enter the mitochondrion once converted to Acetyl-CoA. Within the cycle, these molecules are oxidized to produce energy and are deviated to fuel the synthesis of lipids and cholesterol. Additionally, alternative nutrients like glutamine can be converted to α-ketoglutarate **to** help maintain the TCA cycle activity.

Antioxidant Activity & Oxidative Stress

Fermentation has been shown to improve the antioxidant capacity of cabbage by increasing the availability of bioactive compounds and improving free-radical scavenging ability.[8] Studies examining different fermentation stages indicate that antioxidant activity increases as fermentation progresses, suggesting that microbial metabolism plays a key role in generating protective compounds. Fermentation improves the bioavailability of antioxidant compounds such as vitamin C (ascorbic acid), polyphenols, flavonoids, and glucosinolate-derived isothiocyanates, which possess anti-inflammatory and anti-carcinogenic properties. Antioxidants are essential for neutralizing reactive oxygen species (ROS), which can cause cellular damage and contribute to inflammation and metabolic disorders. Compared to heat-based cooking methods, fermentation better preserves antioxidant compounds that are degraded by heat exposure. For example, studies have demonstrated the increase in phenolic compound content and radical-scavenging activity by approximately 15-30% during fermentation, whereas boiling can reduce vitamin C by 30-50%.[9] This increased antioxidant activity provides an explanation for decreased oxidative stress and inflammation associated with fermented cabbage consumption.

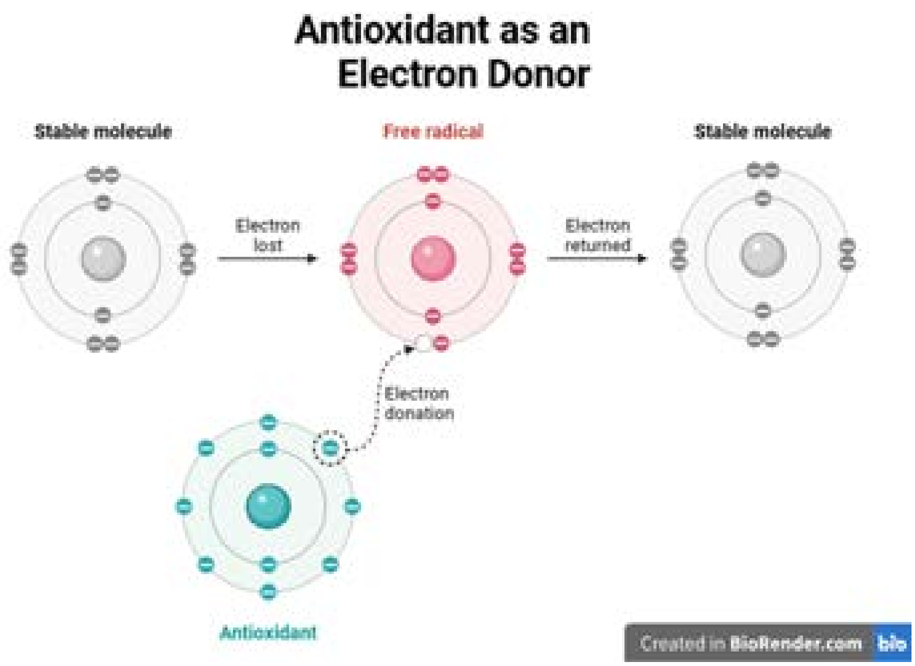

Fig. 3. Antioxidant activity demonstrating how free radicals are stabilized through election donation.

As shown in Fig. 3, antioxidants help reduce oxidative damage by donating an electron to unstable free radicals to neutralize them. A free radical is formed when an electron is lost from an originally stable molecule, making the unpaired electron high energy. This unstable state normally triggers chain reactions that can damage nearby molecules, but instead of the free radical attacking a stable molecule, the antioxidant molecule donates one of its own electrons to stabilize the free radical. Although the antioxidant might become a weak radical, it is more stable and less reactive, preventing further chain reactions and limiting cellular damage.

Nutrient Bioavailability & Human Health

Fermentation not only preserves nutrients but also enhances their bioavailability, meaning that the body can absorb and utilize the nutrients more efficiently.[10] Many vegetables, including cabbage, naturally contain antinutrients such as phytates as part of their plant defense mechanisms against pests, which can bind to minerals or interfere with its digestion and absorption of nutrients. While beneficial to the plant, these compounds can bind to minerals like iron and zinc, which reduces their absorption in the human digestive system. During fermentation, microbial enzymes break down plant cell walls and reduce antinutritional factors, allowing nutrients such as Vitamin C and other antioxidants to be more easily absorbed by the body.[11] Additionally, a more acidic environment can improve mineral solubility, specifically for iron and calcium, which can improve the absorption in the small intestine. The breakdown of plant tissues also increases the release of antioxidant compounds, further supporting cellular protection. These biochemical changes can help explain why fermented cabbage may often be associated with improved nutrient utilization and metabolic efficiency.

Methods

Sample Preparations

Napa cabbage was prepared using three methods: fermentation, steaming, and frying. For each preparation method, three replicates were created to guarantee its consistency and reliability of the results. The nutrient measurements were obtained using colorimetric test strips (Bartovation Vitamin C Test Strips, Macherey-Nagel Medi-Test Glucose Test Strips, and HYDRION pH Test strips 0-13 pH Range).

Fermented Cabbage with gochujang

Approximately 500 g of napa cabbage was finely chopped to increase the surface area and was submerged in one liter of NaCl brine prepared by dissolving table salt in distilled water until a concentration of 2% (w/v) was achieved. The solution was mixed until the salt was fully dissolved, and the cabbage was covered by the brine. Gochujang was added to simulate a kimchi-style fermentation environment, but it is important to note that the inclusion of gochujang may have influenced the results, as it contains additional ingredients such as sugars, starches, and soybean products, which could alter the microbial activity. The mixture was then placed in a plastic container with a loosely covered lid to allow carbon dioxide to escape. The cabbage sample was left to ferment at room temperature (approximately 20-22°C) for 24 hours to allow salt to draw the water out of the cabbage and for the bacteria to break down sugars, forming acids, and stabilizing vitamin C. Afterwards, the samples were stored in a refrigerator to slow fermentation and stabilize the biochemical changes for 12 hours. Prior to testing, the samples were brought to room temperature to temper for 15 minutes before allowing the test strips to be submerged for three seconds and the results were recorded after 35 seconds under consistent light conditions. This procedure was repeated for all three replicates.

Fermented Cabbage without gochujang

Approximately 500 g of napa cabbage was finely chopped to increase the surface area and was submerged in one liter of NaCl brine prepared by dissolving table salt in distilled water until a concentration of 2% (w/v) was achieved. The solution was mixed until the salt was fully dissolved, and the cabbage was covered by the brine. The mixture was then placed in a plastic container with a loosely covered lid to allow carbon dioxide to escape. The cabbage sample was left to ferment at room temperature (approximately 20-22°C) for 24 hours to allow salt to draw the water out of the cabbage and for the bacteria to break down sugars, forming acids, and stabilizing vitamin C. Afterwards, the samples were stored in a refrigerator to slow fermentation and stabilize the biochemical changes for 12 hours. Prior to testing, the samples were brought to room temperature to temper for 15 minutes before allowing the test strips to be submerged for three seconds and the results were recorded after 35 seconds under consistent light conditions. This procedure was repeated for all three replicates.

Fried Cabbage

Approximately 150 g of napa cabbage was used to cut into uniform pieces and fried in a pan over medium heat for six minutes, using a small and consistent amount of oil. The cabbage was stirred continuously to ensure even heating. After frying, the samples were allowed to cool in room temperature (approximately 20-22°C) for 15 minutes. Each replicate was then blended using a standard household blender until a consistency of a uniform mixture was achieved. Accordingly, a small amount of distilled water (approximately 15 mL) was added to facilitate blending and maintain its consistency across all three samples. The mixture was then filtered using an organic cotton cheesecloth to obtain a liquid extract. Lastly, the colorimetric test strips were submerged into the liquid extract for three seconds and were recorded after developing for 35 seconds under consistent lighting conditions. This procedure was repeated for all three replicates.



Steamed Cabbage

Approximately 150 g of napa cabbage was cut into uniform pieces and steamed in boiling water (approximately 100°C) for five minutes until it softened. After steaming, the samples were allowed to cool to room temperature (approximately 20-22°C) for 15 minutes. Each replicate was blended using a standard household blender until a consistency of a uniform mixture was achieved. Consequently, a small amount of distilled water (approximately 15 mL) was added to facilitate the blending and maintain its consistency across the three samples. The mixture was then filtered using an organic cotton cheesecloth to obtain a liquid extract for measurement. Colorimetric test strips were submerged into the liquid extract for three seconds and were recorded after allowing it to develop for 45 seconds under consistent lighting conditions. This procedure was repeated for all three replicates.



Results

Fermented Cabbage with gochujang

Replicate	Vitamin C (mg/dL)	Glucose (mg/dL)	pH
Trial 1	40 ± 5 mg/dL	60 ± 5 mg/dL	3.7
Trial 2	40 ± 5 mg/dL	60 ± 5 mg/dL	3.7
Trial 3	35 ± 5 mg/dL	65 ± 5 mg/dL	3.8

Fermented Cabbage without gochujang

Replicate	Vitamin C (mg/dL)	Glucose (mg/dL)	pH
Trial 1	40 ± 5 mg/dL	30 ± 5 mg/dL	3.6
Trial 2	35 ± 5 mg/dL	30 ± 5 mg/dL	3.5

Trial 3	40 ± 5 mg/dL	30 ± 5 mg/dL	3.6

Fried Cabbage

Replicate	Vitamin C (mg/dL)	Glucose (mg/dL)	pH
Trial 1	15 ± 5 mg/dL	110 ± 5 mg/dL	6.6
Trial 2	10 ± 5 mg/dL	105 ± 5 mg/dL	6.5
Trial 3	10 ± 5 mg/dL	105 ± 5 mg/dL	6.5

Steamed Cabbage

Replicate	Vitamin C (mg/dL)	Glucose (mg/dL)	pH
Trial 1	20 ± 5 mg/dL	85 ± 5 mg/dL	6.4
Trial 2	20 ± 5 mg/dL	90 ± 5 mg/dL	6.5
Trial 3	20 ± 5 mg/dL	85 ± 5 mg/dL	6.4

Discussion

In conclusion, fermentation was determined to be the most effective method for preserving vitamin C, as it avoids high heat exposure while promoting an acidic environment that helps preserve ascorbic acid by slowing the oxidative degradation. As a result, the fermented cabbage samples retained the highest vitamin C concentrations, ranging from 30-45 mg/dL across all the trials, whereas steamed cabbage demonstrated moderate levels (approximately 20-25 mg/dL) and fried cabbage samples showed the greatest loss (approximately 10-20 mg/dL). This supports the conclusion that thermal processing accelerates vitamin C degradation due to its heat and oxygen exposure, particularly demonstrated through frying. The most significant biochemical change observed in the fermented cabbage was its reduction in pH, as it decreased to 3.5-3.8, confirming the production of organic acids (primarily lactic acid) through microbial activity metabolized available sugars under anaerobic conditions, which converted glucose into lactic acid and lowering the pH. Glucose data can further support that fermented cabbage without gochujang showed the lowest glucose concentration of approximately 30-35 mg/dL, proving a significant reduction because of its microbial consumption. Meanwhile, the fermented cabbage samples with gochujang exhibited higher glucose levels of approximately 60-70 mg/dL because of its additional sugars present in the sauce, which limited the extent of the glucose reduction, but did not prevent it. In contrast, steamed cabbage had maintained relatively stable glucose levels (approximately 85-96 mg/dL) and had neutral pH levels of 6.4-6.5, indicating that heat-based cooking does not significantly reduce its carbohydrate content or promote acid formation. Fried cabbage showed the highest glucose concentrations of approximately 105-115 mg/dL, which can be explained by its loss of moisture during the cooking that concentrates the existing sugars rather than increasing the sugar content, meanwhile, its pH had remained nearly neutral (approximately 6.5-6.6) that reflects its absence of fermentation. Overall, fermentation causes significant biochemical modifications through microbial activity, such as acid production and glucose metabolism, while preserving its vitamin C, whereas steaming and frying mainly cause physical and thermal changes that lead to nutrient degradation but minimal biochemical shifts, with consistent trends across all the replicates that support the reliability of the observed results.

Limitations

The color-based test strips are often subject to visual interpretation, which can vary due to lighting conditions, color perception differences, and slight inconsistencies between replicates. Additionally, the inclusion of gochujang in the fermentation process had introduced external sugars and compounds that could have influenced its glucose and pH measurements, making it difficult to separate the effects of the cabbage alone. The variations in blending using a standard household blender, distilled water purchased via a local grocery store, and making all the samples uniform may have impacted the concentration levels of the extracted liquids. Furthermore, the small variations in temperature and fermentation could have altered the microbial activities and its biochemical outcomes. These listed factors could limit the precision of the results and should be more strictly controlled for future lab-based experiments.

Conclusion

The results of this study demonstrate that fermentation leads to the most favorable biochemical outcomes in napa cabbage compared to steaming and frying. Unlike heat-based methods, which cause nutrient loss, fermentation promotes chemical alterations determined by microbial activity, resulting in decreasing glucose levels and increased acidity. These changes show active metabolic processes that not only preserve important nutrients like vitamin C, but also alter the composition of cabbage that may enhance its nutritional purposes. In contrast, the steamed cabbage samples produced moderate nutrient loss with minimal biochemical changes, meanwhile the fried cabbage samples resulted in the greatest reduction in vitamin C and a noticeable increase in glucose concentration due to its moisture loss. The consistent lower pH and glucose concentrations in the fermented cabbage samples support the improvement of food stability and influencing metabolic responses after consumption. Overall, these findings suggest that fermentation is the most functional method for maintaining nutritional quality and promoting beneficial biochemical changes rather than conventional cooking techniques. Future studies could investigate longer fermentation periods, different cabbage varieties, ingredient combinations, or home testing versus laboratory experimenting to improve nutrient preservation, functional benefits, and practical recommendations for at-home fermentation.

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