

The potential of fermented cabbage waste liquid as a natural preservative for large red chili (*Capsicum annuum* L.)

[Potensi cairan limbah fermentasi kubis sebagai bahan pengawet alami cabai merah besar (*Capsicum annuum* L.)]

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ABSTRACT

Large red chili peppers are highly susceptible to postharvest deterioration, including physiological, physical, mechanical, and microbiological damage. This decline in quality results from continuous respiration during storage, leading to weight loss, wilting, and ultimately decay. One promising approach to minimizing these postharvest losses is the use of fermented cabbage waste liquid as an environmentally friendly and cost-effective natural preservative. Therefore, the study evaluated the potential of fermented cabbage waste liquid as a natural preservative for large red chili peppers. The experiment comprised two stages. In the first stage, fermented cabbage waste liquid was produced using a Completely Randomized Design (CRD) involving two factors with three replications: NaCl concentrations of 3%, 5%, and 7%, and fermentation durations of 4, 6, 8, and 10 days. The second stage involved soaking large red chili peppers in the fermented liquid from the first stage for 12 h, followed by air-drying and storage at room temperature (27–29°C). The results revealed a significant interaction between NaCl concentration and fermentation duration on the characteristics of the fermented cabbage waste liquid as a natural preservative. The optimal treatment consisted of 7% NaCl with a fermentation duration of 4 days, resulting in a shelf life of 16.67 ± 0.90 days, weight loss of $2.42 \pm 1.77\%$, firm texture, and bright red color. These findings indicate that fermented cabbage waste liquid has considerable potential as a natural preservative for large red chili peppers.

Keywords: Cabbage fermentation waste liquid, fermentation duration, large red chili peppers, NaCl concentration, natural preservative

ABSTRAK

Cabai merah besar sangat rentan mengalami kerusakan pascapanen, baik kerusakan fisiologis, fisik-mekanis, maupun mikrobiologis. Penurunan mutu tersebut terjadi akibat proses respirasi yang terus berlangsung selama penyimpanan sehingga menyebabkan susut bobot, pelayuan, hingga pembusukan. Salah satu upaya yang dapat dilakukan untuk mengurangi kerugian tersebut adalah pemanfaatan cairan limbah kubis sebagai pengawet alami yang ramah lingkungan dan berbiaya rendah. Tujuan penelitian ini adalah mengevaluasi potensi cairan limbah fermentasi kubis sebagai pengawet alami pada cabai merah besar. Penelitian terdiri atas dua tahap, dengan tahap pertama meliputi pembuatan cairan fermentasi menggunakan Rancangan Acak Lengkap (RAL) dengan tiga ulangan, yang terdiri atas tiga konsentrasi NaCl (3%, 5%, dan 7%) dan empat durasi fermentasi (4, 6, 8, dan 10 hari). Tahap kedua meliputi perendaman cabai merah besar dalam cairan fermentasi pada tahap 1 selama 12 jam, kemudian dikeringanginkan dan disimpan pada suhu ruang (27–29°C). Hasil menunjukkan bahwa interaksi antara konsentrasi NaCl dan lama fermentasi berpengaruh signifikan terhadap karakteristik cairan limbah fermentasi kubis sebagai pengawet alami. Perlakuan terbaik diperoleh pada penambahan NaCl 7% dengan lama fermentasi empat hari yang mampu mempertahankan mutu cabai dengan umur simpan $16,67 \pm 0,90$ hari, susut bobot $2,42 \pm 1,77\%$, tekstur tetap keras, dan warna merah cerah. Dengan demikian, cairan limbah kubis hasil fermentasi berpotensi sebagai pengawet alami untuk cabai merah besar.

Kata kunci: Cabai merah besar, cairan limbah fermentasi kubis, konsentrasi NaCl, lama fermentasi, pengawet alami

Introduction

Large red chili pepper (*Capsicum annuum* L.), belonging to the genus *Capsicum* within the Solanaceae family, is among Indonesia's horticultural commodities with high economic value (Anjaneyulu & Sharangi, 2022). The demand for fresh chili peppers remains consistently high due to their extensive use as food ingredients and industrial raw materials. Beyond their economic value, large red chili peppers possess nutritional and functional benefits associated with their carotenoid content, particularly capsanthin, and the presence of capsaicin, which contributes to their antioxidant activity (Ko et al., 2022). Consequently, preserving the quality and ensuring a steady supply of fresh chili peppers are important, particularly during the rainy season, when declining production can result in substantial increases in market prices (Jamilah et al., 2026).

Despite their high value, large red chili peppers are highly perishable and require careful postharvest handling to maintain quality throughout distribution (Anjaneyulu & Sharangi, 2022). Chili peppers have a high moisture content (70–90%), making them highly susceptible to water loss and physiological changes after harvest. These conditions can lead to tissue softening, reductions in bioactive compounds and nutritional value, and consequently affect shelf life, consumer acceptance, and resistance to deterioration during transportation (Liu et al., 2025). Postharvest deterioration of chili peppers is influenced by physiological, environmental, mechanical, and microbial factors. High respiration rates, moisture loss, inappropriate storage temperatures, and mechanical damage can accelerate weight loss and quality deterioration (Peng et al., 2023). In addition, infections by pathogens such as *Colletotrichum*, *Botrytis*, *Alternaria*, and *Fusarium* spp. can cause postharvest diseases that accelerate deterioration and shorten the shelf life of chili peppers (Liu et al., 2025 ; Kovács et al., 2025). The hollow structure of chili fruit and its high surface-area-to-weight ratio also contribute to rapid water loss, resulting in fruit shriveling and reduced turgidity (Díaz-Pérez et al., 2024).

The increasing demand for safer and more sustainable preservation technologies has stimulated interest in natural preservatives derived from agricultural by-products. Fresh fruits and vegetables are rich sources of bioactive compounds with antioxidant, antifungal, and antimicrobial activities, making their processing residues promising alternatives to synthetic preservatives (Blejan et al., 2023). Tropical fruit and vegetable wastes, including peels and discarded plant materials, have demonstrated inhibitory activity against several pathogenic bacteria, indicating their potential to enhance food safety and extend the shelf life of fresh produce (Budiaty et al., 2022). Moreover, the valorization of these by-products contributes to reducing food waste and supporting more sustainable food systems (Pautposis et al., 2025).

Among vegetable by-products, cabbage waste represents a particularly promising resource. Cabbage is one of Indonesia's major vegetable crops, contributing 20.45% of national vegetable production, with total production reaching 1,399,005 tons in 2023 and placing Indonesia among the world's leading cabbage-producing countries (Ghiffar et al., 2025). A substantial portion of cabbage waste originates from unsold vegetables in traditional markets, where inadequate management may contribute to environmental pollution because of its high moisture content and rapid decomposition (Junitasari et al., 2023). Nevertheless, cabbage waste provides an excellent substrate for the growth of lactic acid bacteria, including *Lactobacillus plantarum*, *L. delbrueckii*, *L. fermentum*, and *L. brevis*. During fermentation, these microorganisms produce organic acids with antifungal activity and bacteriocins, peptide-based antimicrobial compounds that have considerable potential as food preservatives (Raman et al., 2022).

According to Li et al. (2026), fermented vegetables generally require relatively high salt concentrations as a preservative; however, excessive salt levels can suppress microbial activity, inhibit the fermentation process, increase production costs, and generate highly saline wastewater. Salt concentrations below 2.5% may promote spoilage microorganisms, whereas concentrations above 10% may inhibit fermentation because of the proliferation of halophilic microorganisms (Anggraeni et al., 2021). Previous studies have

shown that optimal fermentation conditions differ among cabbage products. Kimchi prepared from Chinese cabbage achieved the best quality using 4% NaCl for six days, whereas sauerkraut produced the highest quality after seven days with 2.25–2.5% NaCl. Fermented purple cabbage has also been successfully produced using 2–3% NaCl for three days (Siska, 2023). This study used fermented cabbage extract as a natural treatment to extend the shelf life of bananas. Spontaneous fermentation by lactic acid bacteria (LAB) produced an acidic environment and antimicrobial metabolites. Treatment with fermented cabbage extract extended the period before the onset of spoilage symptoms from 7 to 11 days (Anik et al., 2024).

However, previous studies have primarily investigated fermented cabbage either as a food product or through the application of its fermented liquid to selected fruits (Cahyaningsih & Sugiharto, 2022; Herman et al., 2024). Information regarding the use of fermented cabbage waste liquid as a natural preservative for other horticultural commodities, particularly large red chili peppers (*Capsicum annuum* L.), remains limited. Considering the high susceptibility of large red chili peppers to physiological deterioration and microbial infection during storage, evaluating the preservative potential of fermented cabbage waste liquid is both scientifically and practically relevant. Therefore, this study aimed to evaluate the potential of fermented cabbage waste liquid as a natural preservative for maintaining quality and extending the shelf life of large red chili peppers.

Materials and method

Materials and equipment

The materials used in this study included white cabbage (*Brassica oleracea* var. *capitata*) leaf waste obtained from a traditional market, fully ripe (100%) large red chili peppers free from physical defects collected from farmers' fields in Malino, South Sulawesi, sodium chloride (NaCl), distilled water, phenolphthalein indicator, buffer solutions, 0.1 N NaOH solution, and starch solution. The equipment used included 100 and 400 mL graduated cylinders (Pyrex, USA), a magnetic stirrer (IKA, Germany), plastic basins, glass jars, test tubes (Pyrex, USA), Pasteur pipettes, an Erlenmeyer flask (DURAN, Germany), a pH meter (Hanna Instruments, Romania), an autoclave (Tomy, Japan), filter cloth, and a Bunsen burner (Fisher Scientific, USA).

Research methods

The research was carried out in two main stages: preparation of the fermented cabbage waste solution, followed by its application to large red chili peppers. A Completely Randomized Design (CRD) with a two-factor factorial arrangement was employed. The first factor was NaCl concentration, consisting of three levels (3%, 5%, and 7%), whereas the second factor was fermentation time, consisting of four levels (4, 6, 8, and 10 days). Each treatment combination was performed in triplicate. The resulting data were subjected to analysis of variance (ANOVA) using IBM SPSS Statistics version 20.0. For treatment effects showing significant differences, Duncan's Multiple Range Test (DMRT) was subsequently conducted to determine differences among treatment means at a significance level of $p < 0.05$.

Preparation of cabbage waste solution

One kilogram of white cabbage leaf waste was thoroughly washed and drained until excess surface water had been removed. The cabbage waste was then cut into pieces approximately 1–2 cm in length using a sterilized knife. The chopped cabbage was transferred into 1000 mL glass jars previously sterilized in an autoclave at 121°C. Sodium chloride (NaCl) was added according to the treatment concentrations (3%, 5%, and 7%), after which the jars were tightly sealed and fermented for 4, 6, 8, or 10 days, depending on the treatment. For the preservation experiment, freshly harvested large red chili peppers were selected based on uniform maturity and the absence of physical defects. Each experimental unit consisted of 240–

250 g of chili peppers. The chilies were washed thoroughly, air-dried, and then immersed in the fermented cabbage waste liquid for 12 h. After soaking, the chilies were drained and stored at room temperature (27–29°C). The weight loss of large red chili peppers was measured following (Ralle et al., 2025).

Lactic acid content

The lactic acid concentration in the fermented cabbage waste liquid was quantified by acid–base titration according to the procedure described by Noor & Wijanarka (2021). Briefly, 15 mL of the sample was placed in an Erlenmeyer flask, after which 50 mL of distilled water and three drops of phenolphthalein indicator were added. Titration was subsequently performed using 0.1 N NaOH until a faint pink coloration developed and persisted for 30 s. The amount of NaOH required to reach the endpoint was recorded. Lactic acid content was then calculated from the NaOH volume consumed, its normality, the molecular weight of lactic acid, the dilution factor, and the sample volume.

Shelf life

The shelf life of large red chili peppers was determined as the storage period from the beginning of storage until the occurrence of quality deterioration (Ridwan et al., 2022). The peppers were considered deteriorated when brown spots appeared on the skin, accompanied by softening and wrinkling of the fruit surface. The end of shelf life was defined as the point at which 50% of the chili peppers in a treatment exhibited these deterioration symptoms.

Vitamin C

Vitamin C in the large red chili peppers was quantified by iodometric titration based on the method of Rahayuningsih et al. (2022). A 20 g portion of the sample was homogenized and brought to a volume of 100 mL with distilled water. The resulting solution was titrated against 0.01 N iodine using starch as the indicator. The titration endpoint was reached when a stable bluish-purple color developed. The vitamin C concentration was subsequently determined using the equation below:

$$\text{Vitamin C (mg)} = \frac{\text{ml Iod} \times N \frac{\text{Iod}}{0.01} \times \frac{100}{10} \times 0.88}{\text{sample weight (g)}} \times 100$$

Sensory evaluation

The sensory evaluation of aroma of fermented cabbage liquid and the texture and color of large red chilli peppers was conducted using 25 untrained panelists employing a scoring test. The aroma scores of fermented cabbage liquid were defined as follows: 5 = odorless; 4 = characteristic cabbage aroma; 3 = slightly pungent odor; 2 = unpleasant odor; and 1 = very unpleasant odor. Texture was evaluated according to the method described by Ashadi et al. (2021) using a seven-point scoring scale, where 1 = very soft and watery, 2 = soft and watery, 3 = soft and wrinkled, 4 = soft and slightly wrinkled, 5 = slightly soft with a smooth surface, 6 = slightly firm with a smooth surface, and 7 = firm with a smooth surface. Color was evaluated visually using a two-point scoring scale, where 2 = bright red skin and 1 = red skin with brown spots.

Results and discussion

Yield of fermented cabbage waste liquid

Both NaCl concentration and fermentation duration significantly affected the yield of fermented cabbage waste liquid ($p < 0.01$), whereas their interaction did not produce a significant effect. The average yields obtained at the three NaCl concentrations are shown in Figure 1.

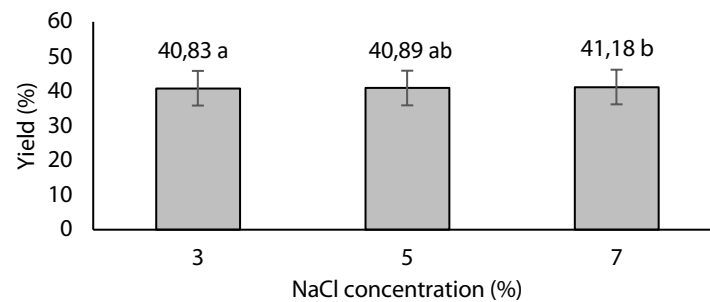


Figure 1. Yield of fermented cabbage waste liquid obtained at different NaCl concentrations. Bars marked with different lowercase letters represent significant differences between treatments ($p < 0.05$)

Figure 1 showed that the addition of 7% NaCl produced the highest yield of fermented cabbage waste liquid ($41.18 \pm 15.19\%$). This value was significantly higher than that obtained with 3% NaCl ($40.83 \pm 14.45\%$), but it did not differ significantly from the 5% NaCl treatment ($40.89 \pm 15.20\%$). These findings differ from those of Anggraeni et al. (2021), who reported that sauerkraut prepared with 2.5% NaCl exhibited the highest moisture content (92.10%). According to Srihardyastutie et al. (2021), the addition of salt is a critical step in cabbage fermentation because it not only promotes the growth of desirable lactic acid bacteria but also improves the organoleptic properties, moisture content, and organic acid composition of the fermented product. The effect of fermentation duration on the yield of fermented cabbage waste liquid is presented in Figure 2.

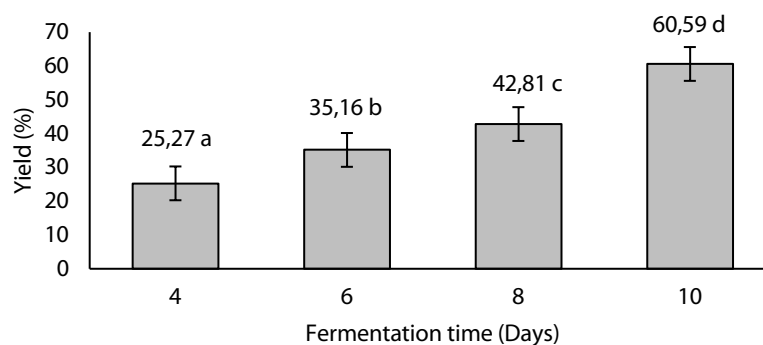


Figure 2. Yield of fermented cabbage waste liquid obtained at different fermentation time. Bars marked with different lowercase letters represent significant differences between treatments ($p < 0.05$)

As shown in Figure 2, fermentation for 10 days resulted in the highest yield of fermented cabbage waste liquid ($60.59 \pm 0.40\%$), which was significantly higher than the yields obtained after 8 days ($42.81 \pm 1.11\%$), 6 days ($35.16 \pm 1.07\%$), and 4 days ($25.27 \pm 1.15\%$) of fermentation. The increase in yield with prolonged fermentation is likely associated with enhanced water release from cabbage tissues as a result of osmotic pressure and microbial activity. During fermentation, NaCl promotes osmotic dehydration, causing water to diffuse from plant cells into the surrounding medium. Simultaneously, the metabolic activity of lactic acid bacteria and the gradual degradation of plant cell walls facilitate further liquid release. Similar observations have been reported during sauerkraut fermentation, where lactic acid bacteria dominate the fermentation process and substantially alter the physicochemical characteristics of cabbage tissues (Wang et al., 2024).

Lactic acid content of fermented cabbage waste liquid

Fermentation duration had a highly significant effect on the lactic acid content of fermented cabbage waste liquid ($p < 0.01$). In contrast, NaCl concentration and the interaction between NaCl concentration and fermentation duration did not significantly affect the lactic acid content. The lactic acid content of fermented cabbage waste liquid at different fermentation durations is presented in Figure 3.

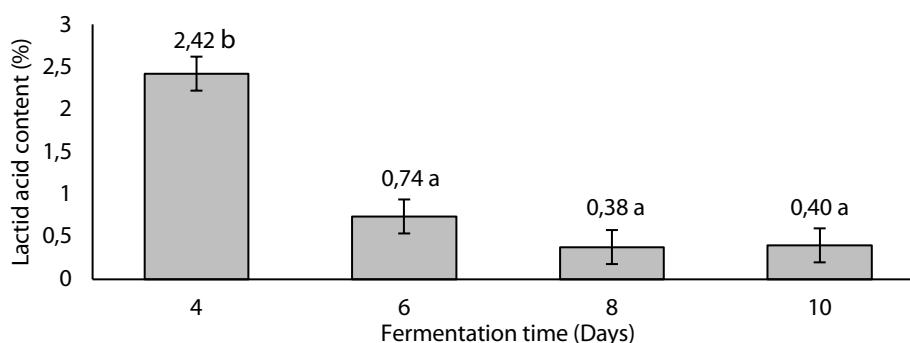


Figure 3. Effect of fermentation duration on the lactic acid content of fermented cabbage waste liquid. Bars marked with different lowercase letters represent significant differences between treatments ($p < 0.05$)

As shown in Figure 3, fermentation for 4 days resulted in the highest lactic acid content ($2.42 \pm 0.53\%$), which was significantly higher than those obtained after 6, 8, and 10 days of fermentation. This finding indicates that LAB were still in their active metabolic phase on day 4, enabling the available fermentable sugars to be efficiently converted into lactic acid. After day 4, the lactic acid content gradually declined and remained statistically unchanged through days 6, 8, and 10, likely due to the depletion of fermentable substrates and the reduced metabolic activity of LAB as the fermentation medium became increasingly acidic. These findings are consistent with those of Gaudioso et al. (2022) and Mayr et al. (2026), who reported that lactic acid production increases rapidly during the early stage of cabbage fermentation and subsequently slows or reaches a plateau as fermentable substrates become limited and the dynamics of the LAB population change.

pH of cabbage waste liquid

Variation in NaCl concentration significantly affected the pH of the fermented cabbage waste liquid ($p < 0.01$). In contrast, neither fermentation duration nor the interaction between NaCl concentration and fermentation duration resulted in a significant effect. The mean pH values obtained from the different NaCl concentration treatments are presented in Figure 4.

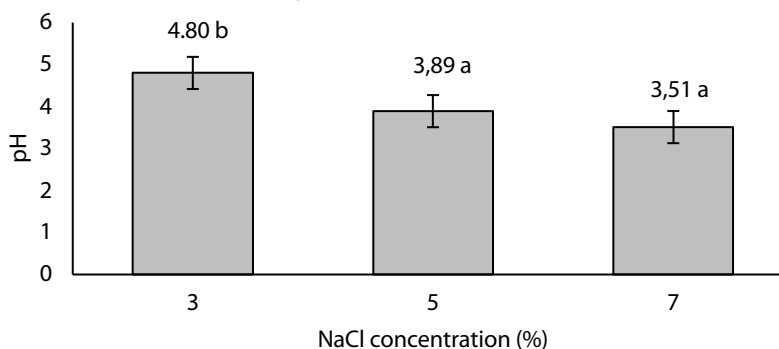


Figure 4. Effect of NaCl concentration on the pH of fermented cabbage waste liquid. Bars marked with different lowercase letters represent significant differences between treatments ($p < 0.05$)

Figure 4 showed that the 3% NaCl treatment resulted in the highest pH value ($4.80 \pm 0.53b$), whereas the 7% NaCl treatment produced the lowest pH value ($3.51 \pm 0.06a$). Increasing the NaCl concentration creates selective conditions that favor the growth of LAB while inhibiting the growth of undesirable microorganisms. As a result, LAB become dominant during fermentation and convert fermentable sugars into lactic acid, leading to a greater accumulation of organic acids and a corresponding decrease in pH. Handayani (2023) also reported that salt plays an important role in promoting LAB dominance and accelerating the acidification process during fermentation. In the present study, the pH values ranged from 3.51 to 4.80, which were generally lower than those reported by Fukuba et al. (2026) in sauerkraut fermentation using NaCl concentrations of 0, 1.6, 2.4, 3.2, and 6.4%. The results showed that NaCl

concentrations of 1.6%, 2.4%, and 3.2% reduced the pH to below 4.60 on days 5, 7, and 14 of fermentation, respectively. In addition, NaCl concentrations of 1.6% and 2.4% significantly increased the population of LAB during the fermentation process.

Aroma of fermented cabbage waste liquid

NaCl concentration, fermentation duration, and their interaction had no significant effect on the aroma of fermented cabbage waste liquid ($p > 0.05$). Figure 5 shows the mean aroma scores of fermented cabbage waste liquid at different NaCl concentrations based on the sensory evaluation results.

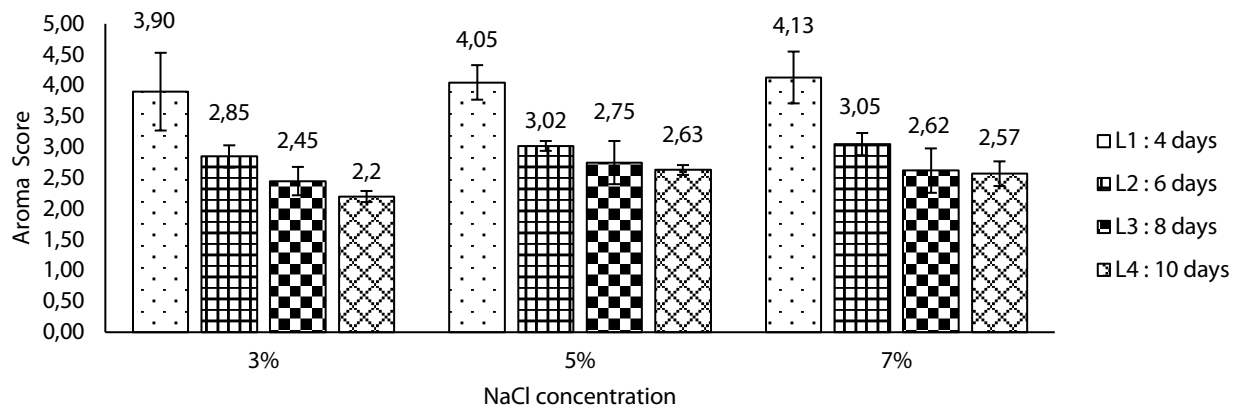


Figure 5. Effect of NaCl concentration and fermentation duration on the aroma of fermented cabbage waste liquid (5 = odorless; 4 = characteristic cabbage aroma; 3 = slightly pungent odor; 2 = unpleasant odor; 1 = very unpleasant odor)

As shown in Figure 5, fermentation with 5–7% NaCl for 4 days resulted in relatively high aroma scores, ranging from 4.05 to 4.13. Statistically, NaCl concentration, fermentation duration, and their interaction had no significant effect on the aroma of the fermented cabbage waste liquid ($p > 0.05$). The results indicate that the treatment variations did not produce detectable differences in aroma among the panelists. Nevertheless, the 5–7% NaCl treatment for 4 days resulted in relatively higher aroma scores, descriptively suggesting a tendency toward more desirable aroma characteristics, although the differences were not statistically significant. Salt concentration plays an important role in determining the flavor characteristics and sensory quality of fermented vegetables by regulating microbial growth and metabolic activity. In addition, salt can influence the formation of flavor compounds, including acids, aldehydes, alcohols, and esters (Tang et al., 2024).

Shelf life of large red chili peppers

In this study, the shelf life of large red chili peppers was highly significantly influenced by NaCl concentration, fermentation duration, and their interaction ($p < 0.01$). The mean shelf life of large red chili peppers following immersion in fermented cabbage waste liquid at various combinations of NaCl concentrations and fermentation durations is presented in Figure 6.

As shown in Figure 6, the shelf life of large red chili peppers was significantly affected by the combined effects of NaCl concentration and fermentation duration. Treatment with fermented cabbage waste liquid as a natural preservative resulted in a shelf life of 16.33–16.67 days under ambient storage conditions. The 5% and 7% NaCl treatments combined with 4 days of fermentation produced the longest storage period. In contrast, treatments involving 3% NaCl with fermentation periods of 6, 8, and 10 days showed lower effectiveness in preserving chili quality throughout storage. A comparable preservation effect was reported by Anik et al. (2024), who found that fermented cabbage extract prolonged banana shelf life by delaying ripening and reducing fruit deterioration. The preservation effect was associated with LAB activity

and their production of organic acids and antimicrobial compounds, which can restrict the proliferation of spoilage bacteria and fungi and consequently help preserve fruit quality.

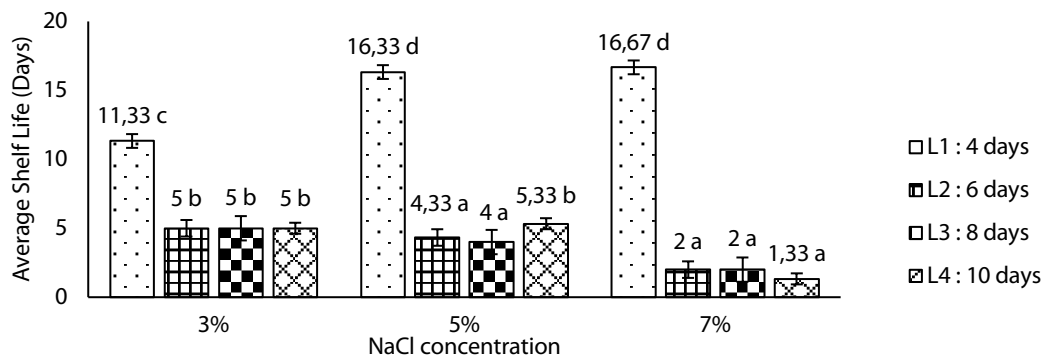


Figure 6. Effect of NaCl concentration and fermentation duration on the shelf life of large red chili peppers. Bars marked with different lowercase letters represent significant differences between treatments ($p < 0.05$) according to Duncan's Multiple Range Test (DMRT)

LAB contribute to food preservation through the formation of antimicrobial metabolites, including lactic acid, acetic acid, and bacteriocins. These metabolites lower the pH of the fermentation medium, creating conditions that restrict spoilage and pathogenic microorganisms while helping to retain product sensory quality during storage (Cahyaningsih & Sugiharto, 2022). An appropriate NaCl concentration can support LAB growth and stimulate the formation of lactic acid and other antimicrobial compounds. Such conditions can suppress spoilage microorganisms and, consequently, contribute to a longer shelf life (Ayivi et al., 2020).

In addition to its selective effect on microbial growth, NaCl creates osmotic pressure that promotes the release of cellular fluids and nutrients from cabbage tissues, providing substrates that support LAB growth during fermentation. However, insufficient salt concentrations may reduce fermentation stability and product safety, whereas excessive salt concentrations can inhibit beneficial microorganisms and slow the fermentation process (Tang et al., 2024). The synergistic effects of NaCl and fermentation-derived organic acids have also been reported to suppress undesirable microorganisms and delay tissue softening in fermented cabbage products such as sauerkraut (Díaz-Pérez et al., 2024).

Weight loss

Transpiration is the major contributor to weight loss because water continuously evaporates from the fruit surface due to differences in vapor pressure between the fruit tissues and the surrounding environment (Sabahannur, 2020). NaCl concentration, fermentation duration, and their interaction had a highly significant effect on the weight loss of large red chili peppers ($p < 0.01$). The mean weight loss values are presented in Figure 7.

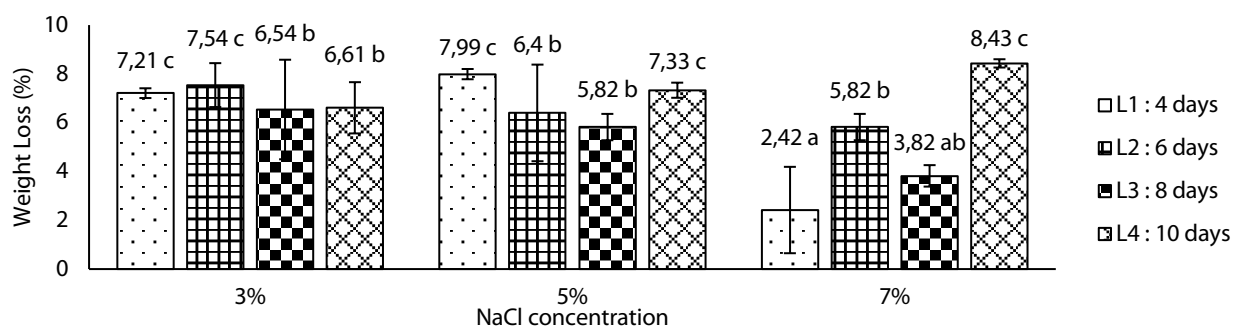


Figure 7. Effect of NaCl concentration and fermentation duration on the weight loss of large red chili peppers. Bars marked with different lowercase letters represent significant differences between treatments ($p < 0.05$) according to Duncan's Multiple Range Test (DMRT)

In this study, large red chili peppers treated with fermented cabbage waste liquid prepared using 7% NaCl and a 4-day fermentation period exhibited the lowest weight loss ($2.42 \pm 1.77\%$), with no significant difference from the treatment using 7% NaCl and 8 days of fermentation. In contrast, the highest weight loss ($8.43 \pm 0.17\%$) was observed in chili peppers treated with fermented cabbage waste liquid prepared using 7% NaCl and 10 days of fermentation. Weight loss in chili peppers is influenced by the high salt concentration in the cabbage waste liquid, which causes water to move out of the chili tissue through osmosis. During the osmotic dehydration process, water moves from the cells into the hypertonic solution, while a small amount of solutes migrate into the cells, resulting in a decrease in moisture content of up to approximately 50%, shrinkage of the cells, and reduced water activity in the product (Mari et al., 2024). Prolonged exposure to the hypertonic salt solution enhances the effect of osmotic dehydration, as the osmotic gradient drives more water out of the cells. Increasing the concentration of the osmotic solution further accelerates this mass transfer, leading to a more significant reduction in both moisture content and product weight (Asghari et al., 2024).

Vitamin C

Vitamin C content of large red chili peppers was significantly affected by NaCl concentration, fermentation duration, and their interaction ($p < 0.05$). The mean vitamin C contents under different treatments are presented in Figure 8. These results indicate that the combination of NaCl concentration and fermentation duration influenced the effectiveness of fermented cabbage waste liquid in preserving vitamin C during storage.

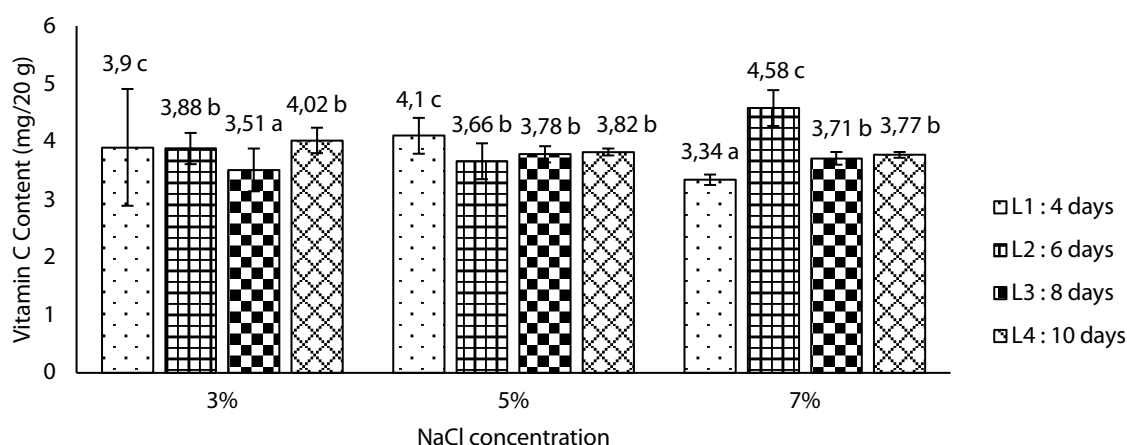


Figure 8. Vitamin C content of large red chili peppers following treatment with different NaCl concentrations and fermentation durations. Different lowercase letters above the bars indicate significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at $p < 0.05$

The differences in vitamin C content were presumably influenced by the fermentation duration, which affected the activity of lactic acid bacteria and the stability of vitamin C during the preservation process. In the treatment with 7% NaCl and 4 days of fermentation, the fermentation process was likely not yet fully stable, allowing vitamin C oxidation to occur at a higher rate. The activity of oxidative enzymes and the presence of oxygen during the early stage of fermentation may have accelerated vitamin C degradation, resulting in lower vitamin C content. In contrast, in the treatment with 7% NaCl and 6 days of fermentation, lactic acid bacteria were presumed to have developed more optimally and produced higher amounts of organic acids. These values were higher than those reported by Sabahannur (2020), who found vitamin C levels of 0.19–0.288 mg/10 g in NaCl-preserved cayenne peppers. This difference may be attributed to variations in the raw materials, preservation methods, and fermentation processes. LAB fermentation produces organic acids and antimicrobial metabolites that lower pH and inhibit spoilage microorganisms, thereby helping to preserve vitamin C during storage (Anumudu et al., 2024; Dissanayake et al., 2025)

Texture

Postharvest moisture loss can cause fruit shrinkage and a decline in firmness. Treatments that suppress the activity of pectin-degrading enzymes and reduce respiration rates can help maintain fruit firmness and quality during storage (Ahmad et al., 2024). Firmness is therefore considered a key indicator of postharvest quality because excessive softening accelerates deterioration, increases susceptibility to microbial spoilage, and reduces marketability (Frempong et al., 2022). Sensory texture scores of large red chili peppers were highly significantly influenced by NaCl concentration, fermentation duration, and their interaction ($p < 0.01$). The mean sensory texture scores under different treatment combinations are presented in Figure 9.

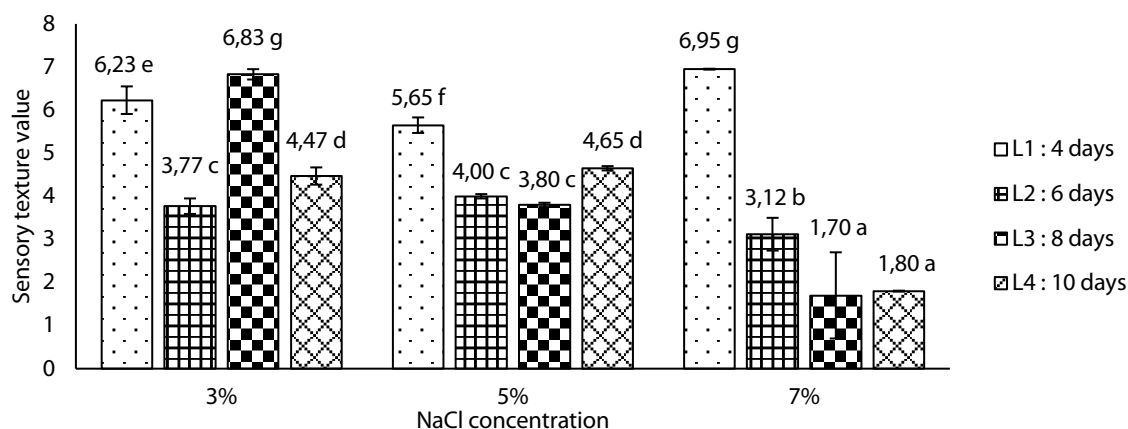


Figure 9. Effect of NaCl concentration and fermentation duration on the texture scores of large red chili peppers (1 = very soft and watery, 2 = soft and watery, 3 = soft and wrinkled, 4 = soft and slightly wrinkled, 5 = slightly soft with a smooth surface, 6 = slightly firm with a smooth surface, 7 = firm with a smooth surface)

Based on sensory observations, the texture quality and surface morphology of large red chili peppers varied among the treatment combinations after storage. At 3% NaCl, peppers treated with fermented cabbage waste liquid for 4 and 8 days maintained a firm texture with a smooth surface, with texture scores of 6.23 and 6.83, respectively. In contrast, fermentation for 6 and 10 days resulted in softer textures with wrinkled or slightly wrinkled surfaces, with scores of 3.77 and 4.47, respectively. At 5% NaCl, the 4-day fermentation treatment maintained a relatively firm texture with a smooth surface (5.65), whereas fermentation for 6, 8, and 10 days resulted in softer textures with slightly wrinkled surfaces, with scores of 4.00, 3.80, and 4.65, respectively. At 7% NaCl, the 4-day fermentation treatment produced the highest texture score (6.95), indicating a firm texture with a smooth surface. Longer fermentation periods of 6, 8, and 10 days resulted in substantially lower texture scores of 3.12, 1.70, and 1.80, respectively, corresponding to soft and wrinkled to soft and watery textures. Representative visual changes in texture and surface morphology after 16 days of storage are presented in Figure 10.

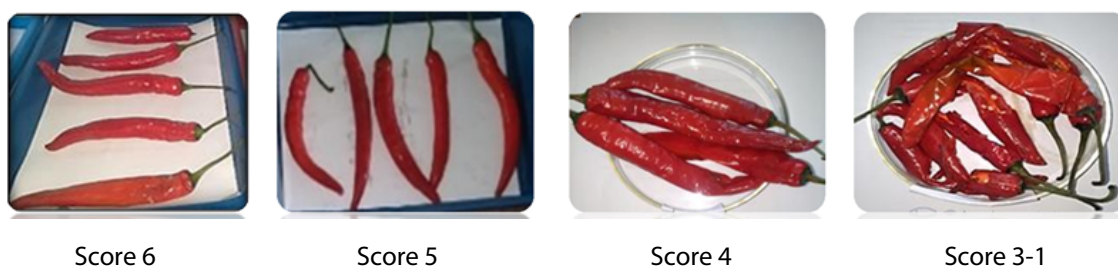


Figure 10. Representative visual appearance of large red chili peppers showing changes in texture and surface morphology after 16 days of storage

Figure 10 shows that large red chili peppers preserved using cabbage waste liquid with 7% NaCl and a fermentation period of 4 days produced the highest texture score (6.95 ± 0.00), characterized by a firm and

smooth texture. In contrast, the use of cabbage waste liquid fermented for 8 days resulted in the lowest texture score (1.70 ± 1.00), indicating tissue softening. Differences in texture among treatments may be influenced by NaCl concentration and fermentation duration, which can affect microbial activity and changes in tissue structure (Tang et al., 2024) reported that salt concentration affects texture characteristics, including firmness, in peppers during fermentation. Similarly, Liu et al. (2025) found that variations in NaCl concentration and fermentation temperature in sauerkraut affected physical properties, such as fracturability, as well as microbial composition during fermentation.

Color

The color of large red chili peppers after storage remained unaffected by NaCl concentration, fermentation duration, or their interaction ($p > 0.05$). The mean color scores of the large red chili peppers, as evaluated by panelists through sensory evaluation under the different treatment combinations, are presented in Figure 11. The highest color score (2.00 ± 0.00), indicating a bright and uniform red skin color, was obtained in treatments using 5% and 7% NaCl with fermentation durations ranging from 4 to 10 days. In contrast, the lowest color scores ($1.00\text{--}1.33 \pm 0.31$), characterized by the presence of brown spots on the fruit surface, were observed in treatments using 3% NaCl with fermentation durations of 6–8 days.

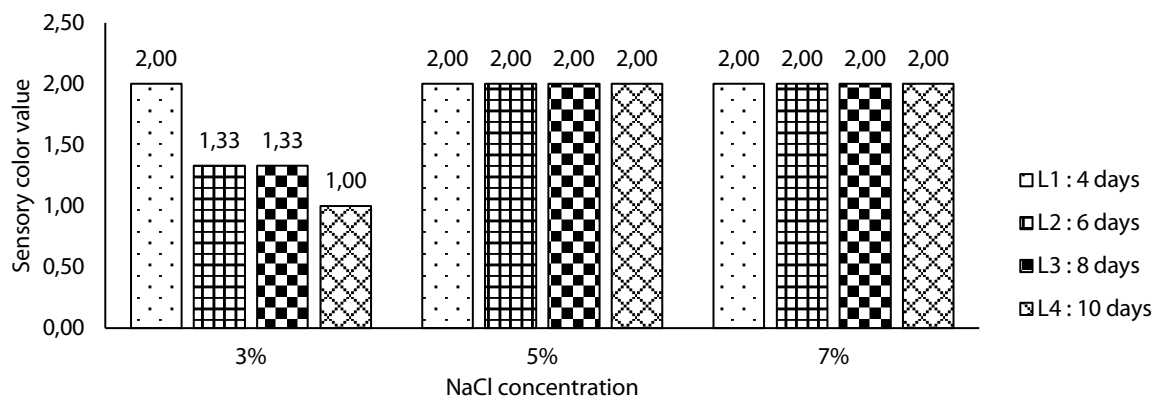


Figure 11. Effect of NaCl concentration and fermentation duration on the color scores of large red chili peppers (2 = bright red skin, 1 = red skin with brown spots)

Figures 12 show the visual differences in the color quality of large red chili peppers after treatment with various salt concentrations and fermentation durations. Figure 11 shows chili peppers with the highest color score of 2.00 ± 0.00 , characterized by a bright and uniform red skin color, indicating better color quality. In contrast, Figure 12 shows chili peppers with the lowest color score of $1.00\text{--}1.33 \pm 0.31$, characterized by a red color accompanied by brown spots on the fruit surface, indicating a decline in visual quality during storage.

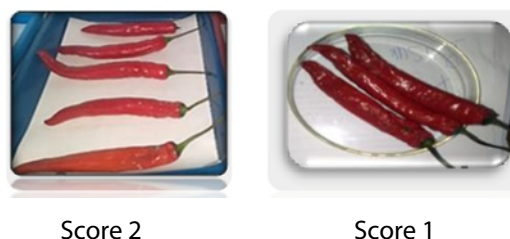


Figure 12. Representative visual appearance of large red chili peppers showing changes in color after 16 days of storage.

Environmental salinity can influence pigment stability and color parameters in chili peppers, particularly those associated with carotenoid compounds responsible for the red coloration of the fruit. Changes in salt conditions may affect pigment stability by altering enzymatic activity, promoting pigment oxidation, and

influencing the structural integrity of fruit tissues. Certain salinity levels may also slow carotenoid degradation by inhibiting microbial activity and oxidative enzymes involved in color changes during storage (Erol, 2024). Microbial activity accelerates tissue degradation by increasing respiration and transpiration rates, leading to water loss, surface wrinkling, and color changes from bright red to brown and eventually black. The appearance of brown spots on the chili skin often indicates tissue damage and potential microbial infection (Sepúlveda et al., 2024).

Conclusion

This study demonstrated the potential of fermented cabbage waste liquid as a natural preservative for large red chili peppers (*Capsicum annuum* L.). Fermented cabbage waste liquid prepared with 7% NaCl and a 4-day fermentation period exhibited the best preservation performance. This treatment effectively maintained the quality of large red chili peppers by extending their shelf life to 16.67 ± 0.90 days, limiting weight loss to $2.42 \pm 1.77\%$, preserving a firm and smooth texture (6.95 ± 0.00), and maintaining a bright red color (2.00 ± 0.00). These findings suggest that fermented cabbage waste liquid prepared under the optimum fermentation conditions could be used as an environmentally friendly natural preservative for preserving postharvest quality and prolonging the storage life of large red chili peppers.

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References

- Ahamad, S., Asrey, R., Vinod, B. R., Meena, N. K., Menaka, M., Prajapati, U., & Saurabh, V. (2024). Maintaining postharvest quality and enhancing shelf-life of bell pepper (*Capsicum annuum* L.) using brassinosteroids: A novel approach. *South African Journal of Botany*, 169, 402–412. <https://doi.org/10.1016/j.sajb.2024.04.049>
- Anggraeni, L., Lubis, N., & Junaedi, E. C. (2021). Review: Pengaruh Konsentrasi Garam Terhadap Produk Fermentasi Sayuran. *Jurnal Sains Dan Kesehatan*, 3(6), 891–899. <https://doi.org/10.25026/jsk.v3i6.459>
- Anik, M. H., Sumi, S. A., Shorna, S. I., & Hossain, M. A. (2024). Enhancing Shelf-Life of Banana Fruit Using Fermented Cabbage Extract. *Journal of the Bangladesh Agricultural University*, 22(2), 241–248. <https://doi.org/10.3329/jbau.v22i2.74556>
- Anjaneyulu, A., & Sharangi, A. B. (2022). Effect of different packaging materials on the shelf life of dried red pepper (*Capsicum annuum* L.) stored in ambient conditions. *Journal of Crop and Weed*, 18(1), 82–89. <https://doi.org/10.22271/09746315.2022.v18.i1.1536>
- Anumudu, C. K., Miri, T., & Onyeaka, H. (2024). Multifunctional Applications of Lactic Acid Bacteria: enhancing safety, quality, and nutritional value in foods and fermented beverages. *Foods*, 13(23), 3714. <https://doi.org/10.3390/foods13233714>
- Asghari, A., Zongo, P. A., Osse, E. F., Aghajanzadeh, S., Raghavan, V., & Khalloufi, S. (2024). Review of osmotic dehydration: Promising technologies for enhancing products' attributes, opportunities, and challenges for the food industries. *Comprehensive Reviews in Food Science and Food Safety*, 23(3). <https://doi.org/10.1111/1541-4337.13346>
- Ashadi, R., Syam, N., & Alimuddin, S. (2021). Pengaruh suhu dan jenis kemasan terhadap daya simpan dan kualitas buah tomat (*Solanum lycopersicum* L.). *AGrotekMAS Jurnal Indonesia: Jurnal Ilmu Peranian*, 2(3), 19–28. <https://doi.org/10.33096/agrotekmas.v2i3.209>

- Ayivi, R. D., Gyawali, R., Krastanov, A., Aljaloud, S. O., Worku, M., Tahergorabi, R., da Silva, R. C., & Ibrahim, S. A. (2020). Lactic acid bacteria: Food safety and human health applications. *Dairy*, 1(3), 202–232. <https://doi.org/10.3390/dairy1030015>
- Blejan, A. M., Nour, V., Păcularu-Burada, B., & Popescu, S. M. (2023). Wild bilberry, blackcurrant, and blackberry by-products as a source of nutritional and bioactive compounds. *International Journal of Food Properties*, 26(1), 1579–1595. <https://doi.org/10.1080/10942912.2023.2224530>
- Cahyaningsih, D., & Sugiharto, A. (2022). The Effect of fermentation time of waste cabbage (*Brassica oleracea*) as a natural preservative in tofu. *Jurnal Teknologi Pangan*, 5(2), 1–6. doi: <http://dx.doi.org/10.26418/jft.v5i2.58155>
- Díaz-Pérez, M., Hernández-García, J. J., Carreño-Ortega, Á., & Velázquez Martí, B. (2024). Post-Harvest behavior of seedless conical and mini-conical peppers: weight loss, dry matter content, and total soluble solids as indicators of quality and commercial shelf-life. *Foods*, 13(12), 1889. <https://doi.org/10.3390/foods13121889>
- Dissanayake, I. H., Tabassum, W., Alsherbiny, M., Chang, D., Li, C. G., & Bhuyan, D. J. (2025). Lactic acid bacterial fermentation as a biotransformation strategy to enhance the bioavailability of phenolic antioxidants in fruits and vegetables: A comprehensive review. *Food Research International*, 209(February). <https://doi.org/10.1016/j.foodres.2025.116283>
- Erol, Ü. H. (2024). Physicochemical and color changes during fruit ripening in pepper species (*C. annuum* L., *C. baccatum* L., and *C. chinense* Jacq.) exposed to salt stress. *Bahçe*, 53(2), 71–79. <https://doi.org/10.53471/bahce.1545211>
- Frempong, K. E. B., Chen, Y., Wang, Z., Xu, J., Xu, X., Cui, W., Gong, H., Peng, D., Liang, L., Meng, Y., & Lin, X. (2022). Study on textural changes and pectin degradation of tarocco blood Orange during storage. *International Journal of Food Properties*, 25(1), 344–358. <https://doi.org/10.1080/10942912.2022.2032736>
- Fukuba, J. A., Sela, D. A., Gibbons, J. G., Moore, M. D., & Kinchla, A. J. (2026). Evaluating the dynamics of fermentation conditions of lacto-fermented sauerkraut produced with various food safety process parameters. *Applied Food Research*, 6(1), 101985. <https://doi.org/10.1016/j.afres.2026.101985>
- Gaudio, G., Weil, T., Marzorati, G., Solovyev, P., Bontempo, L., Franciosi, E., Bertoldi, L., Pedrolli, C., Tuohy, K. M., & Fava, F. (2022). Microbial and metabolic characterization of organic artisanal sauerkraut fermentation and study of gut health-promoting properties of sauerkraut brine. *Frontiers in Microbiology*, 13. <https://doi.org/10.3389/fmicb.2022.929738>
- Ghiffar, H. M., Rostaman, R., Nurchasanah, S., Faris Syaukany, R., & Manoworn, C. (2025). Performance of five introduced cabbage varieties (*Brassica oleracea* var. *capitata* L.) planted at the highland of Pemalang Regency. *E3S Web of Conferences*, 609, 6003. <https://doi.org/10.1051/e3sconf/202560906003>
- Handayani, I. (2023). Review Literatur : Pengaruh konsentrasi garam terhadap hasil fermentasi *Brassica juncea* L. untuk pembuatan kimchi. *Biocaster: Jurnal Kajian Biologi*, 3(1), 46–52. <https://doi.org/10.36312/bjkb.v3i1.158>
- Herman, A., Matulewicz, O., Korzeniowska, E., & Herman, A. P. (2024). Determination of post-fermentation waste from fermented vegetables as potential substitutes for preservatives in o/w emulsion. *International Journal of Molecular Sciences*, 25(10), 5510. <https://doi.org/10.3390/ijms25105510>
- Jamilah, J., Fadil, A. R., Ermawati, E., Diyanti, A., Thesiawati, A. S., & Yusnawati, Y. (2026). Enhancing corn yields on alluvial soil through dolomitic lime and *Azolla* sp. liquid organic fertilizer. *PLANTA TROPIKA*, 14(1), 139–151. <https://doi.org/10.18196/pt.v14i1.24679>
- Junitasari, A., Rosahdi, T. D., & Lestari, Y. S. (2023). Isolation and identification of lactic acid bacteria from chinese cabbage waste by 16s rRNA amplification using the polymerase chain reaction (PCR) method. *Jurnal Kimia Valensi*, 9(1), 136–144. <https://doi.org/10.15408/jkv.v9i1.29466>

- Ko, H.-C., Haile, M., Lee, S., Hwang, A., Lee, G.-A., Choi, Y.-M., Hahn, B.-S., & Ro, N. (2022). Correlation of carotenoids content and ASTA values of pepper (*Capsicum chinense*) genetic resources. *Horticulturae*, 8(6), 486. <https://doi.org/10.3390/horticulturae8060486>
- Kovács, Z., Csilléry, G., Daood, H. G., Posta, K., Bedő, J., Tóth-Lencsés, K. A., Veres, A., Szőke, A., Tarnawa, Á., & Juhász, Á. (2025). Polyphenolic and anthocyanin responses to postharvest fungal pathogen infection in purple and green near isogenic pepper (*Capsicum annuum*) Lines. *Antioxidants*, 14(12), 1–23. <https://doi.org/10.3390/antiox14121440>
- Li, M., Fan, H., & Lü, M. (2026). Sodium reduction in traditional fermented vegetables: Challenges, strategies, and perspectives. *Fermentation*, 12(3), 162. <https://doi.org/10.3390/fermentation12030162>
- Liu, Y., Song, Q., Yin, F., Liang, Y., Song, M., He, M., & Shuai, L. (2025). Colletotrichum capsici-Induced disease development in postharvest pepper associated with cell wall metabolism and phenylpropanoid metabolism. *Horticulturae*, 11(7), 1–18. <https://doi.org/10.3390/horticulturae11070794>
- Mari, A., Parisouli, D. N., & Krokida, M. (2024). Exploring osmotic dehydration for food preservation: methods, modelling, and modern applications. *Foods*, 13(17), 2783. <https://doi.org/10.3390/foods13172783>
- Mayr, C., Dankó, E., Antonielli, L., & Kostić, T. (2026). Influence of cabbage farming practice and potato peel addition on the endpoint microbial community in sauerkraut fermentation. *International Journal of Food Microbiology*, 454(September 2025), 111742. <https://doi.org/10.1016/j.ijfoodmicro.2026.111742>
- Noor, P. S., & Wijanarka, W. (2021). Analisis total kadar asam laktat hasil fermentasi pare (momordica charantia) secara spontan dengan konsentrasi garam berbeda. *Jurnal Biologi Papua*, 13(2), 112–117. <https://doi.org/10.31957/jbp.1642>
- Pautposis, K., Shams, Z., Yazdani, M., Muneer, F., Rahmatov, M., Shariatipour, N., Villanueva-Gutierrez, E. E., & Sahoo, M. (2025). Natural preservation strategies: The potential of bioactive compounds from fruit and vegetable waste to reduce postharvest losses. In *Food Chemistry: X* (Vol. 30). <https://doi.org/10.1016/j.fochx.2025.102917>
- Peng, S., Xu, J., Xu, J., Wang, J., Zhang, Y., Liao, X., & Zhao, L. (2023). Microbial community and volatile metabolites related to the fermentation degree of salted fermented chili peppers. *LWT*, 181(April), 114752. <https://doi.org/10.1016/j.lwt.2023.114752>
- Rahayuningsih, J., Sisca, V., & Eliyarti, E. (2022). Analisis vitamin c pada buah jeruk pasaman untuk meningkatkan imunitas tubuh pada masa pandemi. *Journal of Research and Education Chemistry*, 4(1), 29. [https://doi.org/10.25299/jrec.2022.vol4\(1\).9363](https://doi.org/10.25299/jrec.2022.vol4(1).9363)
- Ralle, A., Sabahannur, S., Alimuddin, S., & Dwizahra, A. (2025). Efektivitas pengemasan vakum dan penyimpanan dingin terhadap umur simpan cabai rawit (*Capsicum frutescens* L.). *AGRITEKNO: Jurnal Teknologi Pertanian*, 14(1), 102–111. <https://doi.org/10.30598/jagritekno.2025.14.1.102>
- Raman, J., Kim, J.-S., Choi, K. R., Eun, H., Yang, D., Ko, Y.-J., & Kim, S.-J. (2022). Application of Lactic Acid Bacteria (LAB) in sustainable agriculture: advantages and limitations. *International Journal of Molecular Sciences*, 23(14), 7784. <https://doi.org/10.3390/ijms23147784>
- Ridwan, M., Sabahannur, St., & Alimuddin, S. (2022). Pengaruh pendinginan awal (pre-cooling) dan konsentrasi cacl2 terhadap umur simpan dan kualitas cabai merah besar (*Capsicum annuum* L.). *AGrotekMAS Jurnal Indonesia: Jurnal Ilmu Peranian*, 3(2), 56–67. <https://doi.org/10.33096/agrotekmas.v3i2.247>
- Sabahannur, St. (2020). Penggunaan NaCl dan asam sitrat untuk memperpanjang umur simpan dan mutu cabai rawit (*Capsicum frutescens* L.). *Jurnal Galung Tropika*, 9(1), 31–40. <https://doi.org/10.31850/jgt.v9i1.546>
- Sepúlveda, M., Costa, J., Cayún, Y., Gallardo, V., Barría, E., Rigotto Caruso, G., von Zeska Kress, M. R., Cornejo, P., & Santos, C. (2024). Chemical composition and antifungal activity of Capsicum pepper aqueous

extracts against plant pathogens and food spoilage fungi. *Frontiers in Cellular and Infection Microbiology*, 14. <https://doi.org/10.3389/fcimb.2024.1451287>

Siska, S. M. T. (2023). Jumlah bakteri asam laktat (BAL) pada sauerkraut dari kubis ungu (*Brasica oleracea* var. capitata L.f. rubra) dengan konsentrasi garam yang berbeda. *Biocelbes*, 17(1), 38–45. <https://doi.org/10.22487/bioceb.v17i1.16328>

Srihardyastutie, A., Prasetyawan, S., Zikri Firdaus, R., Berenice Prayugo, F., Kresmonia, Y., Dwi Ananda, T., & Salamah, A. (2021). The Effect of NaCl concentration and incubation time on oxalate and total acid in fermented cabbage using various microorganisms. *The Journal of Pure and Applied Chemistry Research*, 10(1), 27–36. <https://doi.org/10.21776/ub.jpacr.2021.010.01.568>

Tang, J., Wu, X., Lv, D., Huang, S., Zhang, Y., & Kong, F. (2024). Effect of salt concentration on the quality and microbial community during pickled peppers fermentation. *Food Chemistry: X*, 23, 101594. <https://doi.org/10.1016/j.fochx.2024.101594>

Wang, W., Li, W., Huang, Y., Yang, Y., Liu, H., Yu, C., Yuan, Q., He, L., Hu, Q., Li, Y., Meng, T., Chen, H., Liao, J., Chen, O., Yu, S., & Zhang, F. (2024). Optimisation of *Lactobacillus* fermentation conditions and its application in the fermentation of salt-free sauerkraut. *Frontiers in Microbiology*, 15. <https://doi.org/10.3389/fmicb.2024.1482163>