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Original Article

Fermentation and Quality Assessment of Mixed Vegetable Sauerkraut: Microbial, Biochemical & Sensory Studies

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Abstract

This study evaluated the microbial, physicochemical, and sensory changes occurring during four weeks of mixed vegetable sauerkraut fermentation using cabbage, carrot, pumpkin, and radish. Fermentation was carried out under anaerobic conditions with 2–3% salt at room temperature. Progressive acidification was observed, with pH decreasing from approximately 6.0 in Week 1 to 3.7–4.0 by Week 4, accompanied by a steady increase in titratable acidity from 1.08% to 5.00%, confirming effective lactic acid production. Lactic acid bacteria (LAB) populations increased during early fermentation, reaching a maximum of 8.8 × 10^5 CFU/ml in Week 2, followed by stabilization under acidic conditions. Starch degradation, monitored by the iodine–starch test, showed gradual hydrolysis of complex carbohydrates, supporting microbial metabolism. Sensory evaluation revealed a transition from fresh and mildly sweet characteristics to a strongly sour flavor, pungent aroma, softened texture, and acceptable appearance by the final week. Overall, the results demonstrate that mixed vegetable sauerkraut undergoes coordinated microbial and biochemical transformations, with optimal product quality and stability achieved between the third and fourth weeks of fermentation.

Keywords*: Sauerkraut, LAB, Fermentation, Acidity, Acidic condition, Pungent aroma, Biochemical transformation.*

Introduction

Fermented foods have long been valued for their role in preservation, nutritional enhancement, and sensory improvement. Vegetable fermentation is mainly driven by lactic acid bacteria (LAB), which metabolize sugars into organic acids, lower pH, and inhibit spoilage microorganisms. Fermented vegetables such as sauerkraut, kimchi, and gundruk are known to improve digestibility, nutrient bioavailability, and antioxidant content (Zabat *et al.*, 2018; Schropp *et al.*, 2025). Traditional sauerkraut fermentation occurs under anaerobic conditions with 2–2.5% salt, where heterofermentative LAB initiate fermentation, followed by homofermentative species that stabilize acidity and ensure product safety (Fijan, 2024; Li *et al.*, 2025).

Although cabbage-based fermentations are well studied, vegetables such as bottle gourd, pumpkin, radish, and carrot also contain fermentable sugars and bioactive nutrients that support LAB growth. Fermentation of these vegetables has been shown to enhance nutrient availability, antioxidant potential, and functional properties (Patel *et al.*, 2020; Chenchen *et al.*, 2022; Li *et al.*, 2025). The use of mixed vegetables may promote microbial diversity during fermentation, leading to improved flavor, texture, and health-promoting attributes (Schropp *et al.*, 2025). Thus, mixed vegetable sauerkraut represents a nutritionally enriched and microbiologically stable fermented food with potential functional benefits.

Materials and Methods

Preparation of Mixed Vegetable Sauerkraut

All vegetables were thoroughly washed. Outer leaves of cabbage were removed; carrot, pumpkin, and radish were peeled. All vegetables were grated coarsely.

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2–3% salt (by weight) was added to the cut vegetable mixture. The mixture was massaged for 5–10 minutes to extract water and form brine. The salted vegetable mixture was transferred into a sterile glass jar. It was pressed firmly so that brine rose above the vegetables; all pieces were ensured to be submerged. The jar was covered with an airtight lid (or loosely to allow gas escape) & incubated at room temperature for 4 weeks. The mixture was checked regularly: foam/bubbles were removed and vegetables were ensured to remain submerged. Fermentation was considered complete when desired sourness was achieved (pH ~3.5–4.0).

pH Measurement of Sauerkraut Using pH Strips

Sauerkraut juice was collected at the end of each fermentation week (Weeks 1, 2, 3, and 4) using a sterile Pipette. Approximately 5 ml of juice was taken for testing. A pH strip was dipped into the prepared sauerkraut juice solution for 1–2 seconds. The strip was removed and allowed to react for 30 seconds. The color change on the strip was compared with the standard color chart provided with the strips to determine the pH value. Each measurement was repeated in triplicate for accuracy. Average pH values were recorded for each week. The pH progression over the 4-week fermentation period was monitored to assess the fermentation process.

Sensory Evaluation of Sauerkraut

Sauerkraut samples were collected at the end of each fermentation week. Small portions of each sample were placed in sterile test tube for evaluation. The team evaluated taste, aroma, texture, and color using descriptive words. Examples: Taste: sour, bitter, mild, salty, strong. Odour/Aroma: fresh, pungent, acidic, fermented. Texture: crisp, soft, firm, mushy. Color: pale, greenish, yellowish, bright Descriptive observations were recorded weekly to monitor changes over the 4-week fermentation period. The progression of sensory attributes was analyzed to determine optimal fermentation and product quality.

Microbial Testing of Sauerkraut

Samples were collected weekly and homogenized aseptically. Tenfold serial dilutions were prepared using sterile distilled water. 0.1 ml from selected dilutions was spread on MRS agar plates. The plates were incubated at 30°C for 48 hours. After incubation, colony characteristic of lactic acid bacteria were counted. Results were expressed as colony-forming units (CFU/g) of sauerkraut, and microbial growth trends were recorded across all four weeks.

Determination of concentration of lactic acid (Titrable Acidity)

10 ml of sauerkraut juice was taken in a conical flask. 10 ml of distilled water was added, and the mixture was heated for 1 minute. The solution was titrated with 0.1 N NaOH using phenolphthalein as an indicator. The endpoint was observed as a color change from colorless to faint pink. Volume of NaOH used was recorded to calculate lactic acid concentration. The procedure was repeated for all four weeks to monitor changes in acidity. Using below formula lactic acid content (g%) was calculated

Lactic acid content (g%) = 0.9* 0.1* Titration reading*100/ Amount of sample

Starch Detection Test

About 2 ml of sauerkraut juice was collected from each weekly sample. Two to three drops of iodine solution were added to each test tube containing the juice. The mixture was gently shaken and the color change was observed.

Result and Conclusion

pH Measurement Analysis

The pH of sauerkraut decreased progressively during fermentation, indicating active lactic acid production by lactic acid bacteria. An initial pH of about 6.0 in Week 1 declined to nearly 5.0 in Week 2, showing the onset of fermentation. Further reduction to around 4.2 in Week 3 reflected continued acid accumulation. By Week 4, pH stabilized between 3.7 and 4.0 (Fig. 1), confirming completion of fermentation and microbial safety. This gradual acidification under 2–3% salt and anaerobic conditions supports effective fermentation and desirable sensory quality.

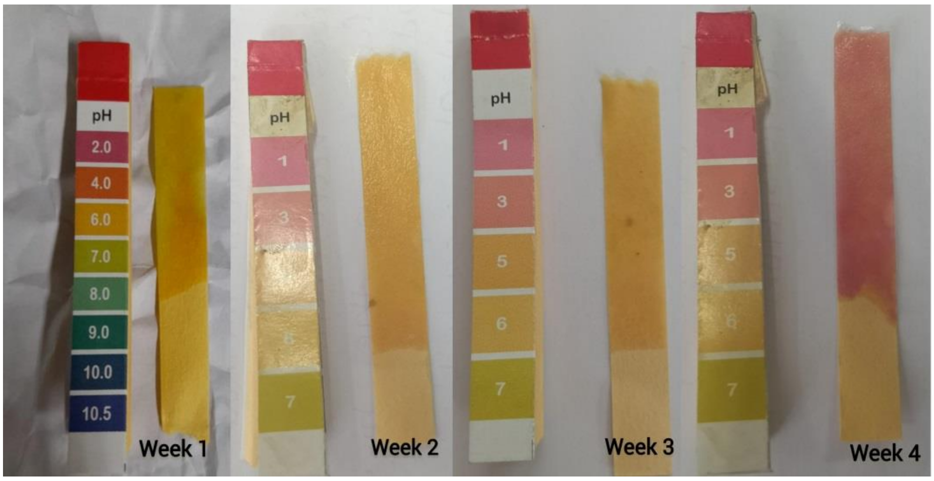

Figure 1: pH of Sauerkraut from first week to last week

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Sensory Evaluation of Mixed Vegetable Sauerkraut (Week 1–4)

Figure 2: Initial and final week sauerkraut

Table 1: Sensory Evaluation of Sauerkraut

Week	Taste	Odour	Texture	Colour
1	Slightly sweet, mild sourness	Fresh, Vegetable like	Crisp, firm	Cabbage pale green, Carrot bright orange, pumpkin pale yellow, radish white
2	Mildly sour, slightly sweet	Mildly acidic, faint Pungency	Slight softening in cabbage and pumpkin, carrot and radish still firm	Cabbage slightly pale, carrot muted orange, pumpkin light yellow, radish slightly faded
3	Noticeable sour, reduced sweet	Sour, slightly pungent	Softer overall, cabbage and pumpkin tender, carrot moderately firm, radish slightly crisp	Cabbage pale green, carrot faded orange, pumpkin yellow, radish light orange brine slightly turbid
4	Strongly sour	Pungent, strongly acidic	Wsoft	Cabbage pale yellow , Carrot muted orange, pumpkin pale yellow, radish off white brine highly turbid

Microbial Count – LAB

The viable population of lactic acid bacteria increased during the early phase of sauerkraut fermentation and declined gradually with extended fermentation. LAB counts were 5.5×10^5 CFU/ml in Week 1, indicating initial microbial establishment, and reached a maximum of 8.8×10^5 CFU/ml in Week 2, corresponding to intense metabolic activity and rapid lactic acid formation. A reduction in LAB numbers was observed in Week 3 (5.0×10^5 CFU/ml), likely due to substrate limitation and increased acidity. By Week 4, the population stabilized at 4.5×10^5 CFU/ml, reflecting microbial adaptation to acidic conditions. This growth–peak–decline trend is characteristic of vegetable fermentations and supports stable acid production and product safety (Fig. 3). Similar LAB dynamics during extended fermentation have been reported by Ozkan (2016).

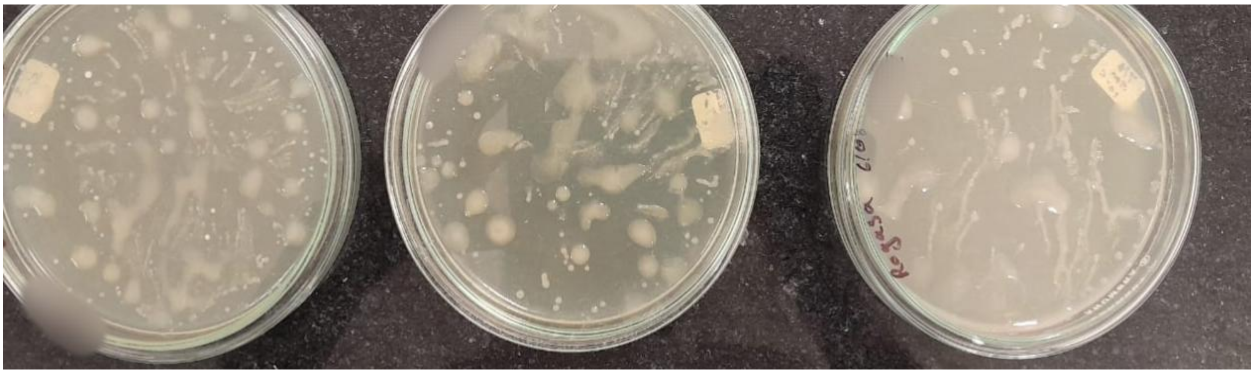

Figure 3: Lactic acid bacteria on MRS agar plates from sauerkraut

Titrable Acidity (TA) Analysis of Mixed Vegetable Sauerkraut

Titrable acidity of mixed vegetable sauerkraut increased progressively during four weeks of fermentation, rising from 1.08% (Week 1) to 2.50% (Week 2) and 4.50% (Week 3), and stabilizing at 5.00% by Week 4. This trend reflects continuous lactic acid production by lactic acid bacteria and indicates completion of fermentation. Similar increases in titrable acidity during sauerkraut fermentation have been reported previously (Ghosh *et al.*, 2020), confirming its usefulness as an indicator of fermentation progress and product readiness.

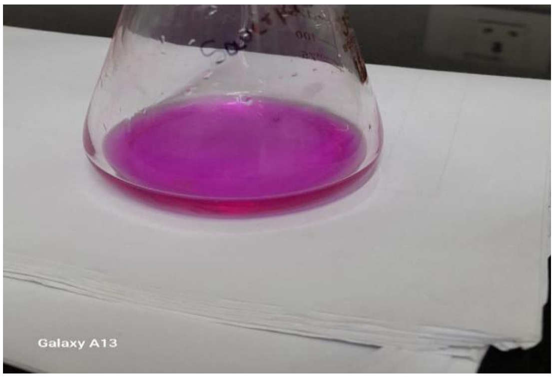

Figure 4: Titrable acidity analysis of Sauerkraut

Starch Detection Analysis of Mixed Vegetable Sauerkraut

Starch degradation during sauerkraut fermentation was monitored using the iodine–starch test. Strong blue-black coloration in Week 1 indicated intact starch in pumpkin and carrot, which gradually decreased by Week 2 and became faint in Week 3 due to starch hydrolysis and microbial utilization. By Week 4, minimal or no coloration was observed (Fig. 5), confirming near-complete starch breakdown and its contribution to fermentation progression.

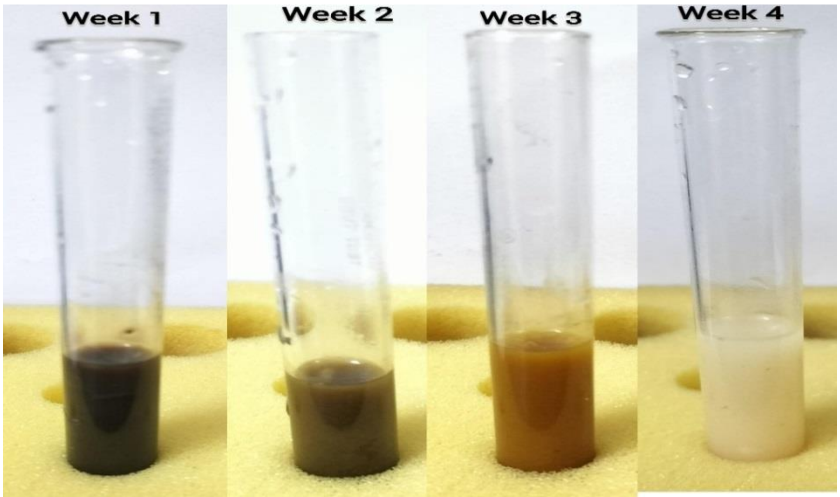

Figure 5: Starch detection of sauerkraut from first week to last week

Conclusion

This study showed that mixed vegetable sauerkraut undergoes systematic microbial, chemical, and sensory changes during four weeks of fermentation. Progressive acid formation, indicated by declining pH and increasing titratable acidity, confirmed active lactic acid bacterial metabolism. LAB populations increased during early fermentation and stabilized as acidic conditions developed, while starch degradation demonstrated effective carbohydrate utilization. Sensory characteristics gradually shifted toward a desirable sour taste, acidic aroma, and softened texture. Collectively, these findings confirm that the third to fourth week of fermentation yields a microbiologically stable and sensorially acceptable product.

Future Prospects

Several areas of future research are recommended to expand upon the findings of the current study. First, long-term studies should investigate how LAB populations and acid concentrations stabilize beyond four weeks, providing insights into extended storage behavior. Second, in vivo or clinical studies could assess the probiotic potential of LAB strains isolated from sauerkraut and their effects on gut health, immunity, and metabolism. Third, comparative studies between mixed vegetable sauerkraut and single-vegetable variants would help identify the nutritional and sensory advantages of blended formulations. Finally, interdisciplinary approaches combining microbiology, nutrition, sensory science, and consumer behavior will be crucial for establishing sauerkraut as both a traditional food and a modern functional product.

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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