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Comparative Studies on the Fermentation Process of Kimchi Made using Different Vegetables

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A B S T R A C T

Kimchi is a traditional fermented food in Korea and there are several types depending on the available seasonal ingredients and the manufacturing methods used. Kimchi fermentation is influenced by the ingredients, fermentation, temperature, salt concentration, oxygen availability and pH which determine the taste and quality of the final fermented product. A comparative study was undertaken to evaluate the fermentation characteristics of Kimchi prepared using different vegetables, namely Beetroot, Carrot, Radish and Cucumber. The investigation focused on analyzing the physical properties, lactic acid bacteria (LAB) population and metabolite composition including organic acids, sugar alcohols and amino acids across the different kimchi samples. Distinct variations were observed in sensory attributes such as texture, color, aroma and taste, which were influenced by the type of vegetable used. Among the samples, Beetroot kimchi (Sample B) demonstrated a deep magenta hue, favorable texture and a well-balanced sensory profile. Microbiological analysis revealed that beetroot kimchi supported a high and stable LAB population (5.9×10^6 CFU/g) during the fermentation process. Furthermore, metabolite profiling indicated elevated levels of beneficial compounds, including lactic acid (63.807 mMol) and essential amino acids specially glutamine (65.597mMol) in beetroot kimchi, reflecting enhanced fermentative activity and superior nutritional value. These findings revealed that, Beetroot Kimchi (Sample B) was identified as the most health-promoting variant among the other Kimchi samples prepared, attributed to its rich antioxidant content, potential cardiovascular benefits and its role as a functional food in supporting gut health and overall well-being.

Introduction

Kimchi is a beloved traditional Korean dish made from fermented vegetables, known for its unique flavors, nutritional benefits and health-boosting properties. It's typically crafted from a mix of vegetables like cabbage, radish, cucumber, carrot and beetroot, all seasoned with Korean red pepper and other spices. There are over 100 different types of kimchi and its fame has spread worldwide, serving as both a tasty side dish and a functional ingredient in various recipes. The quality and features of kimchi can vary based on the ingredients used, fermentation temperature, salt levels, oxygen availability and pH balance. The fermentation process of

kimchi is mainly driven by lactic acid bacteria (LAB), which are essential for developing its flavor, ensuring preservation and maintaining safety. These bacteria break down carbohydrates to create organic acids, which lower the pH and help stabilize the product. Along with organic acids, LAB also produce a range of bioactive compounds like carbon dioxide, ethanol, mannitol, bacteriocins, γ-aminobutyric acid (GABA), conjugated linoleic acidsand oligosaccharides. These byproducts are what give kimchi its distinctive taste and health benefits. The main LAB groups involved in kimchi fermentation include Leuconostoc, Lactobacillus and Weissella and their presence changes depending on the ingredients and the stages of fermentation. From a nutritional standpoint, kimchi is a low-calorie, low-fatand cholesterol-free food that's packed with dietary fiber, vitamins (A, B, Cand K)and essential minerals like calcium, iron, phosphorus and selenium. Its probiotic qualities are linked to various health advantages, such as boosting the immune system, reducing inflammation, lowering cholesterol and possibly even fighting cancer. While many studies have looked into cabbage-based kimchi, there's been less focus on kimchi made with other vegetables. This study aims to explore the fermentation characteristics, microbial community structure and metabolite production in kimchi made from alternative vegetables.

The objectives of the present study were to systematically collect and characterize commercially available kimchi with respect to its sensory attributes, ingredient composition, physicochemical properties, and lactic acid bacterial (LAB) community, and to prepare kimchi using different vegetables-beetroot, carrot, radish, and cucumber as principal ingredients. The study further aimed to isolate and purify bacterial strains from the prepared kimchi samples, optimize the fermentation process, and conduct comparative analyses of fermentation dynamics among kimchi prepared with different vegetables. In addition, a comparative evaluation between naturally fermented kimchi and commercially available kimchi was undertaken to assess differences in fermentation characteristics, microbial profiles, and overall quality.

Materials and Methods

This investigation was undertaken in the Department of Microbiology, Faculty of Agriculture, Annamalai University, Annamalai Nagar-608 002, Tamil Nadu, India.

Collection of Samples

Commercially manufactured Kimchi (Mavi's vegan Kimchi) (sample A) was purchased through an online vendor Amazon (Amazon.in). Vegetables like Beetroot, Carrot, radish and cucumber were collected from Chidambaram market. All the samples collected were stored in sterilized containers and kept in refrigerator at 4°C till further use.

Preparation of Kimchi Samples

Four types of Kimchi were prepared using four different main ingredients: Beetroot, Carrot, Radish and Cucumber. The Kimchi was prepared by mixing ingredients in the following proportions: 85% main ingredient, 2.5% garlic, 3% red pepper, 3% salt, 1% rice flour paste and 5.5% tap water. Four samples (Sample B prepared using Beetroot; sample C prepared using carrot; sample R prepared using Radish; sample U prepared using Cucumber) were prepared.The vegetables were cut into small pieces and then rinsed with water. 3% salt solution was used to dip vegetable pieces for 4 hours. Then the vegetable pieces were rinsed thrice with water. Then the rice flour paste and other ingredients were mixed with the chopped vegetables thoroughly. Finally the kimchi were packed tightly in air tight containers to prevent air exposure and promote brine formation and stored at 4° C for 30 days (Begum *et al*., 2024).

Analysis of Physical Characteristics of Different Kimchi Samples

Physical characteristics like color, texture, aroma, taste and shelf life of a Kimchi samples A, B, C, R and U were analyzed using the sensory evaluation method. Samples were given to few selected members for visual assessment, tactile assessment, olfactory assessment and gustatory assessment and the results were analyzed.

Enumeration of Bacterial Population from Kimchi Samples

The enumeration of total bacterial count and lactic acid bacterial count in the samples A, B, C, R and U were carried out by standard plate count method. Homogenized ten ml of each samples were transferred to 90 ml alkaline peptone water (Angelotti, 1963) and the samples were serially diluted up to 10^{-6} dilution For estimating the total number of bacterial population,

transferred one ml of 10^{-4} to 10^{-6} dilutions of the sample aseptically to petri dishes and the melted nutrient agar medium (Lapage, 1970) was added; For total lactic acid bacterial count, transferred one ml of 10^{-3} to 10^{-6} dilutions of the three samples to the petri dishes by employing MRS agar medium (de Man *et al.,* 1960) containing 0.3 per cent calcium carbonate (Maragkoudakis *et al*., 2006). The uninoculated MRS agar plates served as control.

The dishes were incubated at 28±2°C and the colonies of bacteria appearing on the incubated plates were counted after two to three days by using colony counter and expressed as $\log_{10}$ cfu g^{-1}/cfu ml^{-1} of food sample.

Isolation, Maintenace and Identification of Lactic Bacterial Population from Kimchi Samples

From the MRS agar plates, few distinct white colonies of 1-2 mm diameter were picked. These colonies streaked on MRS agar containing 0.17 per cent bromocresol purple (MRSBP) and kept for incubation at 28±2°C for two days. Lactic acid bacterial colonies were surrounded by a yellow color zone in the MRSBP medium. These well isolated colonies were inoculated to MRS broth. They were propagated twice and streaked on MRS agar to check the purity of the isolates and stored in MRS agar slants. Identification of bacterial isolates was carried out by the routine bacteriological methods like by the colony morphology , by Preliminary tests like gram staining and motility, by performing biochemical tests and by molecular identification.

Morphological Characterization

Based on the colony morphology, colony surface, margin, color and size, two different lactic acid bacterial strains were named as LB1, LC1, LR1 and LU1 obtained from sample B ,C,R ,U and used for further studies.

Staining techniques

Gram staining of the bacterial strains was carried out as per Hucker's modified method (Rangaswami, 1975). Spores staining was performed as per Downson (1957).

Measurement of cell shape and size

The cell shape of the stained bacterial strains was observed under oil immersion objective and noted. The cell size of the four bacterial strains in micron was measured using stage and ocular micrometer (M/s. Erma, Tokyo, Japan).

Motility test

Hanging- drop method by phase contrast microscopy.

In this method, a small drop of the suspension of the bacterial culture in nutrient broth was transferred to a clean cover glass and inverted over a hanging- drop slide or cavity slide. The edge of the cover glass was covered with a layer of Vaseline to check evaporation from the drop. The slide was then examined under the phase contrast microscope for motility.

Biochemical characterization

Catalase tests

The catalase test is useful for the identification of aerobic bacteria. A small amount of pure culture of the bacterial strains *viz*., LB1, LC1, LR1 and LU1 from the MRS agar was transferred to a clean, dry glass slide with the help of a sterile wooden stick. A drop of 3 per cent hydrogen peroxide was placed on a clean microscopic slide. A visible amount of bacterial growth was added aseptically with the help of an inoculating loop. Both were mixed and observed for gas bubble production.

Oxidase tests

This reaction is due to a cytochrome oxidase which catalyses oxidation of reduced cytochrome by oxygen. A freshly prepared 1.0 to 1.5% solution of tetramethyl p-phenylene diamine hydrochloride was poured over the colonies. Oxidase positive colonies become maroon, purple and black within 10 to 30 minutes.

Production of ammonia from Arginine

Production of ammonia in MRS broth omitting glucose and beef extract, while containing 0.3 per cent arginine and 0.2 per cent sodium citrate replacing ammonium citrate was observed. The production of ammonia in the inoculated broth was monitored by using Nessler’s reagent (Zuniga *et al*., 1993).

Production of gas and from glucose

The MRS broth was prepared and dispended in 5.0 ml quantities in test tubes and sterilized. Durham's tubes filled with the broth was inserted in an inverted position

and incubated for 48 h. The tubes were inoculated with 0.1 ml of 24 h cultures of lactic acid bacterial strains and incubated at 37°C ± 2°C. The growth of the cultures was visually observed for 48 h of incubation. The inoculated tubes were observed for the change in broth color or appearance of bubbles or both by comparing with an uninoculated control (Schillinger and Lucke, 1987).

Carbohydrate fermentation

Fermentative degradation of various carbohydrates by lactic acid bacterial strains under anaerobic condition was carried out in a fermentation tube (with Durham tube) for the detection of gas production as end product of metabolism (Schillinger and Lucke, 1987). The fermentation tubes with the broth were autoclaved at 15 lbs pressure for 20 min. The sugar fermentation tubes were inoculated with the bacterial strains *viz*., LB1, LC1, LR1 and LU1 incubated at 35±2°C for 24 to 48 h. After incubation, the tubes were observed for acid and gas production indicating fermentation

Molecular characterization of efficient bacterial strain

Molecular identification of the efficient strain was carried out by 16S rRNA gene sequencing. DNA from the selected bacterium was extracted. Amplification of 16s rRNA gene was carried out for the samples using universal primers 27F: AGAGTTTGATCMTGGCTCAG and 1492R : TACGGYTACCTTGTTACGACTT were used for amplification. Expected band was amplified in all the samples PCR-generated amplicon was confirmed and purified using GeneJET PCR purification kit (Thermo Scientific, EU Lithuania) to remove the primer dimer and other carryover contaminations. The quality of the product was assessed using 1.8% agarose gel along with 100bp DNA ladder assize standard and the product was found to be good for sequencing. PCR products were purified and prepared for Cycle sequencing using the Big Dye® Terminator 3.1 sequence kit (Applied Biosystems, Foster City, California, USA). After cycle sequencing, the products were purified using Ethanol-EDTA purification protocol to remove the un-incorporated dntp's, ddntp's and primer dimer. The purified cycle sequencing products were dissolved in 12µl Hi-Di formammide and the samples were subjected for denaturation at 95ºC for 5mins. Denatured products were subjected for sequencing in forward and reverse direction using Genetic Analyzer 3500 (Life Technologies Corporation, Applied Biosystems ® California 94404, USA) as per manufacture's instruction. Sequences were aligned and edited using Mega software version 11 (Tamura et al., 2020) to confirm the species.

Analyses of pH of Different Kimchi Samples Over Fermentation Time

The soup of the different kimchi samples were periodically collected at 0, 5, 15and 30 days. pH values were measured using a pH meter (Thermo fisher scientific, Waltham, MA, USA).

Metabolite Analysis of Kimchi Samples

All the prepared different Kimchi samples were analyzed for production of metabolites such as organic acids, sugar alcohol and amino acids upto 30 days of fermentation. Metabolites were extracted from 50 g of each sample B, C, R and U which was homogenized using a hand blender. After centrifugation at 5,000 rpm for 20 min, salicin (0.5 mM) was added to clear supernatants as an internal standardand the solution was extracted using 50% acetonitrile. The Kimchi extracts (10µL) were analyzed using LC-MS – liquid chromatography-tandem mass spectrometry.

Comparison of Characteristics of Naturally Prepared and Fermented Kimchi with Commercial Kimchi

Physical characteristics and metabolite profiling of Kimchi samples B,C,R and U are compared with the Commercial kimchi

Results and Discussion

Analysis of Physical Characteristics of Different Kimchi Samples

The table 1 provides a summary of the sensory and physical characteristics of five different kimchi samples: commercial kimchi (A) and vegetable-based kimchi varieties made from beetroot (B), carrot (C), radish (R)and cucumber (U). Sample A showcased a dark red hue, a texture that was both softened and crisp, a strong tangy aroma, a spicy-tangy flavorand an impressive shelf life of up to 6 months when stored at 4 °C. The beetroot kimchi presented a rich purple color, an earthy-tangy scentand a spicy-sweet-tangy taste, remained good for about 2 months. Carrot kimchi was a bright orange, with

a strong tangy aroma and a flavor profile that was spicy-sweet with a hint of sour, lasting for 3 months. Radish kimchi had a white, translucent appearance, a mildly candy-like texture, a strong aromaand a mild spicy-sweet-sour flavor, also lasting 3 months. Lastly, cucumber kimchi varied from dark green to pale, had a moist texture, a tangy tasteand the shortest shelf life of around 3 weeks at 4 °C.

Enumeration of Bacterial Population from Kimchi Samples

The table 2 outlines the bacterial populations found in various kimchi samples, focusing on the total bacterial count and the population of lactic acid bacteria (LAB), measured in CFU g^{-1} (or CFU ml^{-1}) in five different kimchi samples: commercial kimchi (A), beetroot kimchi (B), carrot kimchi (C), radish kimchi (R)and cucumber kimchi (U), each tested in triplicate (R_1, $R_2$and R_3). The findings revealed that sample A had the highest total bacterial and LAB counts, followed by samples B and R, while sample U had the lowest numbers. It included statistical measures like the standard error of difference (SEd) and the critical difference at a 5% level (CD, p = 0.05) to highlight the significance of the differences among the samples. Furthermore, the percentage of lactic acid bacteria in relation to the total bacterial population, showed that LAB made up a significant portion of the microflora in all kimchi samples, ranging from about 70% to 81%. This underscores the prominent role of LAB during the fermentation process of kimchi.

Isolation and Identification of Lactic Acid Bacteria from Kimchi Samples

Table 3 and 4 presents the morphological and biochemical characteristics of Lactic acid bacteria isolated from the commercial kimchi and four prepared kimchi samples.

Analyses of Average pH of different Kimchi Samples over Fermentation Time

Table 5 presents the average pH of all 5 kimchi samples, At the beginning of fermentation, the average pH of all the samples ranged from 4.44 to 4.68 which increased to 5.12 to 5.50 after 5 days. As the fermentation progressed the pH dropped in all samples, ranging from 3.9 to 4.36 after 30 days of fermentation.

Molecular Characterization of Efficient Bacterial Strain

Molecular identification of the one best isolate from different kimchi samples were done by 16s rRNA sequencing.

The 16s rRNA analysis suggested that the strain is found to be *Lactiplantibacllius plantarum.* (LB1) (Accession No. PV596323).

Metabolite Analysis of Kimchi Samples

Table 6 shows that among all the sample, commercial kimchi exhibited the most balanced and optimal organic acid profile, with the highest lactic acid content (65.807 mMol), indicating efficient lactic acid fermentation and superior probiotic quality. Among the prepared kimchi samples**,** Sample B (beetroot kimchi) showed a comparatively high lactic acid concentration (63.807 mMol), closely approaching that of commercial kimchi. Lactic acid is a key marker of probiotic fermentation and is associated with improved gut health, antimicrobial activity and enhanced shelf life.

Table 7 shows the sugar alcohol content detected in different kimchi samples, Among the samples analysed, commercial kimchi exhibited the highest mannitol concentration (50.089mMol), indicating well controlled fermentation, efficient microbial metabolism and superior functional quality, while among the laboratory prepared kimchi samples, Beettoot kimchi (sample B) showed a comparatively high mannitol content next to commercial kimchi (44.282mMol) which indicated the hetero-fermentative lactic acid bacterial activity and suggests favourable probiotic potential.

The Table 8 presents the amino acid composition present in four prepared kimchi samples and commercial kimchi sample after 30 days of fermentation in which the commercial kimchi exhibited the superior amino acid profile with high concentrations of key amino acids such as L-glutamine,L-cystine and L-valine, while among the laboratory prepared kimchi samples, Beettoot kimchi (sample B) showed a comparatively higher levels of essential amino acids which resembled that of the commercial kimchi, indicating the effective fermentation and enhanced nutritional value.

Table.1 Analysis of physical characteristics of a kimchi samples

S.No	Sensory Attributes	Physical Characteristics of Samples				
		A	B	C	R	U
1.	Color	Bright red hue	Deep magenta to dark purple	Vibrant orange	White to translucent	Dark green to pale green
2.	Texture	softened with crisp texture	softened with crisp texture	softened with crisp texture	softened with crunchy texture	softened and mushy
3.	Aroma	pungent and sour	Earthy and tangy	Pungent and tangy	Pungent and tangy	Tangy
4.	Taste	spicy and tangy flavoured	Spicy, Sweetand tangy flavoured	Spicy, Sweetand slightly sour	Spicy, mildly sweetand slightly bitter	Spicy, sour and tangy flavoured
5.	Shelf life	Upto 6 months (if stored under 4°C)	Up to 2 months (if stored under 4°C)	Up to 3 months (if stored under 4°C)	Up to 3 months (if stored under 4°C)	Up to 3 weeks (if stored under 4°C)

Table.2 Enumeration of bacterial population from kimchi samples

Replications of Samples	Average total bacterial population (CFU g-1 (or) ml^{-1})					Average lactic acid bacterial population (CFU g^{-1} (or) ml^{-1})					Percentage of lactic acid bacteria to total bacteria (%)				
	A	B	C	R	U	A	B	C	R	U	A	B	C	R	U
R_1	8.0 x 10^6	8.1 x 10^6	7.2 x 10^6	8.0 x 10^6	6.5 x 10^6	6.5 x 10^6	5.9 x 10^6	5.1 x 10^6	5.7 x 10^6	4.6 x 10^6	81	72	70	71	70
R_2	7.3 x 10^6	7.2 x 10^6	6.5 x 10^6	6.9 x 10^6	6.0 x 10^6	6.7x 10^6	6.1 x 10^6	5.3 x 10^6	5.9 x 10^6	4.8 x 10^6					
R_3	6.5 x 10^6	6.8 x 10^6	6.4 x 10^6	6.7 x 10^6	5.8 x 10^6	6.4 x 10^6	5.8 x 10^6	5.0 x 10^6	5.6 x 10^6	4.5 x 10^6					
SEd	0.28	0.28	0.28	0.28	0.28	0.3	0.3	0.3	0.3	0.3					
CD (p=0.05)	0.7	0.7	0.7	0.7	0.7	0.123	0.123	0.123	0.123	0.123					

Table.3 Isolation of lactic acid bacteria from kimchi Samples based on morphological characteristics

Isolates from samples	Isolate number	Isolated Lactic acid bacteria	Morphological characteristics				
			Gram reaction	Shape	Size	Spore	Motility
A	CMK1	***Lactobacillus lactis***	+	Rod	0.7 – 1 x 2.4 µm	Non spore forming	Non - motile
	CMK2	***Leuconostoc citreum***	+	Coccoid to short rod	0.5–0.7 × 1.0–2.0 µm	Non spore forming	Non - motile
	CMK3	***Leuconostoc mesenteroides***	+	Coccoid to short rod	0.5–0.7 × 0.7–1.0 µm	Non spore forming	Non - motile
	CMK4	***Pediococcus pentosaceus***	+	Cocci	0.4 – 0.14 µm	Non spore forming	Non - motile
	CMK5	***Lactobacillus acidophilus***	+	Rod	0.6-0.9 x 1.3-6 µm	Non spore forming	Non - motile
B	LB1	***Lactobacillus plantarum***	+	Rod	0.5-0.6 x 1.5 µm	Non spore forming	Non - motile
C	LC1	***Lactobacillus brevis***	+	Rod	0.7-1.2 x 2.0-5.0 µm	Non spore forming	Non - motile
R	LR1	***Lactobacillus lactis***	+	Rod	0.7 – 1 x 2.4 µm	Non spore forming	Non - motile
U	LU1	***Pediococcus pentosaceus***	+	Cocci	0.4- 0.14 µm	Non spore forming	Non - motile

Table.4 Isolation of lactic acid bacteria from kimchi Samples based on Biochemical characteristics

Isolates from samples	Isolate number	Isolated Lactic acid bacteria	Biochemical characteristics				
			Catalase test	Oxidase test	NH3 from arginine	Gas production from glucose	Lactose fermentation
A	CMK1	***Lactobacillus lactis***	-	-	-	+	+
	CMK2	***Leuconostoc citreum***	-	-	+	+	+
	CMK3	***Leuconostoc mesenteroides***	-	-	+	+	+
	CMK4	***Pediococcus pentosaceus***	-	+	+	-	**d**
	CMK5	***Lactobacillus acidophilus***	-	-	-	-	+
B	LB1	***Lactobacillus plantarum***	-	-	-	-	+
C	LC1	***Lactobacillus brevis***	-	-	+	+	-
R	LR1	***Lactobacillus lactis***	-	-	-	+	+
U	LU1	***Pediococcus pentosaceus***	-	+	+	-	**d**

*d- Delayed utilization

Table.5 Average pH of different kimchi samples during fermentation period

Fermentation Days	0	5	15	30
Average pH of kimchi samples	4.44 to 4.68	5.12 to 5.50	4 to 4.6	3.9 to 4.36

Table.6 Organic Acid Composition in different Kimchi samples after 30 days of Fermentation

Organic Acid	Sample B (Beetroot Kimchi)	Sample C (Carrot Kimchi)	Sample R (Radish Kimchi)	Sample U (Cucumber Kimchi)	Commercial Kimchi (Jeong *et al.*, 2023)
(mMol)	D.L	D.L	D.L	D.L	D.L
Malic acid	63.807	59.901	62.468	61.777	65.807
Lactic acid	0.572	0.663	0.517	0.172	0.663
Succinic acid	0.165	0.452	0.154	0.032	0.165
Citric acid	0.512	0.490	0.450	0.486	0.490
2-hydroxyisocaproic acid	0.053	0.040	0.035	0.050	0.055

*DL: below detection limit

Table.7 Sugar Alcohol Content in different Kimchi samples after 30 days of Fermentation

Sugar Alcohol (mMol)	Sample B (Beetroot Kimchi)	Sample C (Carrot Kimchi)	Sample R (Radish Kimchi)	Sample U (Cucumber Kimchi)	Commercial Kimchi (Jeong *et al.*, 2023)
Mannitol	44.282	48.483	D.L	35.098	50.089

*DL: below detection limit.

Table.7 Amino Acid Composition in different Kimchi samples after 30 days of Fermentation

Amino Acid (mMol)	Sample B (Beetroot Kimchi)	Sample C (Carrot Kimchi)	Sample R (Radish Kimchi)	Sample U (Cucumber Kimchi)	Commercial Kimchi (Jeong *et al.*, 2023)
L- alanine	2.913	2.849	3.165	3.177	2.913
L- arginine	0.035	0.046	0.023	0.020	0.035
L-cystine	7.865	5.912	6.001	5.305	7.865
L-glutamine	65.597	63.326	64.671	61.198	65.597
L- serine	2.922	2.590	2.270	3.214	2.922
L- threonine	0.625	0.441	0.591	0.725	0.625
L- valine	3.149	2.729	2.906	2.140	3.149
L-phenylalanine	1.476	1.078	2.906	0.913	1.476
L-tyrosine	8.452	8.033	8.056	8.005	8.452
L-histidine	2.179	1.729	1.929	1.378	2.179
MEAN	9.5213	8.8733	9.0875	8.6075	2.913

In conclusion, a comparative study was undertaken to evaluate the fermentation characteristics of different kimchi samples made using different vegetables. The naturally prepared and fermented kimchi samples are compared with a commercial kimchi sample for its sensory characteristics, microbial properties and health promoting factors. Among the kimchi samples, Commercial kimchi stands out due to its superior texture retention, longer preservation period and pronounced sensory and metabolite profile, making it more favorable overall due to the added preservatives , artificial inoculation of effective and selected microbial strains and controlled fermentation. But among the four different laboratory prepared kimchi varieties, Beetroot Kimchi (Sample B) was identified as the most health-promoting variant, compared to the commercial kimchi as it is purely natural with no added preservatives with probiotic microbes which can also be prepared easily in every household and also it posses rich antioxidant content, potential cardiovascular benefitsand its role as a functional food in supporting gut health and overall well-being.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author contributions

V. Shiny Pears: Investigation, analysis, writing original draft, V. Prabudoss: Methodology, investigation,, writing-reviewing, D. Binny: Conceptualization, methodology, writing and funding acquisition protocol validation.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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