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Production and Acceptance of Gamma-Aminobutyric Acid (GABA)-Kimchi using *Tetragenococcus halophilus* and Monosodium Glutamate

(Penghasilan dan Penerimaan Kimchi yang Mengandungi Asid Gamma-Aminobutirik (GABA) menggunakan *Tetragenococcus halophilus* dan Monosodium Glutamat)

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ABSTRACT

The addition of gamma-aminobutyric acid (GABA) to fermented foods has been progressively expanded to produce 'Superfood'. In this study, *Tetragenococcus halophilus* was extracted from soy sauce *moromi* from local factory and evaluated for its potential of Gamma-Aminobutyric Acid (GABA) production in kimchi fermentation. There were four different formulations that were fermented for 20 days. Kimchi fermentation was performed on kimchi added with Monosodium Glutamate (MSG) (T1), kimchi inoculated with *T. halophilus* (T2), kimchi with combined MSG and *T. halophilus* (T3), and plain kimchi with no additional starter as a control (C), respectively. A spectral HPLC analysis confirmed that the control sample (C) obtained the highest GABA with 10.90 mg/L followed by T2 with 6.02 mg/L, T1 with 5.72 mg/L, and the lowest content of GABA is produced by T3 with 3.74 mg/L. Sensory analysis was performed by a total of 50 panellists examined the colour, flavour, texture, taste, and overall acceptance of kimchi samples. Kimchi with MSG (T1) received the highest scores for overall acceptance including flavour and taste. This study demonstrated the development of GABA-kimchi using *T. halophilus* and MSG as future food comprising substantial nutritional profile and improved sensory characteristics.

Keywords: Fermentation; GABA; kimchi; MSG; superfood; *Tetragenococcus halophilus*

ABSTRAK

Penambahan asid gamma-aminobutirik (GABA) kepada makanan yang ditapai telah diperluaskan secara berperingkat untuk menghasilkan makanan super. Dalam kajian ini, *Tetragenococcus halophilus* telah diekstrak daripada *moromi* kicap daripada kilang tempatan dan dinilai untuk potensi penghasilan asid gamma-aminobutirik (GABA) dalam penapaian kimchi. Terdapat empat formulasi berbeza yang ditapai selama 20 hari. Penapaian kimchi dilakukan pada kimchi yang ditambah dengan Monosodium Glutamat (MSG) (T1), kimchi yang digabungkan dengan *T. halophilus* (T2), kimchi dengan gabungan MSG dan *T. halophilus* (T3) dan kimchi biasa tanpa pemula tambahan sebagai kawalan (C), secara berturutan. Analisis HPLC spektrum mengesahkan bahawa sampel kawalan (C) memperoleh GABA tertinggi dengan 10.90 mg/L diikuti oleh T2 dengan 6.02 mg/L, T1 dengan 5.72 mg/L dan kandungan terendah GABA dihasilkan oleh T3 dengan 3.74 mg/L. Analisis deria telah dilakukan terhadap sejumlah 50 ahli panel yang meneliti warna, rasa, tekstur, rasa dan penerimaan keseluruhan sampel kimchi. Kimchi dengan MSG (T1) menerima markah tertinggi untuk penerimaan keseluruhan termasuk perasa dan rasa. Kajian ini menunjukkan bahawa pengeluaran GABA-kimchi menggunakan *T. halophilus* dan MSG sebagai makanan masa depan dengan profil nutrisi pemakanan yang tinggi dan ciri deria yang lebih baik.

Kata kunci: Fermentasi; GABA; kimchi; makanan super; MSG; *Tetragenococcus halophilus*

INTRODUCTION

A traditional fermented vegetable dish from Korea, kimchi has garnered enormous appeal all over the world. Its market value reached USD3,377.43 million in 2021, and it is projected to grow at a compound annual growth rate (CAGR) of 5.1%, reaching USD5,302.40 million by 2030

(Lim & Koh 2021). There are nearly 200 recipes of kimchi (Jang et al. 2015) and the most common recipe is using the Chinese or Napa cabbage, along with green onions, garlic, and ginger as primary ingredients. The Korean red pepper powder is a crucial component to achieve that savory and delightfully distinctive flavor (Hajar-Azhari et al. 2024). To obtain the desired quality of kimchi, a careful fermentation process and parameters are required. The fermentation process of kimchi is facilitated by lactic acid bacteria (LAB), which play a crucial role in increasing the probiotic content and contributing to the organoleptic properties of the food (Wan-Mohtar et al. 2022). Lactic Acid Bacteria (LAB), such as *Tetragenococcus halophilus* strain KBC which was isolated from the soy sauce *moromi* at the commercial soy sauce factory (Kwong Bee Chun Soy Sauce Sdn Bhd) have demonstrated significant potential in producing the bioactive compound gamma-aminobutyric acid (GABA) during milk fermentation. This innovative approach holds promise for creating GABA-rich yogurt, a functional food positioned as a future 'superfood' (Azizan et al. 2022) and used as a starter culture for promoting GABA-rich fermented food in conjunction with other cultures (Sassi et al. 2022).

Given its rich nutritional profile and the presence of probiotics, kimchi is regarded as a healthy and functional Asian dish with many potential health advantages such as calming effects on the mood and reduction of antinutrients and allergens (Faizal et al. 2023). Furthermore, this GABA is present naturally from microorganisms, plants, and animals (Hepsomali et al. 2020) and provides therapy for a variety of neurological conditions including stiff-person syndrome, epilepsy, schizophrenia, and anxiety disorder (Ting Wong, Bottiglieri & Carter Snead III 2003). Its neuroprotective properties make it a subject of interest in both clinical and dietary contexts.

In parallel to the significance of GABA, another substance that has garnered attention in the realm of food additives is monosodium glutamate (MSG). MSG has been extensively used as food additives in the world, specifically in commercial processed food. MSG as a flavor enhancer is ingested in the form of hydrolyzed protein or as purified monosodium salt which clarified as food additive (E621) (Kazmi et al. 2017). MSG was discovered by a Japanese Biochemist, Kikunae Ikeda who isolated glutamic acid from *konbu* seaweed and described it as the umami taste prevalent in the Japanese stock or soup (Löliger 2000). Incorporation of MSG and starter *Lactobacillus* sp. OPK 2-59 has proven to lead to higher GABA production in kimchi (Seok et al. 2008) and also supported by a study by Lee et al. (2018) which the GABA content was highest in kimchi with co-inoculation of the starter and MSG (1% (w/w)) with 95.6 mg/100 g kimchi. This study investigated the impact of MSG, *T. halophilus*, and their combination on kimchi fermentation. Four kimchi samples were produced and evaluated after 20 days for GABA concentration, sensory attributes, and overall acceptability.

MATERIALS AND METHODS

Tetragenococcus halophilus PREPARATION

Tetragenococcus halophilus strains KBC was sourced from the isolation of bacteria in the Functional Omics and Bioprocess Development Laboratory, Institute of Biological Sciences, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia. The strain was previously isolated successfully from a soy sauce *moromi* from Kwong Bee Chun Soy Sauce Sdn. Bhd., Kamunting, Perak, Malaysia (Wan-Mohtar et al. 2020; Yee et al. 2021). *T. halophilus* was cultured by inoculating bacteria from the slant onto De Man–Rogosa–Sharpe (MRS) agar plates, which were then incubated at room temperature 18 °C for 8 h. Subsequently, the MRS agar plates were refrigerated at 5-16 °C for 3 days. A single colony of bacteria from after 3-days incubation plate was transferred to 50 mL of MRS broth (Sigma-Aldrich, Dorset, UK) in a 250 mL Erlenmeyer flask and additional three days to further incubated at 36 °C for pure culture broth establishment. A triplicate 10-fold dilution (1 mL:9 mL) was performed to reduce the concentration for kimchi fermentation.

KIMCHI FERMENTATION PREPARATION

Kimchi preparation was initiated by soaking Chinese or Napa cabbage with crisp once pressed, green leaves (not wilted yellow) that are fresh and vibrant colour into pieces measuring approximately 5 cm × 5 cm in a saline solution of 2-3% w/v for 30 min. The cabbage was rinsed after every 30 minutes with tap water and repeated three times, and then dried at room temperature for one hour. Concurrently, other vegetables such as carrots were cut into julienne-shaped, and radishes were sliced. The dimensions of the other vegetables were not explicitly emphasized; instead, consistency was achieved through weight standardization, ensuring a consistent ratio of the non-cabbage vegetables to the napa cabbage.

Kimchi dressing paste comprising garlic, ginger, and holland (yellow onion) was prepared and mixed with slow-cooked rice flour, sugar, and drinking water to reduce the spiciness of Korean red pepper powder. Kimchi dressing pastes recipe is as shown in Table 1. The salted cabbage, other vegetables and kimchi dressing paste were mixed in a ratio of 7:3:3 (w/w), and an additional 1% of salt was added based on the total weight of the mixture and thoroughly mixed with a spatula (for sensory evaluation purposes) as the traditional culture was using hand (Surya & Lee 2022).

The samples were: 1) Control kimchi (C), 2) Kimchi with MSG (T1), 3) Kimchi with *T. halophilus* (T2), and 4) Kimchi with MSG+*T. halophilus* (T3). MSG and *T. halophilus* were added to the total weight 1% and 10 mL, respectively (Table 2). The kimchi was then stored in an airtight container at 15-20 °C for 24 h and afterward was kept in the refrigerator at 5-16 °C for 20 days. Alternately by three days, kimchi was sampled and evaluated. The overall kimchi-making process is summarised in Figure 1.

TABLE 1. The kimchi dressing pastes ingredients

Ingredient	Weight (g)
Garlic	400
Ginger	175
Holland (yellow onion)	650
Rice flour	200
Sugar	80
Drinking water	600
Korean red pepper powder	200

*NA – readily to be mixed into the dressing paste

TABLE 2. The production method of kimchi samples

Kimchi sample	MSG (kg)	*T. halophilus* (mL)	Salted cabbage (kg)	Dressing paste (kg)
Control kimchi (C)	*NA*	*NA*	1.5	0.65
Kimchi with MSG (T1)	0.010	*NA*	1.5	0.65
Kimchi with *T. halophilus* (T2)	*NA*	10	1.5	0.65
Kimchi with MSG+*T. halophilus* (T3)	0.010	10	1.5	0.65

*NA – not included in the kimchi samples making

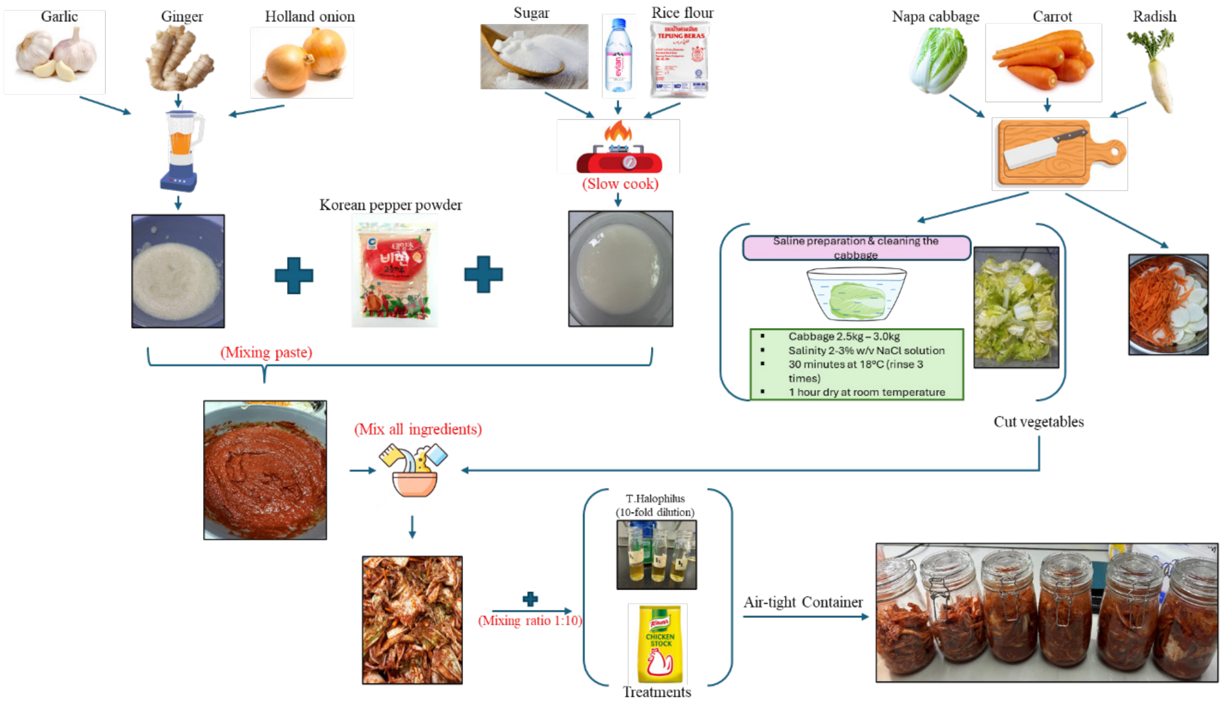


FIGURE 1. The preparation process for kimchi fermentation

pH ANALYSIS

All C, T1, T2, and T3 kimchi samples were assessed for pH levels on days 1, 3, 5, 7, and 20. Prior to pH measurement, each sample was thoroughly mixed using spatula before taking the kimchi extract. 10 mL of kimchi water was extracted using a 10 mL syringe and transferred into a 50 mL beaker. The pH readings of the kimchi extract were taken using an Eutech pH 2700 Meter. The pH meter electrode was thoroughly cleansed using distilled water between measurements to ensure accuracy. After measurement, the kimchi water was discarded to preserve the quality of the kimchi for sensory evaluation.

GABA CONCENTRATIONS ANALYSIS

The concentration of GABA content identification of kimchi samples was performed according to the method of Wan-Mohtar et al. (2021) and Yang et al. (2006) with slight modifications. In short, 2 mL of kimchi sample was extracted using a pipette into a centrifuge tube and centrifuged at 10,000 rpm × 4 °C, 10 min to obtain the supernatant of layer containing the GABA. The filtrate was subsequently passed through a 0.22 micrometre pore-size nylon filter from Fisher Scientific in Brecon, UK. A 60% solution A, consisting of an aqueous solution of 8.205 g of sodium acetate, 0.5 mL of triethylamine, and 0.7 mL of acetic acid in 1000 mL, was adjusted to a pH of 5.8. Solution B, consisting of 28% deionized water, and solution C, consisting of 12% acetonitrile, were pumped at a rate of 0.6 mL/min into the mobile phase. Analysis of the filtrate supernatant was conducted using high-performance liquid chromatography (HPLC) to determine the concentration of GABA. The detection of GABA concentration of filtered supernatant was measured at a wavelength of 254 nm with a gradient separation analysis using a Hypersil Gold C-18 column (250 × 4.6 mm I.D., particle size 5/um; Thermo Scientific, Meadow, UK) with Shimadzu LC 20AT instrument integrated with a Model SPD-M20A PDA detector and a DELL Optiplex integrator. The GABA concentration in the sample was assessed by comparing the highest point of the graph with the established GABA standard curve. The standard curve was obtained by running 4 different concentrations of pure GABA (0.125 mg/L, 0.5 mg/L, 0.75 mg/L, and 1.0 mg/L) through an HPLC machine and a tabulate data was obtained using GraphPad Prism (v 9.1.1).

GRAM STAINING OF KIMCHI SAMPLES

A drop of kimchi extract was applied onto a clean microscope slide and spread evenly. The slide was dried by passing it through the flame of a Bunsen burner several times. Crystal violet, the primary stain, was then added to the bacterial smear and allowed to react for 1 min. The excess stain was removed by rinsing with distilled water. Subsequently, Gram's iodine solution was applied to the smear and allowed to sit for another 1 min. The slide was gently rinsed with 95% ethanol. Gram-positive bacteria retained the crystal violet-iodine complex, appearing purple under the microscope, whereas Gram-negative bacteria lost the complex and appeared colourless. For counterstaining, safranin was applied to the smear and left for 1 min. After that, the slide was delicately washed with distilled water to eliminate any remaining discolouration.

Excess water was gently blotted from the slide without disturbing the bacterial smear, and the slide was dried by passing it through the flame. Once dry, a coverslip was placed over the bacterial smear. The stained slide was then examined under a microscope to observe and analyse the bacterial cells.

SENSORY EVALUATION

To assess consumer acceptance of different kimchi samples, sensory analysis was carried out. The kimchi samples were assessed after 20 days of fermentation period along with the commercial kimchi samples by 50 untrained panellists. The panellists were chosen based on a requirement for research participation which was asked on health problems and/or allergies to certain products prior to analysis briefing (Rakotosamimanana & De Kock 2020). Each panellist was given five kimchi samples: the control kimchi (C), kimchi with MSG (T1), kimchi with *T. halophilus* (T2), kimchi with both MSG and *T. halophilus* (T3), respectively, as shown in Figure 2 were tested with sushi rice. Orange fruit became the palate cleanser before tasting the kimchi samples with the sushi rice. Colour, flavour, texture, taste, and the overall acceptability were the sensory attributes examined using 5-hedonic scales (Lee et al. 2018) with 1 denoting 'strong dislike' and 5 denoting 'strong like'.

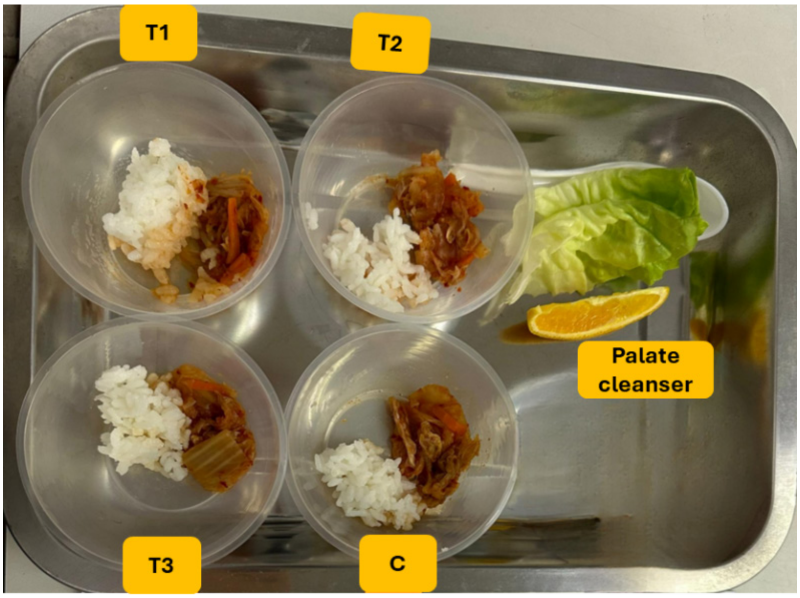
STATISTICAL ANALYSIS

The GABA concentration experiment was run in triplicate and the results are presented as mean±standard deviation using Graphpad Prism (v 9.1.1) and analysis of variance (ANOVA) was utilized to evaluate significant differences between variables with *p*-value greater or lesser than 0.05. The statistical data from the sensory analysis were analysed using IBM SPSS Statistics software (version 29; IBM, Chicago, Illinois, USA). The results are presented as mean± standard deviation. One-way ANOVA and Tukey multiple range test were applied to analyse the sensory data. The result was considered statistically significant if the *p*-value is lesser than 0.05 ($p<0.05$).

RESULTS AND DISCUSSION

pH

The pH values of different kimchi samples were monitored over a 20-day fermentation period. Data collected were analysed using Graphpad Prism (v 9.1.1). The *p*-value for the period of fermentation has a significant difference



(C-Control kimchi, T1-Kimchi with MSG, T2-Kimchi with *T. halophilus* and T3-Kimchi with MSG+*T. halophilus*)

FIGURE 2. The kimchi samples used for sensory evaluation

($p<0.0001$) between Day 1 and Day 20 (initial pH to final pH taken). Initially, control kimchi (C) exhibited the lowest average pH on Day 1 with 5.17 compared to other kimchi treatments, indicating a prompt initiation of fermentation processes likely driven by native lactic acid bacteria where no starter cultures predominate and are able to produce antagonistic substances (Lee et al. 2015). In contrast, kimchi with MSG (T1) started with a marginally higher average pH 5.52, suggesting a slower onset of fermentation. Kimchi with *T. halophilus* (T2) displayed initial pH variability Day 1 average of 5.21 but stabilized at a moderately higher final pH 3.88 by Day 20. Conversely, kimchi with both MSG+*T. halophilus* (T3) began with the highest initial pH 5.49 and achieved a final pH of 3.93 by Day 20. The kimchi with MSG+*T. halophilus* (T3) was the highest final pH among all kimchi treatments indicates the incorporation of both resulted in higher pH and acid stability throughout the time (Figure 3). Despite the differences in fermentation period, the addition of starters such as MSG and *T. halophilus* (either individually or in combination) did not lead to any significant differences ($p > 0.0001$) in the measured outcomes compared to the control kimchi. This suggests that the kimchi treatments, regardless of the microbial starter, did not have a noticeable impact on the fermentation process or the final product characteristics over the fermentation period.

However, it is important to consider that other factors, such as salt concentration during the pre-fermentation stage, may influence the fermentation process and final pH. As demonstrated by Susilowati, Laia and Purnomo (2018) in their study on pickled ginger, a higher salt concentration (7.5%) resulted in a higher pH after 5 days of fermentation (pH 4.77 ± 0.21), compared to a lower salt concentration (2.5%) which produced a significantly lower pH (3.47 ± 0.06). This suggests that variations in salt concentration could potentially influence the pH of kimchi during fermentation, which may explain the lack of significant differences observed in this study.

GABA CONCENTRATION ANALYSIS

The data collected were analyzed using GraphPad Prism (v 9.1.1) and presented means with standard deviation as in Table 3. The p-value ($p > 0.05$) of all kimchi types were not significant to each kimchi types. The results may be due to uncontrolled conditions conducted during kimchi preparation and fermentation. Also, the results could be due to natural variability or the possibility that the additional starters amount were insufficient. However, the control kimchi(C) produced the highest concentration of GABA at 10.90 mg/L. Control kimchi typically undergoes fermentation primarily through naturally occurring lactic acid bacteria present in the vegetables and salt without starter culture or additive MSG, which contributed to higher GABA levels (Lee et al. 2015). While *T. halophilus* and MSG have the potential to contribute to GABA production, their combined effect in kimchi with MSG+*T.halophilus* (T3) resulted in a lower GABA concentration (3.74 mg/L) compared to control kimchi (C, 10.90 mg/L). This suggests that their interactions in the fermentation process may have influenced GABA production differently than anticipated. Factors such as competition for resources, pH changes, or metabolic pathways may have affected their ability to enhance GABA synthesis synergistically. Initial pH for the kimchi incorporated with MSG, *T. halophilus* and MSG+*T. halophilus* were higher compared to control kimchi which plays a crucial role in GABA synthesis as it affects microbial growth and glutamate decarboxylase (GAD) activity (Cui et al. 2020). At a lower or higher initial pH, the GAD enzyme is disrupted, which lowers the GABA production (Rayavarapu, Tallapragada & Usha 2019). GAD activity aids bacterial cells in enduring acidic stress by exchanging hydrogen ions and glutamate with the surroundings, which raises the pH outside the cell (Cui et al. 2020; Di Cagno et al. 2010; Hussin et al. 2021; Lyu et al. 2018).

In addition, these results also suggest that GABA production in kimchi can be influenced by the presence of specific additives like MSG. Recent study stated that the addition of MSG exhibited the most significant effect on GABA production. The yield of GABA rose substantially with increasing concentrations of MSG, peaking at 653.101 mg/L when the MSG concentration reached 5 g/L taken from soy sauce moromi. Consequently, it can be concluded that the artificial introduction of MSG into the fermentation media significantly enhances GABA accumulation in THSK (Sassi et al. 2022). Conversely, elevated concentrations of MSG activated GABA-T and simultaneously inhibit and degrade GABA synthesis. The optimal MSG concentrations for GABA synthesis vary according on the type of microorganisms which are comparable to pH levels (Cui et al. 2020; Phuengjayaem et al. 2021; Wan-Mohtar et al. 2020). Previous study by Rayavarapu, Tallapragada and Usha (2019) only produced 5.34g/L of GABA using 1.5% MSG with *Lactobacillus fermentum* isolated from palm wine while Kwon et al. (2016) reported 3% MSG using *Lactobacillus plantarum* K154 in a fermented water dropwort (*Oenanthe javanica* DC) and produced 10 mg/mL of GABA.

GRAM STAINING BACTERIA

A Gram stain was conducted on the kimchi extracts, and observations were made using a Leica DM500 microscope at 40× magnification. Based on Figure 4, it can be concluded that there are Gram-positive bacteria that appear purple colour with clumping of four shaped cocci (*tetra*). These characteristics are similar to the lactic acid bacteria, *T. halophilus* that incorporated in the kimchi samples.

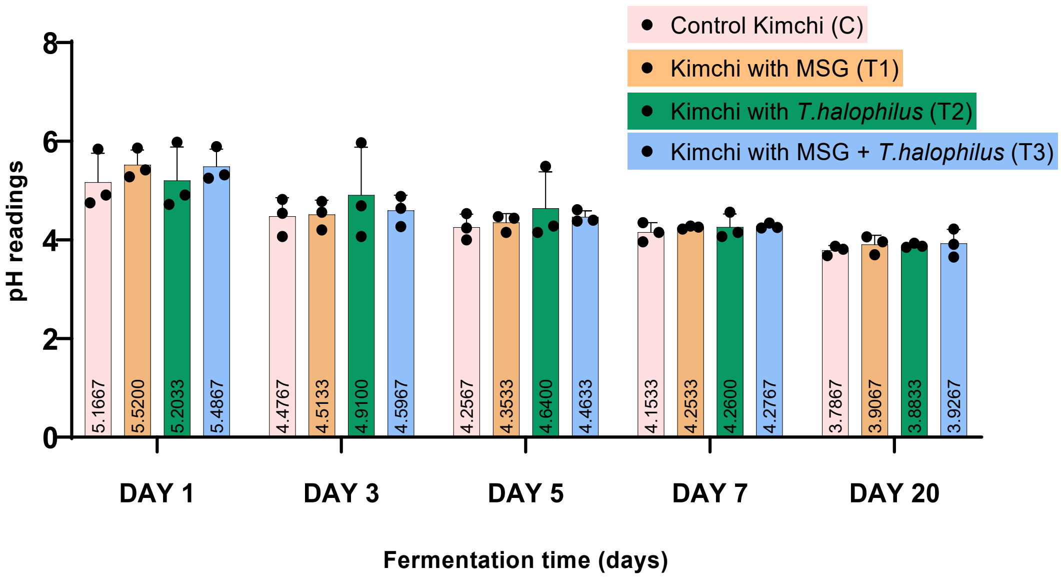


FIGURE 3. The pH average readings over 20-days fermentation period

TABLE 3. The average mean scores for GABA concentrations from different types of kimchi treatments

Treatment	GABA concentration (mg/L)
Control kimchi (C)	*10.8979±12.49
Kimchi with MSG (T1)	5.7232±1.165
Kimchi with *T. halophilus* (T2)	6.0201±3.643
Kimchi with MSG+*T. halophilus* (T3)	6.2701±4.409

*the highest mean score for the attribute group between kimchi samples and no significant difference between each kimchi types

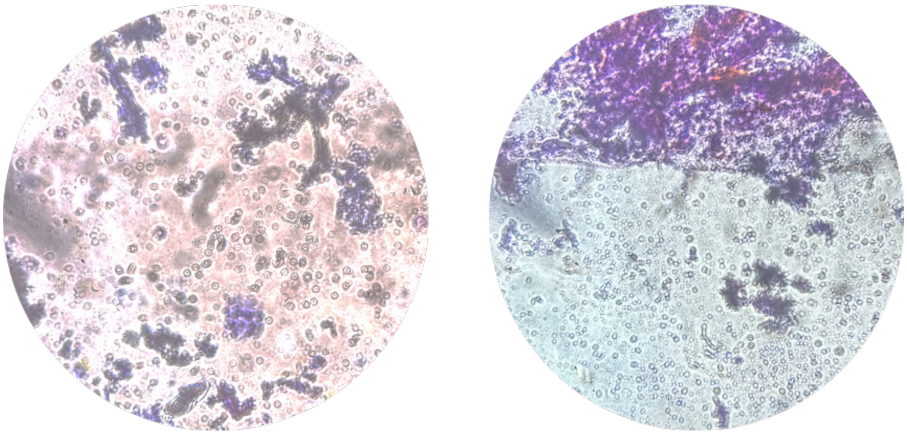


FIGURE 4. *T. halophilus* strain KBC observation by X40 magnification

SENSORY ANALYSIS

Kimchi was tested for five sensory attributes consists of 'colour', 'flavour', 'texture', 'taste' and 'overall acceptability'. Table 4 shows the average mean scores for all sensory attributes assessed from different kimchi formulations; plain kimchi (C), kimchi with MSG (T1), kimchi with *T. halophilus* (T2), kimchi with MSG and *T. halophilus* (T3). Figure 2 shows the four different formulations of kimchi that were assigned to each panellist for the sensory evaluation. One-way ANOVA and Tukey multiple range test of the IBM SPSS Statistics software (version 19; IBM, Chicago, Illinois, USA) were applied to analyse the sensory data. Based on Table 4, p-value is lesser than 0.05 ($p<0.05$). Therefore, all the kimchi formulations have significantly different and have no homogeneity of variances.

Kimchi with *T. halophilus* (T2) received the highest score (3.86 ± 0.857), followed closely by control kimchi (3.76 ± 0.87) and kimchi with both MSG and *T. halophilus* (3.76 ± 1.061) in term of colour. The kimchi perceived as having a vibrant and attractive red hue. This vibrant colour is often associated with freshness and appeal in kimchi, contributing to its visual appeal and potentially enhancing its perceived deliciousness which supported by the old Korean proverb says 'what looks good tastes good' (Chung et al. 2016).

Kimchi with MSG (T1) scored the highest (3.16 ± 0.955) and (3.02 ± 1.02) indicating it was favoured for its flavour and taste, respectively, compared to other treatments. The higher score for flavour and taste suggest that it had a more desirable and pronounced taste profile, likely enhanced by the umami-rich MSG. Panellists perceived this kimchi as having a well-balanced and enjoyable flavour profile. Recently, kimchi has been produced commercially by incorporating with the starter culture (Jung, Lee & Jeon 2014) which developed beneficial alterations in kimchi, enhancing its sensory characteristics and prolonging its shelf-life (Lee et al. 2015). Thus, the useful properties of the kimchi will be enhanced even more by using a GABA-producing strain as the starter in the fermenting process. A multitude of additional species of lactic acid bacteria (LAB) have been extracted from several fermented foods and employed as starter cultures, including *Streptococcus thermophilus* and *Lactobacillus bulgaricus* in yogurt (Yilmaz-Ersan & Kurdal 2014) and *Lactobacillus zymae* GU240 in kimchi (Lee et al. 2018). Kimchi with both MSG and *T. halophilus* (T3) had the highest score (2.84 ± 1.149), the best texture among all treatments. Lee et al. (2018) reported similar results where the addition of starter and L-glutamic acid monosodium salt in kimchi sample (MSG; Sigma G1626, USA, 1% (w/w)) received higher scores for the kimchi texture.

Notably, kimchi with MSG (T1) indicating it was the most accepted overall by the panellists (3.00 ± 1.088). In summary, the higher overall acceptance score for kimchi with MSG (T1) suggests that it effectively combined favourable sensory attributes, likely including enhanced flavour from MSG, to become the preferred choice among the panellists in this study. Kimchi with *T. halophilus* comes second for the overall acceptance with 2.94 ± 0.956. A study by Udomsil et al. (2011) also agreed that by using *T. halophilus* as a starter culture improved the flavour in the fish sauce fermentation whereby the fish sauce predominantly produced high glutamic acid and high level of total amino acids while reducing dimethyl disulfide that gives an off-flavour note. In other studies, it shows that the GABA-producing strain such as *T. halophilus* plays important roles in generating volatile aromatic compounds beside adding taste and fragrance to fermented food such as soy sauce (Hajar-Azhari et al. 2024). Devanthi et al. (2018) found that *T. halophilus* and *Zygosaccharomyces rouxii* incorporated as a starter during *moromi* stage preparation improved the soy sauce taste and produced a more complex aroma profile. Figure 5 visually illustrates the average scores from 50 panellists evaluated. Kimchi with MSG (T1) received the highest scores for flavour, taste and the overall acceptability.

TABLE 4. The average mean scores and standard deviation from different types of kimchi treatments

Treatment	Sensory attributes				
	Colour	Flavour	Texture	Taste	Overall acceptance
Control kimchi (C)	3.76 ± 0.87	2.84 ± 1.149	2.74 ± 1.084	2.62 ± 1.086	2.7 ± 0.995
Kimchi with MSG (T1)	3.66 ± 0.961	*3.16 ± 0.955	2.82 ± 1.063	*3.02 ± 1.02	*3 ± 1.088
Kimchi with *T. halophilus* (T2)	*3.86 ± 0.857	2.84 ± 0.912	2.82 ± 1.004	2.76 ± 0.916	2.94 ± 0.956
Kimchi with MSG+*T. halophilus* (T3)	3.76 ± 1.061	2.86 ± 1.143	*2.84 ± 1.149	2.78 ± 1.148	2.88 ± 1.1

*The highest mean score for the attribute group between kimchi samples

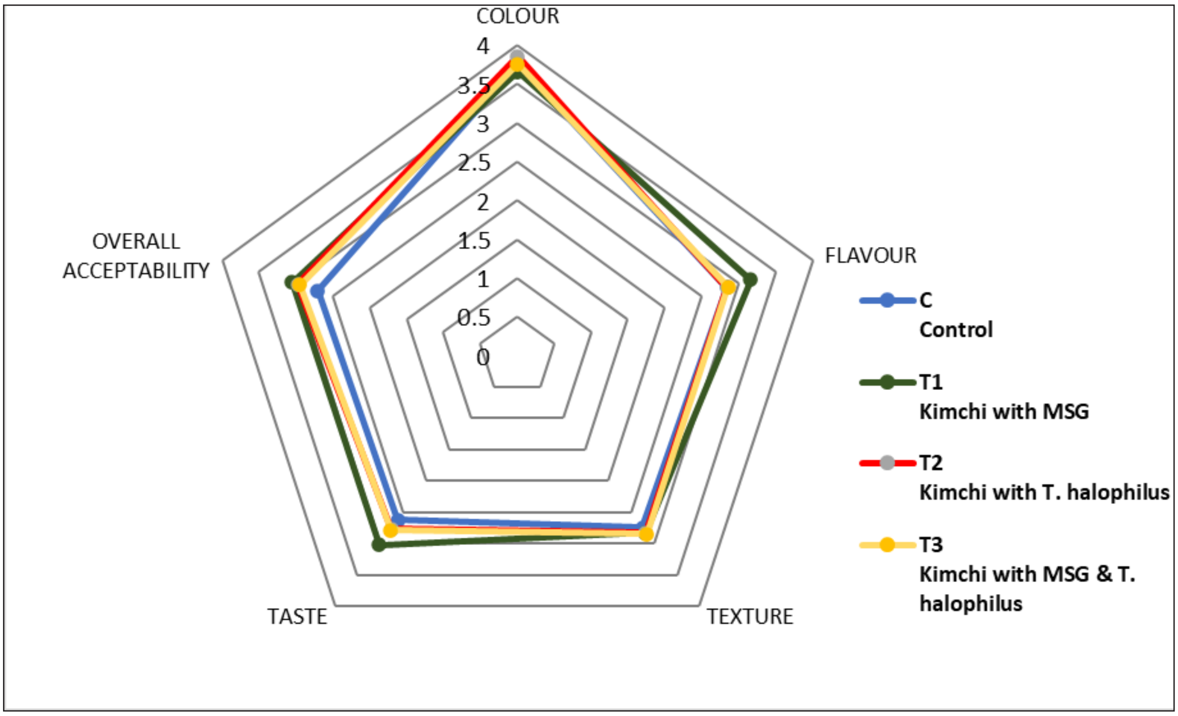


FIGURE 5. The radar chart shows overall acceptability scores of five attributes (colour, flavour, texture, taste and overall acceptability) on 5 different kimchi samples

CONCLUSIONS

By Day 20, kimchi with both MSG and *T. halophilus* (T3) exhibited a higher pH stabilization than other formulations. This indicates that the combination of both create a more stable acidity levels in kimchi. However, despite their role in fermentation, *T. halophilus* and MSG did not significantly enhance GABA production and has no significant effects for each kimchi treatments either individually or combination of both where the control kimchi (T1) is more effective in producing higher levels of GABA even with no additional starters. The outcomes of GABA production may be influenced by the complex interactions of microbial communities and biochemical pathways during fermentation. Meanwhile, the sensory analysis has a significant effect where the kimchi with MSG (T1) had the highest scores and more favourable on the sensory profile within consumers. However, optimum conditions and parameters need to be enhanced to produce more crunchy texture and vibrant attractive colour as the kimchi with *T. halophilus* (T2). Therefore, further studies with the appropriate amount of MSG and *T. halophilus* incorporation with controlled conditions, possibly improves the sensory profiles and GABA content of the kimchi.

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