e-ISSN: 2757-8836
ORIGINAL ARTICLE
J. Raw Mater. Process. Foods vol.6(2), (2025), 122-131

Recieved: 06/11/2025 Revised: 04/12/2025 Accepted article published: 27/12/2025 Published online: 30/12/2025

Effect of Different Lactic Acid Bacteria Strains on Red Beet Kvass VOCs

Onur Sevindik, Haşim Kelebek

Department of Food Engineering, Faculty of Engineering, Adana Alparslan Turkes Science and Technology University, Turkey

*Corresponding author: hkelebek@atu.edu.tr

DOI: https://doi.org/10.57252/jrpfoods.2025.11

Abstract

Red beet kvass (RBK) is a traditional fermented beverage that has gained attention because of its unique flavor and potential health benefits. In the present study, four different kvass batches were produced: one was fermented spontaneously (K), while the others were pasteurized and inoculated with three *Lactobacillus* strains (*Lactobacillus casei*: LC, *Lactobacillus delbrueckii*: LD, and *Lactobacillus plantarum*: LP). Volatile compounds were extracted by solvent extraction followed by solvent-assisted flavour evaporation and analyzed using GC-MS. A total of 46 volatile compounds were identified, with ketones and carboxylic acids as the dominant groups. LAB inoculation significantly affected the volatile composition of RBK samples. Controlled fermentations, particularly with LP and LD strains, resulted in higher total volatile concentrations than spontaneous fermentation. Acetoin, ethyl lactate, acetic acid, and 3-methyl-1-butanol were among the major compounds detected in inoculated samples. In addition, strain-dependent differences were observed in ester and alcohol formation. These findings demonstrate that LAB strain selection is an effective approach to modulate the volatile profile of red beet kvass.

Keywords: *Red beet kvass; lactic acid bacteria; volatile compounds; aroma profile; GC-MS; fermentation; Lactobacillus strains*

1.INTRODUCTION

Red beet (*Beta vulgaris* L.) has attracted considerable attention in recent years as a valuable raw material for functional beverage production due to its high content of biologically active constituents, including betalains, phenolic compounds, vitamins, minerals, and dietary fiber (Neelwarne, 2012; Grönroos et al., 2024; Stoica et al., 2025). In addition to its intense natural pigmentation, red beet is widely recognized for its antioxidant, anti-inflammatory, and health-promoting properties (Georgiev et al., 2010). Besides direct consumption and juice production, the use of red beet in fermentation-based products has recently gained increasing interest.

Red beet kvass (RBK) is a lactic acid fermented beverage produced from red beet juice and traditionally consumed in several Eastern European countries. Unlike traditional bread kvass prepared from rye, RBK is a relatively recent plant-based alternative that has become increasingly popular among consumers interested in fermented and clean-label beverages (Bazhenova et al., 2021). During production, ingredients such as salt, garlic, ginger, or spices may also be incorporated to enhance flavor characteristics. In addition to its nutritional value and probiotic potential, RBK is characterized by a complex volatile composition formed throughout fermentation.

Volatile compounds are among the main quality parameters influencing the aroma properties of fermented beverages. The metabolic activities of lactic acid bacteria (LAB) during fermentation lead to the formation of numerous volatile metabolites, including alcohols, aldehydes, ketones, esters, acids, terpenes, and sulfur-containing compounds. These compounds are responsible for the characteristic aroma notes of fermented products and play an important role in product differentiation and consumer perception (Kumari et al., 2022). The composition and concentration of volatile compounds may vary considerably depending on the microbial culture used during fermentation. Previous studies on fermented beverages such as kombucha, shalgam, and Iben demonstrated that different LAB strains significantly influence volatile profiles and aroma development (Pessione, 2012; Tanguler et al., 2017; Sarhir et al., 2019). However, information regarding the volatile composition of RBK and the role of specific LAB strains in aroma formation remains very limited.

Therefore, the aim of the present study was to investigate the effect of different LAB strains on the volatile composition of red beet kvass. For this purpose, one spontaneously fermented kvass sample and three pasteurized samples inoculated with *Lactobacillus casei, Lactobacillus delbrueckii*, and *Lactobacillus plantarum* were produced and comparatively evaluated in terms of their volatile compounds using GC-MS analysis.

2. MATERIALS AND METHOD

2.1. Materials

Red beet (*Beta vulgaris* var. *conditiva*) samples used for kvass production were obtained from a local producer located in Pınarcık village, Niğde, Türkiye (38.135178° N, 34.676476° E) during the 2024 harvest season. Approximately 100 kg of red beet roots were supplied in four separate batches and kept under cool, dark conditions prior to processing. Before fermentation, beet roots were washed thoroughly, peeled, and cut into small cubes.

Fermentation was carried out at 25 ± 2 °C for 12 days.

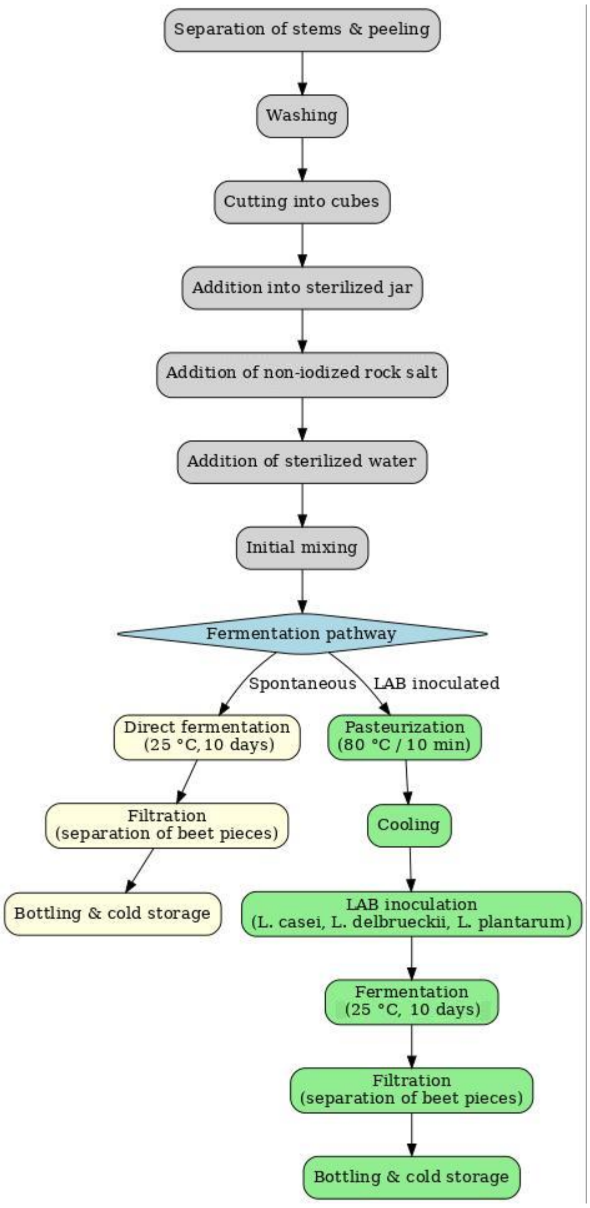

Figure 1. Kvass production flow-chart

Kvass production (Figure 1) was carried out in sterilized glass jars previously autoclaved at 121 °C for 30 min. For inoculated samples, the beet–brine mixture was pasteurized at 80 °C for 10 s to reduce the native microbiota before fermentation (Kirlangic et al., 2021). One batch was produced by spontaneous fermentation without pasteurization or starter inoculation and used as the control sample (K). The remaining batches were inoculated with three different lactic acid bacteria strains: *Lactobacillus casei* (ATCC 431, LC), *Lactobacillus delbrueckii* (ATCC 9649, LD), and *Lactobacillus plantarum* (ATCC 14917, LP). Prior to use, LAB cultures were activated in MRS broth at 30 °C for 18–24 h. Stock cultures were maintained in 40% glycerol solution at −18 °C. All bacterial strains were purchased from Labor Wiesby (Germany).

Kvass samples were prepared in 350 mL sterile glass jars containing approximately 80 g diced red beet, 1 g non-iodized rock salt (0.5%, w/v), and 220 mL boiled and cooled drinking water.

2.2. Method

2.2.1. Aroma extraction

Volatile compounds were extracted using direct solvent extraction combined with solvent-assisted flavour evaporation (SAFE) according to Engel et al. (1999) with slight modifications. Briefly, 50 mL of kvass sample was mixed with 100 mL dichloromethane in a 500 mL round-bottom flask. 4-Nonanol (41.5 µg/L) and 2-methyl-3-heptanone (40.5 µg/L) were added as internal standards. Following solvent extraction for 4 h, the organic phase was subjected to SAFE distillation under high vacuum conditions (approximately 10^{-3}–10^{-4} Pa) at 42 °C. Residual moisture in the distillate was removed using anhydrous sodium sulfate. The extract was first concentrated to 2–3 mL using a Vigreux column and then reduced to 0.5 mL under a gentle nitrogen stream prior to GC-MS analysis. All extractions were performed in triplicate.

2.2.2. GC-MS Analysis of Volatile Compounds

Volatile compounds of RBK samples were analyzed using a Shimadzu Nexis GC-2030 gas chromatography system coupled with a GCMS-QP2020 NX mass spectrometer. Separation was performed on a DB-WAX capillary column (60 m × 0.25 mm i.d., 0.4 µm film thickness). The injector temperature was set at 220 °C and helium was used as the carrier gas at a constant flow rate of 1.5 mL/min. The oven temperature program was as follows: initial temperature of 60 °C held for 3 min, increased to 220 °C at 2 °C/min, and then raised to 245 °C at 3 °C/min and held for 20 min. A 3 µL aliquot of each extract was injected into the system.

The mass spectrometer operated under electron ionization mode at 70 eV. Ion source and quadrupole temperatures were maintained at 250 °C and 120 °C, respectively. Mass spectra were recorded within a scan range of m/z 29–350.

Identification of volatile compounds was achieved by comparing retention characteristics and mass spectra with those of authentic standards when available. For compounds lacking standards, identification was performed using mass spectral libraries including Wiley 11.0, NIST-98, and Flavor2L. Quantification was carried out using internal standards and response factor calculations. Method validation, including calibration performance, detection limits, quantification limits, and recovery assays, was previously reported by Sevindik et al. (2020). Recovery values ranged between 91% and 97%, with relative standard deviations below 5%. All analyses were performed in triplicate.

2.2.3. Calculation of amounts of volatile compounds

To calculate the amounts of volatile compounds after identifying the peaks, calibration curves were obtained from standard compounds and the amounts were calculated using the following formula with the internal standard method. The response factor of each compound was taken into account in the calculation.

$$C_i = (A_i / A_{st}) \times C_{st} \times RF \times HF$$

Ci: Concentration of the compound
Ai: Peak area of the compound
Ast: Peak area of internal standard
Cst: Concentration of internal standard (40 µg/100 ml)
RF: Response factor

HF: Calculation factor (factor for converting the sample amount to kg: 10).

2.2.4 Statistical Analyses

The data obtained as a result of this study were analyzed with 95% confidence interval and analysis of variance (One-way ANOVA) using the statistical program (SPSS 23.0.0, SPSS Inc., USA). Whether the difference between the averages of the experimental groups was significant or not was determined by the Duncan multiple comparison tests performed after analysis of variance（p<0.05). Results were presented as mean ± standard deviation. (Bek and Efe, 1988; Özdamar, 1999; Landau and Everitt, 2004).

3. RESULTS AND DISCUSSION

A total of 46 volatile compounds belonging to different chemical classes, including alcohols, carboxylic acids, esters, ketones, terpenes, aldehydes, sulfur compounds, furans, furanones, and pyranones, were identified in RBK samples (Table 1). LAB inoculation significantly influenced both the qualitative and quantitative distribution of volatile compounds. The highest total volatile concentration was observed in LP (14,874 µg/L), followed by LD (9,093 µg/L), LC (8,481 µg/L), and the spontaneously fermented control sample K (4,493 µg/L). These findings indicate that controlled fermentation enhanced volatile formation and contributed to a more complex aroma profile compared to spontaneous fermentation. Similar increases in VOC production during LAB fermentation have also been reported for fermented vegetable beverages (Di Cagno et al., 2013; Marco et al., 2017).

Analysis confirmed strain-dependent differences among RBK samples. LP was clearly separated from the other groups due to its higher abundance of esters, ketones, alcohols, and terpene compounds. LC and LD exhibited relatively similar distributions, while the control sample showed lower normalized intensities for most aroma-related compounds and a simpler volatile profile dominated mainly by acids and a limited number of secondary volatiles.

3.1. Alcohols

Eleven alcohols were identified across all samples. Total alcohol concentrations followed the order LP (1,386 µg/L) > LC (703 µg/L) > K (553 µg/L) > LD (368 µg/L). The LP sample was characterized by high levels of 3-methyl-1-butanol and 2,3-butanediol, compounds commonly associated with amino acid metabolism during LAB fermentation. These alcohols contribute fermented, sweet, and mildly alcoholic aroma notes and are frequently reported as major fermentation-derived volatiles in vegetable-based products (Zabat et al., 2018). Compared to spontaneous fermentation, LAB inoculation generally promoted higher alcohol production, particularly in LP.

3.2. Carboxylic Acids

Eight carboxylic acids were detected in RBK samples. Total acid concentrations ranged from 1,381 µg/L in the control to 2,448 µg/L in LD. Acetic acid was the dominant acid in all samples and reached its highest concentration in LP (1,572 µg/L). In addition, LD contained notably higher amounts of hexanoic acid, whereas LP showed relatively elevated levels of branched-chain acids such as 3-methyl-butanoic acid. These differences indicate that LAB strains affected organic acid metabolism through different biochemical pathways.

3.3. Esters

Esters were among the volatile groups most affected by fermentation strategy. LP exhibited the highest total ester concentration (2,380 µg/L), followed by LC (940 µg/L), K (617 µg/L), and LD (299 µg/L). Ethyl lactate was the predominant ester, particularly in LP (2,048 µg/L), suggesting enhanced esterification activity by L. plantarum. Other esters, including isoamyl lactate and phenylethyl acetate, also varied depending on the starter culture used. The elevated ester production observed in LP contributed substantially to the increased aroma complexity of this sample.

3.4. Ketones

Ketones represented one of the dominant volatile groups detected in RBK. The highest total ketone concentration was observed in LP (7,970 µg/L), whereas the control sample exhibited markedly lower levels. Acetoin was the major ketone identified and reached 7,477 µg/L in LP. This compound is known as a characteristic fermentation metabolite formed through pyruvate metabolism in LAB and is frequently associated with buttery and creamy aroma notes. The higher ketone accumulation in LP indicates a stronger metabolic activity of L. plantarum during fermentation.

3.5. Terpenes and Other Volatiles

Four terpene compounds, namely limonene, linalool, anethole, and geranial, were identified in RBK samples. Linalool and geranial were mainly detected in LP, while LC showed the highest concentration of anethole. In addition, several sulfur compounds, aldehydes, furans, furanones, and pyranones were detected at lower levels. Although these compounds were present in

Table 1. Aroma profile of RBK

No	LRI	Compounds	K	LC	LD	LP
Alcohols						
1	1056	2-Methyl- 2-butanol	nd	199 ± 3.1^{a}	16.6 ± 0.6^{c}	171 ± 8.7^{b}
2	1115	2-Methyl-1-propanol	nd	34.2 ± 3.1^{b}	11.5 ± 0.2^{c}	58 ± 0.9^{a}
3	1165	3-Methyl-1-butanol	79.6 ± 1.3^{d}	334 ± 15.3^{b}	219 ± 9.3^{c}	802 ± 8.7^{a}
4	1254	3-Methyl-3-buten-1-ol	13.5 ± 0.1^{a}	6.8 ± 0.2^{b}	nd	5.4 ± 0.2^{c}
5	1265	1-Pentanol	49.3 ± 1.3^{a}	3.9 ± 0.2^{c}	nd	22.6 ± 0.9^{b}
6	1294	2-Propanol	44.7 ± 2.6^{a}	2.7 ± 0.2^{c}	nd	23.2 ± 0.4^{b}
7	1460	2,3-Butanediol	270 ± 1.3^{a}	19.3 ± 0.2^{c}	64.1 ± 3.8^{b}	60.5 ± 0.9^{b}
8	1764	Benzyl alcohol	26.8 ± 0.8^{a}	20.3 ± 0.2^{b}	7.5 ± 0.6^{c}	28.9 ± 0.1^{a}
9	1864	2-Phenylethanol	5.6 ± 0.1^{c}	31.6 ± 1.5^{b}	33.6 ± 1.7^{b}	138 ± 2.3^{a}
10	2236	1-Hexadecanol	17.4 ± 0.3^{b}	45.8 ± 1.5^{a}	3.9 ± 0.2^{d}	10.7 ± 0.1^{c}
11	2466	1-Heptadecanol	45.5 ± 2.6^{b}	5.0 ± 0.2^{d}	11.5 ± 0.2^{c}	66.0 ± 0.9^{a}
		Total	553 ± 12.6^{d}	703 ± 11.9^{b}	368 ± 7.5^{c}	1386 ± 21.8^{a}
Acids						
12	1415	Acetic acid	938 ± 52.7^{c}	880 ± 15.3^{d}	1230 ± 52.9^{b}	1572 ± 27.0^{a}
13	1530	2-Methyl-propanoic acid	73.4 ± 2.6	10.7 ± 0.3	19.9 ± 0.8	21.3 ± 0.3
14	1556	Butanoic acid	53.6 ± 0.9^{d}	75.5 ± 3.1^{c}	94.0 ± 0.8^{b}	103 ± 0.9
15	1593	3-Methylbutanoic acid	61.5 ± 5.3^{a}	12.4 ± 0.3^{d}	16.0 ± 0.5^{c}	55.9 ± 0.5^{b}
16	1731	Hexanoic acid	134 ± 1.3^{c}	281 ± 15.3^{b}	873 ± 2.9^{a}	207 ± 3.4^{b}
17	1845	Octanoic acid	31.2 ± 1.5^{c}	43.6 ± 1.5^{c}	161 ± 5.3^{b}	186 ± 5.6^{a}
18	2059	Nonanoic acid	89.2 ± 0.9^{a}	nd	19.9 ± 0.8^{c}	52.5 ± 0.9^{b}
19	2171	Decanoic acid	nd	nd	34.0 ± 1.8	nd
		Total	1381 ± 34.6^{c}	1303 ± 9.8^{c}	2448 ± 32.9^{a}	2198 ± 13.6^{b}

Esters						
20	1276	Ethyl lactate	286 ± 6.6^{c}	894 ± 15.3^{b}	224 ± 9.6^{c}	2048 ± 78.0^{a}
21	1368	Hexyl acetate	252 ± 13.2^{a}	46.3 ± 3.1^{c}	11.6 ± 0.2^{d}	137 ± 0.2^{b}
22	1391	Ethyl 2-hydroxybutyrate	nd	nd	nd	9.8 ± 0.1
23	1460	Ethyl octanoate	nd	nd	nd	17.0 ± 0.9
24	1489	Isoamyl lactate	32.6 ± 1.3^{b}	nd	2.5 ± 0.1^{c}	103 ± 0.9^{a}
25	1601	Ethyl nonanoate	nd	nd	nd	6.8 ± 0.1
26	1620	1,3-Propanediol diacetate	nd	nd	nd	19.6 ± 0.3
27	1654	Phenylethyl acetate	46.2 ± 1.3^{b}	nd	60.7 ± 3.6^{a}	39.2 ± 0.9^{c}
		Total	617 ± 11.3^{c}	940 ± 12.6^{b}	299 ± 21.5^{d}	2380 ± 54.1^{a}
Ketones						
28	1265	3-Hydroxy-2-butanone	343 ± 1.3^{d}	4955 ± 153^{c}	5592 ± 326^{b}	7477 ± 87.0^{a}
29	1276	1-Hydroxy-2-propanone	11.6 ± 0.3^{c}	81.6 ± 3.1^{a}	38.8 ± 2.1^{b}	16.4 ± 0.6^{c}
30	1282	3-Hydroxy-3-methyl-2-butanone	38.6 ± 2.6^{a}	nd	11.7 ± 0.2^{c}	23.0 ± 0.2^{b}
31	1350	2-Hydroxy-3-pentanone	42.1 ± 1.3^{a}	4.8 ± 0.3^{b}	3.8 ± 0.2^{c}	1.9 ± 0.1^{d}
32	1360	4-Hydroxy-4-methyl-2-pentanone	431 ± 13.2^{b}	676 ± 15.3^{a}	58.4 ± 3.4^{c}	452 ± 8.7^{b}
33	1382	2-Acetoxy-3-butanone	nd	nd	52.6 ± 3.0	nd
		Total	866 ± 18.7^{c}	5717 ± 21.3^{b}	5757 ± 32.4^{b}	7970 ± 26.5^{a}
Lactones						
34	1495	Butyrolactone	783 ± 13.2^{a}	34.1 ± 3.1^{c}	38.9 ± 2.1^{c}	436 ± 3.7^{b}
35	1936	2-Hydroxy-3-methyl-2-cyclopentene-1-one	nd	103 ± 1.5a	9.9 ± 1.2^{c}	50.5 ± 0.1^{b}
36	2303	Mevalonic acid lactone	6.0 ± 0.1^{c}	nd	57.7 ± 3.4^{a}	46.6 ± 0.3^{b}
		Total	789 ± 9.7^{a}	137 ± 9.6^{c}	107 ± 8.6^{c}	533 ± 21.1^{b}
Terpenes						
37	1240	Limonene	12.9 ± 0.1^{b}	35.8 ± 1.5^{a}	12.7 ± 0.3^{b}	5.6 ± 0.1^{c}
38	1552	Linalool	nd	nd	45.1 ± 2.5	3.2 ± 0.1

39	1716	Anethole	78.7 ± 0.7	nd	nd	189 ± 8.3
40	1855	Geranial	nd	4.2 ± 0.2^{b}	1.8 ± 0.2^{c}	33.6 ± 0.5^{a}
		Total	91.6 ± 3.4^{b}	40.0 ± 2.1^{d}	59.6 ± 3.4^{c}	231 ± 8.7^{a}
Sulfurous Compounds						
41	1582	Methionol	nd	nd	nd	4.1 ± 0.2
42	1836	Dimethyl sulfone	8.9 ± 0.1^{b}	nd	26.6 ± 1.3^{a}	22.4 ± 0.9^{a}
		Total	8.9 ± 0.1^{b}	nd	26.6 ± 1.3^{a}	22.4 ± 0.9^{a}
Aldehydes						
43	1149	2-Methyl-2-butenal	nd	4.3 ± 0.2^{c}	6.9 ± 0.4^{b}	16.1 ± 0.7^{a}
		Total	nd	4.3 ± 0.2^{c}	6.9 ± 0.4^{b}	16.1 ± 0.7^{a}
Furans						
44	1606	Furfuryl alcohol	21.3 ± 0.5	nd	nd	15.1 ± 0.9
		Total	21.3 ± 0.5	nd	nd	15.1 ± 0.9
Furanones						
45	1256	Dihydro-2-methyl-3(2H)-furanone	150.3 ± 2.6^{a}	nd	16.8 ± 0.6^{c}	53.9 ± 0.5^{b}
		Total	150.3 ± 2.6^{a}	nd	16.8 ± 0.6^{c}	53.9 ± 0.5^{b}
Pyranones						
46	1894	3-Hydroxy-2-methyl-4H-pyran-4-one	16.0 ± 0.1^{b}	3.2 ± 0.2^{d}	5.4 ± 0.3^{c}	63.3 ± 0.9^{a}
		Total	16.0 ± 0.1^{b}	3.2 ± 0.2^{d}	5.4 ± 0.3^{c}	63.3 ± 0.9^{a}
		General Total	**4493.5 ± 56.7^{d}**	**8848.1 ± 62.3^{c}**	**9093.4 ± 78.9^{b}**	**14874.1 ± 122^{a}**

minor concentrations, they contributed to the differentiation of the volatile profiles among the samples.

Overall, LAB inoculation significantly enhanced volatile production and aroma complexity in RBK compared to spontaneous fermentation. Among the tested strains, L. plantarum showed the strongest effect on VOC formation and produced the richest volatile profile.

4. CONCLUSION

The present study demonstrated that the volatile composition of red beet kvass was significantly influenced by the lactic acid bacteria strain used during fermentation. A total of 46 volatile compounds belonging to different chemical classes were identified, with ketones, carboxylic acids, alcohols, and esters representing the major groups. Compared with spontaneous fermentation, LAB inoculation markedly increased both the concentration and diversity of volatile compounds.

Among the tested strains, L. plantarum produced the richest volatile profile and exhibited the highest total volatile concentration, particularly through elevated levels of acetoin, ethyl lactate, and higher alcohols. In contrast, LD was characterized by higher acid production, while LC showed a more moderate volatile composition. These findings indicate that each LAB strain directed aroma formation through different metabolic pathways, resulting in clearly distinguishable volatile profiles.

Overall, controlled fermentation with selected LAB strains can be considered an effective strategy to enhance aroma complexity and modulate the volatile composition of RBK. In particular, L. plantarum showed strong potential as a starter culture for the production of aroma-rich red beet kvass.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of Adana Alparslan Science and Technology University. This manuscript was derived from a part of the doctoral dissertation of Onur Sevindik.

Conflict of interest

The author declares no conflicts of interest, financial or otherwise.

Ethical Review

Ethical approval was not required for this research.

Data availability statement- The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

Di Cagno, R., Coda, R., De Angelis, M., Gobbetti, M. (2013). Exploitation of vegetables and fruits through lactic acid fermentation. Food Microbiology, 33(1), 1–10. https://doi.org/10.1016/j.fm.2012.09.003

Engel, W., Bahr, W., Schieberle, P. (1999). Solvent assisted flavour evaporation: A new and versatile technique for the careful and direct isolation of aroma compounds from complex food matrices. European Food Research and Technology, 209(3), 237–241. https://doi.org/10.1007/s002170050486

Foss, K., Starowicz, M., Kłębukowska, L., Sawicki, T. (2023). Effect of lactic acid fermentation of red beetroot juice on volatile compounds profile and content. European Food Research and Technology, 249(9), 2401–2418. https://doi.org/10.1007/s00217-023-04304-y

Gänzle, M. G. (2015). Lactic metabolism revisited: Metabolism of lactic acid bacteria in food fermentations and food spoilage. Current Opinion in Food Science, 2, 106–117. https://doi.org/10.1016/j.cofs.2015.03.001

Georgiev, V. G., Weber, J., Kneschke, E. M., Denev, P. N., Bley, T., Pavlov, A. I. (2010). Antioxidant activity and phenolic content of betalain extracts from intact plants and hairy root cultures of the red beetroot Beta vulgaris cv. Detroit Dark Red. Plant Foods for Human Nutrition, 65(2), 105–111. https://doi.org/10.1007/s11130-010-0156-6

Grönroos, R., Eggertsen, R., Bernhardsson, S., Björk, M. P. (2024). Effects of beetroot juice on blood pressure in hypertension according to European Society of Hypertension Guidelines: A systematic review and meta-analysis. Nutrition, Metabolism and Cardiovascular Diseases, 34(10), 2240–2256. https://doi.org/10.1016/j.numecd.2024.06.009

Jakubczyk, K., Melkis, K., Janda-Milczarek, K., Skonieczna-Żydecka, K. (2023). Phenolic compounds and antioxidant properties of fermented beetroot juices enriched with different additives. Foods, 13(1), 102. https://doi.org/10.3390/foods13010102

Kırlangıç, O., Ilgaz, C., Kadiroğlu, P. (2021). Influence of pasteurization and storage conditions on microbiological quality and aroma profiles of shalgam. Food Bioscience, 44, 101350. https://doi.org/10.1016/j.fbio.2021.101350

Kumari, V. C., Huligere, S. S., Ramu, R., Naik Bajpe, S., Sreenivasa, M. Y., Silina, E., Stupin, V., Achar, R. R. (2022). Evaluation of probiotic and antidiabetic attributes of Lactobacillus strains isolated from fermented beetroot. Frontiers in Microbiology, 13, 911243. https://doi.org/10.3389/fmicb.2022.911243

Liu, S. Q., Holland, R., Crow, V. L. (2004). Esters and their biosynthesis in fermented dairy products: A review. International Dairy Journal, 14(11), 923–945. https://doi.org/10.1016/j.idairyj.2004.02.010

Marco, M. L., Heeney, D., Binda, S., Cifelli, C. J., Cotter, P. D., Foligné, B., Gänzle, M., Kort, R., Pasin, G., Pihlanto, A., Smid, E. J., Hutkins, R. (2017). Health benefits of fermented foods: Microbiota and beyond. Current Opinion in Biotechnology, 44, 94–102. https://doi.org/10.1016/j.copbio.2016.11.010

Neelwarne, B. (2012). Red beet: An overview. In B. Neelwarne (Ed.), Red Beet Biotechnology (pp. 1–43). Springer Science & Business Media. https://doi.org/10.1007/978-1-4614-3458-0_1

Nicolotti, C., Cirlini, M., Del Vecchio, L., Hadj Saadoun, J., Bernini, V., Gatti, M., Bottari, B., Martelli, F. (2025). Lactic acid fermentation of Chlorella vulgaris to improve the aroma of new microalgae-based foods: Impact of composition and bacterial growth on the volatile fraction. Foods, 14(9), 1511. https://doi.org/10.3390/foods14091511

Pico, J., Bernal, J., Gómez, M. (2015). Wheat bread aroma compounds in crumb and crust: A review. Food Research International, 75, 200–215. https://doi.org/10.1016/j.foodres.2015.05.051

Pozo-Bayón, M. A., G-Alegría, E., Polo, M. C., Tenorio, C., Martín-Álvarez, P. J., Calvo de la Banda, M. T., Ruiz-Larrea, F., Moreno-Arribas, M. V. (2005). Wine volatile and amino acid composition after malolactic fermentation: Effect of Oenococcus oeni and Lactobacillus plantarum starter cultures. Journal of Agricultural and Food Chemistry, 53(22), 8729–8735. https://doi.org/10.1021/jf050739y

Sevindik, O., Güçlü, G., Ağırman, B., Selli, S., Kadiroğlu, P., Bordiga, M., Capanoglu, E., Kelebek, H. (2022). Impacts of selected lactic acid bacteria strains on the aroma and bioactive compositions of fermented gilaburu (Viburnum opulus) juices. Food Chemistry, 378, 132079. https://doi.org/10.1016/j.foodchem.2022.132079

Smid, E. J., Kleerebezem, M. (2014). Production of aroma compounds in lactic fermentations. Annual Review of Food Science and Technology, 5(1), 313–326. https://doi.org/10.1146/annurev-food-030713-092339

Smit, G., Smit, B. A., Engels, W. J. (2005). Flavour formation by lactic acid bacteria and biochemical flavour profiling of cheese products. FEMS Microbiology Reviews, 29(3), 591–610. https://doi.org/10.1016/j.fmrre.2005.04.002

Stoica, F., Râpeanu, G., Rațu, R. N., Stănciuc, N., Croitoru, C., Țopa, D., Jităreanu, G. (2025). Red beetroot and its by-products: A comprehensive review of phytochemicals, extraction methods, health benefits, and applications. Agriculture, 15(3), 270. https://doi.org/10.3390/agriculture15030270

Tanguler, H., Selli, S., Sen, K., Cabaroglu, T., Erten, H. (2017). Aroma composition of shalgam: A traditional Turkish lactic acid fermented beverage. Journal of Food Science and Technology, 54(7), 2011–2019. https://doi.org/10.1007/s13197-017-2637-1

Wang, D., Deng, Y., Chen, X., Wang, K., Zhao, L., Wang, Z., Liu, X., Hu, Z. (2023). Elucidating the effects of Lactobacillus plantarum fermentation on the aroma profiles of pasteurized litchi juice using multi-scale molecular sensory science. Current Research in Food Science, 6, 100481. https://doi.org/10.1016/j.crfs.2023.100481

Zabat, M. A., Sano, W. H., Wurster, J. I., Cabral, D. J., Belenky, P. (2018). Microbial community analysis of sauerkraut fermentation reveals a stable and rapidly established community. Foods, 7(5), 77. https://doi.org/10.3390/foods7050077