REVIEW
e-ISSN: 2757-8836
J. Raw Mater. Process. Foods vol.7(1) (2026) 13-39

Recieved: 13/03/2026 Revised: 18/04/2026 Accepted article published: 08/05/2026 Published online: 30/06/2026

Traditional Fermented Foods and Beverages as Sources of Flavor Innovation: Current Trends and Consumer Perspectives

Mehmet Turan AYSELI[1]*

1 Genetris Consulting, Mersin, Türkiye
*Correspondence;
M. T. AYSELI
E-mail adress: tayseli@genetris.com
ORCID No: 0000-0002-4196-1348

DOI: https://doi.org/10.57252/jrpfoods.2026.2

Abstract

Traditional fermented foods and beverages (TFFBs) have gained renewed global interest owing to their distinctive sensory characteristics, clean-label image, and perceived health benefits. At the same time, consumer preferences have shifted from simple flavor profiles toward more complex, authentic, and fermentation-derived sensory experiences. TFFBs are attracting increasing attention, particularly among younger consumers, because of their umami-rich and complex flavor profiles exemplified by products such as miso, doenjang, koji-based foods, and kombucha. Emerging flavor trends, including honey–miso, in which miso is blended with honey and incorporated into ice cream, confectionery, and snack products, further illustrate the expanding application of fermented ingredients in modern food formulations. Therefore, this review evaluates recent flavor trends in TFFBs and highlights the role of microbial fermentation in shaping contemporary consumer preferences. It also discusses the increasing demand for swicy (sweet–spicy), sweet–savory, fruity, and floral flavor combinations, which have promoted the incorporation of fermented ingredients into desserts, snacks, condiments, and beverages. The contribution of fermentation-derived metabolites, including volatile compounds and flavor precursors in representative products such as miso, doenjang, and kombucha, is also discussed. Collectively, these findings demonstrate that traditional fermentation continues to serve as an important source of flavor innovation while meeting evolving consumer expectations for natural, diverse, and sensory-rich food experiences.

Keywords: *Fermented foods, flavour, aroma compounds, consumer preferences*

1.INTRODUCTION

Consumers across the globe have become increasingly aware of the relationship between diet and wellness, resulting in a shift from simple and highly sweet flavor profiles toward more complex, authentic, and fermentation-derived sensory experiences (Ajibola, Hipolito, & Thomas, 2026).

This transition is associated with growing consumer interest in exploring novel culinary experiences and seeking products that provide greater sensory depth and satisfaction, which has encouraged food manufacturers to increasingly incorporate flavors derived from traditionally fermented products (Ayseli, 2023; Cvetan, 2025). As consumers seek more depth and nuance in food, the "swicy" trend has evolved into more complex variations such as "swangy" (spicy, sweet, and sour) and "swavory" (spicy, sweet, and salty/umami)(Dion, 2025). In particular, younger consumers, especially Generation Z, are becoming increasingly attracted to umami-rich, tangy, and intensely savory / aromatic flavor profiles commonly found in traditional fermented foods and beverages (TFFBs)(Hanlon et al., 2026). These products offer multi-layered sensory experiences that are difficult to replicate using conventional formulations, thereby creating perceptions of superior quality, authenticity, and craftsmanship among consumers.

Consumers today are more informed and conscientious about their food choices, seeking products with simple, understandable ingredients. This shift in consumer preference is compelling food and beverage manufacturers to reformulate products using clean label ingredients, which typically exclude artificial additives, preservatives, and colorants (Ayseli, 2023). Moreover, the growing incorporation of TFFBs as flavor-enhancing ingredients in diverse food products is closely associated with consumer perceptions of authenticity, gut health, functional value, and sustainable food traditions (X. Shi et al., 2026). This finding is consistent with a recent study showing that approximately 50% of consumers cite taste as the primary reason, while 35% cite health benefits for consuming fermented foods (Hanlon et al., 2026).

Although previous reviews have comprehensively summarized the nutritional, functional, microbiological, and health-related aspects of fermented foods and beverages, their flavor characteristics have generally been discussed from a product-specific or compositional perspective. In contrast, this review adopts a consumer-oriented approach by integrating recent flavor trends with the underlying flavor chemistry of traditional fermented foods and beverages. Particular emphasis is placed on the relationship between emerging sensory preferences, representative fermented products, and fermentation-derived aroma-active compounds, thereby providing a comprehensive overview of flavor innovation in this rapidly evolving field.

2. FLAVOUR TRENDS

TFFBs continue to attract considerable consumer interest due to their complex, multidimensional, and distinctive flavor profiles (Table 1). In recent years, evolving consumer preferences and the growing demand for authentic, clean-label, and sensory-rich food experiences have driven flavor innovation within this category. Between 2020 and 2026, several prominent flavor trends have emerged in TFFBs, including the increasing popularity of umami- and kokumi-rich flavor profiles, the growing demand for fruity and floral sensory attributes in fermented beverages, and the incorporation of fermented ingredients into sweet, sweet-savory, and dessert applications (Table 2).

2.1. Consumer Preference Shifts Toward Complex and Umami-Rich Flavors

Consumer taste preferences have shifted toward bold, complex, and plant-derived flavor experiences, including pungent, earthy, and fermented flavor profiles (such as aged cheese, kimchi, fish sauce, tempeh, and natto), as well as umami (such as soy sauce, miso, koji, and fermented shrimp juice) (Ayseli, 2023; Dhiman et al., 2025; Kim et al., 2020).

This trend is partly driven by the growing demand for authentic and naturally generated flavors that provide greater sensory complexity than conventional formulations. Microbial fermentation promotes the production of aroma-active compounds, including amino acids, organic acids, and umami peptides, which serve as important flavor contributors and precursors. In particular, microbially derived umami peptides have attracted increasing attention because of their cost-effective production and significant contribution to umami perception (Y. Fan et al., 2025).

Table 1 Comprehensive volatile and non-volatile compounds in traditional fermented foods and beverages

Compound	CAS No.	Flavor Descriptor	Typical Occurrence and Representative Primary Reference(s)	Origin / Microbial Source
Acids				
Acetic acid	64-19-7	Sharp, vinegar-like	Kombucha (Jayabalan et al., 2014), miso (Kaku et al., 2000; S. Wang et al., 2021), doenjang (Lee, Lee, Lee, & Kim, 2024), shalgam (Altay, Karbancioglu-Güler, Daskaya-Dikmen, & Heperkan, 2013), pickle juice (Hooper Marosek, Antharam, & Dowlatshahi, 2020), kefir (X. Li et al., 2023), Coffee cascara kombucha (Sales et al., 2023)	Produced by acetic acid bacteria (*Acetobacter* and *Komagataeibacter* spp.) via ethanol oxidation, as well as by heterofermentative lactic acid bacteria (*e.g.*, *Lactobacillus* spp.) through the phosphoketolase pathway during fermentation.
Butyric acid	107-92-6	Rancid, cheesy	Kimchi, kefir (X. Li et al., 2023), Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Produced primarily by *Clostridium spp.* through carbohydrate fermentation and by certain lactic acid bacteria via amino acid and carbohydrate metabolism during fermentation.
Citric acid	77-92-9	Sour, fresh, citrusy	Pixian Doubanjiang (PXDBJ)(Yang et al., 2020), miso (N. Xu et al., 2016)	Naturally present in raw materials and produced or metabolized through the tricarboxylic acid (TCA) cycle by yeasts, lactic acid bacteria, and filamentous fungi during fermentation
Decanoic acid	334-48-5	Soapy	Miso (JPRN-UMIN000051444, 2023)	Produced through microbial lipid hydrolysis and β-oxidation during fermentation.
Gluconic acid	526-95-4	Tart, clean	Kombucha (Kaewkod, Bovonsombut, & Tragoolpua, 2019)	Produced by acetic acid bacteria (mainly *Gluconobacter spp.*) through oxidation of glucose during fermentation.

Glutamic acid	56-86-0	Umami, savory	Miso (Tamura, Kirimura, Hara, & Sugimura, 1952), doenjang-guk (Yul Lee et al., 2024)	Released from raw plant/soybean proteins via proteolysis mediated by fungal proteases (*e.g.*, *Aspergillus oryzae*) and intracellular peptidases from lactic acid bacteria and yeasts during fermentation.
Hexanoic acid	142-62-1	Fatty, cheesy	Shalgam (Tanguler, Selli, Sen, Cabaroglu, & Erten, 2017)	Produced through fatty acid de novo synthesis and chain elongation pathways by yeasts and bacteria, as well as microbial lipid hydrolysis during fermentation.
Heptanoic acid	111-14-8	Rancid, fatty, cheesy	Shalgam (Tanguler et al., 2017)	Produced via microbial fatty acid metabolism, chain elongation, and enzymatic lipid hydrolysis during fermentation.
Isobutyric acid	79-31-2	Sweaty, cheesy	Fermented soy, natto (D. H. Wang et al., 2019), kombucha (Phung et al., 2023)	Produced through microbial catabolism of valine by *Bacillus* spp., yeasts, and lactic acid bacteria during fermentation.
Lactic acid	50-21-5	Smooth, sour	Kombucha (Jannah, Wakiah, Sandi, Islamawan, & Wulan, 2025), miso (N. Xu et al., 2016), pickle juice, fermented apple juice (J. R. Liang, Deng, Hu, Zhao, & Meng, 2022), kefir (X. Li et al., 2023)	Produced primarily by lactic acid bacteria through carbohydrate fermentation (glycolysis) during fermentation.
Malic acid	6915-15-7	Sour, tart, fruity	Kefir (X. Li et al., 2023), Pixian Doubanjiang (PXDBJ)(Yang et al., 2020)	Naturally present in plant materials and modified during fermentation through microbial metabolism of carbohydrates and the tricarboxylic acid (TCA) cycle by yeasts and lactic acid bacteria.
Octanoic acid	124-07-2	Fatty, rancid	Kombucha (Sales et al., 2023), Coffee cascara kombucha (Sales et al., 2023)	Produced by yeasts (*e.g.*, *Saccharomyces cerevisiae*) during fatty acid synthesis and incomplete esterification, as well as microbial lipid hydrolysis during fermentation.

Pentanoic acid	109-52-4	Cheesy, rancid, sweaty	Shalgam (Tanguler et al., 2017)	Produced through microbial β-oxidation of fatty acids and amino acid catabolism during fermentation.
Succinic acid	110-15-6	Acidic, salty	Soy sauce, miso, kefir (X. Li et al., 2023)	Produced through the tricarboxylic acid (TCA) cycle by yeasts and certain lactic acid bacteria during fermentation.
Tartaric acid	87-69-4	Sour, tart, astringent	Kefir (X. Li et al., 2023),Kombucha, fermented orange vinegar, grape-based fermented beverages (Leal, Suárez, Jayabalan, Oros, & Escalante-Aburto, 2018; Sanwal et al., 2023)	Naturally abundant in grapes and other fruits; retained or concentrated during fermentation and may be partially metabolized by certain lactic acid bacteria and acetic acid bacteria, contributing to the sour taste and overall acidity of fermented beverages.
2-methylbutanoic acid	116-53-0	Cheesy, sweaty, rancid, fruity	Pixian douban (Lu & He, 2021)	Produced through microbial catabolism of isoleucine during fermentation, primarily by *Bacillus* spp. and yeasts, contributing to the characteristic matured aroma
3-methylbutanoic acid	503-74-2	Cheesy, sweaty, rancid, malty	Kombucha (Sales et al., 2023), Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Produced through microbial catabolism of leucine by yeasts, lactic acid bacteria, and *Bacillus* spp. during fermentation.
Aldehydes				
Benzaldehyde	100-52-7	Almond-like	Miso (S. Wang et al., 2021), Doenjang-guk (Yul Lee et al., 2024) kombucha (Marsh et al., 2014)	Formed through microbial catabolism of phenylalanine via the Ehrlich pathway, Strecker degradation, and Maillard reactions during fermentation.
Citral	5392-40-5	Lemon, citrus, fresh	Finger citron kombucha (Y. Xu et al., 2024), pickle juice (A. Fan et al., 2015)	Naturally present as a major monoterpene in botanical raw materials (*e.g.*, finger citron, lemongrass); retained, biotransformed, or partially degraded by yeasts and acetic acid bacteria (*Gluconobacter* spp.) during fermentation.

Decanal	112-31-2	Orange-like	Kombucha (Sales et al., 2023), fermented Sichuan pickle (M. Shi et al., 2023)	Formed via enzymatic lipid cleavage and oxidative degradation of unsaturated fatty acids (primarily oleic and linoleic acids) during fermentation and matrix aging.
(E, E)-2,4-decadienal	25152-84-5	Fried, fatty, deep-fried, green	Kimchi (Cha, Kim, & Cadwallader, 1998), miso	Formed mainly via lipid oxidation, particularly of linoleic acid
(E, Z)-2,6-nonadienal	557-48-2	Cucumber-like, green, fresh, fatty	Kimchi (Cha et al., 1998), Pickle juice (Tong et al., 2026)	Formed primarily via lipid oxidation of polyunsaturated fatty acids (e.g., linoleic acid)
(E)-2-Nonenal	18829-55-5	Cucumber-like, fatty, green	Pickle juice (Tong et al., 2026)	Formed mainly via lipid oxidation (especially of unsaturated fatty acids) during fermentation and storage; detected in aged beverages, rice milk, and cucumber
Furfural	98-01-1	Sweet, caramel, bready	Doenjang-guk (Yul Lee et al., 2024), Pixian douban (Lu & He, 2021)	Formed through carbohydrate degradation, Maillard reactions, and thermal dehydration of pentoses during fermentation and heat processing.
Hexanal	66-25-1	Green, grassy	Kombucha, kimchi (Seo, You, & Baek, 2024), Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Formed through oxidative degradation of unsaturated fatty acids, particularly linoleic acid, during microbial lipid oxidation and fermentation.
Heptanal	111-71-7	Fatty, green	Fish-based miso (Giri, Osako, & Ohshima, 2010)	Formed through the oxidative cleavage of 9-hydroperoxides derived from unsaturated fatty acids (*e.g.*, oleic acid) via microbial lipid degradation and auto-oxidation during fermentation.
Nonanal	124-19-6	Fatty, citrus	Kimchi, miso, Kombucha (Sales et al., 2023), Pickle juice (Tong et al., 2026), Coffee cascara kombucha (Sales et al., 2023),	Formed through the oxidative cleavage of 9-hydroperoxides derived from unsaturated fatty acids (*e.g.*, oleic acid) via microbial lipid degradation and

			fermented Sichuan pickle (M. Shi et al., 2023)	auto-oxidation during fermentation.
Octanal	124-13-0	Citrus, fruity	Kombucha (Sales et al., 2023), fermented Sichuan pickle (M. Shi et al., 2023)	Formed via enzymatic lipid cleavage and oxidative degradation of unsaturated fatty acids (primarily oleic and linoleic acids) during fermentation and matrix aging.
Phenylacetaldehyde	122-78-1	Floral, sweet, honeysuckle-like	Miso (S. Wang et al., 2021), rice milk, soy milk, pistachio milk, and Kimchi (Cha et al., 1998), Coffee cascara kombucha (Sales et al., 2023)	Formed through microbial catabolism of phenylalanine via the Ehrlich pathway and Strecker degradation during fermentation.
(Z)-3-hexenal	6789-80-6	Green, grassy	Kimchi (Seo et al., 2024)	Formed through lipoxygenase-mediated oxidation of polyunsaturated fatty acids, particularly linolenic acid, during fermentation.
2-Methylbutanal	96-17-3	Malty, nutty, cocoa-like, fruity	Miso (S. Wang et al., 2021), Fish-based miso (Giri, Osako, et al., 2010), kimchi, soy sauce, Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Formed through microbial catabolism of isoleucine via transamination and decarboxylation steps of the Ehrlich pathway, as well as Strecker degradation during fermentation
2-Methylpropanal	78-84-2	Malty, cocoa-like, nutty, chocolate-like	Horse mackerel miso (Giri, Okamoto, et al., 2010)	Formed via microbial catabolism of valine through the Ehrlich pathway, as well as Strecker degradation and thermal Maillard reactions during processing and fermentation.
3-Methylbutanal	590-86-3	Malty, cocoa-like, chocolatey, nutty	Miso (Giri, Okamoto, et al., 2010), Fish-based miso (Giri, Osako, et al., 2010), Doenjang-guk (Yul Lee et al., 2024)(Jo et al., 2011)	Produced via microbial catabolism of leucine through the Ehrlich pathway by yeasts, lactic acid bacteria, and *Bacillus* species, supplemented by Strecker degradation.
5-Methyl-2-furaldehyde	620-02-0	Caramel, sweet, roasted,bready	Miso (Dutta, De, Saha, & Alam, 2012)	Formed via Maillard reaction and sugar degradation; present in fermented beverages (beer, sake), roasted or cooked plant-based ferments.

Alcohols				
Citronellol	106-22-9	Rose-like	lychee kefir (Chen et al., 2025), rose fermented beverage (Zhou et al., 2025), fermented apple juice (H. Li et al., 2021), pickle juice (A. Fan et al., 2015)	Naturally present in botanical raw materials; released from glycosidically bound precursors through enzymatic hydrolysis (mediated by microbial β-glucosidases) and biotransformed from geraniol/neral by yeasts and lactic acid bacteria during fermentation.
Geraniol	106-24-1	Floral, citrus	Finger citron kombucha (Y. Xu et al., 2024),	Naturally present in botanical raw materials; liberated from bound glycosides via microbial β-glucosidase activity and biotransformed through enzymatic isomerization by yeasts and acetic acid bacteria during fermentation.
Isoamyl alcohol	123-51-3	Whiskey-like	Miso (S. Wang et al., 2021), Shalgam (Tanguler et al., 2017), Coffee cascara kombucha (Sales et al., 2023)	Produced through the Ehrlich pathway via transamination, decarboxylation, and reduction of leucine (or de novo via α-ketoisocaproate) primarily by yeasts during fermentation.
Linalool	78-70-6	Floral, citrus	Finger citron kombucha (Y. Xu et al., 2024), Kimchi (Cha et al., 1998), Pickle juice (Tong et al., 2026), Coffee cascara kombucha (Sales et al., 2023)	Naturally present in finger citron (*Citrus medica* var. *sarcodactylis*); retained and partially transformed during fermentation by acetic acid bacteria (*Gluconobacter* spp.) and yeasts.
1-Butanol	71-36-3	Alcoholic, sweet, slightly woody or fruity	Shalgam (Tanguler et al., 2017), Miso (Lee et al., 2024)	Produced by yeasts and certain lactic acid bacteria through carbohydrate fermentation and amino acid metabolism
1-Hexanol	111-27-3	Leafy, green	Miso (Lee et al., 2024), Fish-based Miso (Giri, Osako, et al., 2010)	Formed mainly through enzymatic oxidation of unsaturated fatty acids and lipid degradation during fermentation
1-Heptanol	111-70-6	Fatty, floral, slightly green or citrusy	Fish-based Miso (Giri, Osako, et al., 2010)	Produced through microbial metabolism of fatty acids and lipid-derived aldehydes during fermentation

1-Nonanol	143-08-8	Fatty, citrusy, floral, slightly waxy	Shalgam (Tanguler et al., 2017)	Produced via microbial reduction of lipid-derived aldehydes (nonanal/octanal) catalyzed by alcohol dehydrogenases (ADH) during fermentation.
1-Octanol	111-87-5	Fatty, waxy, citrusy, slightly floral	Shalgam (Tanguler et al., 2017)	Produced via microbial reduction of lipid-derived aldehydes (nonanal/octanal) catalyzed by alcohol dehydrogenases (ADH) during fermentation.
1-Octen-3-ol	3391-86-4	Mushroom, earthy	Miso (Lee et al., 2024), Fish-based Miso (Giri, Osako, et al., 2010)	Generated through fungal lipoxygenase- and hydroperoxide lyase-mediated cleavage of linoleic acid during koji or solid-state fermentation (*e.g.*, by *Aspergillus oryzae*).
1-Propanol	71-23-8	Alcoholic	Shalgam (Tanguler et al., 2017)	Produced during microbial fermentation through amino acid catabolism and carbohydrate metabolism.
2-Butanol	78-92-2	Alcoholic, sweet, solvent-like, fruity	Shalgam (Tanguler et al., 2017)	Produced by microbial reduction of 2-butanone during fermentation by yeasts and certain bacteria.
2-Methyl-1-butanol	137-32-6	Malty, alcoholic, whiskey-like, fruity	Pixian douban (Lu & He, 2021)	Produced through microbial catabolism of isoleucine via the Ehrlich pathway (or de novo carbohydrate synthesis via α-keto-β-methylvalerate) primarily by yeasts during fermentation.
6-Methyl-5-hepten-2-ol	1569-60-4	Green, citrus, floral	Shalgam (Tanguler et al., 2017)	Formed through enzymatic degradation of carotenoids and terpenoid metabolism during fermentation.
2-Phenylethanol	60-12-8	Rose, honey	Miso (Kaku et al., 2000; S. Wang et al., 2021)., Shalgam (Tanguler et al., 2017), kombucha (Marsh et al., 2014)	Produced from phenylalanine via the Ehrlich pathway by yeasts and some lactic acid bacteria during fermentation.

Ketones				
Acetoin	513-86-0	Buttery	Miso (Lee et al., 2024), Fish-based Miso (Giri, Osako, et al., 2010), Horse mackerel miso (Giri, Okamoto, et al., 2010), fermented Sichuan pickle (M. Shi et al., 2023)	Produced primarily by lactic acid bacteria (*e.g.*, *Lactococcus*, *Leuconostoc* spp.) via pyruvate catabolism and citrate metabolism through α-acetolactate decarboxylation, as well as the reversible enzymatic reduction of diacetyl.
β-Ionone	79-77-6	Floral, woody	Pickle juice (Tong et al., 2026)	ormed via enzymatic oxidative cleavage of β-carotene catalyzed by microbial carotenoid cleavage dioxygenases (CCDs) or non-enzymatic auto-oxidation during fermentation.
β-Damascenone	23726-93-4	Floral, fruity, rose-like, honey, apple	Coffee cascara kombucha (Sales et al., 2023)	Formed through acid-catalyzed degradation of allenic carotenoid precursors (such as neoxanthin) and microbial β-glucosidase hydrolysis of glycosidic precursors during fermentation and aging.
Diacetyl (2,3-butanedione)	431-03-8	Buttery, creamy	Miso, soy milk, Kimchi (Cha et al., 1998)	Produced primarily by lactic acid bacteria through pyruvate and citrate metabolism via spontaneous oxidative decarboxylation of α-acetolactate during fermentation.
Geranyl acetone	3796-70-1	Floral, citrus, green, fruity	Coffee cascara kombucha (Sales et al., 2023)	Formed through oxidative degradation of open-chain carotenoids (*e.g.*, phytoene, lycopene) or terpene catabolism, mediated by microbial oxidative enzymes during fermentation.
2-Heptanone	110-43-0	Fruity, cheese-like	Cheonggukjang (Lee et al., 2024)	Formed via microbial β-oxidation of free fatty acids followed by decarboxylation of β-ketoacids, catalyzed primarily by fungal and bacterial lipases/decarboxylases during fermentation.

2-Butanone	78-93-3	Sweet, solvent-like	Cheonggukjang (Lee et al., 2024)	Produced through microbial catabolism of 2,3-butanediol or via acetoacetate decarboxylation by yeasts and bacteria during carbohydrate fermentation.
2,3-Pentanedione	600-14-6	Butter, caramel	Miso (Kumazawa, Kaneko, & Nishimura, 2013)	Produced by lactic acid bacteria through amino acid and pyruvate metabolism via spontaneous oxidative decarboxylation of α-acetohydroxybutyrate during fermentation.
3-Octanone	106-68-3	Fruity	Miso (S. Wang et al., 2021)	Produced through lipoxygenase-mediated oxidative degradation of unsaturated fatty acids (predominantly linoleic acid) by fungi and bacteria during fermentation.
Phenols and Polyphenols				
Acetovanillone	498-02-2	Vanilla-like, sweet, smoky, phenolic	Shalgam (Tanguler et al., 2017)	Formed through microbial biotransformation and oxidative degradation of ferulic acid and lignin-derived phenolic intermediates by yeasts and lactic acid bacteria during fermentation.
Daidzein	486-66-8	Bitter, astringent, mild beany	Fermented soy products such as soy milk, doenjang-guk and miso (Kaufman, Duke, Brielmann, Boik, & Hoyt, 1997)	Liberated from its glycoside precursor (daidzin) through enzymatic cleavage by microbial β-glucosidases produced by filamentous fungi (*e.g.*, *Aspergillus oryzae*), yeasts, and lactic acid bacteria during fermentation.
Eugenol	97-53-0	Clove, spice	Cinnamon enriched kombucha (Tamer, Özkan Karabacak, & Durgut Malçok, 2025), Shalgam (Tanguler et al., 2017)	Naturally present in botanical spices (*e.g.*, cinnamon, clove); released from bound glycosidic precursors via microbial hydrolysis and partially transformed by yeasts and acetic acid bacteria during fermentation.

Guaiacol	90-05-1	Smoky, medicinal	Pixian douban (Lu & He, 2021), Sesame flavoured baijiu (Deng et al., 2024)	Produced through microbial decarboxylation of ferulic acid to p-vinylguaiacol followed by demethylation/dealkylation, as well as thermal degradation of lignin derivatives during fermentation and thermal processing.
Genistein	446-72-0	Bitter, astringent, mild beany	Fermented soy products such as soy milk, soy sauce, doenjang-guk, natto, tempeh and miso (Kaufman et al., 1997)	Released from its glycosidic form (genistin) via microbial β-glucosidase-mediated hydrolysis during fermentation, leading to enhanced bioavailability and modified matrix interactions.
Propiovanillone	1835-14-9	Sweet, vanilla-like, smoky, phenolic	Shalgam (Tanguler et al., 2017)	Produced via microbial degradation and biotransformation of phenylpropanoid precursors and lignin-derived phenolic intermediates during fermentation.
p-Vinyl guaiacol	7786-61-0	Clove-like, smoky, spicy, phenolic	Shalgam (Tanguler et al., 2017)	Formed through non-oxidative decarboxylation of ferulic acid catalyzed by phenolic acid decarboxylase (PAD) expressed by yeasts (*e.g.*, *Saccharomyces cerevisiae*) and lactic acid bacteria.
3-Methylacetophenone	585-74-0	Sweet, floral, almond-like, fruity	Shalgam (Tanguler et al., 2017)	Formed via microbial metabolism of aromatic amino acids (*e.g.*, phenylalanine) and secondary biotransformation of phenylpropanoid-derived intermediates during fermentation.
4-Vinylphenol	2628-17-3	Sweet, floral	Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Formed through microbial decarboxylation of *p*-coumaric acid by phenolic acid decarboxylase during fermentation.
4-Ethylphenol	123-07-9	Smoky, earthy	Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Formed via microbial decarboxylation of p-coumaric acid catalyzed by phenolic acid decarboxylase (PAD) from yeasts and lactic acid bacteria during fermentation.

Esters				
Ethyl acetate	141-78-6	Fruity, solvent-like	Horse mackerel miso (Giri, Okamoto, et al., 2010), Pixian douban (Lu & He, 2021),Coffee cascara kombucha (Sales et al., 2023)	Produced by yeasts through enzymatic esterification of ethanol and acetic acid via alcohol acetyltransferases during fermentation.
Ethyl butyrate	105-54-4	Fruity, pineapple	Coffee cascara kombucha (Sales et al., 2023)	Produced by yeasts and bacteria through enzymatic condensation of butyryl-CoA and ethanol, or via esterase-catalyzed esterification during fermentation.
Ethyl decanoate	110-38-3	Fruity, floral, grape-like	Horse mackerel miso (Giri, Okamoto, et al., 2010)	Produced by yeasts through acyl-CoA:ethanol O-acyltransferase-catalyzed condensation of decanoyl-CoA and ethanol during fermentation.
Ethyl hexanoate	123-66-0	Apple, pineapple	Fish-based miso (Giri, Osako, et al., 2010)	Produced primarily by yeasts through acyl-CoA:ethanol O-acyltransferase-catalyzed condensation of hexanoyl-CoA and ethanol during fermentation.
Ethyl heptanoate	106-30-9	Fruity, pineapple-like, sweet, wine-like	Horse mackerel miso (Giri, Okamoto, et al., 2010)	Produced through yeast-mediated condensation of heptanoyl-CoA and ethanol or esterase-catalyzed biotransformation during fermentation.
Ethyl octanoate	106-32-1	Fruity, floral	Shalgam (Tanguler et al., 2017)	Produced primarily by yeasts through acyl-CoA:ethanol O-acyltransferase-catalyzed condensation of octanoyl-CoA and ethanol during fermentation.
Ethyl propionate	105-37-3	Fruity, pineapple-like, sweet	Shalgam (Tanguler et al., 2017)	Produced by yeasts through enzymatic condensation of propionyl-CoA and ethanol or esterase activity during fermentation.

Isoamyl acetate	123-92-2	Banana-like	Fish-based miso (Giri, Osako, et al., 2010)	Produced primarily by yeasts through alcohol acetyltransferase-catalyzed esterification of isoamyl alcohol and acetyl-CoA during fermentation.
Sulfur compounds				
Allyl methyl trisulfide (AMTS)	34135-85-8	Garlic-like, onion-like, sulfurous, pungent, savory	Kimchi (Seo et al., 2024)	Formed from the enzymatic degradation of sulfur-containing compounds in *Allium* vegetables (e.g., garlic and onion) during fermentation and subsequent oxidation/rearrangement of allyl sulfur intermediates.
Dimethyl Sulfide (DMS)	75-18-3	Sulfurous, cooked vegetable	Doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011)	Produced during microbial metabolism of sulfur-containing amino acids (e.g., methionine) and degradation of S-methylmethionine
Dimethyl disulfide (DMDS)	624-92-0	Garlic, onion-like	Fish-based miso (Giri, Osako, et al., 2010),fermented Sichuan pickle (M. Shi et al., 2023)	Formed via microbial degradation of methionine to methanethiol, followed by air oxidation and dimerisation during fermentation.
Diallyl disulfide (DADS)	2179-57-9	Garlic-like, pungent, savory	Kimchi (Cha et al., 1998)	Formed primarily from alliin in garlic and other Allium species via enzymatic cleavage (alliinase)
Dimethyl trisulfide (DMTS)	3658-80-8	Pungent	Kimchi (Cha et al., 1998; Seo et al., 2024), Pickle juice (Tong et al., 2026), Horse mackerel miso (Giri, Okamoto, et al., 2010), fermented Sichuan pickle (M. Shi et al., 2023)	Formed via microbial degradation of methionine to methanethiol, followed by oxidative coupling and reaction with hydrogen sulfide or elemental sulfur during fermentation.
Diallyl trisulfide (DATS)	2050-87-5	Garlic-like, pungent, savory, slightly sweet	Kimchi (Cha et al., 1998)	Formed from the enzymatic degradation of allicin and other sulfur-containing compounds in Allium vegetables

Dimethyl tetrasulfide (DMTTS)	5756-24-1	Sulfurous, garlic-like, cooked cabbage, onion-like	Kimchi (Seo et al., 2024)	Formed through microbial degradation of methionine into methanethiol and subsequent oxidative condensation with hydrogen sulfide and sulfur species during fermentation.
Methional (3-(methylsulfanyl)propanal)	3268-49-3	Boiled potato, cooked cabbage, onion-like, savory, meaty	Pixian douban (Lu & He, 2021), miso (S. Wang et al., 2021), Fish-based miso (Giri, Osako, et al., 2010), Horse mackerel miso (Giri, Okamoto, Okazaki, & Ohshima, 2010), doenjang and fermented soybean paste (Lee et al., 2024), kimchi (Cha et al., 1998) and other protein-rich fermented foods	Formed through the microbial degradation of methionine and cysteine via methanethiol condensation with C1 metabolic intermediates and subsequent oxidation during fermentation.
Methyl allyl disulfide (MADS)	719-59-9	Garlic-like, oniony, pungent, savory	Kimchi (Cha et al., 1998)	Formed from enzymatic degradation of sulfur-containing compounds in Allium vegetables (e.g., garlic, onion) during fermentation; found in fermented garlic, onion, and other sulfur-rich vegetable ferments.
Methyl (methylthio)methyl disulfide	42474-44-2	Sulfurous, garlic-like, cabbage-like, onion-like	Kimchi (Seo et al., 2024)	Formed through microbial metabolism of sulfur-containing amino acids (primarily methionine and cysteine) during fermentation and subsequent oxidation of volatile sulfur intermediates.

Table 2. *Major flavor trends and representative products in traditional fermented foods and beverages (2020–2026).*

Flavor Trend	**Representative Products**	**Consumer Appeal / Key Drivers**
	Miso & Doenjang: Fermented soybean pastes are transcending traditional soups. Chefs and manufacturers are using them in	Increasing demand for savory, deep, and complex flavor experiences

Complex Umami & Deep Earthiness	glazes, marinades, and even desserts to add savory depth **Koji-fermentation:** Used as a base for marinades and alternative protein products to mimic the savory, meaty notes of traditional dishes	
Kokumi and Mouthfulness	Long-ripened miso, aged cheeses, fermented bean pastes	Enhanced mouthfeel, continuity, richness, and flavor persistence
Plant-Based Savory Flavors	Tempeh, natto, koji-fermented products, fermented legumes	Growth of plant-based diets and demand for natural flavor enhancement
Fermented Vegetables and Condiments	Kimchi, sauerkraut, fermented lemon, pickles	Desire for authentic, tangy, and culturally distinctive flavors
Culinary Fermentation Innovations	Koji-cured vegetables, smoked miso caramel, fermented sauces, umami-enriched vegan broths	Fusion cuisine, premium gastronomy, and novel sensory experiences
Swicy (Sweet + Heat) & Bold Spices	Miso chocolate, soy sauce caramel, fermented honey, traditional Asian fermented pastes (*gochujang, doubanjiang),* fermented hot sauces (Sriracha, harissa, and fermented	Growing interest in sweet–savory flavor combinations and artisanal products

	jalapeños), swicy snacks (honey or chili crisps paired with fermented tang)	
Fermented Beverages	Kombucha, kefir, coffee, tea, fruit vinegars, fermented fruit beverages such as tepache	Preference for refreshing, natural, fruity, and functional beverages (sport performance beverage, enery-boosting drink, cognitive-enhancing beverage, detoxification tonics)

Beyond traditional applications, koji-based ingredients are increasingly incorporated into snacks, condiments, and emerging fermented products, reflecting the growing consumer appreciation for fermentation-derived umami flavors. One example is fermented shrimp juice, commonly referred to as shrimp oil, a fermented extract derived from fresh shrimp. During koji-assisted fermentation, enzymatic hydrolysis and microbial metabolism enhance the formation of amino acids, esters, alcohols, and sulfur-containing compounds, thereby increasing flavor complexity and umami intensity. These flavor characteristics have contributed to the increasing consumer and industrial interest in fermented shrimp products as novel umami-rich ingredients (W. Liang et al., 2025). This trend is further reflected in a variety of culinary applications, including koji-cured vegetables with mushroom-like depth, smoked miso caramel used in desserts, and umami-enriched vegan broths such as ramen (An et al., 2023).

2.1.1 Miso

Among these umami-rich fermented products, miso represents one of the best examples of how microbial fermentation generates aroma-active compounds that shape contemporary consumer preferences. Miso is a traditional and widely consumed Japanese fermented soybean paste produced by fermenting soybeans with salt and koji (steamed rice inoculated with Aspergillus oryzae). The growing global popularity of miso is closely associated with the increasing consumer demand for umami-rich, complex, and authentic flavor experiences (Inoue et al., 2016). Beyond its traditional applications in soups and sauces, miso is increasingly incorporated into plant-based foods, gourmet sauces, marinades, and even confectionery and bakery products. The primary driver of this growing interest is its unique combination of savory, roasted, floral, earthy, and buttery aroma notes generated during fermentation, which provide the flavor depth and complexity increasingly sought by modern consumers (Cvetan, 2025).

Yeast and Lactic Acid Bacteria (LAB) contribute to the characteristic flavor of miso by producing a wide range of volatile compounds, some of which have been identified as key aroma-active compounds. The predominant aroma-active aldehydes include 2-methylbutanal (malty, chocolate), 3-methylbutanal (malty, cocoa), phenylacetaldehyde (floral, honey-like), benzaldehyde (almond-like), 3-methylthiopropanal (musty, cabbage), and 3-methylsulfanylpropanal (sulfurous). Alcohols constitute the second major group of aroma-active compounds, with 2-phenylethanol (rose), 3-methyl-1-butanol (malty), and 3-methylsulfanylpropan-1-ol (cooked potato) being the most important contributors. Furthermore, 3-Methyl-1-butanol and 2-phenylethanol are quantitatively the main aroma-active compounds in salty red rice miso (Kaku, Sugawara, & Takahashi, 2000).

Sulfur compounds contribute to the characteristic sulfurous and savory notes of miso and originate from both the raw materials and biochemical reactions occurring during fermentation. Among them, methional (3-methylsulfanylpropanal) is produced from methionine through Strecker degradation under the reducing conditions of fermentation (S. Wang et al., 2021).

Diacetyl (2,3-butanedione) is a diketone that imparts a characteristic buttery aroma and creamy mouthfeel. 1-Octen-3-one is associated with mushroom-like and earthy notes and is mainly formed through the oxidation of linoleic acid. During heat processing, the concentrations of 1-octen-3-one and 3-octanone decrease in the presence of amino acids, contributing to changes in the characteristic flavor of miso (S. Wang et al., 2021). Esters also play an important role in the aroma profile of miso. Among them, 2-phenylethyl acetate provides distinctive floral and sweet notes and is formed through the esterification of acetic acid and 2-phenylethanol, whereas ethyl acetate contributes pleasant fruity characteristics (Kaku et al., 2000; S. Wang et al., 2021).

Collectively, these aroma-active compounds contribute to the distinctive sensory characteristics of miso, including umami intensity, flavor complexity, and mouthfulness, supporting its increasing use in modern culinary applications.

2.1.2 Doenjang-guk

Doenjang-guk is a traditional Korean soup prepared with fermented soybean paste (doenjang), which is produced by fermenting soybeans with salt using naturally occurring microorganisms, together with vegetables such as spinach, zucchini, mushrooms, seaweed, tofu, and garlic (Kang, Hwang, & Kim, 2026). The growing consumer acceptance of doenjang has stimulated increasing research into the aroma-active compounds responsible for its characteristic sensory profile. Similar to miso, the increasing popularity of doenjang-based products reflects growing consumer demand for deeply savory, earthy, and fermented flavor profiles. Its characteristic combination of roasted, smoky, nutty, sulfurous, and umami-related aroma notes provides the sensory complexity increasingly valued in both traditional and contemporary gastronomy (Kang et al., 2026).

Previous studies have shown that the flavor profile of doenjang-guk is dominated by pyrazines, phenols, organic acids, furans, sulfur-containing compounds, and aldehydes) (Jo, Cho, Song, Shin & Kim, 2011). Major aroma-active compounds include 2-ethyl-5-methylpyrazine and 2,3-dimethylpyrazine (roasted), butanoic acid, acetic acid, 2-methylbutanoic acid, and 3-methylbutanoic acid (acidic and cheesy), dimethyl disulfide (sulfurous), 4-vinylphenol (4-VP) and 4-ethylphenol (4-EP) (phenolic), hexanal, 2-methylbutanal, 3-methylbutanal (malty and green), and the furan derivatives dihydro-5-methyl-2(3H)-furanone and 2-pentylfuran, which collectively contribute to the characteristic roasted, savory, and fermented flavor of doenjang-guk (Jo, Cho, Song, Shin & Kim, 2011). Among these compounds, 4-ethylphenol (4-EP) is formed through the microbial decarboxylation and subsequent reduction of p-coumaric acid, while short-chain organic acids, including acetic, 2-methylbutanoic, and 3-methylbutanoic acids, are key contributors to flavor development in doenjang produced with bacterial starter cultures (Jo et al., 2011; Kheir, Salameh, Strehaiano, Brandam,2013).

Fermentation enzymes modify the structure of polysaccharides (pectin, cellulose, and hemicellulose) and proteins derived from soybeans through enzymes. These structural changes enhance the water-binding capacity, viscosity, and gel-forming properties of doenjang-guk, resulting in the characteristic texture and mouthfeel valued by consumers. Additionally, oligosaccharides and bioactive peptides are released during fermentation, leading to improved digestibility. Therefore, the relationship between microbial enzymes and native hydrocolloids during fermentation plays an essential role in improving the textural properties of TFFBs without the need for synthetic additives, further supporting their development as functional foods (Choi, Lee, & Kim, 2018).

Collectively, these sensory and textural characteristics have supported the increasing incorporation of doenjang-guk and related fermented soybean products into contemporary food formulations as natural flavor-enhancing ingredients.

2.2. Fruity, Floral, Botanical, and Mushroom-Based Fermented Beverages

Recently, consumers have shown increasing interest in refreshing, fruity, floral, and citrus-like flavor profiles, particularly in functional and fermented beverages. This trend is driven by the demand for lighter sensory experiences, natural ingredients, and products perceived as healthier alternatives to conventional soft drinks (Reinoso, 2026).

Lactic acid bacteria (LAB) such as Lactiplantibacillus plantarum play an important role in shaping these sensory attributes through the production of aroma-active compounds such as esters, aldehydes, alcohols, and organic acids. Compounds such as linalool contribute floral and citrus notes, whereas esters and alcohols provide fruity and sweet characteristics. The growing popularity of non-alcoholic craft beverages has further stimulated the use of traditional microbial fermentation with fruits such as blackcurrant and tropical botanicals to create balanced fruity and acidic flavor profiles. Similarly, tepache, a traditional Mexican fermented beverage prepared from pineapple or orange peels, piloncillo sugar, cinnamon, and cloves, has recently attracted increasing consumer interest (Karim, Jumadi, Hartati, Arsal, & Suryani, 2024).

Fermented drinks like kombucha and botanical vinegars increasingly incorporate floral notes like hibiscus, rose, and elderflower. Likewise, products such as kombucha, natural vinegars, and fermented citrus fruits (such as preserved lemon or fermented yuzu) have gained popularity due to their fresh, tangy, and aromatically complex flavor profiles. The popularity of kombucha is further supported by growing consumer interest in gut health, digestive wellness, and functional beverage (Fraiz et al., 2025).

Synbiotic mushroom-based beverages are emerging as a rapidly growing category within the functional beverage market, particularly among physically active consumers seeking products that support energy metabolism and sports performance. Commercial examples include mushroom coffees enriched with Reishi (Ganoderma lucidum) or Lion's Mane (Hericium erinaceus), as well as fermented mushroom–

kombucha beverages (Ajibola et al., 2026). In addition to their perceived health benefits, mushroom fermentation can substantially modify aroma profiles. For example, fermentation of green tea with enokitake (Flammulina velutipes) reduces grassy notes while promoting the formation of aroma-active compounds such as 2-ethyl-3,5-dimethylpyrazine and β-damascenone, resulting in desirable nutty and chocolate-like aroma characteristics (Rigling et al., 2021). These findings demonstrate the potential of mushroom fermentation to simultaneously improve sensory quality and enhance the functional value of fermented beverages.

2.2.1. Kombucha

Kombucha has become one of the fastest-growing fermented beverage worldwide, largely driven by consumer demand for refreshing, functional, and naturally flavored products (Andrade et al., 2025). Its characteristic balance of sweetness, acidity, mild bitterness, and fruity-floral aromas aligns well with current flavor trends emphasizing freshness and sensory complexity (Frolova, 2022). Reflecting this increasing consumer demand, the global kombucha market is estimated to be worth US$ 2.85 billion in 2025 and is projected to reach US$ 5.9 billion by 2029.

The distinctive sensory characteristics of kombucha are largely determined by microbial fermentation and the formation of a diverse range of aroma-active compounds. Traditionally, kombucha is produced by fermenting sweetened tea with a symbiotic culture of bacteria and yeast (SCOBY), resulting in the formation of organic acids (acetic, gluconic, glucuronic, and lactic) (Mohd Ariff et al., 2023), ethanol, and numerous aroma-active compounds (Sanwal, Gupta, Bareen, Sharma,2023). Kombucha can be prepared using a variety of tea types and fruit substrates, thereby expanding its flavor diversity (Mohd Ariff et al., 2023).

To meet the growing consumer demand for novel flavor profiles, ingredients such as coffee, hibiscus, ginger, bee pollen, guava, and papaya have increasingly been incorporated into kombucha formulations (Mohd Ariff et al., 2023; Sanwal, Gupta, Bareen, Sharma & Sahu, 2023). Fermentation parameters, such as pH, temperature, time, and substrate, play critical roles in determining the final aromatic complexity of kombucha (Villarreal-Soto, Beaufort, Bouajila, Souchard, & Taillandier, 2018).

The main volatile compounds found in traditional kombucha include benzaldehyde (nutty, almond-like), 2-phenylethanol (floral and fruity), phenolic compounds (smoky)(Marsh et al., 2014), ethyl acetate, and isoamyl acetate (sweet and fruity) (Kong et al., 2019). Yeasts play a key role in the biosynthesis of alcohols and esters, which are major contributors to the characteristic aroma of kombucha (Dufresne & Farnworth, 2000). Recent studies have further demonstrated that B. bruxellensis and A. indonesiensis produce characteristic apple-like aroma notes during kombucha fermentation (Tran et al., 2022).

Furthermore, organic acids such as gluconic and acetic acids, together with ethanol, contribute to the tangy taste of kombucha (Jayabalan et al., 2014). Prolonged fermentation promotes the formation of complex volatiles and acids (Greenwalt et al., 2000). Microbial enzymes also transform tea polyphenols and polysaccharides, including hydrocolloids such as glucans, thereby influencing the viscosity and mouthfeel of kombucha (Jayabalan, Marimuthu & Swaminathan, 2014). Collectively, these fermentation-derived metabolites and structural modifications contribute to the fruity, floral, tangy, and refreshing sensory profile that has driven the increasing consumer preference for kombucha and other fermented functional beverages.

According to recent data from global and local food markets, functional hybrids, floral and botanical blends, and sugar-free formulations have emerged as major trends in the kombucha market. Consumers are increasingly seeking premium kombucha products that offer not only distinctive sensory characteristics but also added functional benefits (Ayseli, 2023). Functional hybrids often incorporate adaptogenic ingredients, such as Ashwagandha, together with medicinal mushrooms including Reishi (Ganoderma lucidum) and Lion's Mane (Hericium erinaceus). Fermentation significantly improves the bioavailability and nutritional value of mushrooms, making it an effective strategy for enhancing both the health-promoting properties and sensory quality of mushroom-based beverages (Di Renzo et al., 2025).

Another major trend involves floral and botanical blends, featuring exotic flavors such as yuzu, orange, and mango–chili combinations (Woo, Lee, Jeong, Choi, & Huh, 2021), fruits (lemon, orange, mango, apple, etc.), vegetables (cucumber, cucumber–mint, beetroot, etc.), berries (cranberries, lingonberries, chokeberry, raspberries, etc.), herbs and spices (mint, nutmeg, star anise, cloves, lavender, vanilla, hibiscus, butterfly pea flower, elderflower), as well as functional ingredients (vitamins, prebiotics, probiotics, and chlorophyll) (Frolova, 2022).

Another important trend is the growing demand for sugar-free formulations. Driven by the preferences of Generations Z and Y for products containing naturally derived sweeteners, manufacturers are developing formulations with no added sugar by replacing artificial sweeteners with monk fruit (Siraitia grosvenorii Swingle) or stevia (Stevia rebaudiana Bertoni)(Pereira, 2026; Tan et al., 2025).

2.3. Swicy, Sweet–Savory, and Dessert-Oriented Fermented Flavors

A notable emerging trend in the food industry is the incorporation of fermented ingredients into confectionery, dessert, and swicy (sweet + heat) formulations. Fermentation-derived ingredients are increasingly utilized to enhance flavor complexity, improve sensory appeal, and introduce functional attributes to sweet products. In recent years, consumers have shown growing interest in products that combine sweetness with spicy, savory, acidic, and umami characteristics, creating multi-layered sensory experiences. Examples include fermented honey and fruit preserves, kefir-based ice creams, kombucha sorbets, miso-infused chocolates, soy sauce caramel, traditional Asian fermented pastes such as gochujang and doubanjiang, and fermented hot sauces including Sriracha, harissa, and fermented jalapeños (Al, Ergin Zeren, Çomak Göçer, Demir, & Küçükçetin, 2025). These products benefit from the unique balance of sweetness, acidity, umami, pungency, and aromatic complexity generated during fermentation, appealing to consumers seeking both indulgence and authenticity. Furthermore, the integration of fermented ingredients is consistent with the growing demand for functional, artisanal, and flavor-rich foods, offering opportunities for product differentiation and flavor innovation (Reinoso, 2026).

Fermented fruit-based pastes prepared from banana, mango, and date have also emerged as a growing market trend and are increasingly incorporated into confectionery formulations because of their rich, fresh, and aromatic flavor profiles. In the plant-based market, fermented oat milk desserts have gained momentum, appealing to consumers seeking dairy-free products with greater flavor complexity.

The growing popularity of global street-food culture has increased consumer exposure to fermented condiments and sauces, particularly kimchi, gochujang, doubanjiang, and fermented chili products. These ingredients are increasingly incorporated into modern snack formulations, street-food-inspired products, and fusion cuisines, where they contribute distinctive spicy, savory, umami-rich, and fermented flavor characteristics (Cvetan, 2025).

3. CONCLUSION

Traditional fermented foods and beverages continue to gain worldwide recognition as consumers increasingly seek authentic, clean-label, and sensory-rich food experiences. The growing demand for umami-rich, fruity, floral, sweet–savory, and swicy flavor profiles has expanded the application of fermented ingredients beyond their traditional uses, driving innovation in condiments, desserts, snacks, and beverages.

Although numerous studies have identified volatile compounds associated with traditional fermented foods and beverages (TFFBs), the biochemical mechanisms governing flavor formation remain only partially understood. Flavor development results from complex interactions among microbial succession, substrate composition, enzymatic activities, and processing conditions. Major pathways, including amino acid catabolism through the Ehrlich pathway and Strecker degradation, lipid oxidation, carbohydrate degradation, esterification, Maillard reactions, and carotenoid degradation, collectively contribute to the formation of aroma-active compounds. However, the relative importance of these pathways varies considerably among fermented products, microbial communities, and processing conditions, highlighting the need for more systematic mechanistic studies. Integrating metabolomics, transcriptomics, isotope-labeling techniques, and microbial ecology will improve our understanding of these interactions and support the development of predictive models linking microbial metabolism to flavor generation. Such knowledge will facilitate the optimization of volatile and non-volatile flavor-active compounds through advanced fermentation technologies and controlled fermentation processes.

Collectively, this review highlights the continuing importance of traditional fermentation as both a source of flavor innovation and a means of meeting evolving consumer expectations for natural, diverse, and high-quality food experiences. Given the remarkable diversity of fermented foods worldwide and their increasing role in flavor innovation, this review provides a comprehensive scientific resource for future research and product development in fermentation and flavor science. Future advances should focus on precision fermentation, targeted microbial strain selection, multi-omics approaches, advanced analytical technologies, and the integration of artificial intelligence, predictive modeling, and sensory science. These interdisciplinary approaches are expected to accelerate the development of next-generation clean-label fermented foods and beverages with tailored flavor profiles, improved sensory quality, and enhanced consumer acceptance.

DECLARATION OF CONFLICTING INTERESTS

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

FUNDING

None.

REFERENCES

Ajibola, O. O., Hipolito, C. N., & Thomas, R. (2026). Fermented mushroom beverages: Exploring probiotic, prebiotic, and synbiotic properties through nanoscience for enhanced health benefits. Future Foods, 13(October 2025). https://doi.org/10.1016/j.fufo.2025.100890

Al, M., Ergin Zeren, F., Çomak Göçer, E. M., Demir, M., & Küçükçetin, A. (2025). Effects of different processing methods on physicochemical and microbiological properties of kefir ice cream. International Dairy Journal, 160. https://doi.org/10.1016/j.idairyj.2024.106111

Altay, F., Karbancioglu-Güler, F., Daskaya-Dikmen, C., & Heperkan, D. (2013). A review on traditional Turkish fermented non-alcoholic beverages: Microbiota, fermentation process and quality characteristics. International Journal of Food Microbiology, 167(1), 44–56. https://doi.org/10.1016/j.ijfoodmicro.2013.06.016

An, F., Wu, J., Feng, Y., Pan, G., Ma, Y., Jiang, J., … Zhao, M. (2023). A systematic review on the flavor of soy-based fermented foods: Core fermentation microbiome, multisensory flavor substances, key enzymes, and metabolic pathways. Comprehensive Reviews in Food Science and Food Safety, Vol. 22. https://doi.org/10.1111/1541-4337.13162

Andrade, D. K. A., Wang, B., Lima, E. M. F., Shebeko, S. K., Ermakov, A. M., Khramova, V. N., … Todorov, S. D. (2025). Kombucha: An Old Tradition into a New Concept of a Beneficial, Health-Promoting Beverage. Foods, Vol. 14. https://doi.org/10.3390/foods14091547

Ayseli, M. T. (2023). New frontiers in flavor, color, and sweeteners during the post-COVID-19 period: A systematic review. Trends in Food Science and Technology, Vol. 140. https://doi.org/10.1016/j.tifs.2023.104144

Cha, Y. J., Kim, H., & Cadwallader, K. R. (1998). Aroma-Active Compounds in Kimchi during Fermentation. Journal of Agricultural and Food Chemistry, 46(5). https://doi.org/10.1021/jf9706991

Chen, X., Xiang, J., Chen, K., Zhang, S., Ma, D., Xiao, S., … Wang, J. hui. (2025). Aroma evolution in lychee Juice: Distinct effects of water kefir grains and liquid cultures on volatile profiles. LWT, 228. https://doi.org/10.1016/j.lwt.2025.118071

Cvetan, D. (2025). Outlook 2026: Flavor Trends. Food Technology, 79(9), 18–23. Retrieved from https://www.ift.org/news-and-publications/food-technology-magazine/issues/2025/october/features/outlook-2026-flavor-trends

Deng, Z., Zhu, M., Du, Y., Wu, Z., Lin, X., Wen, J., … Zhang, W. (2024). Exploring the Enhancement of Guaiacol Compounds in Sesame-Flavored Baijiu via Inoculation with Pseudomonas azotoformans YF-58. Applied Biochemistry and Microbiology, 60(6). https://doi.org/10.1134/S0003683824605365

Dhiman, S., Kaur, S., Thakur, B., Singh, P., & Tripathi, M. (2025). Nutritional Enhancement of Plant-Based Fermented Foods: Microbial Innovations for a Sustainable Future. Fermentation, Vol. 11. https://doi.org/10.3390/fermentation11060346

Di Renzo, T., Reale, A., Nazzaro, S., Marena, P., Rahim, M. H. A., Mohd Zaini, N. A., … Wan-Mohtar, W. A. A. Q. I. (2025). Performance of Mushrooms in Fermented Beverages: A Narrative Review. Beverages, Vol. 11. https://doi.org/10.3390/beverages11010019

Dion, M. (2025). Part of. Global Food Trends Report 2025. Https://Tastewise.Io/2025-Trends-Report, 0–23.

Dutta, S., De, S., Saha, B., & Alam, M. I. (2012). Advances in conversion of hemicellulosic biomass to furfural and upgrading to biofuels. Catalysis Science and Technology, Vol. 2. https://doi.org/10.1039/c2cy20235b

Fan, A., Dong, P., Su, Y., Hu, X., Wu, J., & Chen, F. (2015). The effect of blanching on flavor compositions of pickles pasteurized by ultra-high hydrostatic pressure. Journal of Chinese Institute of Food Science and Technology, 15(11). https://doi.org/10.16429/j.1009-7848.2015.11.034

Fan, Y., Gan, R., Zhang, Z., Xu, J., Liu, S., Bu, Y., … Sun, F. (2025). Flavor effect, application status, and research trend of umami peptides based on microbial fermentation in food. Food Microbiology, Vol. 130. https://doi.org/10.1016/j.fm.2025.104769

Fraiz, G. M., Bonifácio, D. B., de Paulo, R. S., Teixeira, C. M., Martino, H. S. D., Barros, F. A. R. de, … Bressan, J. (2025). Benefits of Kombucha Consumption: A Systematic Review of Clinical Trials Focused on Microbiota and Metabolic Health. Fermentation, Vol. 11. https://doi.org/10.3390/fermentation11060353

Frolova, Y. V. (2022). Russian market of fermented kombucha beverages. Voprosy Pitaniia, 91(3). https://doi.org/10.33029/0042-8833-2022-91-3-115-118

Giri, A., Okamoto, A., Okazaki, E., & Ohshima, T. (2010). Headspace volatiles along with other instrumental and sensory analyses as indices of maturation of horse mackerel miso. Journal of Food Science, 75(8). https://doi.org/10.1111/j.1750-3841.2010.01780.x

Giri, A., Osako, K., & Ohshima, T. (2010). Identification and characterisation of headspace volatiles of fish miso, a Japanese fish meat based fermented paste, with special emphasis on effect of fish species and meat washing. Food Chemistry, 120(2). https://doi.org/10.1016/j.foodchem.2009.10.036

Hanlon, M., Van Beeck, W., Wei, L., Tosta, I., Liao, R., Marco, M. L., & DiCaprio, E. (2026). Consumer knowledge and motivations for consumption of fermented foods. Frontiers in Microbiology, 17(April). https://doi.org/10.3389/fmicb.2026.1789825

Hooper Marosek, S. E., Antharam, V., & Dowlatshahi, K. (2020). Quantitative Analysis of the Acetic Acid Content in Substances Used by Athletes for the Possible Prevention and Alleviation of Exercise-Associated Muscle Cramps. Journal of Strength and Conditioning Research, 34(6). https://doi.org/10.1519/JSC.0000000000003595

Inoue, Y., Kato, S., Saikusa, M., Suzuki, C., Otsubo, Y., Tanaka, Y., … Hayase, F. (2016). Analysis of the cooked aroma and odorants that contribute to umami aftertaste of soy miso (Japanese soybean paste). Food Chemistry, 213. https://doi.org/10.1016/j.foodchem.2016.06.106

Jannah, M., Wakiah, N., Sandi, O. M., Islamawan, P. A., & Wulan, N. L. N. (2025). Microorganisms in probiotic beverage fermentation: Health benefits and mechanisms in dairy and non-dairy products. Jurnal Inovasi Pangan Dan Gizi, 2(1). https://doi.org/10.61511/jipagi.v2i1.1773

Jo, Y. J., Cho, I. H., Song, C. K., Shin, H. W., & Kim, Y. S. (2011). Comparison of fermented soybean paste (Doenjang) prepared by different methods based on profiling of volatile compounds. Journal of Food Science, 76(3). https://doi.org/10.1111/j.1750-3841.2011.02068.x

JPRN-UMIN000051444. (2023). About the difference in efficacy depending on the carbon number of medium-chain fatty acids. Https://Trialsearch.Who.Int/Trial2.Aspx?TrialID=JPRN-UMIN000051444.

Kaewkod, T., Bovonsombut, S., & Tragoolpua, Y. (2019). Efficacy of kombucha obtained from green, oolongand black teas on inhibition of pathogenic bacteria, antioxidation, and toxicity on colorectal cancer cell line. Microorganisms, 7(12). https://doi.org/10.3390/microorganisms7120700

Kaku, Y., Sugawara, E., & Takahashi, K. (2000). Effect of the manufacturing process (the hardness of steamed-cooked soybeans and the temperature during the aging process) on the formation of aroma components of red salty rice miso with aging. Nippon Shokuhin Kagaku Kogaku Kaishi, 47(12). https://doi.org/10.3136/nskkk.47.919

Kang, D., Hwang, J. sun, & Kim, M. K. (2026). Effect of rice koji levels on the physicochemical and sensory aroma profiles of doenjang. Journal of the Science of Food and Agriculture, 106(3). https://doi.org/10.1002/jsfa.70292

Karim, H., Jumadi, O., Hartati, H., Arsal, A. F., & Suryani, A. I. (2024). Utilization of pineapple peels in the production of probiotic Tepache for immune enhancement among members of Majelis Taklim Nurul Muhajirin in Makassar. Jurnal Hasil Inovasi Masyarakat, 2(2). https://doi.org/10.70310/925rmr35

Kaufman, P. B., Duke, J. A., Brielmann, H., Boik, J., & Hoyt, J. E. (1997). A comparative survey of leguminous plants as sources of the isoflavones, genistein and daidzein: Implications for human nutrition and health. Journal of Alternative and Complementary Medicine, Vol. 3. https://doi.org/10.1089/acm.1997.3.7

Kim, M. R., Chung, S. J., Adhikari, K., Shin, H. W., Cho, H., & Nam, Y. (2020). Cross-cultural consumer acceptability for ethnic fermented sauce products: Comparisons among Korean, UAE, and us consumers. Foods, 9(10). https://doi.org/10.3390/foods9101463

Kumazawa, K., Kaneko, S., & Nishimura, O. (2013). Identification and characterization of volatile components causing the characteristic flavor in miso (Japanese fermented soybean paste) and heat-processed miso products. Journal of Agricultural and Food Chemistry, 61(49). https://doi.org/10.1021/jf404082a

Leal, J. M., Suárez, L. V., Jayabalan, R., Oros, J. H., & Escalante-Aburto, A. (2018). A review on health benefits of kombucha nutritional compounds and metabolites. CYTA - Journal of Food, 16(1). https://doi.org/10.1080/19476337.2017.1410499

Lee, D. N., Lee, K. M., Lee, S. E., & Kim, T. O. (2024). Flavor identification and analysis of fermented soybean pastes. Food Science and Preservation, 31(3). https://doi.org/10.11002/fsp.2024.31.3.374

Li, H., Huang, J., Wang, Y., Wang, X., Ren, Y., Yue, T., … Gao, Z. (2021). Study on the nutritional characteristics and antioxidant activity of dealcoholized sequentially fermented apple juice with Saccharomyces cerevisiae and Lactobacillus plantarum fermentation. Food Chemistry, 363. https://doi.org/10.1016/j.foodchem.2021.130351

Li, X., He, Y., Xie, Y., Zhang, L., Li, J., & Liu, H. (2023). Effects of fermentation with Kefir grains on nutrient composition, flavor volatiles, and product physical stability of a hemp seed (Cannabis sativa L.) beverage. LWT, 183. https://doi.org/10.1016/j.lwt.2023.114934

Liang, J. R., Deng, H., Hu, C. Y., Zhao, P. T., & Meng, Y. H. (2022). Vitality, fermentation, aroma profile, and digestive tolerance of the newly selected Lactiplantibacillus plantarum and Lacticaseibacillus paracasei in fermented apple juice. Frontiers in Nutrition, 9. https://doi.org/10.3389/fnut.2022.1045347

Liang, W., Nong, Q., Huang, H., Huang, J., Shao, J., Wang, M., … Hong, Y. (2025). Effects of different koji-making conditions on volatile flavor compounds in fermented shrimp juice. International Journal of Gastronomy and Food Science, 42. https://doi.org/10.1016/j.ijgfs.2025.101357

Lu, Y., & He, Q. (2021). Studies on Evolution of the Odor-active Volatile Compounds of Pixian-douban and Its Aroma Characteristics. Journal of Chinese Institute of Food Science and Technology, 21(4). https://doi.org/10.16429/j.1009-7848.2021.04.039

Mohd Ariff, R., Chai, X. Y., Chang, L. S., Fazry, S., Othman, B. A., Babji, A. S., & Lim, S. J. (2023). Recent trends in Kombucha: Conventional and alternative fermentation in development of novel beverage. Food Bioscience, Vol. 53. https://doi.org/10.1016/j.fbio.2023.102714

Pereira, A. G. (2026). Kombucha as a Bioactive Functional Beverage: Current Evidence, Production Challenges, and Future Perspectives. International Journal of Molecular Sciences, 27(6), 1–33. https://doi.org/10.3390/ijms27062739

Phung, L. T., Kitwetcharoen, H., Chamnipa, N., Boonchot, N., Thanonkeo, S., Tippayawat, P., … Thanonkeo, P. (2023). Changes in the chemical compositions and biological properties of kombucha beverages made from black teas and pineapple peels and cores. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-34954-7

Reinoso, K. L. (2026). Fermented Food & Beverage Trends. 1–7.

Rigling, M., Yadav, M., Yagishita, M., Nedele, A. K., Sun, J., & Zhang, Y. (2021). Biosynthesis of pleasant aroma by enokitake (Flammulina velutipes) with a potential use in a novel tea drink. Lwt, 140(November 2020), 110646. https://doi.org/10.1016/j.lwt.2020.110646

Sales, A. L., Cunha, S. C., Morgado, J., Cruz, A., Santos, T. F., Ferreira, I. M. P. L. V. O., … Farah, A. (2023). Volatile, Microbial, and Sensory Profiles and Consumer Acceptance of Coffee Cascara Kombuchas. Foods, 12(14). https://doi.org/10.3390/foods12142710

Sanwal, N., Gupta, A., Bareen, M. A., Sharma, N., & Sahu, J. K. (2023, December 1). Kombucha fermentation: Recent trends in process dynamics, functional bioactivities, toxicity management, and potential applications. Food Chemistry Advances, Vol. 3. https://doi.org/10.1016/j.focha.2023.100421

Seo, W. H., You, Y., & Baek, H. H. (2024). Changes in volatile flavor compounds of Kimchi cabbage (Brassica rapa subsp. pekinensis) during salting and fermentation. Food Science and Biotechnology, 33(7). https://doi.org/10.1007/s10068-023-01469-w

Shi, M., Yang, K., Lyu, P., Zhang, Q., Chen, G., Wang, Y., … Wu, Y. (2023). Effects of single-bacteria and multi-bacteria inoculation on the flavor of Sichuan pickles of multi-round fermentation. Food and Fermentation Industries, 49(14). https://doi.org/10.13995/j.cnki.11-1802/ts.033418

Shi, X., Li, Y., Cheng, Y., Liu, W., Li, Z., Jin, H., … Sun, Z. (2026). Emerging roles of lactic acid bacteria in health management: Insights from fermented foods to microbiota. Food Bioscience, Vol. 75. https://doi.org/10.1016/j.fbio.2025.108088

Tamer, C. E., Özkan Karabacak, A., & Durgut Malçok, S. (2025). Drinks and foods enriched with cinnamon. In Cinnamon: Production, Processing, and Functional Properties. https://doi.org/10.1016/B978-0-443-21820-0.00033-7

Tamura, G., Kirimura, J., Hara, H., & Sugimura, K. (1952). The microbiological determination of amino acids in “miso.” Nippon NÅ□geikagaku Kaishi, 26(9). https://doi.org/10.1271/nogeikagaku1924.26.483

Tan, D., Tinardi, C., Eldyjoe, A. G., Josephine, S. T., Sastra, T., & Dewi, D. P. A. P. (2025). Physicochemical and Sensory Analysis of Monk Fruit (Siraitia grosvenorii) Sweetener as Sucrose Substitute in Black Tea Kombucha. Journal of Functional Food and Nutraceutical. https://doi.org/10.33555/jffn.v7i1.8

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). https://doi.org/10.1007/s13197-017-2637-1

Tong, J., Li, S., Wang, Z., Zeng, M., He, Z., Chen, J., & Chen, Q. (2026). Screening and application of lactic acid bacteria for mustard leaves (Brassica juncea var. multiceps) pickle directed by sensory omics and volatile flavor profiling. Food Bioscience, 81, 109068. https://doi.org/10.1016/J.FBIO.2026.109068

Tran, T., Billet, K., Torres-Cobos, B., Vichi, S., Verdier, F., Martin, A., … Tourdot-Maréchal, R. (2022). Use of a Minimal Microbial Consortium to Determine the Origin of Kombucha Flavor. Frontiers in Microbiology, 13. https://doi.org/10.3389/fmicb.2022.836617

Villarreal-Soto, S. A., Beaufort, S., Bouajila, J., Souchard, J. P., & Taillandier, P. (2018). Understanding Kombucha Tea Fermentation: A Review. Journal of Food Science, Vol. 83. https://doi.org/10.1111/1750-3841.14068

Wang, D. H., Yang, Y., Wang, Z., Lawrence, P., Worobo, R. W., & Brenna, J. T. (2019). High levels of branched chain fatty acids in nātto and other Asian fermented foods. Food Chemistry, 286. https://doi.org/10.1016/j.foodchem.2019.02.018

Wang, S., Liu, X., Tamura, T., Kyouno, N., Zhang, H., & Chen, J. Y. (2021). Effect of volatile compounds on the quality of miso (traditional Japanese fermented soybean paste). LWT, 139. https://doi.org/10.1016/j.lwt.2020.110573

Woo, H. G., Lee, C. M., Jeong, J. H., Choi, B. K., & Huh, C. K. (2021). Quality characteristics of kombucha made with different mixing ratios of green tea extract and yuzu juice during fermentation. Korean Journal of Food Preservation, 28(5). https://doi.org/10.11002/kjfp.2021.28.5.646

Xu, N., Liu, Y., Hu, Y., Zhou, M., Wang, C., & Li, D. (2016). Autolysis of Aspergillus oryzae Mycelium and Effect on Volatile Flavor Compounds of Soy Sauce. Journal of Food Science, 81(8). https://doi.org/10.1111/1750-3841.13396

Xu, Y., Yao, L., Song, S., Sun, M., Wang, H., Yu, C., … Feng, T. (2024). Revealing the microbial diversity and volatile flavor formation in finger citron kombucha by metagenomic and GC-MS analysis. Food Bioscience, 59. https://doi.org/10.1016/j.fbio.2024.104087

Yang, M., Huang, J., Zhou, R., Qi, Q., Peng, C., Zhang, L., … Tang, Q. (2020). Characterization of the flavor in traditional Pixian Doubanjiang by polyphasic quantitative detection technology. Food Research International, 138. https://doi.org/10.1016/j.foodres.2020.109753

Yul Lee, H., Haque, M. A., Yong Cho, D., Bin Jeong, J., Ho Lee, J., Young Lee, G., … Man Cho, K. (2024). Comparison of microbial diversity and metabolites on household and commercial doenjang. Food Chemistry: X, 21. https://doi.org/10.1016/j.fochx.2023.101101

Zhou, Y., Chao, Y., Huang, C., Li, X., Yi, Z., Zhu, Z., … Xie, C. (2025). Influence of Lactiplantibacillus plantarum and Saccharomyces cerevisiae Individual and Collaborative Inoculation on Flavor Characteristics of Rose Fermented Beverage. Foods, 14(11). https://doi.org/10.3390/foods14111868