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Compensative role of autochthonous lactic acid bacteria in physical properties and taste profiles of dry sausage with partial substitution of NaCl by KCl

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ABSTRACT

The defects of quality and taste caused by the partial substitution of NaCl by KCl limit the widespread use of KCl as salt substitute in fermented sausages. The objective of this study was to investigate the compensative role of four autochthonous lactic acid bacteria (LAB) strains, including *Latilactobacillus curvatus*, *Latilactobacillus sakei*, *Weissella hellenica*, and *Lactiplantibacillus plantarum*, in the physicochemical properties and taste profiles of the dry sausages with 40% substitution of NaCl by KCl. The results demonstrated that LAB inoculated reduced the pH, moisture content, and water activity and increased the organic acid contents and certain free amino acid (FAA) contents ($P < 0.05$). Higher contents of total acids was detected in the *L. curvatus*-inoculated and *L. sakei*-inoculated sausages ($P < 0.05$). Sweet FAAs contents in *L. sakei*-inoculated sausages increased by 36.90% and bitter FAAs contents decreased by 18.18%. According to the results of the electronic tongue, the sausage inoculated with *L. sakei* reduced the response value of bitterness by 5.7% ($P < 0.05$) and exhibited the most similar overall taste profile to traditional sausages. Overall, *L. sakei* could be used as a potential starter culture to enhance the physicochemical and compensate for the flavour deficiencies of NaCl-substituted dry sausages.

1. Introduction

Salt (NaCl) performs crucial physiological functions, such as regulating the osmotic pressure of the extracellular fluid and the acid−base balance in body fluids (Pateiro, Munekata, Cittadini, Domínguez, & Lorenzo, 2021; Quilaqueo, Duizer, & Aguilera, 2015). It is also a traditional food preservative and flavoring agent commonly used in food processing to prolong the shelf life of food by inhibiting the reproduction of spoilage microorganisms (Zhang, Guo, Peng, & Jamali, 2022), provide a salty taste, and affect the activity of endogenous enzymes and microbial metabolism, ultimately impacting the final characteristic flavor (Gaudette & Pietrasik, 2017; Liang et al., 2020; Zhao et al., 2020). However, the global average estimate of daily sodium consumption is 3.54–4.72 g/days, which far exceeds the maximum level recommended by the World Health Organization (WHO) of <2 g salt/day (He & Tan, 2024; WHO, 2020). Previous studies have shown that high sodium intake is a major cause of hypertension, cardiovascular damage, chronic kidney disease, stomach disease, and osteoporosis (He, Tan, Ma, & MacGregor, 2020; Zheng, Han, Ge, Zhao, & Sun, 2019). Therefore, the global target is to reduce 30% of the salt/sodium intake by 2025 to ensure the health of consumers (Trieu et al., 2015).

Meat products are the essential sources of sodium, contributing approximately 20–30% (Aaslyng, Vestergaard, & Koch, 2014). The NaCl provides saltiness, attenuate bitterness, and inhibits spoilage and pathogenic bacteria in meat products (Barcenilla, Álvarez-Ordóñez, López, Alvseike, & Prieto, 2022). In addition, NaCl has the facilitating capacity to extract myofibrillar proteins, resulting in the promotion of gel formation and optimal texture development of dry sausages (Hu et al., 2022). Dry sausages, the traditional Chinese fermented meat products, are a key source of sodium (Hu et al., 2020). Usually, about 2–3% NaCl is added in the preparation of dry sausages, which can reach 6% after long-term fermentation and dehydration (Campagnol, dos Santos, Wagner, Terra, & Pollonio, 2011). Consequently, reformulating recipes for dry sausage to reduce salt content can help consumers meet their

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Table 1
The recipes and starter cultures for different dry sausages.

	CT	CS	*L. curvatus*	*L. sakei*	*W. hellenica*	*L. plantarum*
Starter culture	–	–	*L. curvatus*	*L. sakei*	*W. hellenica*	*L. plantarum*
Lean pork (g)	3600	3600	3600	3600	3600	3600
Pork back fat (g)	400	400	400	400	400	400
Salt (g)	100	60	60	60	60	60
Sodium chloride (g)	–	40	40	40	40	40
Sodium nitrite (g)	0.36	0.36	0.36	0.36	0.36	0.36
Monosodium glutamate (g)	12	12	12	12	12	12
Dextrose (g)	40	40	40	40	40	40
Yuquan *Daqu* liquor (g)	40	40	40	40	40	40
Mixed spices (g)	32	32	32	32	32	32

CT: 2.50% NaCl; CS: 1.50% NaCl + 1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

health targets.

Partial substitution of sodium with chlorinated salts is a common way to reduce sodium intake (Pateiro et al., 2021). In meat products, partial substitution of NaCl by sodium chloride (KCl) is the most widely used substitution method because of the similar taste and antibacterial efficiency between KCl and NaCl (Armenteros, Aristoy, Barat, & Toldrá, 2008). Moreover, increasing the potassium intake appropriately may reduce the incidence rate of many health disorders (including hypertension and cardiovascular diseases) (Taylor, Loring, Singer, & Moore, 2020). However, the bitter, metallic, and astringent tastes caused by a high-level substitution of NaCl (≥40%) by KCl are the main reasons limiting its widespread use in meat products (Buren, Dötsch-Klerk, Seewi, & Newson, 2016; Gelabert, Gou, Guerrero, & Arnau, 2003). Similarly, our previous study has been demonstrated that partial substitution of NaCl with KCl (40%) had a negative impact on the quality and sensory attributes of dry sausages (Qin, Li, Huang, Li, & Chen, 2023). To minimize the amount of NaCl addition, our aim in the current study was to find an effective means of compensating for the adverse effects of partial substitution of NaCl by KCl.

Inoculation of lactic acid bacteria (LAB) may be an effective approach to enhancing the quality and taste of fermented meat products with NaCl substitution by KCl. On the one hand, LAB strains have the capacity to accelerate water loss and acidification, promote the formation of flavor compounds and thus shorten the fermentation time (Visessanguan et al., 2006), and inhibit the growth of undesirable microorganisms and by generating antimicrobial compounds (Maidana et al., 2020). LAB also contribute to the inhibition of biogenic amines and nitrites accumulation, thereby improving the safety of reduced-salt food (Zeng et al., 2014; Zhang et al., 2020); On the other hand, LAB strains have the ability to mask the bitterness in fermented foods. For instance, Song et al. (2021) reported the reduced bitterness of *Suancai* (a traditional Chinese pickled Chinese cabbage) when inoculated with *Lactiplantibacillus plantarum* and *Pediococcus pentosus*. Møller, Rattray, and Ardö (2013) demonstrated that *Lactobacillus helveticus* could increase the degradation of bitter peptides in low-salt Cheddar cheese. Furthermore, LAB carbohydrate metabolism contributes to the accumulation of organic acids involved in sourness, and at medium intensity/concentration, sourness can suppress bitterness (Keast & Breslin, 2003).

In a previous study, we isolated autochthonous LAB strains from traditional dry sausages, of which four strains, including *Latilactobacillus curvatus*, *Latilactobacillus sakei*, *Weissella hellenica*, and *L. plantarum*, have been proved to have excellent fermentation capability (Hu et al., 2022a). Furthermore, the introduction of these LAB strains markedly improved the taste characteristics of the dry sausages with directly reduced salt addition (Hu et al., 2021). Nevertheless, the in-depth studies are still needed in the case of NaCl-substituted dry sausage system. Thus, in the present work, we endeavored to assess the potential physicochemical improvement and taste-compensating role of these LAB strains in the dry sausages with partial substitution (40%) of NaCl by KCl. In addition, the relationships among physicochemical characteristics, LAB counts, and taste profiles are analyzed based on a partial least squares regression (PLSR) model. The purpose of this study was to investigate the compensative role of four autochthonous LAB strains in the physicochemical properties and taste profiles of NaCl-substituted dry sausages. This study may provide valuable information for the development and the control of quality in low-sodium fermented meat products.

2. Materials and methods

2.1. Preparation of starter cultures

The LAB strains (*L. curvatus* SYS29, *L. sakei* HRB10, *W. hellenica* HRB6, and *L. plantarum* MDJ2) have been identified by 16S rDNA sequence analysis and their DNA sequences were compared with those from the GenBank database. The LAB strains were cultured in the de Man Rogosa and Sharpe (MRS, Haibo Biotechnology Co., Qingdao, China) broth at 37 °C for 24 h. Subsequently, the cell pellets were harvested, washed, and resuspended in sterile saline as described by Hu et al. (2021). The concentrations of each LAB strains were adjusted according their OD_{600}/stain count standard curves to ensure that the respective inoculation level was approximately 10^7 CFU/g.

2.2. Preparation of dry sausage

Three independent batches of dry sausages were prepared and a total of six treatments of dry sausages were prepared in each batch (3 batches × 6 treatments). Lean pork and pork back fat were purchased within 24 h post-mortem from local fresh market and were transported to the laboratory at 4 °C. The dry sausage preparation was carried out as reported by Wen et al. (2023). Briefly, the dry sausages were manufactured with lean pork and pork back fat minced through a 1.5 cm plate with salt, KCl, sodium nitrite, monosodium glutamate, dextrose, Yuquan *Daqu* liquor (a strong aroma-type Chinese traditional liquor; 42% Vol.), and mixed spices (Shiyitang, Heilongjiang, China). The mixed spices consist mainly of certain proportions of *Pericarpium zanthoxyli*, *Cinnamomum cassia*, *Syzygium aromaticum*, *Amomum cardamon*, *Angelica sinensis*, *Amomum villosum*, *Amomum villosum Lour*., *Piper nigrum* L., and *Foeniculum vulgare Mill*. The recipes and starter cultures are shown in Table 1. Altogether, six treatments of dry sausages were prepared: the traditional dry sausages with 2.5% NaCl (CT) and the low-sodium dry sausages with 1.5% NaCl and 1.0% KCl (CS, equivalent to the replacement of 40% NaCl by KCl) were considered as the control treatments. The other four low-sodium treatments with the same salt contents as the CS treatment were separately inoculated with *L. curvatus*, *L. sakei*, *W. hellenica*, and *L. plantarum* at 10^7 CFU/g in minced meat. Subsequently, the fermentation was carried out for 1 day in an incubator (Fitoclima 600 pH, ARALAB Co. Ltd., Lisboa, Portugal) at a relative humidity 30–50% (ambient temperature 25 ± 2 °C). Then, sausages

Table 2
Changes in physicochemical properties and lactic acid bacteria counts of the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains during a 9-day fermentation.

Attribute	Fermentation time (day)	Treatment					
		CT	CS	*L. curvatus*	*L. sakei*	*W. hellenica*	*L. plantarum*
Moisture content (%)	0	67.55 ± 0.51^{Aa}	67.39 ± 0.34^{Aa}	67.89 ± 0.41^{Aa}	67.80 ± 0.37^{Aa}	66.86 ± 0.18^{Aa}	68.52 ± 0.74^{Aa}
	3	44.47 ± 0.73^{Bb}	48.98 ± 1.05^{Ba}	36.66 ± 0.31^{Bc}	44.64 ± 0.32^{Bb}	41.57 ± 0.91^{Bb}	34.34 ± 0.75^{Bc}
	6	27.47 ± 0.81^{Ca}	28.66 ± 0.71^{Ca}	22.98 ± 0.59^{Cb}	27.45 ± 0.49^{Ca}	26.78 ± 0.93^{Ca}	28.18 ± 0.80^{Ca}
	9	24.07 ± 0.53Da	24.36 ± 0.32Da	21.79 ± 0.28^{Cab}	20.81 ± 0.85^{Db}	24.04 ± 0.33^{Ca}	20.36 ± 1.13^{Db}
a_w	0	0.98 ± 0.01^{Aa}	0.98 ± 0.01^{Aa}	0.97 ± 0.01^{Aa}	0.98 ± 0.01^{Aa}	0.98 ± 0.01^{Aa}	0.98 ± 0.01^{Aa}
	3	0.91 ± 0.01^{Bab}	0.91 ± 0.01^{Ba}	0.89 ± 0.01^{Bc}	0.91 ± 0.01^{Ba}	0.91 ± 0.01^{Bab}	0.89 ± 0.01^{Bbc}
	6	0.80 ± 0.01^{Ca}	0.81 ± 0.01^{Ca}	0.73 ± 0.01^{Cc}	0.78 ± 0.01^{Cb}	0.80 ± 0.01^{Ca}	0.78 ± 0.01^{Cb}
	9	0.72 ± 0.01^{Da}	0.72 ± 0.01^{Da}	0.69 ± 0.01^{Dc}	0.70 ± 0.01^{Db}	0.72 ± 0.01^{Da}	0.71 ± 0.01^{Db}
LAB count (log CFU/g)	0	5.24 ± 0.12^{Bb}	5.27 ± 0.09^{Cb}	6.87 ± 0.09^{Ba}	6.89 ± 0.08^{Ca}	6.94 ± 0.07^{Ba}	6.90 ± 0.06^{Ba}
	3	7.25 ± 0.05^{Ab}	7.21 ± 0.06^{Bb}	8.05 ± 0.03^{Aa}	8.01 ± 0.04^{Ba}	8.10 ± 0.07^{Aa}	8.21 ± 0.14^{Aa}
	6	7.58 ± 0.08^{Ab}	7.60 ± 0.05^{Ab}	7.99 ± 0.11^{Aab}	8.30 ± 0.03^{Aa}	8.33 ± 0.14^{Aa}	8.37 ± 0.12^{Aa}
	9	7.41 ± 0.08^{Ab}	7.33 ± 0.04^{ABb}	7.98 ± 0.07^{Aa}	8.06 ± 0.04^{ABa}	8.18 ± 0.08^{Aa}	7.94 ± 0.08^{Aa}
pH	0	6.31 ± 0.01^{Aa}	6.32 ± 0.02^{Aa}	6.32 ± 0.01^{Aa}	6.32 ± 0.01^{Aa}	6.31 ± 0.01^{Aa}	6.30 ± 0.01^{Aa}
	3	5.76 ± 0.01^{Ba}	5.82 ± 0.01^{Ba}	5.31 ± 0.01^{Bb}	5.05 ± 0.01^{Cc}	5.09 ± 0.02^{Bc}	5.22 ± 0.05^{Bb}
	6	5.62 ± 0.03^{Ca}	5.68 ± 0.02^{Ca}	5.30 ± 0.01^{Bb}	5.14 ± 0.04^{BCc}	4.94 ± 0.02^{Cd}	5.13 ± 0.03^{Bc}
	9	5.64 ± 0.01^{Ca}	5.66 ± 0.02^{Ca}	5.21 ± 0.01^{Cb}	5.21 ± 0.03^{Bb}	5.02 ± 0.02^{BCc}	5.15 ± 0.04^{Bb}

Different lowercase letters (a–e) within the same row indicate a significant difference among the different treatments ($P < 0.05$).
Different uppercase letters (A–D) within the same column indicate a significant difference among the different fermentation days ($P < 0.05$).
CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

were fermented for 11 days in the same incubator where the ambient temperature and relative humidity were 25 ± 2 °C and 65–75%, respectively (Hu et al., 2022b). A total of 18 dry sausages (6 treatments × 3 sausages [each treatment]) in each batch were sampled on each time point (days 0, 3, 6, and 9) to determinate physicochemical properties and LAB counts. Three sausage samples from each treatment were sampled on days 0 and 9 to determine the sodium and potassium contents, the Na/K ratio, free amino acids (FAAs), organic acids, as well as the taste attributes by an electronic tongue (E-tongue). Additionally, three sausage samples from each treatment were sampled on day 9 to determine sensory attributes.

2.3. Determination of moisture content, water activity and pH of dry sausages

By dehydrating the sausage sample until constant weight at 105 °C to determine the moisture content (AOAC, 1995). Water activity (a_w) was determined using the AquaLab PawKit (Labo-Scientifica, Parma, Italy) at 25 °C. The pH was determined as suggested by Wen et al. (2019).

2.4. Determination of LAB counts

After aseptically removing the casing, 10 g of chopped and well-mixed sausage were homogenized with 90 mL sterile saline. The appropriate serial decimal dilutions of sample homogenates were prepared and then the LAB counts were counted onto the de Man-Rogosa-Sharpe agar after 72 h of incubation at 37 °C (Wen, Sun, Wang, Chen, & Kong, 2021).

2.5. Determination of the sodium and potassium contents and Na/K ratio

The contents of sodium and potassium were measured following a previously reported method (Barretto et al., 2020) with slight modifications. In brief, samples were ashed at 450 °C in a muffle furnace (Hereaus GMBH, Hanau, Germany), and then the ash was dissolved in a 1% nitric acid solution. Sodium and potassium contents were ascertained using a flame photometer (Spectrum Instruments Co, Ltd., Shanghai, China). The values obtained were compared with their respective standard curves for calculation of the milligrams of sodium and potassium per 100 g of dry sausage and the Na/K ratio.

2.6. FAA analysis

A high-performance liquid chromatography (HPLC) system (Agilent, 1100 LC, Agilent Technologies Co. Ltd., USA) with an exchange column (3 × 150 mm, 2.6 μm) was utilized for FAA analysis, according to the previous reported of Hu et al. (2021). The FAA contents were expressed as milligrams of amino acids per 100 g of dry matter.

2.7. Organic acid analysis

The contents of organic acids were determined following a previously method reported by Hu et al. (2021). In brief, 5 g of the sausage were used to extract the organic acids. The extract analysis was determined by the same equipment with FAA analysis, except that the column was replaced with C18 (4.6 × 250 mm, 5.0 μm). The contents were expressed as milligrams per gram of dry matter.

2.8. E-tongue analysis

The taste characteristics of sausage was detected and analyzed by the SA402B E-tongue (Insent Company, Atsugi-shi, Japan) with five chemical sensors (AAE [umami], AE1 [astringency], CT0 [saltiness], CA0 [sourness], and C00 [bitterness]) and two reference electrodes referred to Yin et al. (2021) with minor modifications. Briefly, the sensors were rinsed for 10 s using deionized water and activated before analysis. Subsequently, the mixed solution of minced sausage (30 g) and deionized water (150 mL) was incubated in a water bath (40 °C for 10 min), then stirred and centrifugated (5000 *g* for 10 min). The sensors were dipped in the water phase for 30 s to detected the response value.

2.9. Sensory evaluation

A total of 20 faculty and graduate students (10 males and 10 females) received professional training on the evaluation of fermented meat products were selected to assess the sensory evaluation of the dry sausage samples after a 9-day fermentation. The participants were selected, trained and monitored according to the method set by ISO 8586 (2012). Prior to the sensory evaluation, a three-week training session was conducted on establish the standards for the quantitative descriptive analysis on colour, hardness, aroma, and bitterness,

Table 3
Contents (mg/100 g dry matter) of sodium and potassium and Na/K ratio of the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains on days 0 and 9.

	Day 0		Day 9					
	CT	CS	CT	CS	*L. curvatus*	*L. sakei*	*W. hellenica*	*L. plantarum*
Sodium	897.58 ± 14.61^{c}	562.53 ± 10.21^{d}	2072.68 ± 15.74^{a}	1171.64 ± 18.35^{b}	1208.81 ± 15.24^{b}	1158.27 ± 19.20^{b}	1156.41 ± 16.45^{b}	1196.18 ± 16.09^{b}
Potassium	221.08 ± 9.57^{c}	592.14 ± 8.38^{b}	527.48 ± 13.01^{b}	1089.82 ± 9.18^{a}	1083.28 ± 16.39^{a}	1047.05 ± 9.19^{a}	1045.54 ± 9.39^{a}	1057.10 ± 10.93^{a}
Na/K	4.06 ± 0.11^{a}	0.95 ± 0.01^{b}	3.93 ± 0.07^{a}	1.08 ± 0.01^{b}	1.12 ± 0.01^{b}	1.11 ± 0.01^{b}	1.11 ± 0.01^{b}	1.14 ± 0.01^{b}

Different lowercase letters (a−c) within the same row indicate a significant difference among the different treatments ($P < 0.05$).
CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

saltiness, sourness. The intensity of each attribute was determined as the mean value of all the tasters using an arbitrary scale on a scale of 1 (low intensity) to 7 (high intensity). The samples were cut into small 2 mm thick slices after cooking at 90 °C for 20 min and placed in opaque white plastic plates that were coded with a random three-digit number. During the evaluation, each panelist was provided with purified water to clear their mouths/taste buds and required to take a 1 min break while tasting different samples.

2.10. Statistical analysis

Three independent batches of dry sausages (replicates) were produced, and all experiments were carried out in triplicate (triplicate observations) for each batch. Data were analyzed by one-way analysis of variance (ANOVA) procedure inbuilt into the Statistix 8.1 software package (Analytical Software, St Paul, MN, USA), followed by Tukey's multiple comparison test. The results were expressed as mean ± standard error (SE) and the significance of differences between samples was defined at $P < 0.05$. The PLSR model generated by Unscrambler software (version 10.4; CAMO ASA, Oslo, Norway) reflected the relationship among physicochemical characteristics, LAB counts, and taste profiles.

3. Results and discussion

3.1. Analysis of physical profile and lactic acid bacteria count

From Table 2, the initial moisture content was approximately 67.66%, and it decreased to less than 25% at the end of the fermentation due to dehydration during the fermentation process (Lorenzo & Franco, 2012). There was no influence on the moisture content of the sausages when 40% NaCl was replaced by KCl (except on day 3). Nevertheless, all four inoculated treatments showed more rapid water loss at different stages of fermentation (mainly on days 3–9) compared to the non-inoculated control sausage (CS) ($P < 0.05$), supporting that the growth and acidification of inoculated LAB facilitate the dehydration (Kaban & Kaya, 2009; Xiao, Li, Zhou, Ma, & Chen, 2018). The change in a_w was similar to the trend of moisture content, both decreasing continuously during fermentation. The L. *curvatus*-inoculated, *L. sakei*-inoculated and *L. plantarum*-inoculated sausages had the significantly lowest a_w from days 6–9 ($P < 0.05$). This phenomenon of accelerated water loss after inoculation with LAB was also seen in the fermented sausages prepared by Hu et al. (2019) and Xiao, Liu, Chen, Xie, and Li (2020). At the end of fermentation (day 9), all sausages had 0.69–0.72 a_w, which is reported to inhibit most microbial growth (Xiao et al., 2020).

The LAB counts in the inoculated sausages ranged from 6.87 to 6.94 log CFU/g on day 0, significantly higher than those in the non-inoculated sausages (approximately 5.26 log CFU/g, $P < 0.05$). For the next 6 days, the appropriate temperature and relative humidity facilitated the rapid proliferation of LAB. These microorganisms have enzymes that can metabolize carbohydrates into various metabolites, such as amino acids, peptides, free fatty acids, and organic acids (Nie, Lin, & Zhang, 2014), and sharply reduce the pH of the sausages. Thereafter, the LAB counts slightly decreased, which may be related to the shortage of available water and nutrients. After fermentation for 6 days, the formation of alkaline compounds (such as peptides, amino acids and ammonia) brought on by microbial action (Benito, Rodriguez, Cordoba, Andrade, & Cordoba, 2005) and the consumption of organic acids by molds and yeasts (Wen et al., 2023) caused the pH to stabilize or increase. Moreover, compared to the control sausages (CT and CS), the higher LAB counts and lower pH of the inoculated sausages ($P < 0.05$) were beneficial in reducing or inhibiting the spoilage and pathogenic microorganisms, thus improving the safety of fermented sausages (Nie et al., 2014). Among the inoculated sausages, those inoculated with *W. hellenica* exhibited the significantly lowest pH from day 6 until day 9 ($P < 0.05$), suggesting that *W. hellenica* had a stronger acidification capacity. Taken together, the four LAB strains involved in the study showed the ability to tolerate high salt concentration and rapid acidification, which may contribute to their key roles in sausage fermentation.

3.2. Analysis of sodium and potassium contents and Na/K ratio

Considering that there were no statistical differences among six treatments on day 0 (based on preliminary experiments and data not given), only one treatment on day 0 was used as the representation ($P > 0.05$). There was a minimum 2-fold increase in the contents of sodium and potassium after the 9-day fermentation ($P < 0.05$) (Table 3). The CS sausages significantly reduced the contents of sodium by 335.05 and 901.04 mg/100 g dry matter and increased the contents of potassium by 371.06 and 562.34 mg/100 g dry matter on days 0 and 9, respectively ($P < 0.05$). In addition, none of the four inoculated treatments affected the sodium and potassium contents of the sausages ($P > 0.05$), suggesting that the inoculation of different LAB strains did not affect the permeation of sodium and potassium in meat. Similarly, the inoculation of LAB did not affect the Na/K ratio ($P > 0.05$). On day 9, the Na/K ratio of the traditional sausages (CT) and the sausages with 40% substitution of NaCl by KCl (CS) was approximately 3.93 and 1.10, respectively, and the latter ratio was closer to the daily dietary Na/K ratio (<0.6) recommended by the WHO to reduce the risk of cardiovascular diseases (Parodi & De Lorenzo, 2003).

3.3. Organic acid analysis

Organic acids not only endow fermented foods with a distinctive taste but also enhance their nutritional value and safety (Cai et al., 2021). These compounds mainly originate as intermediates and products of secondary metabolism during microbial growth and reproduction and by the catabolism of some amino acids in foods (Liu et al., 2020). According to the results of organic acids, no statistical difference was observed among the six sausages on day 0 ($P > 0.05$), so only one sausage on day 0 (0d) was selected for analysis.

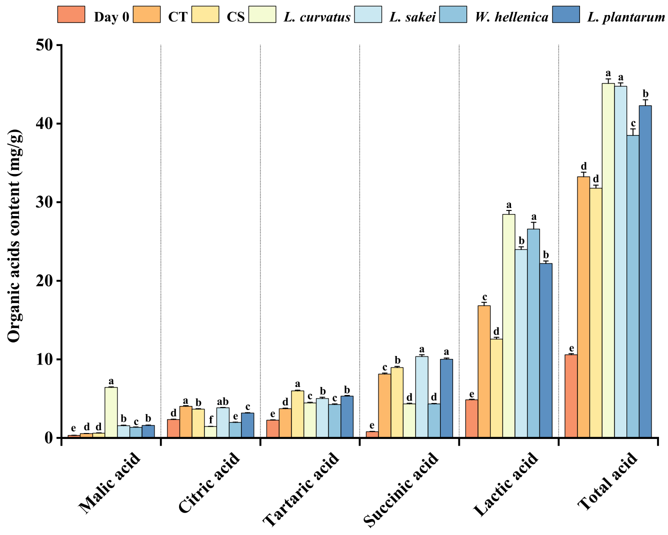

Fig. 1. Contents (mg/g) of organic acids in the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains on days 0 and 9. Different lowercase letters (a–f) within the same organic acid indicate a significant difference among the different treatments ($P < 0.05$). CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

Among the five kinds of organic acids detected in all sausages after the 9-day fermentation (Fig. 1), lactic acid showed the highest contents (12.58–26.59 mg/g), followed by succinic acid (4.34–10.02 mg/g), tartaric acid (3.72–5.98 mg/g), citric acid (1.45–3.84 mg/g), and malic acid (0.54–1.58 mg/g). As the main source of sourness, lactic acid is a good flavoring agent with mild acidity (Wang et al., 2022). The highest contents of lactic acid were found in the inoculated sausages (especially *L. curvatus* and *W. hellenica*). Succinic acid, the second-most abundant organic acid, promotes the production of its esters, contributing to the mellow mouthfeel of fermented products (Spitaels et al., 2015). Compared to the non-inoculated sausages, the contents of succinic acid were significantly higher in the *L. plantarum*-inoculated and *L. sakei*-inoculated sausages, and significantly lower in the *L. curvatus*-inoculated sausages and *W. hellenica*-inoculated sausages ($P < 0.05$). Furthermore, the contents of citric acid and tartaric acid in the *L. plantarum*-inoculated and *L. sakei*-inoculated sausages were higher than those in the *L. curvatus*-inoculated and *W. hellenica*-inoculated sausages. In terms of malic acid, the sausage inoculated with *L. curvatus* showed the highest content (6.43 mg/g). This phenomenon is likely due to the differences in the corresponding genes and enzymes participated in the organic acid biosynthesis metabolic pathways of the four LAB strains (Okoye et al., 2022). In addition, the organic acids produced would be consumed and interconverted during fermentation (Gao, Li, Xia, Xu, & Liu, 2020; Zang et al., 2020).

3.4. Free amino acid analysis

FAAs, the ultimate products of proteolysis, contribute directly to the final taste characteristics of fermented sausages (Buscailhon, Monin, Cornet, & Bousset, 1994; Tian et al., 2020). Moreover, some branched-chain amino acids (e.g., Val, Iso, and Leu) can act as precursors of flavor substances and indirectly improve the aroma of fermented sausages (Aro et al., 2010). According to their taste characteristics, FAAs can be mainly classified into umami FAAs (Asp and Glu), sweet FAAs (Ser, Thr Ala, Lys, Pro, and Gly), bitter FAAs (BFAAs; Phe, His, Arg, Val, Met, Tyr, Ile, and Leu), and the odorless amino acid (Cys) (Li et al., 2023; Wang et al., 2019). The FAA contents were similar among the six sausages on day 0 ($P > 0.05$), so only one sausage on day 0 (0d) was selected as representative.

Altogether 14 kinds of FAAs were identified in the sausages (Table 4). Various FAA profiles were exhibited in different sausages, of which Ser (0–309.77 mg/g), Gly (157.90–282.16 mg/g), Thr (49.92–172.19 mg/g), His (107.65–295.05 mg/g), and Cys (0–206.16 mg/g) were the dominant FAAs. After 9 days of fermentation, the

Table 4
Contents (mg/g dry matter) of free amino acids (FAAs) in the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains on days 0 and 9.

	Day 0	Day 9					
		CT	CS	*L. curvatus*	*L. sakei*	*W. hellenica*	*L. plantarum*
Glu	25.76 ± 0.47^{b}	89.46 ± 1.76^{a}	86.45 ± 1.97^{a}	84.82 ± 1.86^{a}	86.04 ± 1.40^{a}	85.67 ± 1.98^{a}	87.66 ± 1.36^{a}
Ser	37.53 ± 0.93^{d}	160.28 ± 3.07^{c}	25.30 ± 0.66^{d}	238.67 ± 4.77^{b}	299.83 ± 5.49^{a}	N.D.	309.77 ± 3.85^{a}
Gly	23.43 ± 0.58^{e}	232.75 ± 3.29^{b}	282.16 ± 4.37^{a}	185.51 ± 3.61^{c}	176.80 ± 3.66^{c}	157.90 ± 3.07^{d}	183.81 ± 2.94^{c}
Thr	49.92 ± 1.03^{f}	69.65 ± 1.98^{e}	108.76 ± 1.98^{d}	172.19 ± 3.40^{a}	124.29 ± 2.74^{c}	141.53 ± 1.98^{b}	143.46 ± 2.71^{b}
Ala	7.23 ± 1.22^{c}	19.19 ± 1.11^{a}	13.00 ± 0.70^{b}	15.52 ± 1.81^{ab}	13.33 ± 1.17^{b}	11.51 ± 0.45^{bc}	13.14 ± 0.71^{b}
Pro	1.43 ± 0.28^{b}	0.81 ± 0.44^{b}	7.60 ± 0.88^{a}	9.93 ± 1.37^{a}	0.60 ± 0.30^{b}	7.98 ± 1.53^{a}	2.74 ± 0.23^{b}
Lys	29.68 ± 0.66^{c}	73.95 ± 2.85^{ab}	71.42 ± 1.53^{b}	77.69 ± 2.04^{ab}	80.93 ± 1.38^{a}	74.53 ± 1.76^{ab}	81.82 ± 1.59^{a}
Tyr	8.51 ± 0.29^{c}	32.24 ± 1.54^{a}	20.14 ± 1.34^{b}	26.15 ± 1.58^{ab}	24.44 ± 1.38^{b}	23.26 ± 1.35^{b}	25.92 ± 2.26^{ab}
Ile	16.46 ± 0.75^{c}	58.37 ± 0.88^{a}	52.51 ± 1.35^{ab}	52.44 ± 2.26^{ab}	50.46 ± 2.07^{b}	49.64 ± 0.92^{b}	52.27 ± 2.04^{ab}
Leu	11.74 ± 0.29^{d}	29.57 ± 0.88^{c}	27.77 ± 1.76^{c}	44.10 ± 0.68^{ab}	40.42 ± 0.92^{b}	40.41 ± 1.12^{b}	47.25 ± 2.27^{a}
Phe	4.73 ± 0.10^{e}	30.96 ± 0.31^{b}	26.04 ± 0.54^{bc}	46.08 ± 1.81^{a}	20.39 ± 1.61^{d}	44.15 ± 1.32^{a}	23.63 ± 0.91^{cd}
His	107.65 ± 2.06^{d}	108.78 ± 1.55^{d}	295.05 ± 3.50^{a}	282.85 ± 3.17^{a}	203.77 ± 3.21^{c}	290.48 ± 3.54^{a}	245.09 ± 2.68^{b}
Arg	8.50 ± 0.85^{b}	21.11 ± 1.12^{a}	15.27 ± 1.98^{a}	16.19 ± 1.14^{a}	17.88 ± 1.60^{a}	15.60 ± 1.54^{a}	19.40 ± 1.15^{a}
Cys	20.35 ± 0.93^{c}	176.35 ± 3.73^{b}	194.54 ± 5.05^{a}	194.14 ± 3.85^{ab}	N.D.	206.16 ± 5.04^{a}	203.74 ± 4.07^{a}
Umami FAAs	25.76 ± 0.47^{b}	89.46 ± 1.76^{a}	86.45 ± 1.97^{a}	84.82 ± 1.86^{a}	86.04 ± 1.40^{a}	85.67 ± 1.98^{a}	87.66 ± 1.36^{a}
Sweet FAAs	149.22 ± 4.11^{e}	556.63 ± 6.58^{b}	508.25 ± 8.74^{c}	699.52 ± 16.93^{a}	695.78 ± 7.33^{a}	393.46 ± 8.77^{d}	734.75 ± 11.99^{a}
Bitter FAAs	157.59 ± 2.81^{e}	281.03 ± 6.14^{d}	436.79 ± 3.27^{ab}	467.79 ± 10.62^{a}	357.36 ± 10.76^{c}	463.53 ± 9.67^{a}	413.55 ± 11.23^{b}
Odorless FAAs	20.35 ± 0.93^{c}	176.35 ± 3.73^{b}	194.54 ± 5.05^{a}	194.14 ± 3.85^{ab}	N.D.	206.16 ± 5.04^{a}	203.74 ± 4.07^{a}
Total FAAs	352.92 ± 7.38^{d}	1103.48 ± 18.19^{c}	1226.04 ± 19.00^{b}	1446.27 ± 33.20^{a}	1139.18 ± 16.71^{bc}	1148.81 ± 25.44^{bc}	1439.71 ± 28.56^{a}

Different lowercase letters (a–e) within the same row indicate a significant difference among the different treatments ($P < 0.05$).
N.D.: not detected.
Umami FAAs: the total contents of umami amino acids (Asp and Glu); Sweet FAAs: the total contents of sweet amino acids (Ser, Gly, Thr, Ala, Pro and Lys); Bitter FAAs: the total contents of bitter amino acids (His, Arg, Tyr, Val, Met, Ile, Leu and Phe); Odorless FAAs: the total contents of odorless amino acids (Cys); Total FAAs: the total contents of amino acids.
CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

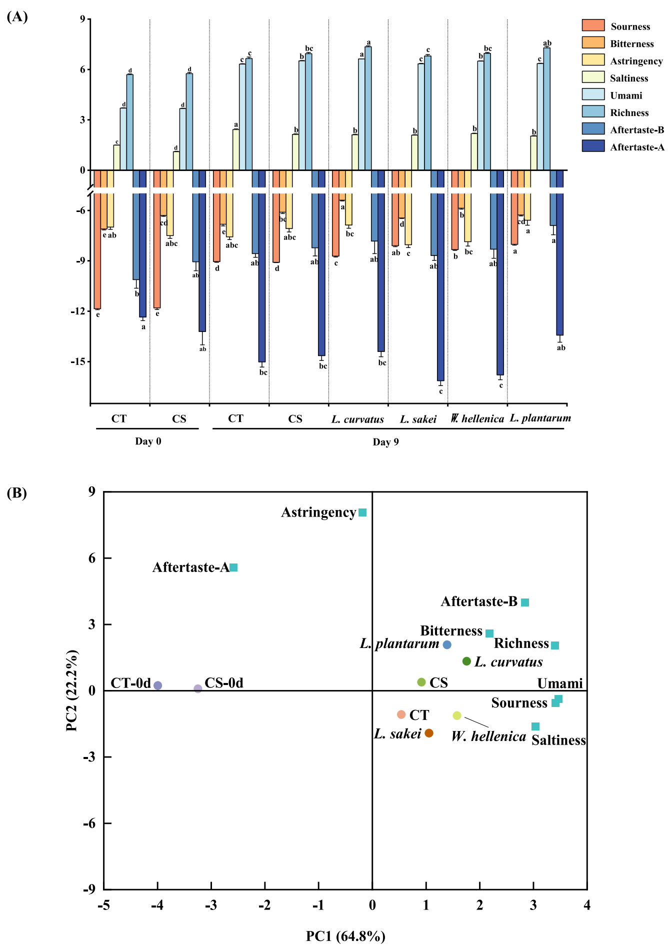

Fig. 2. Taste assessment (**A**) based on the electronic tongue responses of the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains and principal component analysis score plot (**B**) on days 0 and 9. Different lowercase letters (a–e) within the same taste indicate a significant difference among the different treatments ($P < 0.05$). CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

contents of all types of FAAs (except Ser, Ala, Pro, His, and Cys) in sausages increased significantly ($P < 0.05$), implying that the rate of formation of FAAs was higher than the rate of their degradation (Tian et al., 2020). The NaCl-substituted influenced FAAs contents, and the low-sodium sausages showed lower sweet FAAs contents and higher BFAAs and odorless FAAs contents compared to the control sausage ($P < 0.05$). Only one umami FAA (Glu) was detected in all sausages, and their contents of Glu were comparable ($P > 0.05$). The contents of sweet FAAs reached 734.75, 699.52, and 695.78 mg/g dry matter of *L. plantarum*-inoculated, *L. curvatus*-inoculated, and *L. sakei*-inoculated sausages, respectively, and were remarkably higher than those in the non-inoculated sausages ($P < 0.05$). Inoculation of L. *sakei* resulted in the lowest total content of BFAAs among the inoculated sausages, implying that inoculation of *L. sakei* could reduce the formation of BFAAs ($P < 0.05$).

In general, the total free amino acids (TFAAs) content is positively correlated with the proteolysis degree (Li et al., 2021). It can be noted that the TFAAs content was higher in the low-sodium sausages than in the CT sausages without NaCl substitution. A similar phenomenon was found in low-sodium Chinese bacon during the post-ripening phase. It is reported that K^+ could increase peptide hydrolysis in microbial cells and thus promote the release of FAA by altering the permeability of the cell membrane and increasing the flow of peptides (Gan, Zhao, Li, Tu, & Wang, 2021). In the current study, the *L. curvatus*-inoculated and *L. plantarum*-inoculated sausages had higher TFAAs than the other sausages ($P < 0.05$), suggesting that these LAB had a relatively higher proteolytic capacity. Previous studies have revealed the proteolytic activity of the four LAB strains employed in our investigation (Chen, Liu, Sun, Kong, & Xiong, 2015; Tulini, Hymery, Haertlé, Blay, & De Martins, 2016). Their proteolytic activity may be related to the exist of multiple intracellular amino, di- and tri-peptidases (Bintsis, 2018). Moreover, some LAB can also activate endogenous proteinases, playing an important role in the initial proteolysis of meats by producing acid (Casaburi et al., 2008; Fadda, Vildoza, & Vignolo, 2010). Similar result was also reported by Chen et al. (2016) who found that the contents of TFAAs were affected by addition of starter cultures in fermented sausages.

3.5. E-tongue analysis

E-tongue is an intelligent sensor system that can quickly, sensitively, and objectively evaluate differences and changes in the taste sensory attributes of foods (Jiang, Zhang, Bhandari, & Adhikari, 2018). As shown in Fig. 2A, the substitution of 40% NaCl by KCl increased the bitterness and reduced the saltiness of the sausages on days 0 and 9, as well as increased the umami taste intensity on day 9 ($P < 0.05$). On day 9, the sourness response value was higher in the LAB-inoculated sausages compared with the CS sausage, which was in accordance with the pH and organic acid results ($P < 0.05$). Furthermore, in line with the results of BFAAs, a reduction in the bitterness response value in sausages inoculated with *L. sakei* was also observed ($P < 0.05$). Binary taste−taste interactions might also be responsible for this reduced bitterness, as at specific concentrations, bitter-tasting compounds can be suppressed by the sourness (Keast & Breslin, 2003). This result could be proved by the higher contents of total organic acids in the sausage inoculated with *L. sakei* compared to the other sausages. In addition, the sausage inoculated with *L. curvatus* exhibited the highest umami and richness response values ($P < 0.05$), showing that *L. curvatus* could produce more umami compounds and numerous and various taste-active compounds compared to the other LAB (Chen, Mi, et al., 2021). Nevertheless, there was no difference in the response values of saltiness, astringency, aftertaste astringent (aftertaste-A), and aftertaste bitter (aftertaste-B) among the inoculated sausages and CS sausage ($P > 0.05$).

Table 5
Sensory evaluation in the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains on days 9.

	CT	CS	*L. curvatus*	*L. sakei*	*W. hellenica*	*L. plantarum*
Color	4.77 ± 0.21^{a}	4.45 ± 0.26^{a}	4.61 ± 0.20^{a}	5.16 ± 0.46^{a}	4.51 ± 0.35^{a}	4.75 ± 0.43^{a}
Hardness	5.54 ± 0.33^{a}	5.61 ± 0.22^{a}	5.23 ± 0.28^{ab}	4.69 ± 0.25^{b}	5.56 ± 0.31^{a}	4.65 ± 0.37^{b}
Aroma	3.78 ± 0.25^{b}	4.44 ± 0.17^{a}	4.43 ± 0.20^{a}	4.51 ± 0.20^{a}	4.45 ± 0.20^{a}	4.38 ± 0.19^{a}
Bitter taste	2.14 ± 0.35^{c}	3.46 ± 0.27^{ab}	3.58 ± 0.28^{a}	2.78 ± 0.36^{bc}	3.39 ± 0.19^{ab}	3.55 ± 0.25^{ab}
Salty taste	5.72 ± 0.26^{a}	4.45 ± 0.32^{b}	4.64 ± 0.19^{b}	4.93 ± 0.25^{b}	4.35 ± 0.17^{b}	4.86 ± 0.27^{b}
Sour taste	3.44 ± 0.36^{b}	3.32 ± 0.29^{b}	4.57 ± 0.25^{a}	5.19 ± 0.33^{a}	4.71 ± 0.46^{a}	4.63 ± 0.37^{a}

Different lowercase letters (a−c) within the same row indicate a significant difference among the different treatments ($P < 0.05$).
CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

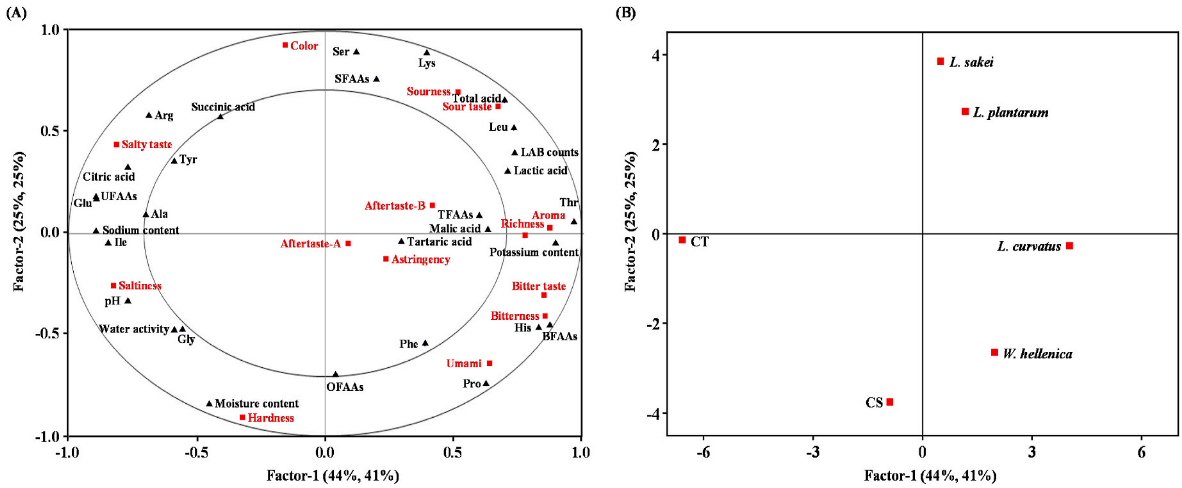

Fig. 3. Correlation loadings plot (**A**) based on partial least squares regression (PLSR) of physicochemical profiles, lactic acid bacteria counts (X-matrix), and electronic tongue sensor responses and sensory attributes (Y-matrix), and score plot (**B**) based on PLSR of the control and NaCl-substituted dry sausages non-inoculated and inoculated with different LAB strains. CT: 2.50% NaCl; CS: 1.50% NaCl +1.00% KCl; *L. curvatus*: 1.50% NaCl +1.00% KCl + *Latilactobacillus curvatus*; *L. sakei*: 1.50% NaCl +1.00% KCl + *Latilactobacillus sakei*; *W. hellenica*: 1.50% NaCl +1.00% KCl + *Weissella hellenica*; *L. plantarum*: 1.50% NaCl +1.00% KCl + *Lactiplantibacillus plantarum*.

To investigate the similarity in overall taste profiles among the sausages after 9 days of fermentation, the PCA score plot based on the E-tongue response values is shown in Fig. 2B. A total of 87.0% of the variance was explained by the PC1 (64.8%) and PC2 (22.2%). The sausages on day 0 were clustered together and away from the sausages on day 9, indicating that fermentation had an appreciable influence on the taste profile of sausages. The CS, *L. curvatus*-inoculated, and *L. plantarum*-inoculated sausages were located in the first quadrant and were associated with aftertaste-B, bitterness, and richness, indicating that the inoculation of *L. curvatus* and *L. plantarum* could cause relatively noticeable taste defects. The CT, *W. hellenica*-inoculated, and *L. sakei*-inoculated sausages clustered together in the fourth quadrant and were related to umami, sourness, and saltiness. This phenomenon suggested that the sausages inoculated with *L. sakei* and *W. hellenica* had more similar overall taste profiles to traditional dry sausages than the other inoculated sausages.

3.6. Sensory evaluation

As shown in Table 5, there was no statistical difference in color among sausages ($P > 0.05$). Compared with the control sausages, the *L. sakei*-inoculated and *L. plantarum*-inoculated sausages showed lowest scores for hardness, which was in line with the results of moisture content ($P < 0.05$). The aroma of dry sausages is the result of multi-faceted biochemical reactions (including carbohydrate fermentation, amino acid degradation, lipid oxidation, microbial esterase activity) and the addition of wine and spices during the process of preparation and fermentation (Flores, Corral, Cano-García, Salvador, & Belloch, 2015). The aroma of dry sausages using NaCl substitutes was more pronounced than in CT sausage ($P < 0.05$). This result was similar with the findings of Qin et al. (2023) who found that 40% substitution of NaCl by KCl reduced the contents of certain ketones, alcohols, acids and esters in dry sausages. However, the effect of LAB inoculation on the aroma of dry sausages was not enough to be perceived by the sensory panelists in this study ($P > 0.05$). For taste attributes, the CT sausage showed the lowest bitterness scores, followed by *L. sakei*-inoculated sausages. This observation matches the results of E-tongue and FAAs. Additionally, CT sausage had highest scores for saltiness and lowest scores for sourness. No significant differences were found in the scores for saltiness and sourness among the NaCl-substitued sausages ($P > 0.05$).

3.7. Correlation between physicochemical properties, lactic acid bacteria count, and taste properties

The PLSR model was used to investigate the potential correlation between the X-matrix, which included the physicochemical properties (a_w, water content, pH, and contents of sodium, potassium, FAAs, and organic acids) and LAB counts, and the Y-matrix, which included the E-tongue response values, sensory attributes and sausage treatment variables. As shown in Fig. 3, the first two factors revealed 69% and 66% of the variation in the X-matrix and Y-matrix, respectively. The X-matrix variables between large ellipses ($R^2 = 1$) and small ellipses ($R^2 = 0.5$) are considered highly correlated with Y-matrix variables (Yin et al., 2021). The sausages were distinguished by factor-1, as presented from left to right, and divided into three groups according to their quadrant position: group 1 (CT and CS sausages), group 2 (*L. curvatus*-inoculated and *W. hellenica*-inoculated sausages), and group 3 (*L. plantarum*-inoculated and *L. sakei*-inoculated sausages). Furthermore, there was a strong correlation between the sourness, saltiness, and bitterness responses derived from E-tongue and the sour, salty, and bitter tastes obtained from sensory evaluation. These findings showed a strong association between the results of E-tongue and taste attributes.

Group 1 (CS and CT sausages) was located in the third quadrant, and CT sausages were characterized by a strong saltiness and salty taste associated with pH, Ile, Gly, Glu, Ala, and sodium content. This result was related to the higher salt content added in the preparation process and was consistent the results of physicochemical and taste profile analysis. In addition, some studies have reported that Glu is the most abundant FAA in meat protein, which could confer foods a salty taste similar to the effect of NaCl (Inguglia, Zhang, Tiwari, Kerry, & Burgess, 2017; Tian et al., 2020). Group 2 sausages were located in the fourth quadrant and were correlated to umami, richness and bitterness, bitter taste, astringency, aftertaste-B, and aftertaste-A, indicating that inoculation of *L. curvatus* and *W. hellenica* could cause relatively noticeable taste defects. Additionally, the TFAAs, malic acid, and potassium contents are important contributors to the bitterness and richness of sausages. It has been reported that the TFAAs are an indicator of the degree of proteolysis (Chen, Mi, et al., 2021; Zhao, Zhang, Devahastin, & Liu, 2019). The release of various taste-active peptides and FAAs by proteolysis further increases the richness of foods. Group 3 sausages (*L. plantarum* and *L. sakei*) were located in the first quadrant and had a higher sour profile than the other sausages, which was mainly associated with Lys, Ser, and total acid, and might have the characteristics of sweet taste because *L. plantarum* and *L. sakei* were surrounded by sweet FAAs and sweet amino acid (Lys and Ser). This may be concluded that the inoculation of LAB could be an effective mean to compensate for the quality and flavor defects cause by the addition of KCl in the low-sodium dry sausages.

4. Conclusion

Inoculation of LAB starter cultures accelerated acidification and water loss and promoted the formation of taste compounds (FAAs and organic acids) in dry sausages with 40% substitution of NaCl by KCl to certain degrees. Inoculation of L. *sakei* effectively reduced the content of BFAAs and increased the content of sweet FAAs. The E-tongue results showed that *L. sakei* reduced the bitterness and compensated for the overall taste defects of sausage with NaCl substitution by KCl. In summary, it seems that *L. sakei* was a suitable starter culture to improve the physical and taste characteristics of low-sodium dry sausage. Further research should focus on the effect of LAB inoculation on the odor characteristics of sausages with NaCl substitution by KCl and on elucidating the specific mechanism of the contribution of LAB to the low-sodium dry sausage quality.

CRediT authorship contribution statement

Xiang-ao Li: Writing – original draft, Data curation. **Yumeng Sui:** Data curation. **Jiasheng Lu:** Investigation. **Jing Ren:** Formal analysis. **Baohua Kong:** Methodology, Conceptualization. **Yongjie Li:** Software, Resources. **Qian Chen:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Weiwei Yang:** Visualization, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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