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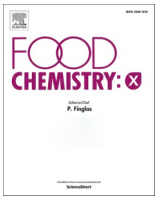

Analysis and comparison of the quality and flavour of traditional and conventional dry sausages collected from northeast China

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ABSTRACT

In this study, the physicochemical properties and flavour profile of traditional dry sausages (T-SH, T-DXAL, T-HG, T-MDJ, T-HRB) collected from various wet markets were compared with those of conventional dry sausages (C-QL, C-ND, C-YSD, C-YC, C-HRL) collected from various food companies in northeast China. Traditional dry sausages were characterised by a low moisture content, a low water activity, and a high shear force after a long fermentation time compared with conventional dry sausages. Electronic nose and electronic tongue signals combined with chemometrics methods were applied for a comprehensive qualitative analysis of the odour and taste of dry sausages. A total of 61 volatile compounds were identified using gas chromatography–mass spectrometry, and the multivariate chemometrics analysis confirmed the difference in volatile compounds between traditional and conventional samples. Moreover, the sensory evaluation revealed that conventional dry sausages lacked the characteristic fermented flavour of traditional dry sausages.

1. Introduction

Dry sausage in northeast China is a typical regional fermented meat product favoured by consumers for its unique flavour and long shelf-life (Chen et al., 2021; Hu et al., 2022). Generally, traditional dry sausage is produced by operators manually mixing minced pork lean meat and pork back fat with salt, sugar, wine, mixed spices, and nitrite, stuffing the mixture into pig small intestine casings, and then allowing it to air dry (approximately 9–12 days) in a ventilated environment at approximately 20 °C, resulting in a final product with an approximate moisture content of 30 % or even lower (Hu et al., 2020; Wen et al., 2021). However, the spontaneous fermentation that occurs during air drying relies on the microorganisms present in the raw materials and the surrounding environment, which raises problems, such as uncontrollable fermentation, long production cycles, and inconsistent product quality.

To address the above issues, industrial roasting technology (approximate 60 °C for 6–10 h) is adopted in the conventional technique instead of natural air drying, which achieves a similar moisture content to traditional dry sausage while greatly shortening the drying time, providing a uniform product quality and increasing the production efficiency. Although the conventional technique can achieve the purpose of dryness, the omission of fermentation and the shortened drying time may result in a lack of typical flavour, thus deviating from the preferences of consumers.

Flavour is among the most important quality attributes for evaluating dry sausages because of its large impact on the overall acceptance by consumers. During traditional dry sausage fermentation, carbohydrates, lipids, and proteins are hydrolysed by microorganisms to generate free fatty acids, free amino acids, and other flavour precursor compounds (Hu et al., 2022). Microorganisms and enzymes convert these flavour precursor compounds into volatile flavour compounds, including aldehydes, ketones, alcohols, acids, sulphur-containing compounds, and nitrogen-containing compounds, which endow the smell and taste of sausages (Khan et al., 2015). Previous studies have focused on exploring the quality and flavour of traditional dry sausages, meticulously describing the characteristic flavour profile of them (Chen et al., 2021; Hu et al., 2020; Wang et al., 2022a). However, with the expansion of product demand and industrialization, the production of dry sausages using conventional manufacturing technique has become a trend. Nevertheless, the short drying time of these conventional dry sausages results in a lack of characteristic flavour profile, and thus how to maintain the traditional flavour of dry sausages during the conventional manufacturing technique has become an urgent problem.

To evaluate and quantify flavour, gas chromatography–mass spectrometry (GC–MS), electronic nose (E-nose), and electronic tongue (E-tongue) are several techniques often used to detect smell or taste (Gao

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et al., 2021; Chen et al., 2021). It is reported that the mutual complement of E-nose, E-tongue, and GC–MS can provide a thorough understanding of the flavour profile (Yang et al., 2015). In our knowledge, there is little information on the flavour profiles of conventional dry sausages and no reports about its comparison with traditional dry sausages. Thus, in the present study, the flavour characteristics of traditional dry sausages collected from five wet markets were analysed alongside conventional dry sausages collected from five food companies for comparison by combined GC–MS, E-nose, E-tongue, and chemometrics methods. Moreover, the chemical composition, quality, and sensory characteristics of dry sausages were analysed and compared, and the effects of the two processing techniques on the products were explored and expounded. The obtained knowledge will be beneficial to the production of conventional dry sausages with improved characteristic flavour profiles.

2. Materials and methods

2.1. Samples

Traditional dry sausages were purchased from five cities in Heilongjiang Province. China: Suihua (T-SH), Daxing'anling (T-DXAL), Hegang (T-HG), Mudanjiang (T-MDJ), and Harbin (T-HRB). These traditional dry sausages were handcrafted by thoroughly mixing the raw materials (Table S1 in the Supplementary Materials), pouring the mixture into porcine casings of 3.0 cm in diameter to prepare sausages of approximately 0.15 kg each, followed by fermentation and natural air drying in a well-ventilated room with 60 %−70 % humidity for approximate 7–9 days. Conventional dry sausages were collected from five food companies in China: Qiulin Lidaosi (C-QL), Harbin Nongda Red Sausage (C-ND), Yishoudian (C-YSD), Yuchang (C-YC), and Harbin Roulian (C-HRL). Unlike the traditional dry sausages, these conventional dry sausages were made by machine filling and roasting, but the used ingredients and the diameter and weight of the sausages before roasting were similar to those in traditional dry sausages (Table S2 in the Supplementary Materials). The conventional sausages were hung on a roasting rack in a well-ventilated chamber at approximately 20 °C to dry naturally for 1 day and then roasted (hot air drying) in a roasting chamber at 55–65 °C for 6–10 h to accelerate the drying process. Three independent batches of dry sausage (replicates) were collected (30 sausages per batch), and the specific experiments were performed in triplicate (triplicate observations) on each sample for each dry sausage batch. Immediately, the collected dry sausages were transported back to the laboratory under vacuum-pack and refrigeration and stored at −80 °C. It is worth emphasising that microbiological analysis was carried out as soon as the sample was transported to the laboratory (not stored at −80 °C). All samples were cooked for 20 min at 100 °C before testing. A total of nine cooked batches were performed (three batches of ten manufacturers/markets per batch × triplicate observations).

2.2. Physicochemical analysis

2.2.1. Chemical composition, water activity (a_w), pH, and lipid oxidation

The chemical composition of dry sausages, including moisture, salt (NaCl), protein, and fat contents, were determined with reference to the ISO standards (ISO, 1973; ISO, 1978; ISO, 1996; ISO, 1997). Measurement of a_w was performed using the AquaLab PawKit (Labo-Scientifica, Parma, Italy), and pH was measured using an electronic pH meter (Mettler Toledo Instruments Co., Ltd., Shanghai, China) according to the method of Wang et al. (2022b). The pH meter was calibrated using pH 4.00, pH 6.86, and pH 9.18 buffer solutions (Biotopped, Beijing, China) at room temperature prior to the determination of the pH.

Lipid oxidation was determined by the thiobarbituric acid-reactive substances (TBARS) assay according to Chen et al. (2017). The chopped samples (3.0 g) were mixed thoroughly with 2-thiobarbituric acid (TBA; 1 %, 3 mL) and trichloroacetic acid (TCA; 2.5 % TCA, 0.6 % HCl, 17 mL). This mixture was heated in a boiling water bath for 30 min, and then cooled immediately. The solution (4 mL) from the cooled mixture was mixed with an equal volume of chloroform (4 mL), and centrifuged at 3,000 × *g* for 10 min. The supernatant was collected to determine the absorbance value at 532 nm, and the result was substituted into the following equation to calculate the TBARS:

$$\text{TBARS (mgMDA/kg)} = \frac{A_{532}}{W_s} \times 9.48$$

where W_s is the sample weight (g), A_{532} is the absorbance (532 nm) of the assay solution, and 9.48 is a constant derived from the molar extinction coefficient (152,000 M^{-1} cm^{-1}) of the TBA reaction product and the dilution factor.

2.2.2. Colour and shear force

Colour parameters L^* (lightness), a^* (redness), and b^* (yellowness) of dry sausages were measured with a ZE-6000 colour meter (Nippon Denshoku, Kogyo Co., Tokyo, Japan) using a 50 mm illumination area, Illuminant D65, and a 10° observer, according to Shi et al. (2020). A white reference tile ($L^* = 95.26$, $a^* = -0.89$, $b^* = 1.18$) was used for calibration. Each sample was measured in three different locations on the sample to obtain an average value as one technical replicate, and three technical replicates (nine measurements) were performed pre batch. The value of ΔE colour difference was calculated by using the following equation:

$$\Delta E = \sqrt{L^{*2} + a^{*2} + b^{*2}}$$

where L^*, a^*, and b^* are measurement of the samples.

Shear force was measured with a TA.XT2i texture analyser (Stable Micro System, UK), according to Lv et al. (2021).

2.3. E-nose analysis

The odour profile of dry sausages was analysed with the PEN3 portable E-nose system (Airsense Analytics GmbH, Schwerin, Germany) according to the method of Yin et al. (2021). The E-nose consists of pattern recognition software and a sensor array unit, and it is these metal–oxide–semiconductor (MOS) sensors that respond to different classes of volatile compounds. The response characteristics of the ten sensors are described in Table S3 in the Supplementary Materials. Briefly, the chopped sample (2.0 g) was placed into a 20 mL headspace vial (CNW Technologies, Duesseldorf, Germany) and incubated in a water bath at 45 °C for 30 min for equilibration. The headspace was transferred to the sensors by pumping the headspace gas into the sensor array at a rate of 200 mL/min, and the measurement phase lasted for 120 s. Each sample was measured in triplicate.

2.4. E-tongue analysis

Taste attributes of dry sausages were analysed with an SA402B E-tongue (Insent Company, Atsugi-shi, Japan), according to the method of Chen et al. (2021). The E-tongue has chemical sensors with high selectivity and sensitivity to compounds involved in the perception of different taste attributes, such as sourness (CA0 sensor), astringency (AE1 sensor), umami (AAE sensor), saltiness (CT0 sensor), and bitterness (C00 sensor). Prior to analysis, the sensors were calibrated. The samples (25.0 g) were homogenised with 125 mL of water for 1 min for complete extraction of the taste substances, and the supernatant was collected after centrifugation at 5,000 × *g*, 4 °C for 10 min. Measurements were carried out by immersing the calibrated sensors in the sample solution for 30 s.

2.5. Volatile compound analysis

The volatile compounds of dry sausages were extracted using a headspace solid-phase microextraction device (Supelco, Bellefonte, PA, USA) and analysed using a GC–MS system (QP2020 NX, Shimadzu Corp., Kyoto, Japan) according to the method of Chen et al. (2021). The chopped samples (3.0 g) and internal standard *o*-dichlorobenzene (3 μL, dissolved in methanol at 100 mg/L) were placed in a 20 mL headspace vial, and then the vial was sealed with polytetrafluoroethylene (PTFE) and equilibrated at 45 °C for 20 min. The PTFE was pierced by the solid-phase microextraction (SPME) fibre coated with polydimethylsiloxane/divinyl benzene/carboxyl (PDMS/DVB/CAR), and the volatile compounds were adsorbed to the fibre by further incubation of the vial in a shaking bath at 45 °C for 35 min. Afterwards, the fibre was immediately inserted into the injection port of the gas chromatography for separation on the installed InertCapWax capillary column (60 m × 0.25 mm, 0.25 μm) and then thermally desorbed at 250 °C for 6 min. After desorption, the column oven was maintained at 40 °C for 2 min, heated to 90 °C at a rate of 3 °C/min, kept at 90 °C for 5 min, raised to 200 °C at a rate of 3 °C/min, further increased to 230 °C at a rate of 15 °C/min and, finally, kept at 230 °C for 15 min. The mass spectrometer was operated at an interface temperature of 280 °C and an ion source temperature of 230 °C with a sample scan range of 45–500 *m/z*. The compounds were semi-quantified by comparison with the internal standard and tentatively identified by comparison with reference spectra in the NIST 17 mass spectral library. Volatile compounds identification was achieved by comparing the experimental mass spectra in a mass spectra library of NIST 14. Linear retention index (LRI) was obtained by calculating retention index relative to a series of standard alkanes (C6–C20) and comparing them with those reported in the database (https://www.flavornet.org/flavornet.html). Identified results were obtained with the semblance degree greater than 90 %. The composition of each volatile compound was expressed as a relative percentage of each single peak area with respect to the total peak area.

2.6. Sensory evaluation

The sensory evaluation of dry sausages was performed following the methods of Hu et al. (2021) with some modifications. Dry sausages were cut into 1 cm thick slices and placed randomly on pre-numbered plates. A total of 16 panellists (8 males and 8 females, aged 23–30 years) who had undergone previous sensory training in meat products were recruited for evaluation. Additional training for the perception of saltiness (tasting dissolved salt), acidity (tasting diluted white vinegar), and odour (smelling of pre-prepared ethyl acetate, phenyl ethyl alcohol, and refined sunflower oil as reference standards for “fruity”, “floral”, and “fatty” flavours, respectively) (Hu et al., 2022; Tian et al., 2019; Wang et al., 2022) was given to these panellists for familiarisation with the product characteristics and criteria before evaluation. All of these panellists attended the training sessions following the procedures described in ISO 8586 (2012), which were held four times a week for two weeks, with each session lasting for 2 h. After the additional training sessions, these panelists scored all samples to assess their sensory attributes in a prepared room in accordance with ISO 8589-1 (2007). During the scoring process, contact and communication were forbidden. Purified water was used for gargling between sample tastings to ensure the accuracy of the evaluation. Each sample was scored on a linear scale of intensity of five attributes (score 1 to 7): colour (1 = dark, dull; 7 = red, shiny), odour (1 = light characteristic odour; 7 = strong characteristic odour), texture (1 = soft texture; 7 = hard texture), salty (1 = light salty; 7 = strong salty), and sour (1 = light sour; 7 = strong sour).

2.7. Statistical analysis

The results are expressed as average ± standard error (SE). Data were statistically analysed using the General Linear Model (GLM) program in Statistix 8.1 software package (Analytical Software, St. Paul, MN, USA). An analysis of variance (ANOVA) with Tukey’s multiple comparison was used to assess the significance of the sample effects ($P < 0.05$). Multivariate statistical analysis, including principal component analysis (PCA), partial least squares discriminant analysis (PLS-DA), orthogonal partial least squares discriminant analysis (OPLS-DA), and the variable importance in projection (VIP) plot, was used to evaluated the differences in flavour compounds between traditional and conventional dry sausages and to search the key flavour compounds, using SIMCA 14.1 (Umetrics, Umeå, Sweden). PCA results of physicochemical characteristics (including moisture content, NaCl content, protein content, fat content, pH, a_w, and TBARS), E-nose and E-tongue data were analysed using OriginPro 2021b (Origin Lab, Massachusetts, USA), and the chord diagram was generated using an online software analysis tool (https://circos.ca/). Spearman correlation analysis was conducted for the relationship between volatile compounds and E-nose by R-4.1.2 software and visualized by drawing a heatmap using OriginPro®2021b.

3. Results and discussion

3.1. Physicochemical analysis

Physicochemical characteristics, including moisture content, NaCl content, protein content, pH, a_w, and TBARS, of traditional and conventional dry sausages are depicted in Table 1. The moisture contents of traditional dry sausages (27.02 %–32.61 %) were lower than those of conventional dry sausages (34.22 %–42.79 %), and the a_w values of the traditional dry sausages were also relatively low. The low moisture content and a_w of traditional dry sausages may be due to moisture loss during the long drying and fermentation process. By contrast, the higher moisture content of the conventional dry sausages was due to the shorter drying time or roasting process, and although the surface moisture was lost quickly, more of the internal moisture was retained. The traditional sample T-DXAL (2.81 %) had the highest NaCl content, followed by the T-HRB (2.74 %), T-SH (2.67 %), C-YSD (2.61 %), T-HG (2.38 %), C-ND (2.27 %), T-MDJ (2.21 %), C-YC (2.06 %), C-QL (2.00 %), and C-HRL (2.00 %) samples. In addition, the protein and fat content of the 10 samples ranged from 22.66 % to 38.73 % and 12.55 % to 26.49 %, respectively. These differences in the protein, fat and NaCl contents can be attributed to the formulation of the various samples or the degree of water evaporation during processing (Xiao et al., 2020).

The pH value of traditional dry sausages and conventional dry sausages ranged from 5.42 to 5.52 and from 5.76 to 5.84, respectively, with T-MDJ (5.42) and T-SH (5.44) samples (traditional dry sausages) displaying significantly lower pH values than those of the other samples ($P < 0.05$). Organic acids likely contributed to the low pH value. Organic acids are produced by the growth and metabolism of lactic acid bacteria, which are essential in traditional fermented dry sausages to kill or inhibit spoilage and pathogenic microorganisms (Muguerza et al., 2002). The TBARS values of the 10 samples ranged from 0.54 to 1.46 mg/100 g, and the significantly highest TBARS value was detected in the traditional sample T-DXAL ($P < 0.05$). However, no significant differences were found among the TBARS values of T-MDJ, C-YC, C-ND, C-YSD, and C-HRL samples ($P > 0.05$). It is reported that the TBARS value reflects the degree of lipid oxidation of products and is closely related to the colour and flavour of meat products (Lv et al., 2021).

PCA was analyzed as a complementary description used to present the spatial distribution and distance of the physicochemical characteristics of the samples (Fig. S1 in the Supplemental Materials), with the first two principal components explaining 55.3 % (PC1) and 19.4 % (PC2). The results showed that samples from the same group (traditional or conventional) were not clustered together based on physicochemical characteristics, indicating the difference of physicochemical characteristics among the same group of samples. It is worth noting that the C-ND sample is a clear outlier from the other samples, showing the great variability in the physicochemical characteristics of C-ND from the

Table 1
Means values and standard error of physicochemical characteristic of traditional dry sausages collected from various wet markets and conventional dry sausages collected from virous food companies in northeast China.

Sample	Moisture content (%)	NaCl content (%)	Protein content (%)	Fat content (%)	pH	Water activity	TBARS (mg/100 g)
Traditional dry sausages							
T-SH	29.02 ± 0.19^{f}	2.67 ± 0.06^{ab}	32.76 ± 0.24^{bc}	24.83 ± 0.46^{ab}	5.44 ± 0.01^{e}	0.865 ± 0.003^{de}	0.59 ± 0.01^{ef}
T-DXAL	32.61 ± 0.76^{de}	2.81 ± 0.09^{a}	32.47 ± 0.55^{bc}	24.45 ± 1.70^{ab}	5.52 ± 0.02^{d}	0.817 ± 0.007 ^{g}	1.46 ± 0.07^{a}
T-HG	28.91 ± 0.58^{f}	2.38 ± 0.06^{c}	33.46 ± 2.54^{b}	21.94 ± 1.85^{abc}	5.51 ± 0.01^{d}	0.857 ± 0.001^{e}	0.67 ± 0.03^{de}
T-MDJ	27.02 ± 0.69^{f}	2.21 ± 0.02^{cde}	33.31 ± 0.61^{b}	24.24 ± 0.47^{ab}	5.42 ± 0.01^{e}	0.875 ± 0.001^{bc}	0.84 ± 0.02^{c}
T-HRB	31.79 ± 0.02^{e}	2.74 ± 0.03^{ab}	38.73 ± 0.85^{a}	17.07 ± 0.96^{cde}	5.50 ± 0.03^{d}	0.840 ± 0.001^{f}	0.54 ± 0.02^{f}
Conventional dry sausages							
C-QL	42.79 ± 0.51^{a}	2.00 ± 0.06^{f}	22.66 ± 0.82^{e}	15.66 ± 1.07^{de}	5.66 ± 0.01^{c}	0.919 ± 0.002^{a}	0.97 ± 0.01^{b}
C-YC	39.39 ± 1.03^{b}	2.06 ± 0.01^{ef}	28.69 ± 0.99^{cd}	12.55 ± 0.09^{e}	5.73 ± 0.01^{b}	0.911 ± 0.003^{a}	0.80 ± 0.02^{c}
C-ND	35.44 ± 0.82^{c}	2.27 ± 0.07^{cd}	25.29 ± 0.85^{de}	19.71 ± 0.58^{bcd}	5.76 ± 0.02^{b}	0.883 ± 0.003^{b}	0.80 ± 0.01^{c}
C-YSD	40.69 ± 0.18^{ab}	2.61 ± 0.08^{b}	23.78 ± 1.19^{e}	13.87 ± 0.61^{e}	5.84 ± 0.01^{a}	0.873 ± 0.003^{c}	0.82 ± 0.04^{c}
C-HRL	34.22 ± 0.58 ^{cd}	2.00 ± 0.06^{f}	33.83 ± 0.03^{b}	26.49 ± 1.01^{a}	5.72 ± 0.02^{b}	0.878 ± 0.002^{bc}	0.82 ± 0.02^{c}

Different letters (a–g) in the same line indicate significant differences ($P < 0.05$).

others.

3.2. Colour analysis and shear force

The colour results for traditional and conventional dry sausages are shown in Table 2. The L^*-value ranged from 44.8 to 47.9 for traditional dry sausages and from 40.6 to 45.2 for conventional dry sausages. Generally, the L^*-value is related to the thin aqueous layer on the surface of the meat, and a long processing time leads to a low (increased darkness) L^*-value (Yin et al., 2021). However, in the present study, the L^*-values of traditional dry sausages (except for the *T*-MDJ sample) were significantly higher than those of conventional dry sausages ($P < 0.05$). It may be that the higher temperature in the conventional process method leads to the Maillard reaction among the sample components and contributes to the darkening of the surface (Gangolli, 1990). The C-YSD (14.7) and T-MDJ (14.5) samples had the significantly highest a^*-values ($P < 0.05$), possibly because of the differences in the raw meat colour or amount of added nitrite among the 10 samples. In particular, nitrite can react with myoglobin during roasting, fermentation or cooking to form stable *S*-nitroso haemoglobin with a bright red colour (Alahakoon et al., 2015). Traditional sausage sample T-DXAL exhibited the highest b^*-value, indicating that it also had the highest level of lipid oxidation (Lv et al., 2021), which was consistent with the TBARS result in Table 1. In addition, ΔE values of the traditional sausages were all significantly higher than those of conventional sausages ($P < 0.05$), indicating that the colour of sausages dramatical difference.

Shear force was determined to characterise the hardness of each sample (Table 2). All the traditional samples presented higher shear force values and thus higher hardness of the traditional samples than the conventional samples. Hardness and moisture content are reported to have a linear relationship (Wezemael et al., 2014). The longer drying time of the traditional samples was accompanied by more moisture loss, which corresponded to the result of moisture content in Table 1.

3.3. E-nose analysis

The E-nose is used to obtain complete odour information of a sample by sensitively responding to slight changes in volatile compounds (Zhang et al., 2021). The radar diagram in Fig. 1A shows the signal intensity of each sensor of the E-nose. Particularly high signals were observed for the W1S, W2S, and W6S sensors in all dry sausages, indicating a predominance of methyls, hydrides, alcohols, aldehydes, and ketones in these samples. In addition, the traditional sample T-DXAL had the highest signals for the W1S, W2S, and W6S sensors, indicating higher contents of methyls, alcohols, aldehydes, ketones, and hydrides in this sausage than in all other samples. The lowest W6S signal was observed for the conventional sample C-HRL, indicating a small amount of hydride in this sausage, which was easily distinguishable from the other samples. The traditional sample C-YC had the highest signals for the W3S and W5S sensors among the samples, indicating more long-chain alkanes and nitrogen oxides in this sample.

PCA showed the spatial distribution and distance of the sample odours, and the results were plotted in relation to the first two principal components (PC1 and PC2) because these components explained 75.0 % and 15.8 %, respectively, that is, the majority (90.8 %) of the variance in the original data (Fig. 1B). Thus, PCA could characterise most of the odour information. The T-HG, T-MDJ, T-SH, and T-HRB samples were clustered on the negative PC1 axis, indicating that these traditional dry sausages were similar in odour. The conventional sample C-ND was distributed on the negative PC1 axis and was correlated with the W5S, W3C, W2W, and W1C sensors. In addition, the conventional sample C-YC was distinguished from other samples by clustering with the W3S and

Table 2
Means values and standard error of colour and shear force of traditional dry sausages collected from various wet markets and conventional dry sausages collected from various food companies in northeast China.

Sample	Colour				Shear force (N)
	L^*-value	a^*-value	b^*-value	ΔE	
Traditional dry sausages					
T-SH	47.4 ± 0.1^{b}	9.4 ± 0.3^{e}	13.2 ± 0.3^{d}	51.51 ± 0.10^{a}	14.8 ± 0.8^{bcd}
T-DXAL	47.6 ± 0.2^{ab}	9.3 ± 0.5^{e}	17.6 ± 0.2^{a}	51.54 ± 0.13^{a}	16.2 ± 0.9^{ab}
T-HG	47.9 ± 0.1^{a}	9.7 ± 0.4^{de}	16.3 ± 0.3^{b}	51.52 ± 0.08^{a}	15.8 ± 0.1^{abc}
T-MDJ	44.8 ± 0.2^{cd}	14.5 ± 0.9^{a}	17.2 ± 0.5^{a}	50.14 ± 0.26^{c}	16.7 ± 0.9^{a}
T-HRB	47.4 ± 0.1^{b}	10.8 ± 0.9^{cd}	14.6 ± 0.2^{c}	50.77 ± 0.24^{b}	15.2 ± 0.6^{abcd}
Conventional dry sausages					
C-QL	44.6 ± 0.3^{d}	13.1 ± 1.2^{b}	14.7 ± 0.3^{c}	48.76 ± 0.21^{d}	9.3 ± 0.0 ^{g}
C-YC	45.2 ± 0.3^{c}	11.3 ± 0.6^{c}	13.1 ± 0.4^{d}	48.40 ± 0.48^{d}	12.1 ± 0.8^{ef}
C-ND	41.7 ± 0.4^{e}	12.8 ± 0.6^{b}	12.8 ± 0.2^{d}	45.46 ± 0.53^{e}	13.6 ± 0.6^{de}
C-YSD	40.6 ± 0.2^{f}	14.7 ± 0.4^{a}	14.3 ± 0.2^{c}	45.49 ± 0.12^{e}	11.5 ± 0.2^{f}
C-HRL	38.7 ± 0.5 ^{g}	13.0 ± 0.4^{b}	12.0 ± 0.4^{e}	42.56 ± 0.30^{f}	14.0 ± 0.5 ^{cd}

Different letters (a–g) in the same line indicate significant differences ($P < 0.05$).

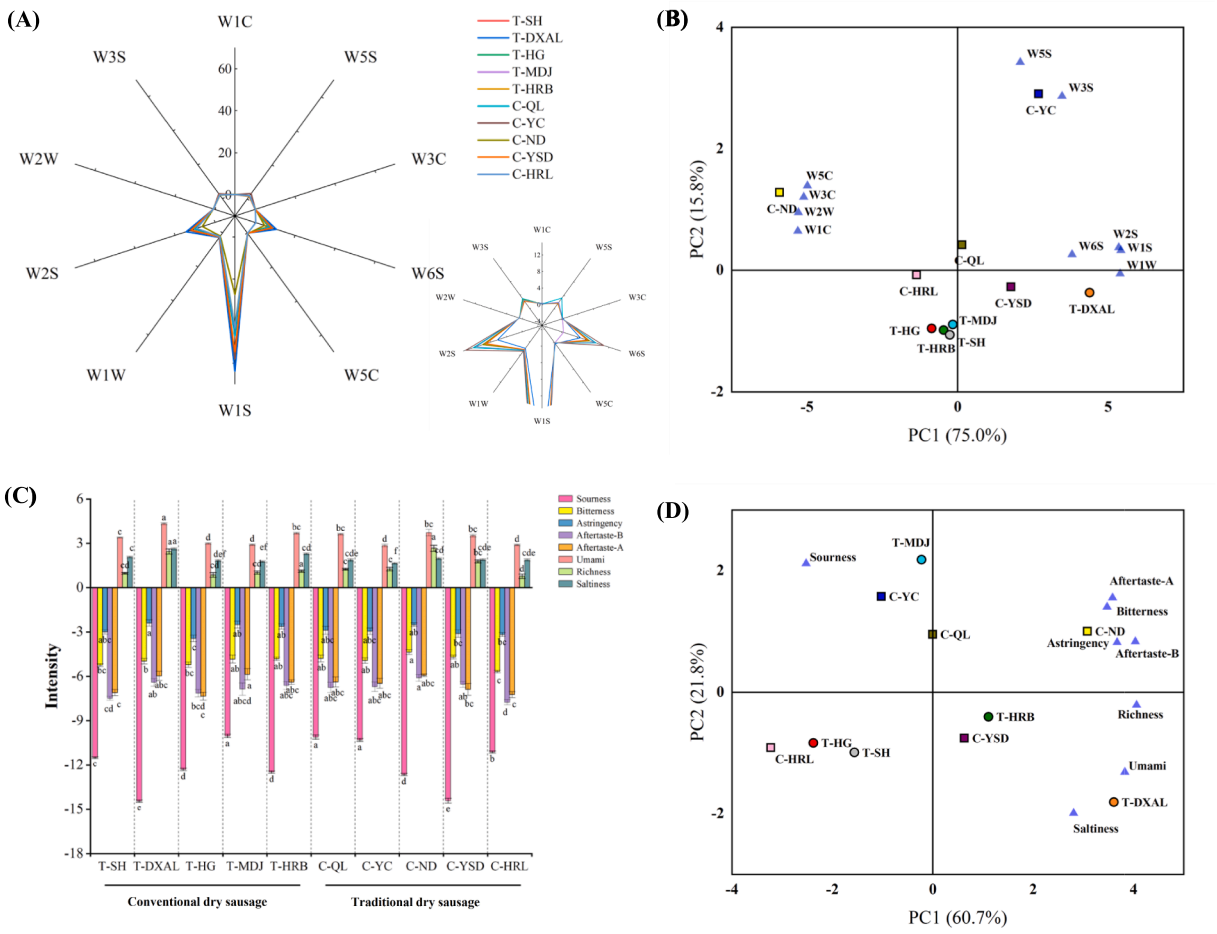

Fig. 1. (A) Sensor responses and (B) principal component analysis based on the electronic nose; and (C) taste assessment and (D) principal component analysis based on the electronic tongue of traditional dry sausages collected from various wet markets and conventional dry sausages collected from various food companies in northeast China. In (B) and (D), circles represent traditional dry sausages, and squares represent conventional dry sausages.

W5S sensors on the positive PC1 axis. These distributions showed that the sensors could effectively distinguish among various dry sausages.

3.4. E-tongue analysis

E-tongue is used to determine and classify taste by simulating the human taste system and recognising taste signals through sensors (Tan & Xu, 2020). The intensity of the eight taste sensors (signals) of different samples is presented in Fig. 1C. The sourness signals of the C-YC, C-QL, and T-MDJ samples were significantly higher than those of other samples ($P < 0.05$), which was consistent with the pH results (Table 1). The conventional sample C-ND was observed to have the highest bitterness, aftertaste-B, and richness value, which may be related to its long roasting time. For the traditional sample T-DXAL, astringency, umami, richness, and saltiness signals were the significantly highest ($P < 0.05$), and its significantly high saltiness value was consistent with the salt content in Table 1.

As shown in Fig. 1D, the majority (82.5 %) of the original E-tongue information was explained by PC1 and PC2 (60.7 % and 21.8 %, respectively). The C-YC, T-MDJ, and C-QL samples aggregated with the sourness sensor, indicating that the overall taste of these samples was relatively similar and correlated to sourness. The traditional sample T-DXAL was distinguished from other samples by the umami, richness, and saltiness sensors on the positive PC1 axis. In addition, the conventional sample C-ND was clustered with the aftertaste-A, aftertaste-B, astringency, and bitterness sensors on the positive PC1 axis.

3.5. Volatile compound profile

3.5.1. Volatile compound composition

To further explore the effect of the two different processing techniques on the flavour formation of dry sausages, the volatile compounds in samples from various wet markets (traditional dry sausage) and various food companies (conventional dry sausage) were determined by GC–MS. A total of 61 volatile compounds were detected in the samples, including 15 alkenes, 13 alcohols, 12 esters, 8 acids, 7 aldehydes, and 6 ketones, as shown in Fig. 2A and Table S4 in the Supplementary Materials.

Esters are formed mainly by the esterification of fatty acids with alcohols (Hu et al., 2020). Due to their low threshold value, esters have an important influence on the flavour formation of dry sausage (Li et al., 2021). Esters were present in a significant proportion in all traditional dry sausages, possibly because the long natural drying and fermentation promoted esterification reactions (Yu et al., 2019). In particular, ethyl butyrate, ethyl caprylate, ethyl heptanoate, and ethyl hexanoate were present in all dry sausages, which can contribute to the “floral” and “fruity” aromas (Zhang et al., 2021) and may be an important source of the pleasant aroma of these dry sausages.

Aldehydes are the major products of lipid oxidation (Zhao et al., 2021). Hexanal, heptanal, nonanal, octanal, benzaldehyde, furfural, and cinnamaldehyde were the main aldehydes detected. All dry sausage samples had low concentrations of aldehydes, but the threshold for aldehydes is low; thus, even at low concentrations, aldehydes can be important contributors to the overall flavour (Hu et al., 2020).

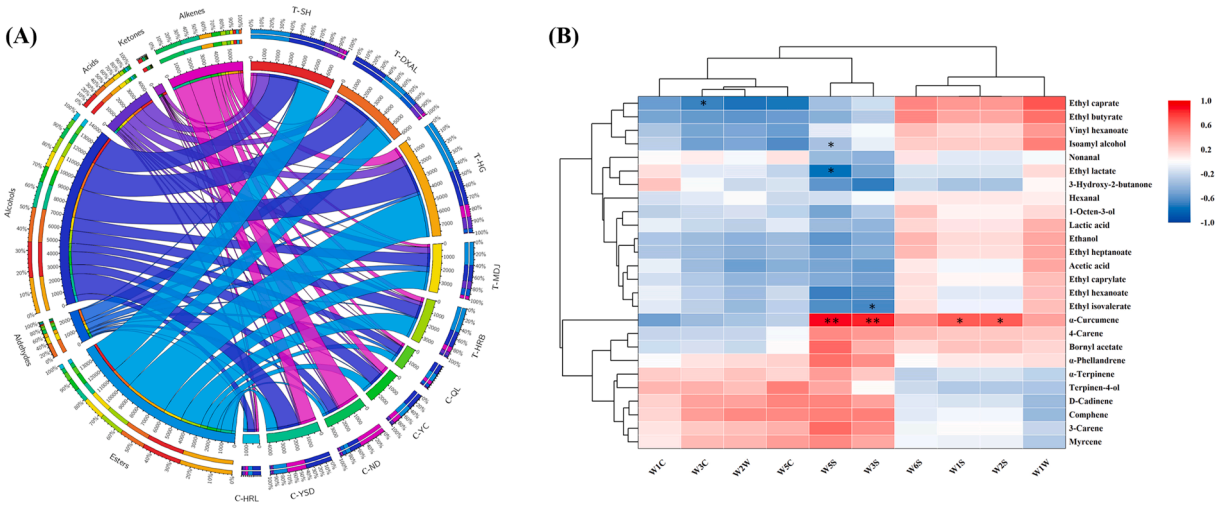

Fig. 2. A chord diagram of volatile compounds (A) and a clustering heatmap of the correlation between volatile compounds (VIP > 1) and electronic nose (B) of traditional dry sausages collected from various wet markets and conventional dry sausages collected from various food companies in northeast China. In (A), the chord diagram consists of external and internal chords: the external chord is the outermost measurement circle and indicates the content of each object; the internal chord characterises the relationship between the samples and the classes of volatile compounds. Different colours (nodes) express the different samples or different classes of volatile compounds, and the connecting lines between the nodes indicate the relationship between the two: the degree of the relationship is indicated by the width of the connecting lines and the width of the contact between the connecting lines and the circle. In (B), red, blue and white denoted positive, negative and no correlation, respectively. Significant correlation was indicated by * and **, representing $P < 0.05$ and $P < 0.01$, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Moreover, aldehydes can also serve as precursors for other aromatic compounds (Asuming-bediako et al., 2014). It is likely that the presence of volatile aldehydes in the conventional dry sausages was promoted by lipid oxidation caused by the high-temperature hot air drying. Hexanal and nonanal were detected in all samples. Hexanal is closely related to lipid oxidation and produces a distinctive "fresh grass" aroma (Hu et al., 2020). The hexanal content of the traditional sample T-DXAL was significantly higher than that of the other samples, indicating a high degree of lipid oxidation in T-DXAL, which was consistent with the TBARS result in Table 1. This sample also had the highest total aldehyde content, in agreement with the results of the W2S sensor of the E-nose.

A total of 13 alcohols were detected in this study, and the metabolic pathways of their biosynthesis in fermented meat products mainly include ketone or aldehyde reduction, amino acid metabolism, and lipid oxidation (Chen et al., 2017; Sidira et al., 2016). Overall, the total alcohol content of the traditional dry sausages, especially the T-SH, T-DXAL, and T-HG samples, was higher than that of the conventional dry sausages. Ethanol accounted for a significant proportion of all alcohols. It is mainly derived from wine in the raw material or formed through the metabolism of carbohydrates during the fermentation process. 1-Octen-3-ol originates from fatty acid oxidation, an unsaturated oxidation product of linoleic acid, and was detected in all samples but especially in T-DXAL ($P < 0.05$), suggesting that this sample underwent a higher degree of oxidation than the other samples. Cineole was detected in all samples except for T-DXAL. Cineole imparts the dry sausages a "cool herbal" aroma and might have originated from the spices used in the formulation.

Acids are produced by aldehyde oxidation and carbohydrate metabolism (Corral et al., 2013; Stahnke, 1994). A total of eight acids were detected in this study, but these acids may not contribute significantly to the flavour of dry sausages due to their high threshold values (Zhang et al., 2021). However, these acids are prerequisites for the synthesis of many flavour compounds, such as acetic acid and butyric acid, which can form other acidic compounds and serve as precursors for the synthesis of esters. Acetic acid was found at significantly greater concentrations in the traditional samples than in the conventional samples, which could be due to fatty acid oxidation or alanine catabolism by lactic acid bacteria and *Staphylococcus* during the fermentation process (Ansorena et al., 2001; Sallan et al., 2021).

Ketones are mainly derived from lipid oxidation, pyruvate metabolism, and branched-chain amino acid catabolism (Sun et al., 2010; Yin et al., 2021). Ketones accounted for a relatively low proportion in all samples (Fig. 2), but they can contribute substantially to the flavour of fermented meat products due to their low odour threshold (Wen et al., 2021). 3-Hydroxy-2-butanone was found at significantly higher concentrations in the traditional samples than in the conventional samples ($P < 0.05$). It mainly originates from pyruvate metabolism and confers unique fermentation aromas ("milk" and "fat" aromas) to the products (Montanari et al., 2016). The detection of 3-hydroxy-2-butanone and 2-heptanone in conventional dry sausages suggests that β-oxidation occurred during the hot-air drying step of their production, imparting their "fat" aroma (Yin et al., 2021).

In terms of alkenes, the distinction is due to differences in the type and content of the spices (Yin et al., 2021). For example, α-curcumene, α-terpinene, *cis*-anethol, and 3-carene mainly derive from spices and provide a pleasing fragrance to sausages. Conventional samples C-ND and C-YSD had the highest total alkene contents among the samples, and the spices mostly provided their flavours.

Considering the above results, aldehydes, and alcohols were the major volatile compounds in conventional dry sausages, whereas esters and alcohols were predominant in traditional dry sausages. Compared to conventional dry sausages, which had low levels of volatile compounds due to their short drying time, traditional dry sausages had higher levels of volatile compounds, especially esters, alcohols, and acids, which may be due to more carbohydrate metabolism, lipid oxidation, and esterification reactions caused by their long microbial fermentation and drying.

3.5.2. *Multivariate statistical analysis*

A PCA linear model was used to discriminate traditional dry sausages from conventional dry sausages by their volatile compounds (Fig. 3A). The contribution rates of PC1 and PC2 are 31.9 % and 14.2 % respectively. The scoring plot of sausages showed two completely different clusters located on the positive and negative PC1 axis, indicating great differences in the volatile compounds between the sausages because of the production technique. Furthermore, a supervised projection method, PLS-DA, was used to analyse the volatile compounds based on the PCA

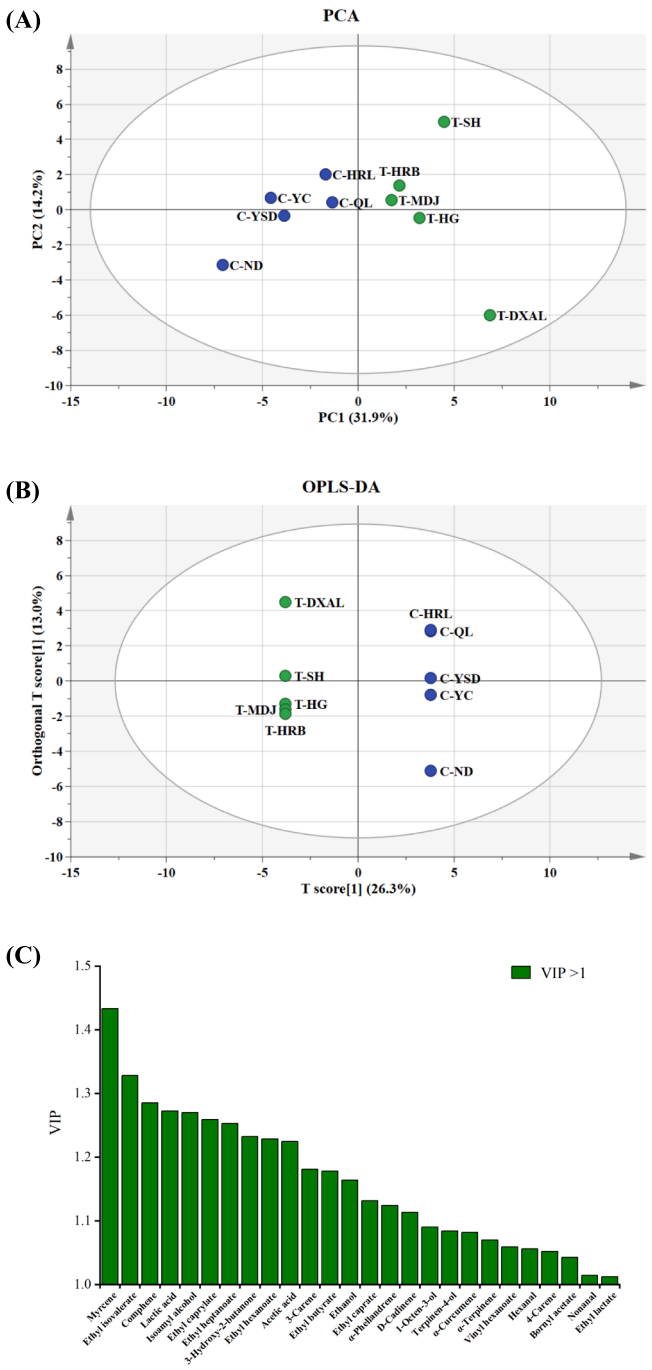

Fig. 3. Multivariate statistical analysis: (A) PCA, (B) OPLS-DA, and (C) VIP of traditional dry sausages collected from various wet markets and conventional dry sausages collected from various food companies in northeast China. In (A) and (B), the green points represent traditional dry sausages, and the blue points represent conventional dry sausages. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

result, and a similar clustering result to PCA was obtained (Fig. S2 in the Supplementary Materials). The OPLS-DA approach has enhanced interpretability compared to the PLS-DA analysis (Zhang et al., 2022). As shown in Fig. 3B, the OPLS-DA score plot showed a more pronounced separation between the two groups, fully and visually illustrating the vast differences in flavour compounds between traditional and conventional dry sausages. Moreover, the OPLS-DA model detected 26 volatile compounds with significant VIP > 1; thus, these compounds can be considered the key compounds in the samples (Fig. 3C).

The relationship between volatile compounds (VIP > 1) and E-nose was evaluated by Spearman's correlation analysis and visualized with a clustered heatmap (Fig. 2B). Obviously, there were various degrees of correlation between the volatile compounds and the sensors of E-nose, where five volatile compounds were significantly correlated with five sensors. Amongst them, several alkenes including myrcene, 3-carene, comphene, D-cadiene, terpinene-4-ol and α-terpinene were clustered and showed positive correlations with W1C (sensitive to aromatic constituents, benzene), W3C (sensitive to aroma, ammonia), W2W (sensitive to organic sulphides), W5C, W5S (sensitive to nitrogen oxides) and W3S (sensitive to long-chain alkanes) sensors, which is consistent with the structural characterization of these compounds themselves. Notably, another alkene, α-curcumene, showed extremely significant positive correlations with W3S and W5S sensors ($P < 0.01$) and significant positive correlations with W1S (sensitive to methyl) and W2S (sensitive to alcohols, aldehydes, and ketones) sensors ($P < 0.05$). In addition, significant negative correlations were also demonstrated including between ethyl caprate and W3C sensor, between isoamyl alcohol and W5S sensor, between ethyl lactate and W5S sensor, and between ethyl isovalerate and W3S sensor ($P < 0.05$). Although the correlation between these volatile compounds and the E-nose was preliminarily described by clustered heatmap, the results based on statistical analysis were not able to fully and accurately elucidate the actual odours of these compounds, and the relationship between the two should be analysed and evaluated in more depth in the future by gas chromatography–olfactometry-mass spectrometry (GC-O-MS).

3.6. Sensory evaluation

The scores assigned for the sensory attributes, including colour, odour, texture, salty taste, and sour taste, are shown in Table 3. Samples T-MDJ (a traditional sample) and C-QL (a conventional sample) were assigned the highest colour scores (5.9; $P < 0.05$), and the traditional sample T-SH received the lowest colour score (4.0, $P < 0.05$). The scores for characteristic odours (fruity, floral, and fatty) of traditional dry sausages were generally higher than those of conventional dry sausages, which could be attributed to the high activity of microorganisms and endogenous enzymes during the long drying process of traditional dry sausages that enriched the volatile flavour compounds (Fig. 2 and Table S4 in the Supplementary Materials) and imparted the "characteristic fermentation flavour". In addition, samples T-HG (4.6) and T-HRB (5.0) received higher texture scores than that of the conventional sample C-QL (4.0; $P < 0.05$). However, there was no significant difference in salty taste and sour taste scores among all sausages ($P > 0.05$). This was inconsistent with the results of E-tongue, and this inconsistency is usually due to the subjectivity of human taste perception (Hu et al., 2021).

4. Conclusion

In this study, comprehensive quality characteristics of traditional dry sausages collected from five wet markets were analysed and compared with those of conventional dry sausages collected from five food companies. The physicochemical analysis showed that traditional dry sausages were characterised by a low moisture content, low a_w, and high shear force due to the long drying process. A holistic view of the smell and taste differences among dry sausages was provided through E-nose and E-tongue, and a total of 61 volatile compounds were identified by GC–MS. The traditional dry sausages had higher contents of characteristic volatile flavour compounds, such as esters, alcohols, and acids, compared to the conventional dry sausages, which had low levels of volatile compounds. Multivariate statistical analysis showed that the traditional and conventional samples had obvious differences in volatile compounds. According to the sensory evaluation, the conventional dry sausages lacked the "characteristic fermentation flavour" of the

Table 3
Means values and standard error of sensory evaluation of traditional dry sausages collected from various wet markets and conventional dry sausages collected from various food companies in northeast China.

Sample	Colour	Odour			Texture	Salty taste	Sour taste
		Fruity	Floral	Fatty			
Traditional dry sausages							
T-SH	4.0 ± 0.6^{e}	5.4 ± 0.3^{abcd}	5.7 ± 0.3^{ab}	4.3 ± 0.2^{a}	4.4 ± 0.1^{ab}	4.3 ± 0.1^{a}	3.1 ± 0.1^{a}
T-DXAL	4.9 ± 0.7^{cd}	5.3 ± 0.3^{abcde}	5.5 ± 0.2^{ab}	4.5 ± 0.3^{a}	4.2 ± 0.2^{ab}	4.4 ± 0.4^{a}	2.9 ± 0.4^{a}
T-HG	4.4 ± 0.7^{de}	5.9 ± 0.4^{a}	5.9 ± 0.4^{a}	4.1 ± 0.4^{ab}	4.6 ± 0.2^{a}	4.2 ± 0.1^{a}	3.0 ± 0.2^{a}
T-MDJ	5.9 ± 0.7^{a}	5.7 ± 0.2^{ab}	5.8 ± 0.3^{ab}	4.4 ± 0.3^{a}	4.2 ± 0.2^{ab}	4.1 ± 0.3^{a}	3.5 ± 0.2^{a}
T-HRB	5.2 ± 0.1^{abc}	5.5 ± 0.4^{abc}	5.9 ± 0.5^{a}	3.9 ± 0.1^{abc}	5.0 ± 0.2^{a}	4.4 ± 0.3^{a}	3.1 ± 0.3^{a}
Conventional dry sausages							
C-QL	5.9 ± 0.5^{a}	4.4 ± 0.5^{e}	4.9 ± 0.3^{b}	3.4 ± 0.1^{bc}	4.0 ± 0.2^{b}	4.1 ± 0.2^{a}	3.3 ± 0.2^{a}
C-YC	5.1 ± 0.8^{bcd}	4.8 ± 0.4^{bcde}	5.2 ± 0.3^{ab}	3.1 ± 0.2^{c}	4.4 ± 0.1^{ab}	4.0 ± 0.4^{a}	3.4 ± 0.2^{a}
C-ND	5.1 ± 0.5^{abcd}	4.6 ± 0.3^{cde}	5.1 ± 0.3^{ab}	3.4 ± 0.4^{bc}	4.18 ± 0.2^{ab}	4.13 ± 0.3^{a}	3.0 ± 0.2^{a}
C-YSD	5.8 ± 0.7^{ab}	5.4 ± 0.3^{abcd}	5.0 ± 0.1^{ab}	3.2 ± 0.4^{c}	4.24 ± 0.2^{ab}	4.3 ± 0.3^{a}	2.9 ± 0.1^{a}
C-HRL	5.6 ± 0.5^{abc}	4.5 ± 0.2^{de}	5.2 ± 0.4^{ab}	3.8 ± 0.2^{abc}	4.3 ± 0.2^{ab}	4.1 ± 0.1^{a}	3.1 ± 0.3^{a}

Different letters (a–e) in the same line indicate significant differences ($P < 0.05$).

traditional dry sausages, which is a drawback of the conventional production method. The results of this study provide a theoretical basis for the future production of dry sausages with the "characteristic fermentation flavour" but under conventional production methods.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.100979.

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