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Bamboo shoots improve the nutritional and sensory quality, and change flavor composition of chicken soup

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(*E,E*)-2,4-decadienal (PubChem CID: 5283349)
(*E*)-2-octenal (PubChem CID: 5283324)
(*Z*)-4-decenal (PubChem CID: 5362620)
(*E,E*)-2,4-nonadienal (PubChem CID: 5283339)

ABSTRACT

The effect of adding bamboo shoots to stewing on the quality and flavor of chicken soup has never been reported. Therefore, this study investigated the effects of 4 kinds of bamboo shoots on the edible quality, volatile and water-soluble flavor components of Chahua chicken soup. The results showed that adding bamboo shoots changed the sensory and nutritional quality of chicken soup. A total of 62 volatile flavor components were identified by HS-SPME-GC–MS, of which 12 were identified as characteristic volatile flavor components, and 9 were the main reasons for the flavor differences between bamboo shoot chicken soup with blank chicken soup. LC-MS found that after adding bamboo shoots, the differential water-soluble components in chicken soup significantly increased, and most of the increased components have been proven to have physiological functional activity. In conclusion, adding bamboo shoots improved the nutritional and sensory quality, and changed the flavor components of chicken soup.

Introduction

Chicken is an important source of high-quality protein, fatty acids, B vitamins, and trace elements. Due to its low price, low fat and cholesterol content, and no religious restrictions, it has become a widely consumed healthy meat (Cao et al., 2021). Chicken soup is a dish made by stewing chicken as raw material, which is highly favored by consumers around the world due to its rich nutrition and unique flavor, and has become a popular food (Qi et al., 2023). In traditional Chinese dietary culture, chicken soup is regarded as a tonic product with therapeutic properties, with prevent colds, relieve inflammation, and improve immunity, especially suitable for children, the elderly and the infirm (Guan et al., 2023; Li et al., 2022). Stewing is a cooking method with prolonged heating, which promotes the release of creatinine, bioactive peptides, flavor peptides, flavor nucleotides, and free amino acids, benefit for the digestion and absorption of chicken meat (Xiao et al., 2020). The sensation of flavor is derived from the combined perception of odor and taste, which are generated by both volatile and water-soluble components. The taste of chicken soup comes from the transfer of chemical components such as protein, fat, carbohydrates and minerals contained in chicken carcasses to chicken soup, as well as taste compounds produced by the reaction of water-soluble taste precursors during stewing (Zhang et al., 2021). The unique odor of chicken soup mostly arises from processes such as lipid oxidation and the Maillard reaction (Qi, Liu, Zhou, & Xu, 2017; Zhang et al., 2018). There have been many studies related to the quality and flavor of chicken meat and soup, but few reports on the effects of adding other ingredients on the quality and flavor of chicken soup.

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Bamboo shoot, a traditional Chinese forest vegetable and the bud of bamboo, is known as the "king of forest vegetables" due to its delicious taste and rich nutrient content (mainly protein, carbohydrates, minerals, and fiber) while being low in fat and sugar (Chongtham, Bisht, & Haorongbam, 2011). Bamboo shoots and their extracts have antimicrobial and antioxidant properties and are also considered to have the potential to prevent obesity and chronic diseases, making them become one of the most popular health foods (Singhal, Bal, Satya, Sudhakar, & Naik, 2013). Fresh bamboo shoots are an important ingredient in many dishes, because they are rich in dietary fiber, and the oil holding capacity of bamboo shoots dietary fiber is better than that of other sources of dietary fiber (Dong, Li, Guo, Zhao, & Cao, 2023), so they are often processed into appetizer soups, stir-fries or other stews (Chongtham et al., 2021). Previous studies mainly focused on the nutrition composition of bamboo shoots and the application of their functional active ingredients in fields such as food and medicine (Singhal et al., 2013). However, few studies report the effects of bamboo shoots on the quality and flavor of dishes.

Bamboo shoots chicken soup is a stew made of bamboo shoots and chicken as the main raw materials. Because of its unique flavor, fresh and fragrant, healthy, nutrition, less oil slick, and stimulate appetite, it has become one of the indispensable traditional delicacies of Chinese people, known as "treasures in dishes". However, most of the current research reports on the quality differences between different varieties or different parts of chicken, as well as the effects of different processing methods on the quality and flavor of chicken soup (Feng et al., 2018; Qi et al., 2023; Zhang et al., 2020), while the effects of adding bamboo shoots stewing on the quality and flavor of chicken soup have never been reported, which limits the research and dissemination of bamboo shoots chicken soup to a certain extent.

Therefore, this study selected Chahua chicken (a high-quality local chicken breed in Yunnan, China, famous for its high quality, sweet, and fresh meat (Zhao et al., 2021) and 4 kinds of bamboo shoots as raw materials to explore the effect of adding bamboo shoots for stewing on the quality and flavor of chicken soup. On the basis of comparing of sensory and nutritional quality of several chicken soups, the differences and changes of volatile and water-soluble components in chicken soup were further analyzed by headspace solid phase micro-extraction gas chromatography-mass spectrometry (HS-SPME-GC–MS) and liquid chromatography-mass spectrometry (LC–MS) techniques to explain the reasons why adding different varieties of bamboo shoots to stew changed the quality and flavor of chicken soups. This will provide a theoretical basis for the quality control, flavor research, and development of bamboo shoots chicken products in the future.

Materials and methods

Materials

Chahua chickens (220 d, 1.6 ± 0.2 kg) were provided by the practice chicken farm of Yunnan Agricultural University. *Dendrocalamus brandisii* was picked from Xishuangbanna, Yunnan Province. *Pleioblastus amarus, Dendrocalamus latiflorus* and *Phyllostachys praecox* were purchased from Zhejiang Gengshengtang Ecological Agriculture Co. 2-octanol is chromatographic grade and other chemical reagents are analytical grade.

Sample preparation and treatment

Raw material pretreatment

Fresh bamboo shoots are shelled, and a knife is used to remove highly lignified tissues. They are then washed multiple times with distilled water to remove impurities such as soil on the surface. After draining the surface moisture, cut lengthwise into strips of 5 × 1 × 1 cm. Chickens were slaughtered by the Yunnan Livestock Processing and Engineering Technology Research Center of Yunnan Agricultural University. The slaughter was performed using cervical dislocation, and the whole process was carried out in accordance with the National Experimental Animal Slaughter Standard of China. All procedures conducted with the chickens were approved by the Yunnan Agricultural University Animal Care and Use committee (approval ID: YAUACUC01). After slaughtering, washing, removal of head, neck, feet and visible fat, Chahua chicken were cut into 3 × 3 × 3 cm pieces, mixed and randomly divided into 5 groups.

Processing of chicken soup samples

The chicken soup was processed according to the method described by Feng et al. (2018), with slight modifications. Simply put, the weight ratio of chicken, bamboo shoots, water, and salt is 100:35:300:2.5. Chicken soup is classified by bamboo shoot type: *Pleioblastus amarus* (PA), *Dendrocalamus latiflorus* (DL), *Phyllostachys praecox* (PP), *Dendrocalamus brandisii* (DB), and control check (CK, no bamboo shoots added). Heat the chicken with water in an induction cooker at 1800 W until it boils, add bamboo shoots and salt, and the stew was simmered at 500 W for 3 h. Add boiling water to the initial level every 30 min during stewing. The chicken soup was filtered through gauze, a part of the sample was used for sensory evaluation, and the remaining samples were stored at −20 °C in the refrigerator for future use.

Sensory evaluation of chicken soup

The overall quality of chicken soup was evaluated by sensory evaluation according to the method described by Zhan et al. (2020), with slight modifications. A panel of 20 professionally trained food master's students (10 men and women, aged 23 to 30, all participants were informed of all the details of the experiment and their consent was obtained prior to the start of the sensory experiment) rated the chicken soup for color (X_1), floating oil (X_2), texture (X_3), aroma (X_4) and taste (X_5). Samples were randomly allocated to group members within the range of 50–60 °C, and the overall score of samples(X) was calculated according to the formula:

$$X = 0.1X1 + 0.1X2 + 0.1X3 + 0.3X4 + 0.4X5$$

Determination of the edible quality of chicken soup

The moisture, total sugar, and crude fat content of chicken soup were determined according to the method prescribed by AOAC (1990). The pH value of chicken soup was determined by pH meter (FE-28, Mettler-Toledo Instruments (Shanghai) Co., China), and the content of soluble solids in chicken soup was determined by portable digital refractometer (PAL-3, Atago, Japan). Amino acid nitrogen was determined by formaldehyde titration (Liu et al., 2021).

Determination of volatile flavor components

Determination of volatile flavor components in chicken soup according to the method of Qi et al. (2023) and slightly modified. 10.00 mL chicken soup was taken into a 40.00 mL headspace bottle (frozen chicken soup samples were thawed at 4 °C for 12 h), and 10.00 μL internal standard solution of 2-octanol (16.40 mg/L) and magnetic rotor were added. The samples were equilibrated at 60 °C for 15 min on a solid-phase microextraction operating platform, followed by headspace extraction with an aged extraction head (fiber) (50/30 μm DVB/CAR/PDMS, Supelco, USA) for 30 min (60 °C). After extraction, the fiber was inserted into the GC injection port for desorption (5 min, 250 °C) and subsequent analysis.

GC–MS conditions: The volatile flavor components were analyzed by gas chromatography-mass spectrometry (7890B/5977B, Agilent Technologies, USA) and HP-5MS quartz capillary column (30 μm × 250 μm × 0.25 μm). The carrier gas was He, and the flow rate was 0.80 mL/min. Electron impact (EI) ion source; electron energy: 70 eV; transmission line temperature 250 °C; ion source temperature 230 °C; quadrupole temperature 150 °C. Full scan acquisition mode, mass scanning range (*m/z*) 35–550 u.

Identification of volatile flavor compounds: The NIST 14.0 standard library computer was used to retrieve the mass spectrometry information of the comparison substance peak. Volatile flavor compounds with a match greater than 80 were retained. Semi-quantitative determination was performed with 2-octanol as internal standard. Odor activity value (OAV) is an important index to evaluate the characteristic aroma components. OAV is determined by the threshold value of volatile flavor components and their concentration in the flavor system. Compounds with OAV ≥ 1 were defined as characteristic flavor components. The OAV of characteristic flavor components was used as the dependent variable, and different experimental groups were used as independent variables for principal component analysis (PCA) and orthogonal partial least squares-discriminant analysis (OPLS-DA).

Determination of water-soluble components

The chicken broth samples were thawed, centrifuged at 12,000 rpm for 10 min at 4 °C, and filtered through 0.22 μm membrane. The chicken broth filtrate was detected by LC–MS.

LC-MS conditions: The LC analysis was performed on ACQUITY UPLC System. Chromatography was carried out with an ACQUITY UPLC ® HSS T3 (100 × 2.1 mm, 1.8 μm) (Waters, USA). Column temperature: 40 °C; flow rate: 0.30 mL/min; injection volume: 2.00 μL. Mass spectrometric detection of metabolites was performed on Q Exactive (Thermo Fisher Scientific, USA) with ESI ion source. Simultaneous MS1 and MS/MS (Full MS-ddMS2 mode, data-dependent MS/MS) acquisition was used. Spray voltage: 3.50 kV and −2.50 kV for positive and negative ions, respectively; sheath gas: 40 rab; auxiliary gas: 10 rab; capillary temperature: 325 °C; primary and secondary resolutions of 70,000 and 17,500, respectively; dynamic exclusion was used to remove unnecessary MS/MS information (Want et al., 2012).

Statistical analysis

All results are expressed as mean ± standard deviation and repeated 3 times for each group. Using IBM SPSS Statistical 26.0 software to perform one-way analysis of variance (ANOVA) and Duncan's multiple tests on experimental data, significant differences are indicated when $P < 0.05$. Use Origin 9.0, GraphPad Prism 9.5.0 software and R language package to draw and process images. Multivariate statistical analysis was performed using SIMCA 14.0 software.

Results and discussion

Effect of bamboo shoots on sensory quality of chicken soup

The appearance and sensory qualities of five kinds of chicken soup processed by stewing are shown in Fig. 1A and B, respectively. In terms of the color, the CK group scored lower than the other four groups, indicating that adding bamboo shoots would change the color of chicken soup, presenting it pale yellow or milky white (Fig. 1A). Similarly, the oil slick score of CK was lower than that of the other four groups, and the oil slick of chicken soup after adding bamboo shoots was reduced, which was consistent with the crude fat measurement results, and may be related to the adsorption of bamboo shoots. The texture of DB and PP is better than CK, while the difference between PA, DL, and CK is not obvious ($P > 0.05$). The aroma of DL, PP, and DB was better than CK, but there was no significant difference between PA and CK ($P > 0.05$). The taste of DB and PP was better than CK and PA, and the difference between DL and CK was not obvious ($P > 0.05$). Overall, DL, PP and DB are better than CK and PA, while the difference between CK and PA is not obvious ($P > 0.05$), DB is the most popular, CK is the worst. PA is the worst of the four kinds of bamboo shoot chicken soup, possibly due to the *Pleioblastus amarus* is too bitter, and the bitter ingredient is dissolved in chicken soup to limit its acceptability (Ao et al., 2022; Gao et al., 2019).

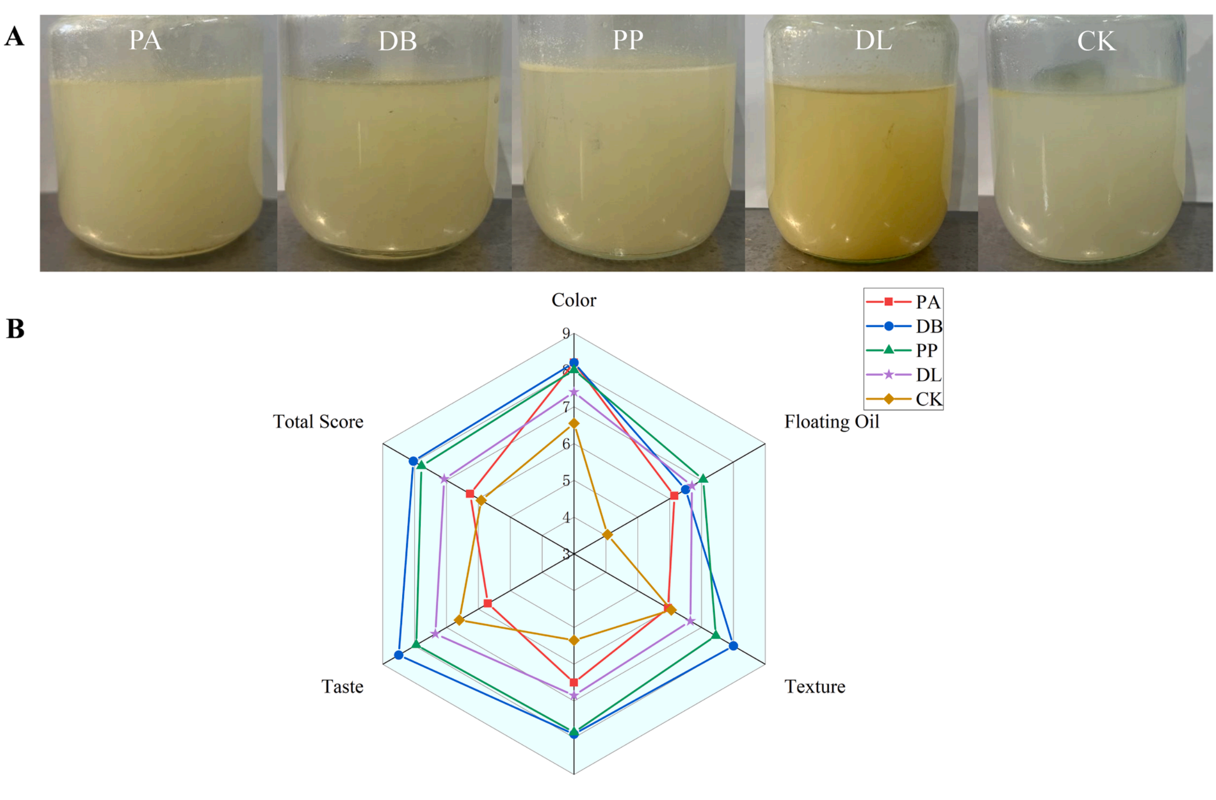

Fig. 1. Five kinds of chicken soup appearance (A) and sensory score radar chart (B).

Effect of adding bamboo shoots on the nutritional quality of chicken soup

The effect of adding bamboo shoots on the nutritional quality of chicken soup was shown in Fig. 2. The moisture content of the five kinds of chicken soup was above 98 %, consistent with the research results of Qi et al. (2022). Among them, CK is the highest (98.99 %), which is significantly higher than PA, DL, and DB ($P < 0.05$), possibly due to the protein, minerals, and other nutritional components of bamboo shoots dissolving into chicken soup during the stewing process, which reduces the overall moisture content (Lin, Tao, Su, Zhang, & Zhong, 2020). Acidity is an important factor affecting the flavor of chicken soup, which not only affects the chemical reaction related to flavor, but also affects the consumer's eating feeling (Shi, Pu, Zhou, & Zhang, 2022). Among the 5 kinds of chicken soup, the pH value of CK was the highest (5.23), PP was the lowest (5.03), and CK was significantly higher than the other 4 groups ($P < 0.05$). Soluble solids are an important indicator for evaluating the nutritional quality of soups, reflecting the overall dissolution of nutrients and flavor components (Lin et al., 2020). After adding bamboo shoots, the soluble solid content of chicken soup significantly increased ($P < 0.05$), may be caused by the dissolution of amino acids, sugars, minerals, and other components in bamboo shoots during the stewing process, and the DB is the highest (Qi et al., 2017; Zhang et al., 2018). The crude fat of CK was significantly higher than that of the other 4 groups ($P < 0.05$), which is consistent with the report of Zeng et al. (2016), and may be due to the adsorption of bamboo shoots dietary fiber reducing the fat content of the soup. Although the fat dissolved during chicken braising increases the nutrition and flavor of the soup, more fat also reduces the acceptability, quality, and increase health risks of the soup. Similarly, the sugar dissolved from bamboo shoots significantly increased the total sugar content of chicken soup ($P < 0.05$), and give the soup more nutrition and flavor (Duan et al., 2021). Amino acid nitrogen content can reflect the levels of peptides and amino acids, and to some extent reflect the freshness (Liu et al., 2021). Except DL and PP, addition bamboo shoots had no significant effect on the content of amino acid nitrogen in chicken soup ($P > 0.05$). Therefore, adding bamboo shoots to stew increases the nutritional quality and health appeal of chicken soup.

Effect of adding bamboo shoot on volatile flavor components of chicken soup

Overall changes in volatile flavor components

As shown in Table S1 and Fig. S1 in the Supplementary materials, a total of 62 volatile flavor compounds were detected by HS-SPME-GC–MS from 5 types of chicken soup. These compounds can be categorized into 4 groups, including alkanes (28 kinds), alcohols (5 kinds), aldehydes (19 kinds) and other ingredients (10 kinds). Specifically, CK, PA, DL, PP, and DB had 34, 32, 34, 25, and 35 volatile flavor compounds detected respectively. Among them, 17 volatile flavor compounds were common to 5 kinds of chicken soup, namely nonanal, hexanal, decanal, heptanal, (*E*)-2-decenal, tetradecane, 2,4-nonadienal, (*Z*)-2-heptenal, (*E,E*)-2,4-decadienal, (*E*)-2-octenal, 2-undecenal, heptadecane, hexadecane, octadecane, 1-octen-3-ol, pentanal, and vinyl hexanoate. Indicating that complex chemical reactions occurred during the stewing process of adding bamboo shoots, and new volatile compounds were generated while volatile compounds were lost or covered (Guan et al., 2023).

For the content of total volatile flavor components, CK was the highest at 357.39 μg/L, significantly higher than PA (128.07 μg/L), DL (227.31 μg/L), PP (154.50 μg/L), and DB (145.69 μg/L) ($P < 0.05$). The reason may be that the bamboo shoots absorb the fat in the soup, which is the main source of volatile flavor components. Lipid oxidation, carbohydrate thermal reaction, thiamine degradation, and Maillard reaction are the main ways of formation of volatile components in chicken soup (Zhang et al., 2018). Alkanes are mainly produced by lipid oxidation. Although the most types of alkanes were identified in chicken

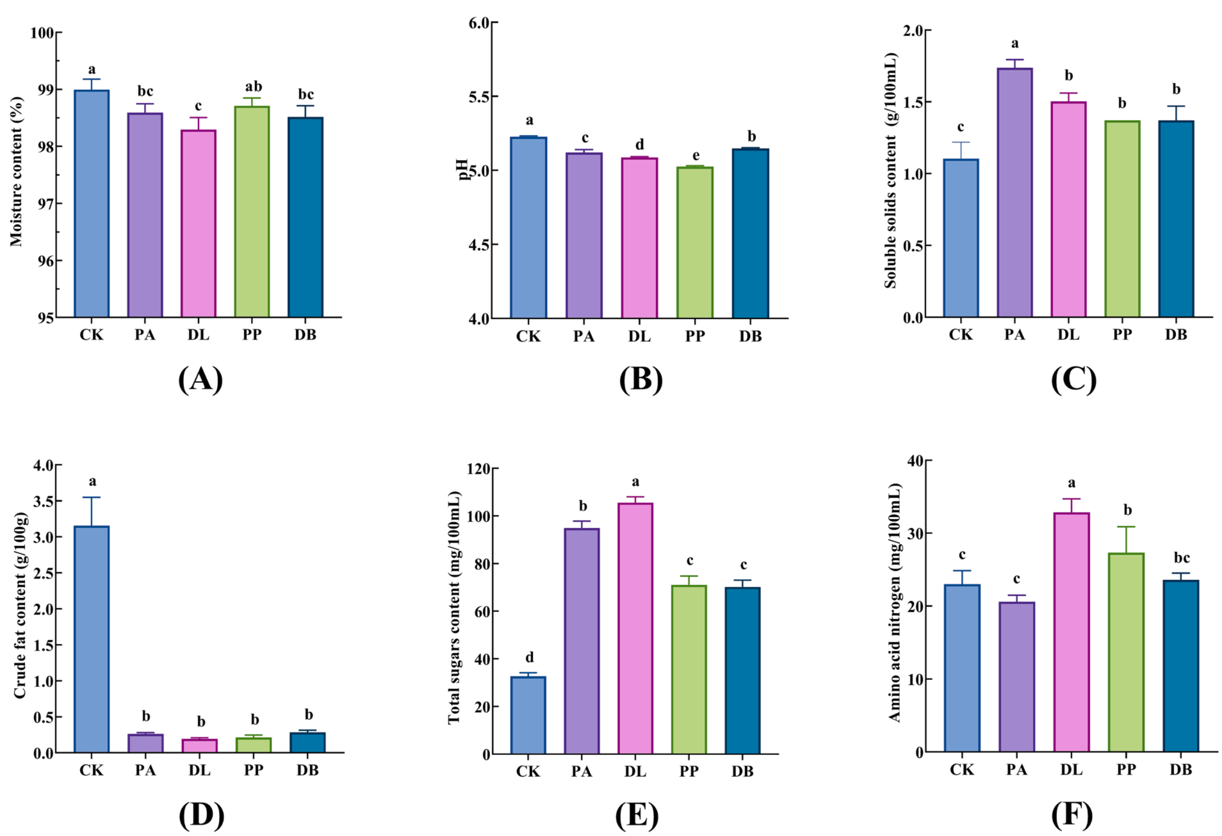

Fig. 2. Effects of bamboo shoot addition on moisture content (A), pH (B), soluble solids content (C), crude fat content (D), total sugar content (E), and amino acid nitrogen content (F) of chicken soup, (n = 3).

soup, alkanes often had a higher threshold value and contributed less to the overall flavor of chicken soup (Zhan et al., 2020). Moreover, the total content of aldehyde compounds in chicken soup was the highest, and its odor threshold was low, which contributed greatly to the overall volatile odor of chicken soups (Qi et al., 2017). In general, the addition of bamboo shoots change the flavor of chicken soup, manifested by changes in the types and content of volatile flavor components in chicken soup, such as (*Z*)-4-decenal, (*E*)-2-decenal, (*E,E*)-2,4-nonadienal, and 2-pentylfuran, etc., which may be related to the decrease of fat content in chicken soup after adding bamboo shoots and the adsorption performance of bamboo shoots dietary fiber.

Changes in characteristic flavor components

Among the many flavor components of chicken soup, only a small portion plays a leading role, and their interaction constitutes the flavor characteristics of chicken soup. The contribution of volatile compounds to the overall flavor of chicken soup was usually evaluated by the size of their OAV. As shown in Table 1, a total of 12 volatile flavor components in the 5 chicken soups with OAV > 1, mainly aldehydes (11 types, namely octanal, nonanal, hexanal, heptanal, (E)-2-nonenal, (E)-2-decenal, (E,E)-2,4-decadienal, (E)-2-octenal, etc), including 10 in the CK, 8 in the PA, 6 in the DL, 7 in the PP, and 6 in the DB. Previous studies reported that aldehydes such as (*E,E*)-2,4-decadienal, hexanal, nonanal, (*E*)-2-decenal, (*E*)-2-octenal, octanal, (*E,E*)-2,4-nonadienal, (*E*)-2-nonenal play an important role in the overall flavor of chicken soup, which is consistent with the results of this study (Feng et al., 2018; Qi et al., 2017). Compared with CK, the types and contents of characteristic flavor components of chicken soup decreased after adding bamboo shoots, indicating that the addition of bamboo shoots could change the contribution of characteristic flavor components to chicken soup. The characteristic flavor components that made a greater contribution to the CK were nonanal, (Z)-4-decenal, and (E,E)-2,4-decadienal. Additionally, nonanal, (E,E)-2,4-decadienal and (E,E)-2,4-nonadienal also made a greater contribution to the four types of bamboo shoot chicken soups. (Z)-4-decenal is the characteristic flavor component of CK, and the key substance to distinguish CK from four types of bamboo shoot chicken soups. Similarly, 2-methylpentanal is the unique flavor component in DB that imparts "ethereal, fruity, green" odors to chicken soup, which makes it the main component that distinguishes DB from other chicken soups.

Key components of flavor difference

PCA analysis and cluster analysis of differential volatile flavor components more directly reflected the changes of flavor components of chicken soup after adding several bamboo shoots (Fig. 3A, C). Due to the different thresholds of flavor components, their content could not fully reflect their contribution to the overall flavor of chicken soup, so this study used the OAV value of flavor components as an evaluation index to conduct OPLS-DA analysis (Fig. 3B) (Yang et al., 2022). The OPLS-DA analysis results showed that DB and DL were clustered together, PP and PA were clustered together, and CK was clustered separately, indicating that the overall contribution of aroma compounds in the four bamboo shoot chicken soups to aroma was similar, but different from the CK chicken soup. Variable importance in projection (VIP) describes the overall contribution of each component to the model, and the VIP value of each component is obtained through OPLS-DA analysis. By limiting the VIP value of flavor components, 9 characteristic flavor components (eucalyptol, (*Z*)-4-decenal, octanal, 2-methylpentanal, (*E*)-2-nonenal, nonanal, hexanal, (*E,E*)-2,4-nonadienal and heptanal) were obtained with VIP > 1. Eucalyptol, 2-methylpentanal, octanal, (*Z*)-4-decenal, (*E*)-2-nonenal, nonanal, hexanal, (*E,E*)-2,4-nonadienal and heptanal were considered to be the main factor contributing to the flavor differences between CK and the other two cluster groups. Among them, eucalyptol, octanal, (*Z*)-4-decenal, (*E*)-2-nonenal, nonanal, hexanal and (*E,E*)-2,4-nonadienal are the main components that cause flavor differences between CK with DB and DL, while eucalyptol, octanal, (*Z*)-4-december, (*E*)-2-nonnal, nonnal, hexanal, and (*E,E*)-2,4-nonadial are the main flavor components that cause flavor differences between CK with PP and PA. In summary, combined with sensory evaluation, basic nutritional quality and flavor analysis, it can be seen that DB group chicken soup is superior in volatile flavor types, flavor coordination and acceptability.

Effect of adding bamboo shoots on water-soluble components of chicken soup

Overall analysis of water-soluble components in chicken soup

A total of 305 water-soluble components, including organic acids and their derivatives, organic heterocyclic compounds, lipids, and lipid molecules, were identified from 5 chicken soups using LC-MS under positive and negative ion modes (Fig. S2A). PCA (Fig. S2B) and OPLS-DA (Fig. S2C–F) analysis of water-soluble components showed that the chicken soup with bamboo shoots was obviously separated from CK, indicating that adding bamboo shoots to stew obviously changed the water-soluble components in chicken soup. The reason may be that water-soluble components such as proteins, lipids, amino acids, and carbohydrates in bamboo shoots dissolve into chicken soup during the stewing process, promoting the formation of water-soluble components in chicken soup (Lin et al., 2020; Qi et al., 2017).

Screening and analysis of differential water-soluble components

Based on the results of OPLS-DA analysis, and with VIP > 1, fold change (FC) ≥ 2 or FC ≤ 0.5, and $P < 0.05$ as the standard, 85 water-soluble components with significant differences between bamboo

Table 1
OAV of characteristic flavor components of chicken soup.

Compound	Odor description	Threshold(ug/L)	OAV				
			CK	PA	DL	PP	DB
Eucalyptol	Eucalyptus, herbal, camphor, medicinal.	1.1	27.88	1.03	3.69	–	–
Octanal	Aldehydic, waxy, citrus, orange, peel, green, herbal, fresh, fatty.	0.587	15.87	12.45	–	9.00	–
Nonanal	Waxy, aldehydic, rose, fresh, orris, orange, peel, fatty, peely.	0.0011	28737.49	11755.57	10281.42	10201.09	6002.32
Hexanal	Fresh, green, fatty, aldehydic, grass, leafy, fruity, sweaty.	5	6.71	5.82	2.88	5.52	4.09
Heptanal	Fresh, aldehydic, fatty, green, herbal, wine-lee, ozone.	2.8	1.04	<1.00	<1.00	<1.00	<1.00
(*E*)-2-nonenal	Fatty, green, cucumber, aldehydic, citrus.	0.19	–	6.48	–	9.57	–
(*E*)-2-decenal	Waxy, fatty, earthy, coriander, green, mushroom, aldehydic.	17	2.20	<1.00	<1.00	<1.00	<1.00
(*E,E*)-2,4-decadienal	Oily, cucumber, melon, citrus, pumpkin, nut, meat.	0.077	231.77	70.05	211.07	241.09	83.01
(*E*)-2-octenal	Fresh, cucumber, fatty, green, herbal, banana, waxy, green, leaf.	3	7.36	2.96	2.42	3.92	2.70
(*Z*)-4-decenal	Citrus, aldehydic, orange, watery, cardamom.	0.004	621.98	–	–	–	–
(*E,E*)-2,4-nonadienal	Fatty, melon, waxy, green, violet, leaf, cucumber, tropical, fruit, chicken, fat.	0.1	93.88	24.88	33.36	28.38	22.86
2-Methylpentanal	Ethereal, fruity, green.	1.6	–	–	–	–	16.46

Note: "–": means not detected. "Threshold" were taken from a book titled "Compilations of odor threshold values in air, water and other media" (Van Gemert, 2011).

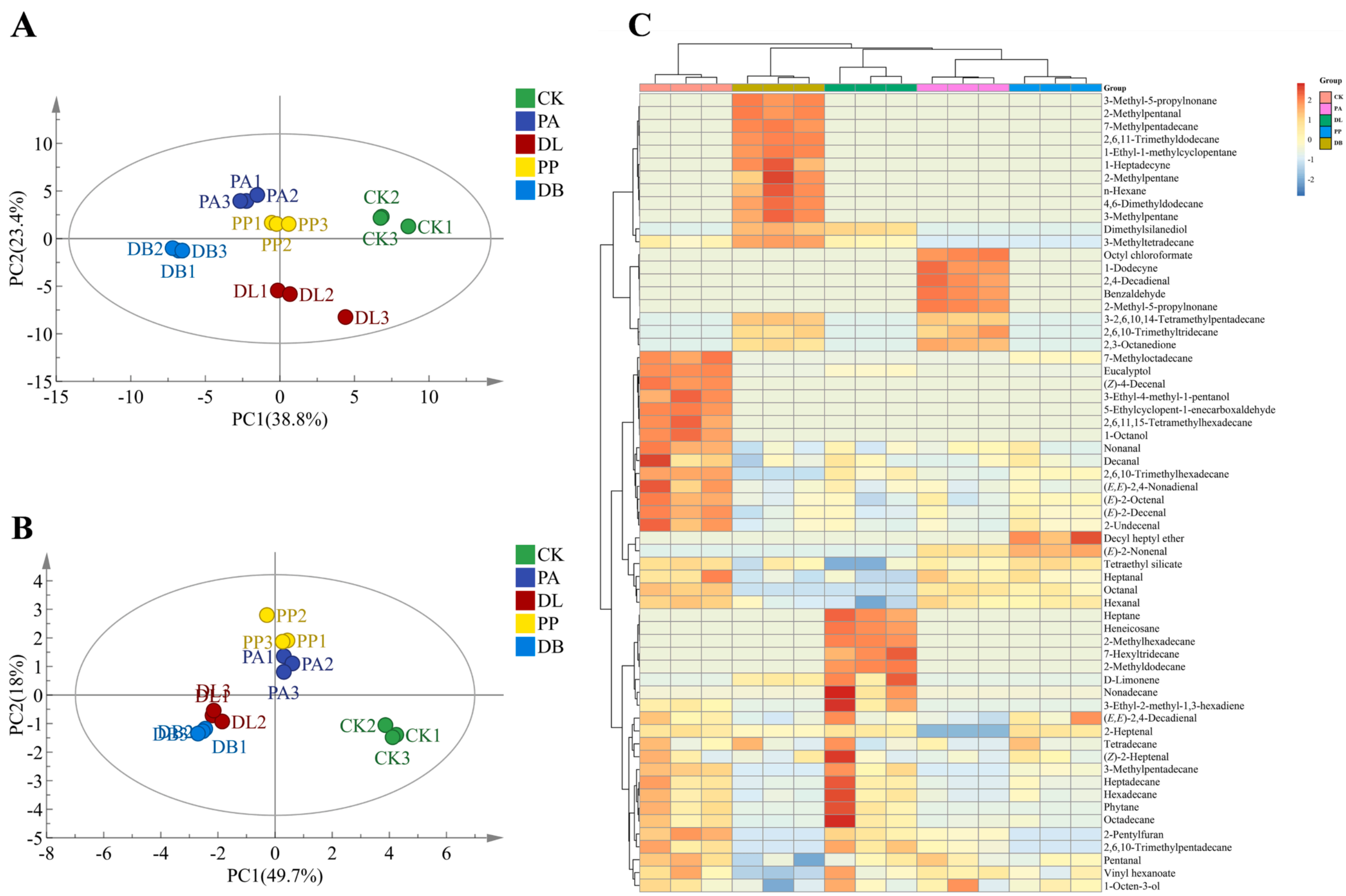

Fig. 3. PCA score plot (A), OPLS-DA score plot (B), and clustering heat map (C) of volatile flavor components.

shoots chicken soup and CK were screened, including organic acids and derivatives, lipids and lipid-like molecules, organoheterocyclic compounds, organic oxygen compounds, and others (Fig. 4A–D). There were 40 significantly different water-soluble components between PP and CK, of which 35 were up-regulated and 5 were down-regulated, while there were 39 components between PA and CK, with 34 up-regulated and 5 down-regulated; Similarly, there were 50 differences components between DL and CK, with 32 up-regulated and 18 down-regulated, while there were 52 components between DB and CK, with 42 up-regulated and 10 down-regulated.

The cluster analysis of different water-soluble components directly reflected the changes of different water-soluble components in chicken soup after adding bamboo shoots, indicating that the addition of bamboo shoots affected the types and contents of water-soluble components in chicken soup (Fig. 4E). In addition, z-score (standardized score) is a converted value based on the relative content of water-soluble components and is used as a measure of the relative content of water-soluble components at the same level. The more the horizontal axis moves to the right, the higher the relative content of the water-soluble components in the group. Z-score analysis of different water-soluble components more directly reflected the differences in the content of each component in different chicken soup (Fig. 4F). For example, the relative content of water-soluble components such as 4-pyridoxic acid, 5′-methylthioadenosine and cellobiose in chicken soup after adding bamboo shoots were obviously higher than those in CK.

Analysis of characteristic and unique water-soluble components

Characteristic and differential water-soluble ingredients are the reasons for the taste differences among several chicken soups. Compared with CK, 19 characteristic water-soluble differences were identified in 4 kinds of chicken soup with bamboo shoots (Fig. 4G), including 2-methylserine, 4-pyridoxic acid, 5′-methylthioadenosine, 5-hydroxypentanoic acid, acetylphosphate, adenine, adenosine, bovinic acid, cellobiose, D-alloisoleucine, fumaric acid, imidazol-5-yl-pyruvate, L-malic acid, O-acetylcarnitine, ostruthin, resorcinol monoacetate, spermine, stearic acid, ureidosuccinic acid, etc., belong to the categories of organic acids and derivatives, lipids and lipid-like molecules, nucleosides, nucleotides, and analogues. The results showed that these substances contributed more to the water-soluble components of chicken soup after adding bamboo shoots. Li et al. (2022) reported in their previous study that organic acids and derivatives, lipids and lipid-like molecules, nucleosides, nucleotides, and analogues are important components that affect the quality of chicken.

In addition, the analysis of unique water-soluble components in bamboo shoot chicken soup showed that compared with CK, DL had 14 unique different components, mainly 12,13-dihydroxy-9Z-octadecenoic acid (12,13-diHOME), pyridoxal, IMP, etc (Table S2). 12,13-diHOME, as an adipokine, has been shown to be an active ingredient in the treatment of metabolic disorders in previous studies (Lynes et al., 2017). Pyridoxal is one of the forms of vitamin B6 (Kall, 2003). There were 7 unique differential components between PA and CK, mainly 3,4-dihydroxyphenylpropanoate, (S)-2-phenyloxirane, 2-pyrocatechuic acid, etc. 3,4-dihydroxyphenylpropanoate and 2-pyrocatechuic acid belong to phenolic acids, which are present in plants and have antioxidant, anticancer, and antibacterial activities (Lodovici, Guglielmi, Meoni, & Dolara, 2001; Zieniuk, 2023). DB contains 13 unique differential components, including 2-ketobutyric acid, methyl beta-D-galactoside, 4-guanidinobutanal, etc. In previous studies, 2-ketobutyric acid has been reported to have antifungal activity (Chen et al., 2023), and 4-guanidinobutanal was considered to be one of the active ingredients against

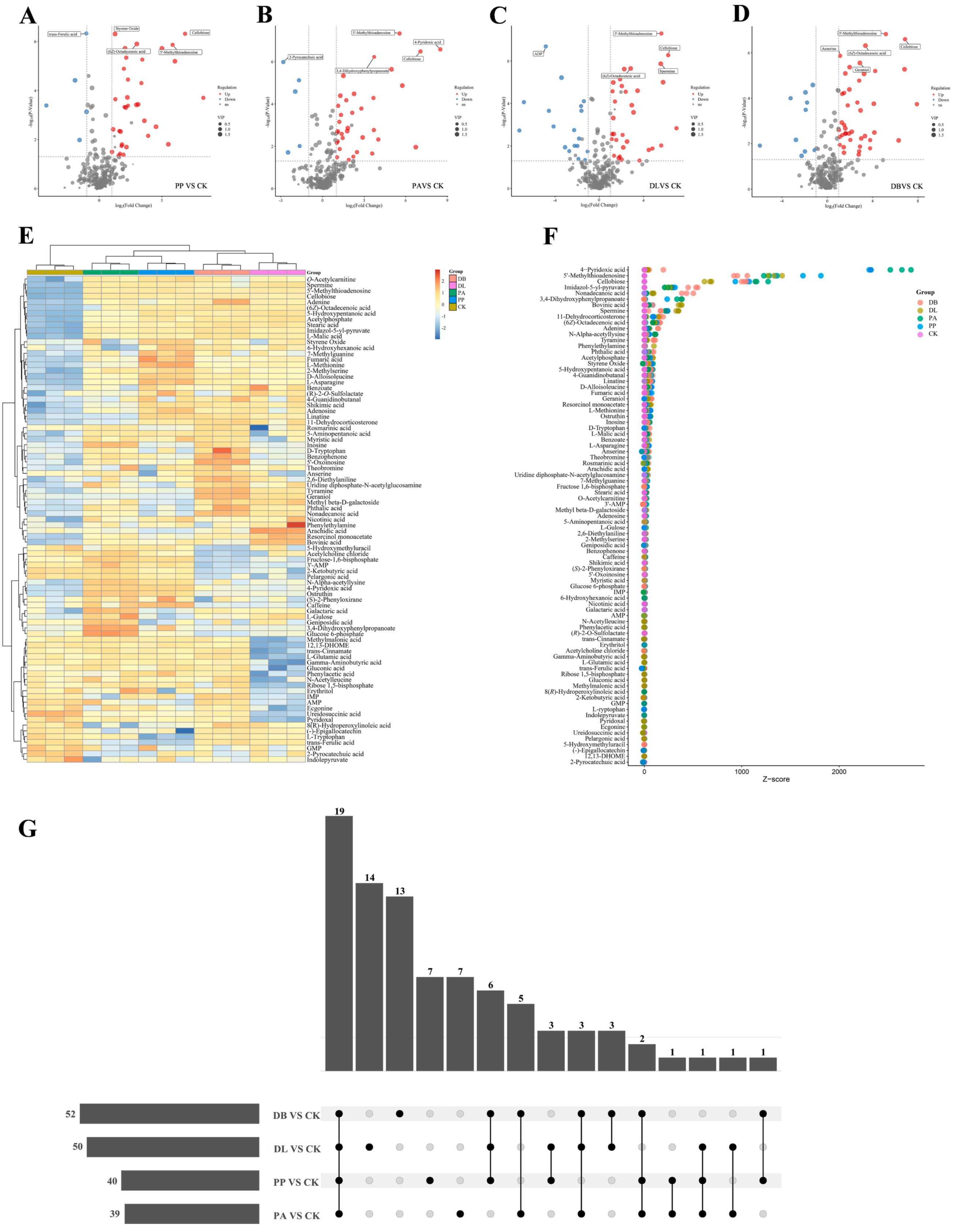

Fig. 4. Volcano map (A–D), heat map (E), z-score map (F) and upset plot (G) of the difference of water-soluble components between bamboo shoots chicken soup and CK group.

influenza virus (Qian et al., 2022). Similarly, PP contains 7 unique differential components including (R)-2-*O*-Sulfolactate, 7-methylguanine, caffeine, etc. 7-methylguanine, a natural nitrogen-containing alkaloid, is a promising new chemotherapy ingredient due to its potential anti-tumor activity and low negative effects (Kirsanov et al., 2022). Caffeine is considered to have neuroprotective, anti-inflammatory, anti-diabetic, and anti-hypertensive effects (Machado, Coimbra, del Castillo, & Coreta-Gomes, 2023). Therefore, the addition of bamboo shoots to stew increases the content of active ingredients in chicken soup, which may improve the physiological function of chicken soup. IMP and GMP, as one of the important umami taste components of chicken meat, were reduced by adding bamboo shoots to stewed chicken soup, which may be due to their chemical reaction with the dissolved components of bamboo shoots or their thermal decomposition at high temperatures (Han et al., 2021). However, as long as IMP and GMP are not completely consumed, the overall quality of chicken soup could be maintained (Feng, Moon, Lee, & Ahn, 2016).

In summary, adding bamboo shoots for stewing significantly increased the water-soluble components in chicken soup, greatly affecting its water-soluble taste components, and the increased water-soluble components may improve the physiological functional activity of chicken soup. Among the four bamboo shoots chicken soups, DB group had the most types of increased water-soluble differential components, the most types of volatile flavor components, and the highest sensory acceptance. Therefore, adding *Dendrocalamus brandisii* has the best effect on the formation of various chemical reactions during the stewing process of bamboo shoot chicken soup, promoting the formation of volatile flavor components and water-soluble taste components to a certain extent, and making the greatest contribution to improving the edible quality, overall flavor, and taste of bamboo shoot chicken soup.

Conclusions

This study confirms that adding bamboo shoots for stewing could change the flavor of chicken soup and improve its sensory and nutritional quality, and different varieties of bamboo shoots have different effects on the quality of chicken soup. Twelve characteristic volatile flavor substances of chicken soup were found by HP-SPME-GC–MS, and nine of them were the main reasons for the flavor difference between bamboo shoot chicken soup with blank chicken soup. LC-MS found that the water-soluble components in chicken soup increased significantly after adding bamboo shoots, and most of the increased water-soluble components have been proved to have physiological functional activities, but the physiological functions of bamboo shoots chicken soup need to be further verified. In addition, based on the analysis of sensory, nutritional, volatile and water-soluble flavor components of chicken soup, *Dendrocalamus brandisii* was the best choice for stewing bamboo shoot chicken soup. These results will provide theoretical basis for the quality and flavor control of chicken soup, as well as the combination of animal and plant foods.

CRediT authorship contribution statement

Hailang Wang: Writing – original draft, Validation, Investigation, Formal analysis, Conceptualization. **Boxiao Wu:** Validation, Investigation, Formal analysis. **Jinyan Zhang:** Investigation, Formal analysis. **Yun Liu:** Validation, Formal analysis. **Min Zhang:** Investigation, Formal analysis. **Lin Chen:** Investigation, Formal analysis. **Weiwei Zhao:** Investigation, Formal analysis. **Huan Kan:** Supervision, Resources. **Changwei Cao:** Writing – review & editing, Validation, 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

Data will be made available on request.

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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.2024.101140.

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