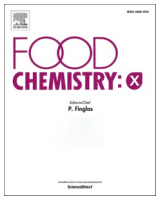
Food Chemistry: X 26 (2025) 102258

Contents lists available at ScienceDirect

Food Chemistry: X

journal homepage: www.sciencedirect.com/journal/food-chemistry-x



Effect of high-voltage electrostatic field salting on the quality of salt-reduced Yi ye Cheng golden pomfret

Chunbei Chen [a], Zefu Wang [a,*], Ziliang Gao [a], Xiaosi Chen [a], Shuai Wei [a], Qiuyu Xia [a], Qinxiu Sun [a], Yantao Yin [a], Yang Liu [a], Shucheng Liu [a,b,*]

[a] College of Food Science and Technology, Guangdong Ocean University, Guangdong Provincial Key Laboratory of Aquatic Product Processing and Safety, Guangdong Province Engineering Laboratory for Marine Biological Products, Guangdong Provincial Engineering Technology Research Center of Seafood, Guangdong Provincial Engineering Technology Research Center of Prefabricated Seafood Processing and Quality Control, Zhanjiang 524088, China
[b] Collaborative Innovation Center of Seafood Deep Processing, Dalian Polytechnic University, Dalian 116034, China

ARTICLE INFO

Keywords:
High-voltage electrostatic field
Salt reduction
Water-holding capacity
Texture
Volatile flavor compounds

ABSTRACT

This study investigates the effect of high-voltage electrostatic field (HVEF) salting on the quality of salt-reduced Yi Ye Cheng golden pomfret. Results showed that the salt content increased with the voltage ($P < 0.05$). The cooking losses of the HVEF-treated groups were significantly lower than those of commercially available products ($P < 0.05$). The 3.0 kV group showed the highest hardness and chewiness. HVEF treatment increased the varieties and contents of volatile flavor substances, with the varieties and contents of aldehydes, ketones, and alcohols being highest at 3.5 kV. No ketones with OAV > 1 were detected in the commercially available products, but all the HVEF-treated groups contained 2,3-octanedione. Lipid and protein oxidation increased with the voltage ($P < 0.05$), which may account for the changes in water retention, texture and flavor. Therefore, moderate HVEF treatment had a positive effect on the quality. This study provides theoretical guidance for curing and improving the quality of salt-reduced fish products.

1. Introduction

Yi Ye Cheng, originating from the folk in Yangjiang, Guangdong, is a type of Chinese traditional cured fish product. To prevent the fish from spoiling, fishermen transfer the whole fish to a container (called Cheng) filled with sea salt. After a night of curing, the fish is taken out, which is called "Yi Ye Cheng". With its simple curing process and distinctive taste of saltiness, fragrance, umami, and tenderness, it is favored by consumers in the coastal areas of Guangdong. Golden pomfret (*Trachinotus ovatus*) is rich in nutrients and delicious in taste. Its total production was 292,000 tons in 2023 (Bureau of Fisheries of the Ministry of Agriculture, 2024), making it the largest marine fish cultured in China. Guangdong is one of the main producing areas that provide abundant raw materials for curing Yi Ye Cheng in the coastal areas.

Commercial Yi Ye Cheng golden pomfret (YYCGP) is mainly cured by traditional dry salting, which requires high curing salt content (20 %–30 %) (Cao et al., 2018), and a long curing time (usually 10–12 h). However, proteins may denature at high salt concentrations, resulting in muscle shrinkage and dehydration (Gallart-Jornet et al., 2007), which may make the product hard and affect its texture. Importantly, traditional dry salting processing results in high salt content in the final products (Li et al., 2023), which may lead to excessive sodium intake by consumers. Excessive sodium intake increases the risk of kidney disease, hypertension, and cardiovascular disease (Li et al., 2023), and the health burden it brings has become an urgent social problem that needs to be solved. The WHO member states have agreed on a proposal to reduce per capita sodium intake by 30 % by 2025 (World Health Organization, 2013). Since the WHO released the salt reduction strategy, many countries such as the United Kingdom, Finland, Australia, and Japan have actively taken measures to reduce the sodium content in food (Nurmilah et al., 2022). Healthy China 2030 planning outline proposed that per capita daily sodium chloride intake in China will be reduced by 20 % by 2030 (The State Council, 2016). Sodium reduction has received increasing attention, and consumer demand for salt-reduced products has gradually increased with the awareness of healthy eating.

Some enterprises have produced YYCGP using direct salt reduction

* Corresponding authors at: College of Food Science and Technology, Guangdong Ocean University, Guangdong Provincial Key Laboratory of Aquatic Product Processing and Safety, Guangdong Province Engineering Laboratory for Marine Biological Products, Guangdong Provincial Engineering Technology Research Center of Seafood, Guangdong Provincial Engineering Technology Research Center of Prefabricated Seafood Processing and Quality Control, Zhanjiang 524088, China.
E-mail addresses: wangzefugdou@163.com (Z. Wang), lsc771017@163.com (S. Liu).

https://doi.org/10.1016/j.fochx.2025.102258
Received 15 November 2024; Received in revised form 13 January 2025; Accepted 2 February 2025
Available online 3 February 2025

methods, such as reducing the amount of salt and shortening the curing time. However, the reduction in salt content may reduce consumer acceptance of food and have negative economic effects (Nurmilah et al., 2022). In addition, salt plays a crucial role in curing products, including providing a salty taste, enhancing the flavor, maintaining the texture, inhibiting microbial growth and reproduction, and extending the shelf life (Wang et al., 2023). Inappropriate salt reduction will affect the quality, safety, and consumer acceptance of products (Nurmilah et al., 2022; Wang et al., 2023). Hence, researchers and technicians have focused on developing salt reduction technology in cured products and explored how to scientifically and effectively reduce the NaCl content while ensuring the quality and acceptability of products.

High-voltage electrostatic field (HVEF, >2.5 kV) is a nonthermal processing technology, with the advantages of environmental friendliness, high efficiency, energy saving, and simple operation, and it has less detrimental effects on food quality (Li et al., 2017; Zhang et al., 2019). A uniform or nonuniform electric field is formed by high-voltage power supply and electrodes of different shapes and changes the transfer of heat and mass under the action of corona wind to have a certain impact on life activities. HVEF can produce enough energy to electrolyze the air medium and generate ozone, which interferes with cell activity (Huang et al., 2020). Current research mainly focused on the thawing, freezing, and preservation of meat (Huang et al., 2020; Jia, He, et al., 2017; Mousakhani-Ganjeh et al., 2016). Only a few studies have been conducted on HVEF in cured products. Jia et al. (2019) investigating the effect of HVEF treatment on thawing characteristics and post-thawing quality of lightly salted pork tenderloin and found that HVEF could enhance salt diffusion during the thawing process, which suggests that HVEF has the potential to promote the diffusion of NaCl during the curing process to achieve salt reduction. However, the role and impact of HVEF-assisted curing on the quality of cured products remain unclear. Importantly, protein oxidation and lipid oxidation are closely related to the texture and flavor of cured products (Rahbari et al., 2020; Wang et al., 2023; Wang et al., 2024), which is necessary to investigate through experiments.

In this study, HVEF was used to cure salt-reduced YYCGP, and the effects of HVEF salting on the quality of salt-reduced YYCGP were examined with traditional high-salt products and directly salt-reduced products as a control. The salt content, water distribution, texture, and volatile flavor compounds under different electric fields were measured. The effect of HVEF-assisted salting on the quality formation of YYCGP was preliminarily explored by analyzing the oxidation of proteins and lipids. This study will provide guidance for the processing of salt-reduced Yi Ye Cheng products and serve as a theoretical basis for the development and application of salt-reduced curing technologies for fish.

2. Materials and methods

2.1. Chemicals

Salt (food grade, sodium chloride content ≥95.00 %) was purchased from Guangdong Salt Industry Group Guangzhou Co., Ltd. (Guangzhou, China). Methyl nonanoate (≥98 %) was obtained from Yuanye Biotechnology Corporation (Shanghai, China). $C_5 \sim C_{32}$ of n-alkanes (>99 %) and $C_4 \sim C_9$ of n-ketones (analytical pure) were provided by Aladdin Reagent Corporation (Shanghai, China). Other chemicals and reagents used were of analytical grade.

2.2. Preparation of samples

This study used five kinds of YYCGP products. In particular, three kinds of directly reduced salt (DRS) products were separately purchased from Guangdong Evergreen Conglomerate Co., Ltd. (Guangdong, China), Zhanjiang Guolian Aquatic Products Co., Ltd. (Guangdong, China), and YangJiang Haina Fisheries Co., Ltd. (Guangdong, China) (samples were named DRS-A, DRS—B, and DRS—C), and two kinds of traditional high-salt (THS) products were acquired from Dongdi Seafood Market (Zhanjiang, China) (samples were named THS-A and THS—B). All the samples were stored at −20 °C.

Three batches of golden pomfret were purchased in the present study, and each batch of 24 golden pomfret (472.90 ± 52.10 g) was acquired from Xiashan Seafood Market (Zhanjiang, China). All the fish were randomly divided into four groups, with six fish in each group. The traditional dry salting of YYCGP was adopted and modified based on the pre-experiment. Golden pomfret specimens were cut into uniform and continuous pieces, and the internal organs and gills were removed. The fish were washed with running water, and 14 % salt (measured relative to the weight of the fish) was applied evenly on the surface. The prepared fish were placed in food-grade polyethylene bags and then placed in the HVEF device (NF-2 Multifunctional Electrostatic Freezing/Thawing/Freshness Experiment machine, New Defrost Technology, INC., Taiwan, China) with different voltages of 2.5, 3.0, 3.5, and 4.0 kV. The salting temperature and time were 20 °C and 4 h. After salting, the samples were washed under running water to desalt, vacuum-packed, and stored at −20 °C. Before analysis, all the samples were thawed at 4 °C until the central temperature of the samples reached 4 °C, and the thawed samples were used for index determination.

2.3. Salt content

In brief, 3 g of minced samples were homogenized with 100 mL of ultrapure water at 9500 rpm for 5 min and then filtered to obtain the extract. The extract was titrated with $AgNO_3$ (0.1 mol/L) in accordance with the ISO (*Meat and meat products-determination of chloride content-part 2: Potentiometric method,* 1996).

2.4. Moisture content

The moisture content was measured using the AOAC Official Method 950.46 (AOAC, 2000). In brief, 2 g of minced fish were dried at 102 °C in an oven until a constant weight was reached.

2.5. Low-field nuclear magnetic resonance (LF-NMR)

The water distribution of fish muscle was measured by adopting the method of Jia, He, et al. (2017) with minor modifications using an NMI 20-060H-I MRI analyzer (Niumag Co., Ltd., Suzhou, China). Thawed samples (2.0 × 1.5 × 1.5 cm^3) were placed in plastic bags and then in the sample cell. The measurement conditions were as follows: temperature, 32 °C; proton resonance frequency, 21.12 MHz; calibration sequence, FID pulse sequence; and measurement sequence, CPMG pulse sequence.

2.6. Cooking loss

Cooking loss was determined using the method described by Huang et al. (2020) with slight modifications. Briefly, 15 × 10 × 10 mm^3 samples (A_1) of back muscle were packed into polyethylene bags and then immersed in a water bath (85 °C, 10 min). After the water on the surface of sample was wiped with filter paper, the mass was reweighed (A_2). Cooking loss was calculated based on the following equation:

$$\text{Cooking loss}\ (\%) = \frac{A_1 - A_2}{A_1} \times 100$$

2.7. Centrifugal loss

Centrifugal loss was determined using the method of Zhang et al. (2019) with some modifications. Approximately 2 g (W_1) of back muscle was placed into a 50 mL centrifuge tube equipped with double-layer filter paper and centrifuged at 2050 ×*g* for 10 min at 4 °C (3–30 KS, Sigma, Germany). Then the mass of the sample was reweighed (W_2).

Centrifugal loss was calculated as follows:

$$\text{Centrifugal loss}\ (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

2.8. Texture profile analysis (TPA)

Thawed samples were cut into cubes (10 × 10 × 10 mm^3) for TPA (TA.XT plusC, Lotun Science Co., Ltd., Beijing, China) using the method of Yang et al. (2020) with modifications. A flat-bottomed cylindrical probe P/36 was used for two-cycle compression tests. The speed of pretest, test, and post-test was 1.00 mm/s, the trigger force was 5.0 g, and the compression rate was 50 %.

2.9. Electronic nose analysis

Electronic nose analysis was performed following the published method of Wang et al. (2024) with modifications. The samples were steamed over boiling water for 10 min, cooled and minced for later use. Briefly, 3 g of evenly minced sample was weighted in a 20 mL headspace bottle, sealed, and water-bathed (40 °C, 30 min). The samples were used for detection with an electronic nose system (PEN3, WinMuster Airsense Analytics Inc., Schwerin, Germany) after equilibration (room temperature, 30 min). The cleaning time, measurement time and carrier gas flow rate were 120 s, 80 s, and 300 mL/min, respectively. The sensors of the electronic nose and their corresponding representative substances are shown in the Table S1.

2.10. GC-IMS

The treatment of sample was the same as 2.2.9. Following the method of Zhang et al. (2020), 2 g of evenly minced sample was placed into a headspace bottle and analyzed for volatile organic compounds (VOCs) using Flavor Spec® GC-IMS (G.A.S., Dortmund, Germany). After the headspace bottles were stirred (60 °C, 500 rpm, 15 min), 300 μL of the headspace samples were automatically injected into the injector (85 °C, no split mode). The GC conditions were as follows: carrier gas, nitrogen (99.999 %); temperature, 60 °C; and flow rate, 2 mL/min for 2 min then increased to 150 mL/min for 23 min and maintained until 30 min. The temperature of drift tube in IMS was 45 °C, and flow rate was 150 mL/min. The retention index (RI) of VOCs was calculated using n-ketones (C_4–C_9) under the same analytical conditions. The IMS database, NIST library, and RI were used as references to identify the VOCs.

2.11. GC–MS

The treatment of sample was the same as 2.2.9. In brief, 3.00 g of minced sample was accurately weighed into a 50 mL headspace bottle and 2 μL of methyl nonanoate (54.69 μg/mL) was added as an internal standard. The VOCs of the samples were extracted (60 °C, 40 min) using a SPME needle (50/30 μm, 1 cm, DVB/CAR/PDMS fiber; Supelco, Bellfonte, USA) and then determined using GC–MS (TQ8050NX, Shimadzu, Tokyo, Japan) equipped with a silica capillary column (60 m × 0.25 mm × 0.25 μm, Shimadzu, Tokyo, Japan) according to the previously published procedure of Zheng et al. (2022).

The RI of VOCs was obtained using n-alkane (C_5–C_{32}) under the same analytical conditions. The VOCs were also identified by comparing the mass spectra with the NIST libraries. The relative content of VOCs was based on internal standard. Odor activity value (OAV) was obtained by the method of Wei et al. (2023). The formulas were given below:

$$\text{RI} = 100 \times \left[\frac{t_x - t_n}{t_{n+1} - t_n} + n\right]$$

$$\text{C}_1 = \frac{A_1 \times M_2}{A_2 \times M_1}$$

$$\text{OAV} = \frac{C_1}{T}$$

where t_n, t_x, and t_{n+1} represent the retention time of n-carbon n-alkanes, each volatile compound, and n + 1 carbon n-alkanes, respectively ($t_n < t_x < t_{n+1}$). A_1, M_1, and C_1 indicate the peak area, mass, and relative content of VOCs, respectively. A_2 and M_2 are the peak area and mass of internal standard, respectively. T denotes the threshold of the compound in water.

2.12. Lipid oxidation analysis

Peroxide value (POV) was assessed using the method of Xu et al. (2019) with mild modification. Briefly, 5.00 g of ground fish sample was homogenized in a precooled mixture of chloroform and methanol (2:1, *v*/v) at 8000 rpm for 1 min. Then 6.16 mL of NaCl solution (0.5 %, *w*/*v*) was added to the sample and centrifuged (2000 *g*, 10 min, 4 °C). After 1 mL of the chloroform layer was taken, 9.8 mL of precooled chloroform: methanol, 100 μL of ammonium thiocyanate (300 g/L), and 100 μL of $FeCl_2$ (3.5 g/L) were added. Absorbance was measured at 500 nm (SpectraMax M2 multifunctional microplate reader, Molecular Devices, LLC, Sunnyvale, CA, USA) after incubation in the dark for 20 min.

Malonaldehyde (MDA) content was measured following the instructions of the MDA Content Assay Kit (BC0025, Solarbio, Beijing, China).

2.13. Protein oxidation assay

Myofibrillar proteins (MPs) extraction was based on the method described by Chen et al. (2024). Approximately 6 g fish flesh was mixed with 30 mL of phosphate buffer (20 mmol/L, 0.1 mol/L NaCl, 1 mmol/L EDTA·2Na, pH 6.0) and then homogenized (8000 rpm, 30 s). The precipitate was retained after centrifugation (10,000 *g*, 15 min, 4 °C,). The above procedure was repeated twice. 30 mL of phosphate buffer (0.1 mol/L NaCl, pH 6.0) was added to the precipitate, homogenized, and centrifuged. Finally, the precipitate was homogenized again with 30 mL of phosphate buffer. After filtration through four layers of gauze and centrifugation, the MP paste was obtained. The protein concentration was determined by the Biuret method. The MP paste was stored at −80 °C.

The carbonyl content was measured following the instructions of the Protein Carbonyl Content Assay Kit (BC1275, Solarbio, Beijing, China).

The total sulfhydryl content was determined using the method of Huang et al. (2023). In brief, 2.0 mL of Tris-HCl (20 mmol/L, pH 6.0) containing urea (8 mol/L) and EDTA (10 mmol/L) was added to 0.20 mL of protein solution and mixed well. The mixture was added with 50 μL of Ellman's reagent and then placed in a 40 °C water bath for 25 min. The content of total sulfhydryl was measured at 412 nm (SpectraMax M2 multifunctional microplate reader, Molecular Devices, LLC, Sunnyvale, CA, USA).

2.14. Data analysis

All experiments were conducted for at least three independent trials, and the results were displayed as mean ± standard deviation. Analysis of data variance was performed using SPSS Statistics 26.0 software (IBM Corporation, Armonk, NY, USA), with $p < 0.05$ showing significance. The figures were plotted using Origin 2024 software (OriginLab Corporation, Northampton, MA, USA).

3. Results and discussion

3.1. Effect of HVEF salting on the salt content of YYCGP

As shown in Fig.1, the salt contents of THS-A, THS—B, DRS-A, DRS—B, and DRS-C were 3.04 % ± 0.18 %, 3.18 % ± 0.14 %, 1.39 %

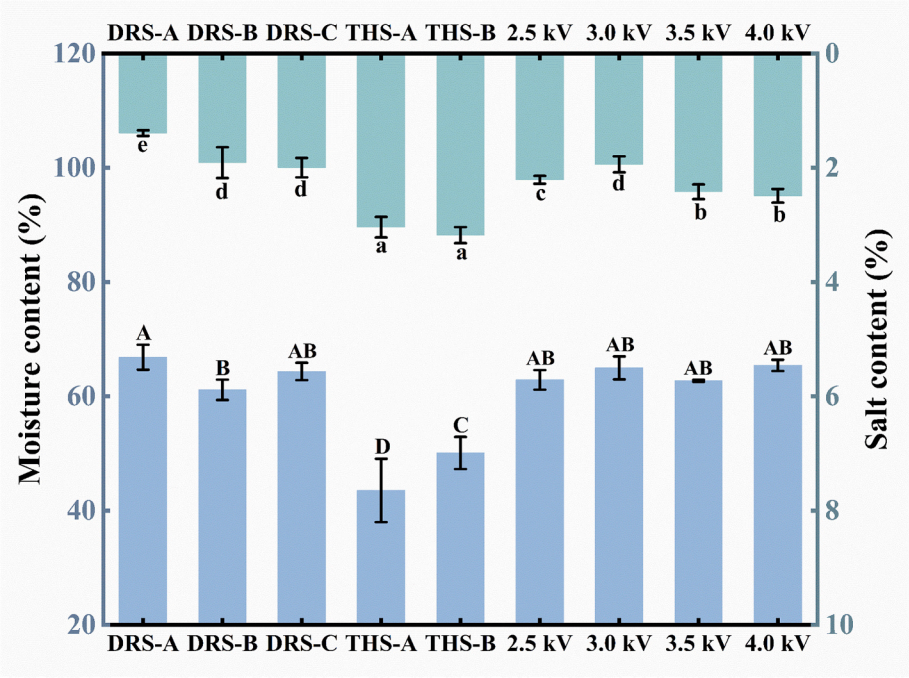


Fig. 1. Effect of HVEF salting on salt content and moisture content of YYCGP. Different letters above the columns indicate significant differences ($P < 0.05$). DRS-A, DRS—B, DRS—C: three kinds of directly reduced salt (DRS) products. THS-A, THS—B: two kinds of traditional high-salt (THS) products. 2.5 kV, 3.0 kV, 3.5 kV, 4.0 kV: HVEF salting with different voltages.

± 0.05 %, 1.91 % ± 0.27 %, and 2.00 ± 0.17 %, respectively. The lowest and highest salt contents in the HVEF salting groups were 1.94 % ± 0.14 % (3.0 kV) and 2.49 % ± 0.12 % (4.0 kV), respectively. Compared with THS products, the salt contents of YYCGP cured in HVEF were decreased by at least 18.10 % and 21.66 %. The salt content of YYCGP showed an overall increasing trend with the applied voltage ($P < 0.05$), indicating that HVEF could promote NaCl diffusion in fish and increase the rate of NaCl transfer, this result was consistent with the findings of Jia et al. (2019). This may be attributed to the fact that corona discharge occurs during the HVEF treatment, and causes ions with different charges to move in a specific direction (Huang et al., 2023). However, Estévez et al. (2021) found that the hardness, chewiness, and water retention of European seabass sausages decreased when the NaCl content was reduced by 50 %. Low-salt or salt-reduced products may also face the problem of flavor loss (Wang et al., 2023). Therefore, the moisture content, texture, and volatile flavor compounds were determined to study the effect of HVEF salting on the quality of salt-reduced YYCGP.

3.2. Effect of HVEF salting on the moisture content of YYCGP

3.2.1. Moisture content

During salting, the moisture content is affected by the chemical potential gradient and the structure changes of fish caused by the increase in salt content (Schmidt et al., 2008; Shi & Le Maguer, 2002). As shown in Fig.1, the moisture contents of THS-A, THS—B, DRS-A, DRS—B, and DRS-C were 43.53 % ± 5.54 %, 50.09 % ± 2.81 %, 66.85 % ± 2.18 %, 61.14 % ± 1.78 %, and 64.36 % ± 1.52 %, respectively. The moisture contents of the 3.0 and 4.0 kV groups were 64.98 % ± 2.00 % and 65.43 % ± 0.99 %, respectively. The moisture contents of THS products were significantly lower than those of DRS products and HVEF salting groups ($P < 0.05$), mainly because traditional dry salting requires a large amount of salt and takes a long time. As a result, the fish loses a large amount of water. In the HVEF salting groups, the moisture content of YYCGP showed no significant difference with the increase in applied voltage ($p > 0.05$) and maintained a range from 62.73 % to 65.43 %, showing that HVEF accelerated salt diffusion in the fish but had no significant effect on the moisture content. Water distribution was then determined to provide a clear understanding of the effect of HVEF salting on the moisture content of YYCGP.

3.2.2. Water distribution

LF-NMR has been extensively used for studying the water distribution and migration of cured products. Salting has an important effect on the water distribution within the muscle (Jia et al., 2019). As shown in Fig. 2A, the P_{22} of all treatment groups was less than 0.6 % (0–0.54 %) and thus was ignored in the analysis. This result was similar to the previous study by Jia et al. (2019). Qin et al. (2017) suggested that salt reduces the mobility of free water within the fish flesh, and may cause free water to diffuse into muscle fibers where it becomes fixed. No significant changes in P_{2b} and P_{21} (except DRS-A and 3.0 kV group) were observed among the treatment groups ($P > 0.05$). This finding was consistent with the result for moisture content.

As shown in Fig. 2B, the T_{21} relaxation times of THS-A, THS—B, DRS-A, DRS—B, and DRS-C were 38.72, 38.72, 58.73, 47.69, and 56.10 ± 2.27 ms, respectively, and those of the 3.5 and 4.0 kV groups in the HVEF salting groups were 45.55 ± 1.85 and 38.72 ms, respectively. The T_{21} relaxation times of the THS products were significantly shorter than those of the DRS products ($P < 0.05$). In the HVEF salting groups, the T_{21} relaxation times of YYCGP showed a decreasing trend with the increase in the treatment voltage ($P < 0.05$), and the 4.0 kV group had the shortest T_{21} relaxation times. This finding indicated that HVEF may change the interaction force between the immobile water and muscle tissue and various macromolecules. These results were consistent with those of Li et al. (2017), who found that the P_{21} of slightly salted fish thawed under −12 kV HVEF was greater than that of samples thawed under −6 kV HVEF and in the air, and its T_{21} relaxation times were shorter than those of the samples thawed in the air. Jia, He, et al. (2017) suggested that the water molecules affected by HVEF would reorient to affect the peak area, and the electrostatic repulsion of MPs caused by HVEF could also change the mobility and proportion of free water and immobilized water.

In addition, there is no significant difference in water content and

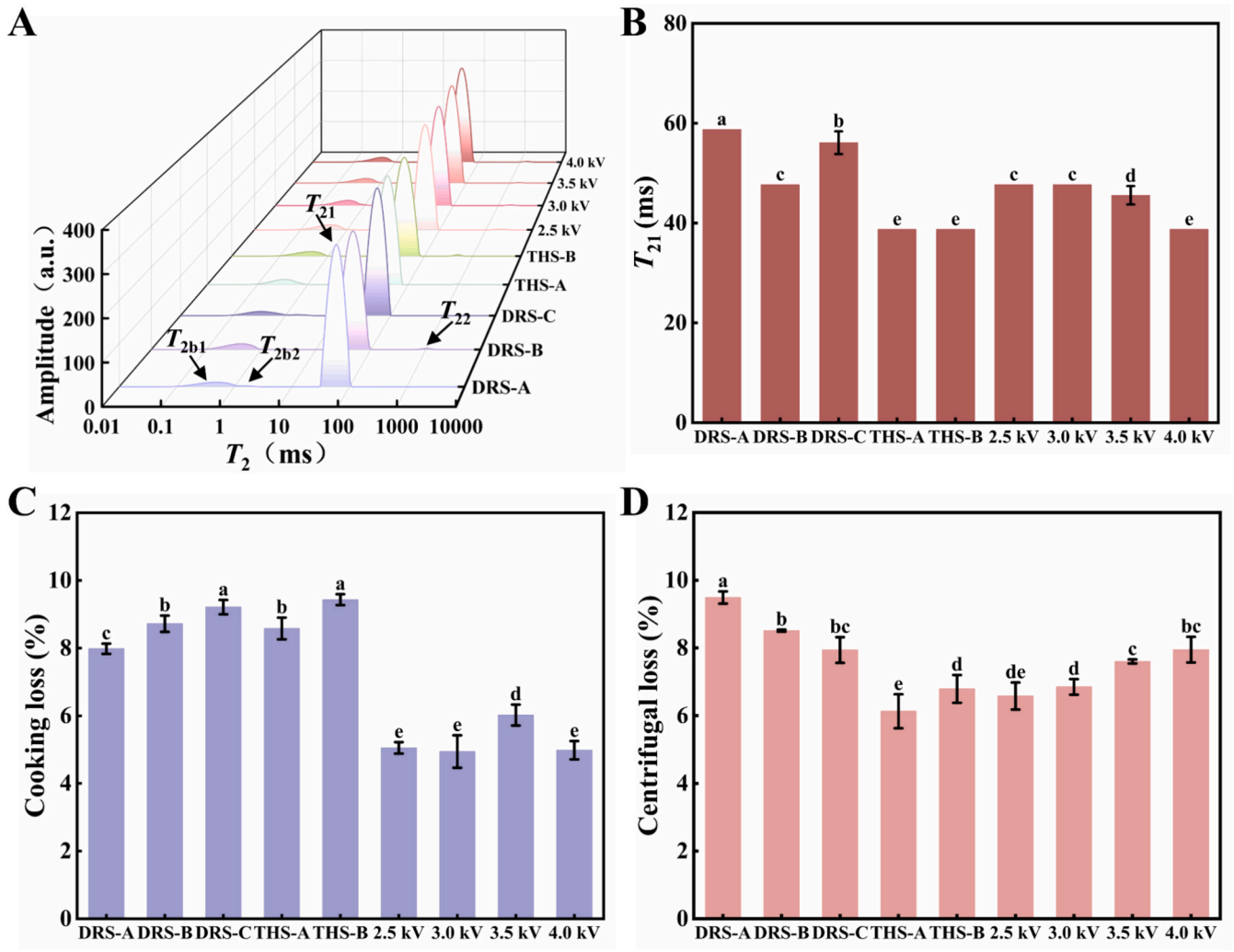


Fig. 2. Effect of HVEF salting on moisture (A LF-NMR curve, B T_{21} relaxation times, C cooking loss, D centrifugal loss) of YYCGP. Different letters above the columns indicate significant differences ($P < 0.05$).

water distribution (P_{2b}, P_{21}) with increasing voltage, while the T_{21} relaxation times gradually decreased ($P < 0.05$), which may be related to the curing time and salt concentration. When investigating the effect of pulsed electric field pre-treatment on the quality of sea bass during brine salting, Cropotova et al. (2021) found that brining time was the only variable that had a significant effect on water distribution ($p < 0.001$), and that brining time and NaCl concentration had significant effects on T_{21} and T_{22}.

3.3. Effect of HVEF salting on the water holding capacity (WHC) of YYCGP

Cooking loss are mainly liquid and soluble components lost during heating, the main component of which is water. The cooking losses of five commercially available products ranged from 7.98 % to 9.43 % (Fig. 2C), those of the 3.0 and 4.0 kV groups in the HVEF salting groups were 4.94 % ± 0.48 % and 4.98 % ± 0.27 %, respectively. In the HVEF salting groups, the cooking loss increased and then decreased when the applied voltage increased ($P < 0.05$), and the highest cooking loss (6.02 % ± 0.31 %) was observed in the 3.5 kV group. The cooking losses of salt-reduced YYCGP salted in HVEF were significantly lower than those of the five commercially available products ($P < 0.05$). Rahbari et al. (2018) observed less water loss when the chicken breasts were treated with higher voltages and suggested that higher voltages affect the protein structure and that the formation of ozone could cause protein denaturation. Huang et al. (2020) also found that HVEF treatment could rearrange the water molecules or muscle structure, and that lower cooking losses in HVEF-treated groups were associated with more intact muscle tissues.

As shown in Fig. 2D, the centrifugal losses of THS-A, THS—B, DRS-A, DRS—B, and DRS-C were 6.13 % ± 0.50 %, 6.79 % ± 0.41 %, 9.49 % ± 0.18 %, 8.51 % ± 0.03 %, and 7.94 % ± 0.38 %, respectively. The THS products showed significantly lower values than the DRS products ($P < 0.05$), and the HVEF salting groups showed less differences from the THS products and slightly lower values than the DRS products. The centrifugal loss increased with the voltage in the HVEF salting groups. When investigating the effect of HVEF on the WHC of frozen beef, Zhang et al. (2019) found that the centrifugal loss first increased and then decreased with the increasing voltage. Li et al. (2017) also found that high voltage treatment could effectively reduce centrifugal loss during thawing and storage. Jia, Liu, et al. (2017) consider HVEF treatment to reduce the denaturation degree of MPs. Therefore, moderate HVEF treatment could improve the WHC of the salt-reduced YYCGP, which was in line with the results of the water distribution described above.

3.4. Effect of HVEF salting on the texture of YYCGP

Fig. 3A shows that among the five commercially available products, the hardness of THS-A was the highest (1478.88 ± 118.86), followed by DRS-B (1101.80 ± 33.10), DRS-A (956.32 ± 56.82), DRS-C (882.00 ±

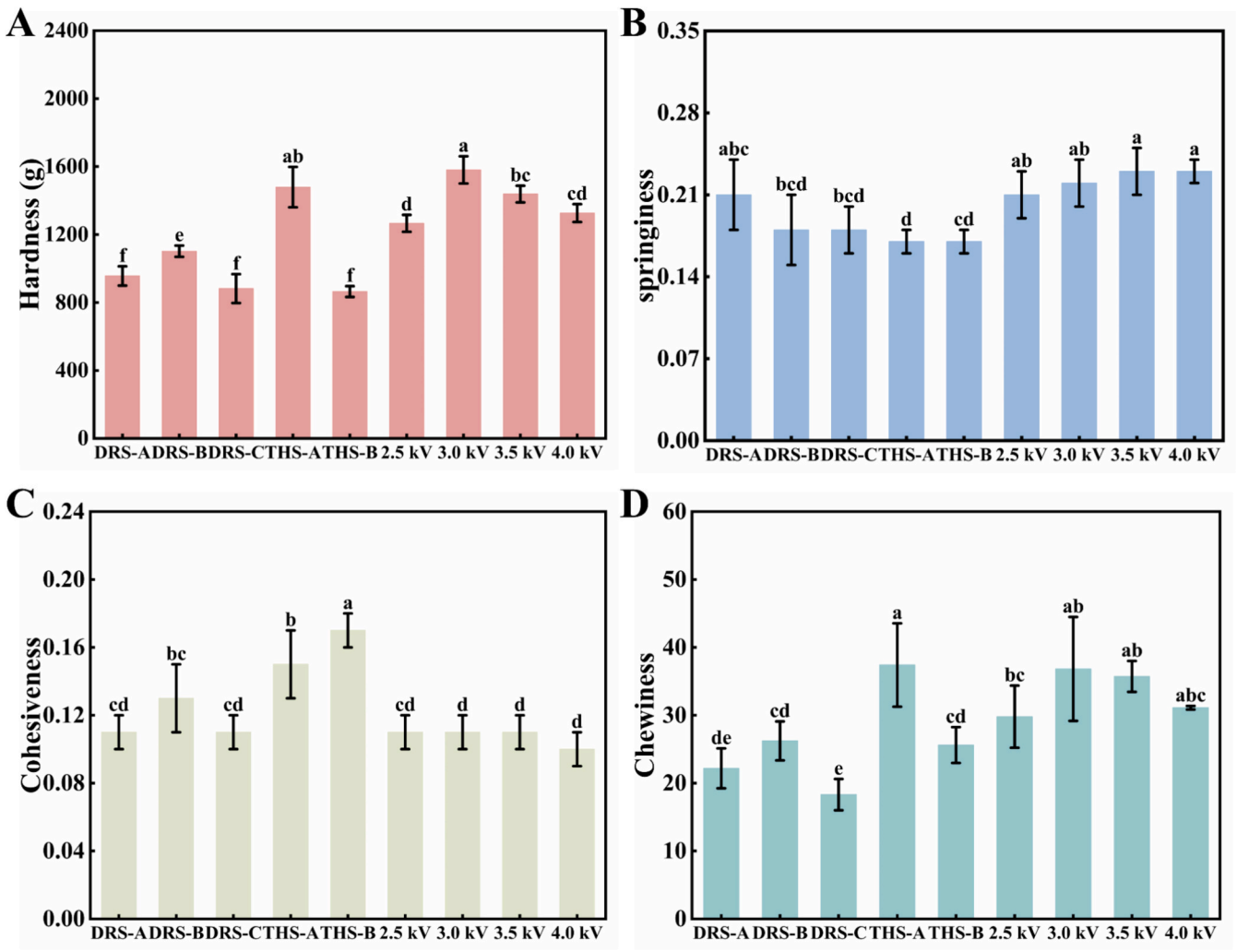


Fig. 3. Effect of HVEF salting on texture (A hardness, B springiness, C cohesiveness, D chewiness) of YYCGP. Different letters above the columns indicate significant differences ($P < 0.05$).

84.67), and THS-B (864.50 ± 31.94). In the HVEF salting groups, the hardness initially increased and then decreased with the increasing voltage ($P < 0.05$), reaching a maximum value (1580.70 ± 80.03) at 3.0 kV.

As shown in Fig. 3B, the springiness was less in the THS products than in the DRS products, and the salt-reduced samples salted in HVEF showed higher springiness than the commercially available products. The increase in springiness may be associated with the disruption and deformation of the collagen fiber network (Bahuaud et al., 2010). In the HVEF-salted groups, the springiness increased slightly but not significantly with the increase in the applied voltage ($P > 0.05$).

The THS products showed significantly higher cohesiveness (0.15–0.17) (Fig. 3C) than the DRS products (0.11–0.13) and HVEF treatment groups (0.10–0.11) ($P < 0.05$). This phenomenon may be related to the moisture content of the products. Jia et al. (2010) found that the cohesiveness increased with the decrease in moisture content, and the correlation was significant between moisture content and the texture of soft grilled scallops. In the HVEF salting groups, no significant difference in cohesiveness was observed among the samples salted under different voltages ($P > 0.05$).

The chewiness followed a similar trend to hardness (Fig. 3D). In general, the HVEF treatment groups showed higher values (29.79–36.82) than the DRS products (18.31–26.22) but exhibited no significant difference with the THS products (25.61–37.40) ($P > 0.05$). The chewiness of the HVEF salting groups tended to increase and then decrease with the increase in voltage, and the largest value was observed in the 3.0 kV group.

HVEF treatment can accelerate the rate of salt penetration. In particular, moderate HVEF diffuses the NaCl content into the fish tissue, resulting in the shrinkage of the muscle fibers and tight meat texture (Gallart-Jornet et al., 2007). However, ozone accumulation occurs at high electric field strengths exceeding 3.0 kV, which may lead to protein denaturation and damage the structure of the muscle, thus resulting in texture reduction (Rahbari et al., 2020). In summary, the application of moderate HVEF for the salting of salt-reduced YYCGP helps improve the texture properties of the products.

3.5. *Effect of HVEF salting on the volatile flavor compounds of YYCGP*

3.5.1. *Electronic nose*

Electronic noses can be used for accurately and quickly detecting VOCs in samples. As shown in Fig. 4A, the response values of sensors W1C, W5S, W3C, W1S, W1W, and W2S were high in THS-A and THS—B; the response values of sensors W5S and W1W were high in DRS-A, DRS—B, and DRS—C; and the response values of sensors W5S, W1S, W1W, and W2S were high in the HVEF-treated groups. These results indicated that nitrogen oxides and sulfides were the main volatile flavor compounds in the DRS products. Meanwhile, the THS products and HVEF treatment groups consisted of many methyl-containing compounds, aldehydes, ketones, and alcohols. In general, the volatile flavor

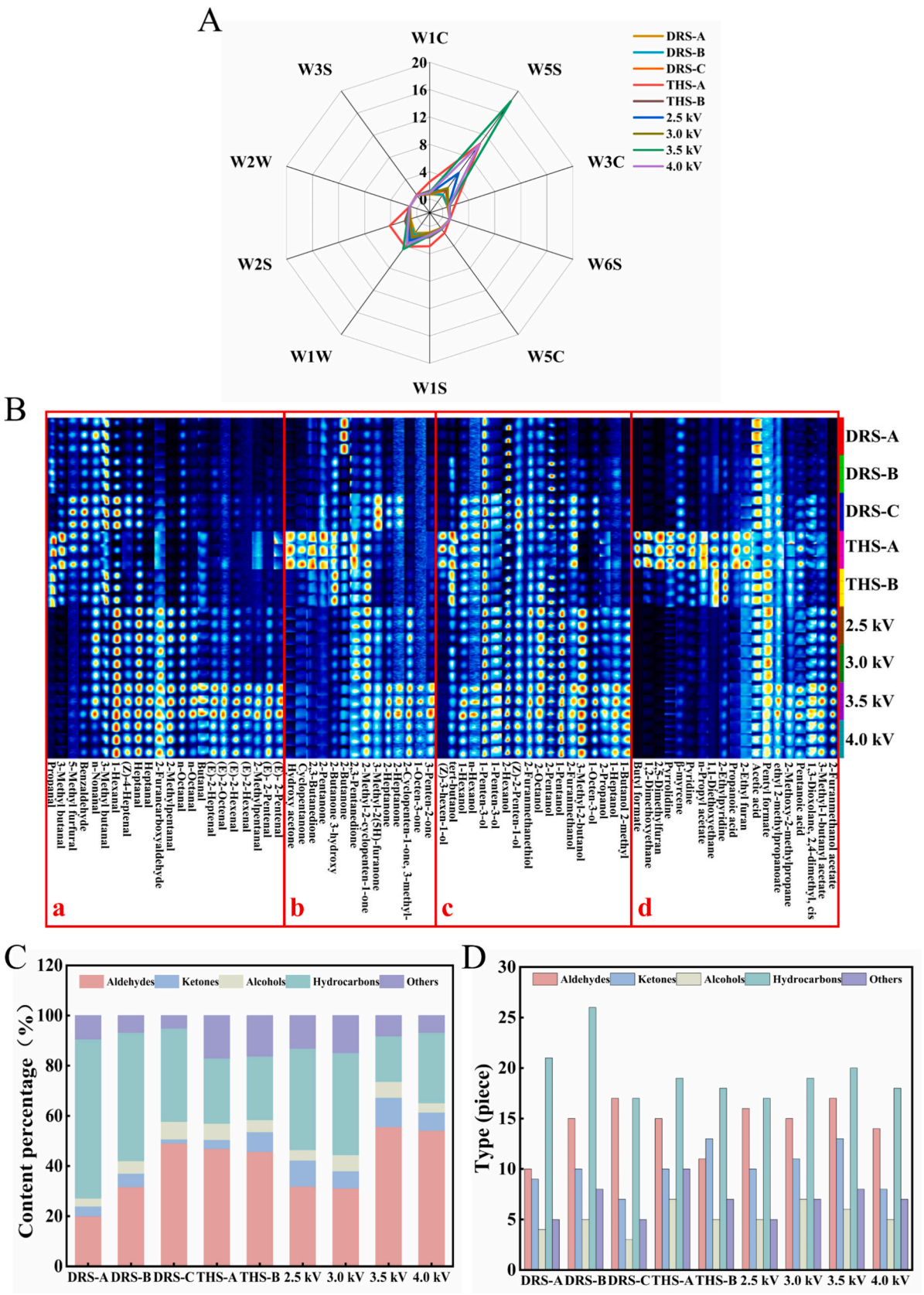


Fig. 4. Effect of HVEF salting on volatile flavor compounds (A electronic nose radar map, B fingerprint spectra, C content percentage, D type) of YYCGP.

substances of the HVEF treatment groups showed less differences from those of the THS products. Meanwhile, they had various types of volatile flavor substances and higher response values compared with the DRS products. In the HVEF treatment groups, the differences in flavor between samples may be related to their salt content. The response value of each sensor followed a similar trend to the salt content, that is, the response values of the samples increased with their salt content. However, the response values of the 3.5 kV group were larger than those of the 4.0 kV group.

3.5.2. GC-IMS

The VOCs of samples were characterized by GC-IMS for a preliminary comparison of the differences in VOCs among the samples (Table S2). In the fingerprint spectra (Fig. 4B), 73 VOCs (including dimers and monomers) were detected in all the samples, including 22 aldehydes, 14 ketones, 18 alcohols, 6 esters, 3 acids, 2 ethers, and 8 other volatile compounds. The fingerprint spectra could be divided into four areas labeled a (aldehydes), b (ketones), c (alcohols), and d (other substances).

In the HVEF salting groups, the types and contents of aldehydes, ketones, and alcohols first increased and then slightly decreased as the applied voltage increased, reaching the maximum at 3.5 kV. This may be related to the fact that HVEF promotes the diffusion of salt, and study has shown contributions to the production of different kinds of VOCs (Wang et al., 2024). Compared with the DRS products, the HVEF-treated groups had more varieties and higher concentrations of aldehydes, ketones, and alcohols, and the flavor composition was similar to that of the THS products. These results indicated that HVEF treatment can improve the flavor quality of salt-reduced cured products. Aldehydes, namely, hexanal, octanal, heptanal, and nonanal, have been identified in many different kinds of dry-cured fish products and have proven to be important volatile flavor compounds (Zhang et al., 2020).

3.5.3. GC–MS

Qualitative and quantitative analyses of VOCs in the samples were then performed using GC–MS (Table S3). In the HVEF treatment groups, the varieties of VOCs first increased and then decreased as the treatment voltage increased, with the highest found in the 3.5 kV group (Fig. 4D). The THS products and HVEF treatment groups showed more varieties of aldehydes than the DRS products. The relative content of aldehydes showed an increasing trend with the treatment voltage and reached 55.70 % under 3.5 kV HVEF treatment (Fig. 4C). In general, the VOCs in salt-reduced YYCGP salted in HVEF were relatively similar to those in the THS products but differed from those in the DRS products. This finding was consistent with the results of GC-IMS and electronic nose.

The OAV can be used to measure the odor activity of each volatile flavor substance and evaluate the contribution of VOCs to the overall flavor profile of the sample. The thresholds of VOCs in water are determined by van Gemert (2011). VOCs with OAV > 1 are considered key flavor components significant contribution to the overall flavor characteristics, and VOCs with $1 >$ OAV > 0.1 are considered to have an important modification effect on the overall flavor. A total of 11 and 6 VOCs with OAV > 1 were found in THS-A and THS—B, respectively (Table S4). Meanwhile, 13, 11, 10, and 9 VOCs with OAV > 1 were detected in 2.5, 3.0, 3.5, and 4 kV HVEF treatment groups, respectively. The VOCs with OAV > 1 were mainly covered hexanal, nonanal, (E, E)-2,4-nonadienal, decanal, (E)-2-nonenal, (E)-2-octenal, (E, Z)-2,6-nonadienal, (E, E)-2,4-decenal, heptanal, (E)-2-decenal, and (E, Z)-2,4-decadienal. These aldehydes mainly originate from the oxidation and degradation of n-6 polyunsaturated fatty acids (Wang et al., 2024). And 1-octen-3-ol was the alcohol with OAV>1 detected in all samples, which is usually formed from arachidonic acid under the action of 12-lipoxygenase (Wei et al., 2023). Therefore, hexanal, nonanal, (E)-2-decenal, (E)-2-nonenal, and 1-octen-3-ol were the key volatile compounds in YYCGP.

All the samples contained (E)-2-nonenal except for THS—B. Hexanal, nonanal, and (E)-2-decenal were detected in all the samples. All the HVEF treatment groups contained (E, Z)-2,6-nonadienal (an aroma of grass, roast and candle) and (E, E)-2,4-decadienal (with fatty, deep fried and waxy aroma) (Wei et al., 2023). No ketones with OAV > 1 were detected in the five commercially available products, but all the HVEF treatment groups contained 2,3-octanedione, which has an aroma of milk and butter (Wei et al., 2023). These results indicated that the quantity and content of the key flavor components of YYCGP cured by HVEF were similar to those of the traditional products. Therefore, HVEF salting can increase the odor richness of salt-reduced YYCGP and promote its flavor formation. Xu et al. (2020) found that HVEF treatment could enhance the characteristic flavor of dry-cured beef, which was consistent with the results of the present study. These differences may be explained by the fact that HVEF affects the formation and the release of flavor compounds (Wang et al., 2024). Studies have shown that the formation and release of flavor compounds are closely related to lipid and protein oxidation (Cao et al., 2018), thus the effect of HVEF on lipid and protein oxidation was further investigated.

3.6. Effect of HVEF salting on the lipid and protein oxidation of YYCGP

3.6.1. Lipid oxidation

The POVs of THS-A and THS-B were 0.94 ± 0.02 and 0.88 ± 0.02 mmol/kg, respectively (Fig. 5A); those of DRS-A, DRS—B, and DRS-C were 0.55 ± 0.02, 0.64 ± 0.02, and 0.69 ± 0.02 mmol/kg, respectively; and those of the 3.0 and 3.5 kV groups were 0.81 ± 0.01 and 0.78 ± 0.01 mmol/kg respectively. In the HVEF salting groups, the POV increased at first and then decreased ($P < 0.05$), reaching the highest at 3.0 kV. The changes in POV depend on the ratio of formation to degradation of hydroperoxides, which are transitory and could be further decomposed into secondary oxidation products, such as acids and aldehydes (Xu et al., 2019). The decrease in POV (3.5 kV, 4.0 kV) may be due to the decomposition of more hydroperoxides formed into carbonyl compounds or other decomposition products.

The MDA contents of THS-A and THS-B were 1.61 ± 0.03 and 0.82 ± 0.02 mg/kg, respectively (Fig. 5B); those of DRS-A, DRS—B, and DRS-C were 0.23 ± 0.01, 0.36 ± 0.01, and 0.50 ± 0.02 mg/kg, respectively; and those of the 3.0 and 3.5 kV groups were 0.18 and 0.50 ± 0.02 mg/kg, respectively. The lipid oxidation degree of the THS products was significantly higher than that of the DRS products and HVEF salting groups ($P < 0.05$). This result was consistent with that of POV. In the HVEF treatment groups, the MDA content increased significantly with the voltage ($P < 0.05$) and was the highest in the 4.0 kV group (0.70 ± 0.01 mg/kg). The increase in MDA content (3.5 kV, 4.0 kV) may be related to the degradation of some hydroperoxides into MDA. These findings indicated that the HVEF could promote the oxidation of lipids, which may be associated with the promotion of salting by HVEF (Mariutti & Bragagnolo, 2017). Mousakhani-Ganjeh et al. (2016) found that the MDA content increased significantly with the applied voltage when HVEF was used to thaw frozen tuna ($P < 0.05$), suggesting that the high energy generated by HVEF may be responsible for air ionization and ozone production and release, thereby aggravating lipid oxidation.

The oxidation and hydrolysis of lipids are the main biochemical reactions in cured products and play an important role in flavor formation (Wang et al., 2024). The degradation of lipids generates free fatty acids (FFAs), which is the first step in transforming lipids into volatile flavor substances. FFAs could further be oxidized to form volatile flavor substances such as aldehydes, alcohols, and ketones, which form characteristic flavors in the final products (Cao et al., 2018; Wang et al., 2024). In addition, it has been demonstrated that sodium chloride could improve the flavor of cured products by regulating lipid hydrolysis and oxidation, inhibiting bitterness and astringency, and removing off-odors (Wang et al., 2023). The volatile flavor compounds in salt-reduced YYCGP salted in HVEF were relatively abundant in quantity and content, especially aldehydes. This phenomenon may be due to HVEF promoting salt diffusion and lipid oxidation and degradation in fish.

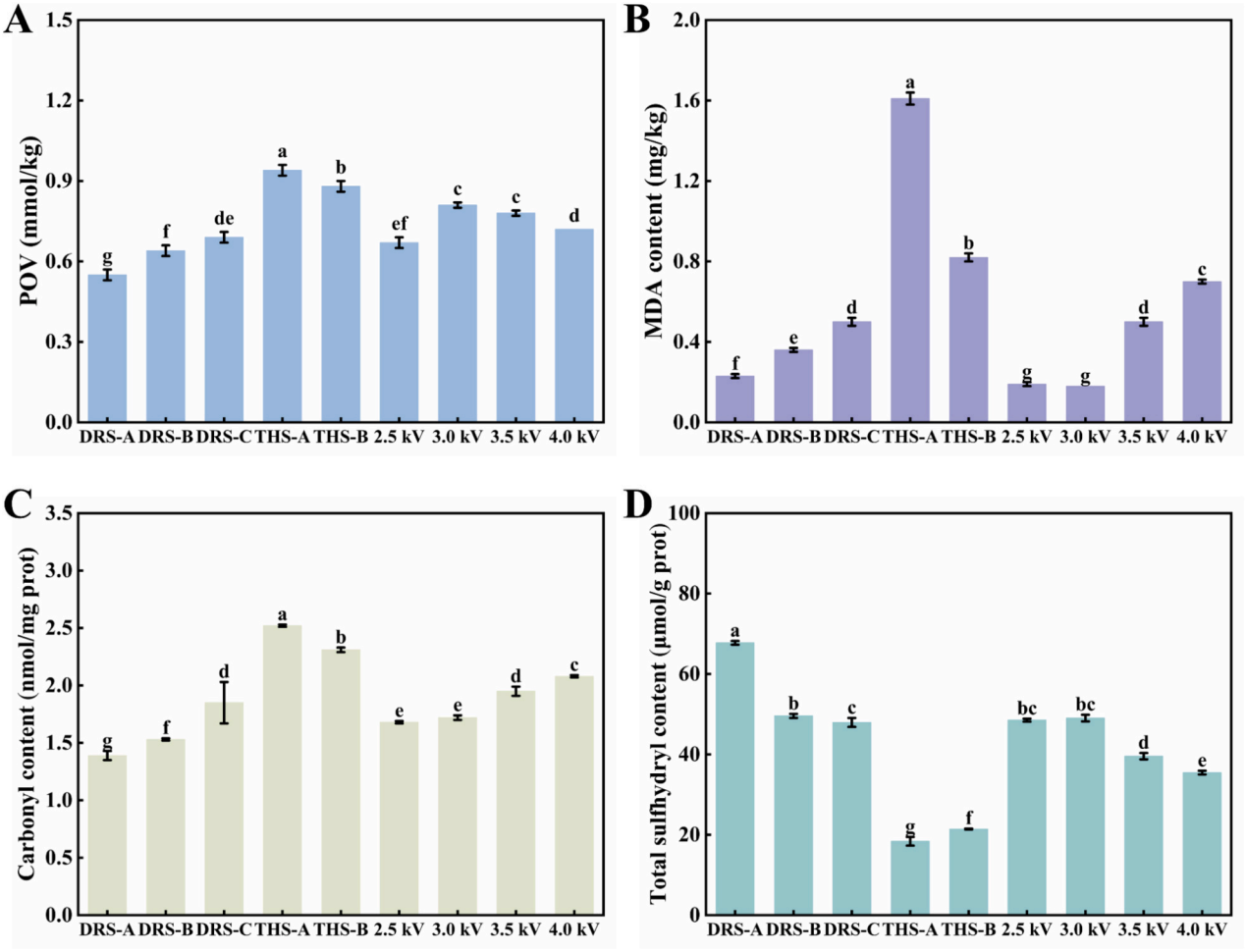


Fig. 5. Effect of HVEF salting on lipid oxidation (A POV, B MDA content) and protein oxidation (C carbonyl content, D total sulfhydryl content) of YYCGP. Different letters above the columns indicate significant differences ($P < 0.05$).

3.6.2. *Protein oxidation*

The carbonyl contents of THS-A and THS-B were 2.52 ± 0.01 and 2.31 ± 0.02 nmol/mg, respectively (Fig. 5C), and those of the 3.0 and 3.5 kV groups in the HVEF salting groups were 1.72 ± 0.02 and 1.95 ± 0.04 nmol/mg, respectively. The carbonyl content gradually increased with the applied voltage ($P < 0.05$). Compared with those of the DRS products and HVEF salting groups, the carbonyl content of the THS products was higher ($P < 0.05$).

The total sulfhydryl content of the THS products was significantly lower than those of the DRS products and HVEF salting groups (Fig. 5D) ($P < 0.05$), showing that the protein oxidation degree of THS products was higher. This result was consistent with that for carbonyl contents. In the HVEF treatment groups, the total sulfhydryl content showed an overall downward trend ($P<0.05$), indicating that HVEF treatment could accelerate protein oxidation. This finding was in agreement with the results of Huang et al. (2023), who found that the total sulfhydryl content of MPs treated with HVEF decreased significantly as the voltage increased (0–30 kV) ($P < 0.05$). The ozone generated by the ionization of air during the HVEF treatment caused the sulfhydryl groups of MPs to be oxidized into disulfide bonds, resulting in protein oxidation (Uzun et al., 2012). In addition, products of lipid oxidation, such as hydroperoxides, would attack MPs to form carbonyl compounds, resulting in promoting protein oxidation (Xiong et al., 2009). Therefore, HVEF salting may lead to lipid oxidation in fish, and the oxidation products then promote protein oxidation.

Existing studies have shown that the oxidation of proteins affects WHC and texture (Rahbari et al., 2018; Rahbari et al., 2020), which are consistent with the above results. And salt substances can promote the Fenton reaction to generate active substances, which will aggravate the oxidation of proteins (Wang et al., 2023). Therefore, HVEF affects the WHC, water distribution and texture in fish by accelerating salt migration and protein oxidation. In addition, the oxidation and degradation of MPs in fish during curing can produce free amino acids and other flavor precursors, which influence the final flavor formation of the products (Lin et al., 2024). The relatively abundant volatile flavor compounds in the samples salted in HVEF may be attributed to HVEF promoting the oxidation and degradation of proteins.

4. Conclusions

In this study, the effects of HVEF on the quality of salt-reduced cured golden pomfret were studied. The reasons for improving the quality of salt-reduced cured YYCGP were investigated from the perspective of lipid oxidation and protein oxidation by comparing DRS products and THS products. HVEF treatment can accelerate salt penetration, and the salt content of the samples showed an increasing trend with the applied voltage. The cooking losses of the HVEF treatment groups were significantly lower than those of commercially available products. In addition, HVEF salting significantly increased the varieties and contents of volatile flavor compounds, especially aldehydes, ketones, and alcohols. Among the treatment groups, the 3.5 kV group had the highest values. Overall, HVEF treatment improved the quality of salt-reducing cured products mainly by accelerating salt penetration, thus changing the water state and organizational structure. It also promoted the oxidation

of proteins and lipids, relating to the accelerated diffusion of salt and the ozone produced by air ionization, which may be the reason for the change in the moisture, texture, and flavor of the samples. This study demonstrated that HVEF-assisted salting shows potential to be a new method to cure salt-reduced fish that improves curing efficiency and product quality.

CRediT authorship contribution statement

Chunbei Chen: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zefu Wang:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Ziliang Gao:** Methodology, Investigation, Formal analysis. **Xiaosi Chen:** Methodology, Investigation, Formal analysis. **Shuai Wei:** Validation, Supervision, Formal analysis. **Qiuyu Xia:** Validation, Supervision, Formal analysis. **Qinxiu Sun:** Methodology, Formal analysis. **Yantao Yin:** Methodology, Formal analysis. **Yang Liu:** Methodology, Formal analysis. **Shucheng Liu:** Supervision, Resources, Project administration, Methodology, Funding acquisition, 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.

Acknowledgements

This work was supported by the National Key R&D Program of China (2023YFD2401404), GuangDong Basic and Applied Basic Research Foundation (2023A1515110246), and the scientific research start-up funds of Guangdong Ocean University (060302042108) for the financial support for the research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2025.102258.

References

AOAC. (2000). *Official methods of analysis* (17th ed.). Arlington, VA: Association of Official Analytical Chemists.

Bahuaud, D., Gaarder, M., Veiseth-Kent, E., & Thomassen, M. (2010). Fillet texture and protease activities in different families of farmed Atlantic salmon (salmo Salar L.). *Aquaculture, 310*(1–2), 213–220. https://doi.org/10.1016/j.aquaculture.2010.10.008

Bureau of Fisheries of the Ministry of Agriculture. (2024). *2024 China fishery statistical yearbook*. Beijing: China Agriculture Press.

Cao, S. M., Wu, Y. Y., Li, L. H., Yang, X. Q., Chen, S. J., Hu, X., & Ma, H. X. (2018). Activities of endogenous lipase and lipolysis oxidation of low-salt lactic acid-fermented fish (decapterus maruadsi). *Journal of Oleo Science, 67*(4), 445–453. https://doi.org/10.5650/jos.ess17176

Chen, G., Xu, C., Wang, Z., Han, Z., Xia, Q., Wei, S., Sun, Q., & Liu, S. (2024). Effect of MDA-mediated oxidation on the protein structure and digestive properties of golden pomfret. *Food Chemistry, 443*, Article 138563. https://doi.org/10.1016/j.foodchem.2024.138563

Cropotova, J., Tappi, S., Genovese, J., Rocculi, P., Laghi, L., Dalla Rosa, M., & Rustad, T. (2021). Study of the influence of pulsed electric field pre-treatment on quality parameters of sea bass during brine salting. *Innovative Food Science & Emerging Technologies, 70*, Article 102706. https://doi.org/10.1016/j.ifset.2021.102706

Estévez, A., Camacho, C., Correia, T., Barbosa, V., Marques, A., Lourenço, H., … Oliveira, H. (2021). Strategies to reduce sodium levels in European seabass sausages. *Food and Chemical Toxicology, 153*, Article 112262. https://doi.org/10.1016/j.fct.2021.112262

Gallart-Jornet, L., Barat, J. M., Rustad, T., Erikson, U., Escriche, I., & Fito, P. (2007). Influence of brine concentration on Atlantic salmon fillet salting. *Journal of Food Engineering, 80*(1), 267–275. https://doi.org/10.1016/j.jfoodeng.2006.05.018

van Gemert, L. J. (2011). *Compilations of odour threshold values in air, water and other media (edition 2011)*. The Netherlands: Oliemans Punter & Partners BV.

Huang, H., Sun, W., Xiong, G., Shi, L., Jiao, C., Wu, W., Li, X., Qiao, Y., Liao, L., Ding, A., & Wang, L. (2020). Effects of HVEF treatment on microbial communities and physicochemical properties of catfish fillets during chilled storage. *LWT, 131*, Article 109667. https://doi.org/10.1016/j.lwt.2020.109667

Huang, J., Que, F., Xiong, G., Qiao, Y., Wu, W., Wang, J., Ding, A., Liao, L., Shi, L., & Wang, L. (2023). Physicochemical and functional properties changes in myofibrillar protein extracted from channel catfish by a high-voltage electrostatic field. *Food and Bioprocess Technology, 16*(2), 395–403. https://doi.org/10.1007/s11947-022-02937-7

Jia, G., He, X., Nirasawa, S., Tatsumi, E., Liu, H., & Liu, H. (2017). Effects of high-voltage electrostatic field on the freezing behavior and quality of pork tenderloin. *Journal of Food Engineering, 204*, 18–26. https://doi.org/10.1016/j.jfoodeng.2017.01.020

Jia, G., Liu, H., Nirasawa, S., & Liu, H. (2017). Effects of high-voltage electrostatic field treatment on the thawing rate and post-thawing quality of frozen rabbit meat. *Innovative Food Science & Emerging Technologies, 41*, 348–356. https://doi.org/10.1016/j.ifset.2017.04.011

Jia, G., Sha, K., Meng, J., & Liu, H. (2019). Effect of high voltage electrostatic field treatment on thawing characteristics and post-thawing quality of lightly salted, frozen pork tenderloin. *LWT, 99*, 268–275. https://doi.org/10.1016/j.lwt.2018.09.064

Jia, Y., Yang, X., Xu, Z., Guo, Q., & Li, X. (2010). Effect of moisture content on the texture and chroma of lightly baked scallop. *Food & Machinery, 26*(3), 47–50. https://doi.org/10.3969/j.issn.1003-5788.2010.03.013 (in Chinese with English abstract)

Li, D., Jia, S., Zhang, L., Wang, Z., Pan, J., Zhu, B., & Luo, Y. (2017). Effect of using a high voltage electrostatic field on microbial communities, degradation of adenosine triphosphate, and water loss when thawing lightly-salted, frozen common carp (cyprinus Carpio). *Journal of Food Engineering, 212*, 226–233. https://doi.org/10.1016/j.jfoodeng.2017.06.003

Li, M., Zhang, X., Yin, Y., Li, J., Qu, C., Liu, L., Zhang, Y., Zhu, Q., & Wang, S. (2023). Perspective of sodium reduction based on endogenous proteases via the strategy of sodium replacement in conjunction with mediated-curing. *Critical Reviews in Food Science and Nutrition, 1–12*. https://doi.org/10.1080/10408398.2023.2212287

Lin, W., Zhu, J., Sun, Y., Pan, D., Xia, Q., Zhou, C., He, J., & Dang, Y. (2024). Effects of ultrasonic-assisted marinating on degradation of beef protein and formation of flavor precursors. *Journal of Food Composition and Analysis, 133*, Article 106407. https://doi.org/10.1016/j.jfca.2024.106407

Mariutti, L. R. B., & Bragagnolo, N. (2017). Influence of salt on lipid oxidation in meat and seafood products: A review. *Food Research International, 94*, 90–100. https://doi.org/10.1016/j.foodres.2017.02.003

ISO1841-2. *Meat and meat products-determination of chloride content-part 2: Potentiometric method* (1996). Switzerland: International Organization for Standardization Genf.

Mousakhani-Ganjeh, A., Hamdami, N., & Soltanizadeh, N. (2016). Effect of high voltage electrostatic field thawing on the lipid oxidation of frozen tuna fish (thunnus albacares). *Innovative Food Science & Emerging Technologies, 36*, 42–47. https://doi.org/10.1016/j.ifset.2016.05.017

Nurmilah, S., Cahyana, Y., Utama, G. L., & Aït-Kaddour, A. (2022). Strategies to reduce salt content and its effect on food characteristics and acceptance: A review. *Foods, 11*(19), 3120. https://doi.org/10.3390/foods11193120

Qin, N., Zhang, L., Zhang, J., Song, S., Wang, Z., Regenstein, J. M., & Luo, Y. (2017). Influence of lightly salting and sugaring on the quality and water distribution of grass carp (ctenopharyngodon idellus) during super-chilled storage. *Journal of Food Engineering, 215*, 104–112. https://doi.org/10.1016/j.jfoodeng.2017.07.011

Rahbari, M., Hamdami, N., Mirzaei, H., & Jafari, S. M. (2020). Investigation of the histological and textural properties of chicken breast thawed by high voltage electric field. *Journal of Food Process Engineering, 43*(11), Article e13543. https://doi.org/10.1111/jfpe.13543

Rahbari, M., Hamdami, N., Mirzaei, H., Jafari, S. M., Kashaninejad, M., & Khomeiri, M. (2018). Effects of high voltage electric field thawing on the characteristics of chicken breast protein. *Journal of Food Engineering, 216*, 98–106. https://doi.org/10.1016/j.jfoodeng.2017.08.006

Schmidt, F. C., Carciofi, B. A. M., & Laurindo, J. B. (2008). Salting operational diagrams for chicken breast cuts: Hydration–dehydration. *Journal of Food Engineering, 88*(1), 36–44. https://doi.org/10.1016/j.jfoodeng.2007.12.005

Shi, J., & Le Maguer, M. (2002). Osmotic dehydration of foods: Mass transfer and modeling aspects. *Food Reviews International, 18*(4), 305–335. https://doi.org/10.1081/FRI-120016208

The State Council. (2016). "Healthy China 2030 plan outline". Retrieved from https://www.gov.cn/zhengce/2016-10/25/content_5124174.htm. Accessed December 19, 2023.

Uzun, H., Ibanoglu, E., Catal, H., & Ibanoglu, S. (2012). Effects of ozone on functional properties of proteins. *Food Chemistry, 134*(2), 647–654. https://doi.org/10.1016/j.foodchem.2012.02.146

Wang, J., Huang, X.-H., Zhang, Y.-Y., Li, S., Dong, X., & Qin, L. (2023). Effect of sodium salt on meat products and reduction sodium strategies—A review. *Meat Science, 205*, Article 109296. https://doi.org/10.1016/j.meatsci.2023.109296

Wang, J., Huang, X.-H., Zhang, Y.-Y., Nie, C., Zhou, D., & Qin, L. (2024). Mechanism of salt effect on flavor formation in lightly-salted large yellow croaker by integrated multiple intelligent sensory and untargeted lipidomics analyses. *Food Chemistry, 435*, Article 137542. https://doi.org/10.1016/j.foodchem.2023.137542

Wei, H., Wei, Y., Qiu, X., Yang, S., Chen, F., Ni, H., & Li, Q. (2023). Comparison of potent odorants in raw and cooked mildly salted large yellow croaker using odor-active

value calculation and omission test: Understanding the role of cooking method. *Food Chemistry, 402*, Article 134015. https://doi.org/10.1016/j.foodchem.2022.134015
World Health Organization. (2013). Salt reduction. Retrieved from https://www.who.int/en/news-room/fact-sheets/detail/salt-reduction/ Accessed December 23, 2023.
Xiong, Y. L., Park, D., & Ooizumi, T. (2009). Variation in the cross-linking pattern of porcine myofibrillar protein exposed to three oxidative environments. *Journal of Agricultural and Food Chemistry, 57*(1), 153–159. https://doi.org/10.1021/jf8024453
Xu, C.-C., Yu, H., Xie, P., Sun, B.-Z., Wang, X.-Y., & Zhang, S.-S. (2020). Influence of electrostatic field on the quality attributes and volatile flavor compounds of dry-cured beef during chill storage. *Foods, 9*(4), 478. https://doi.org/10.3390/foods9040478
Xu, Y., Li, L., Xia, W., Zang, J., & Gao, P. (2019). The role of microbes in free fatty acids release and oxidation in fermented fish paste. *LWT, 101*, 323–330. https://doi.org/10.1016/j.lwt.2018.11.027
Yang, W., Shi, W., Qu, Y., Wang, Z., Shen, S., Tu, L., Huang, H., & Wu, H. (2020). Research on the quality changes of grass carp during brine salting. *Food Science & Nutrition, 8*(6), 2968–2983. https://doi.org/10.1002/fsn3.1599
Zhang, Q., Ding, Y., Gu, S., Zhu, S., Zhou, X., & Ding, Y. (2020). Identification of changes in volatile compounds in dry-cured fish during storage using HS-GC-IMS. *Food Research International, 137*, Article 109339. https://doi.org/10.1016/j.foodres.2020.109339
Zhang, Y., Ding, C., Ni, J., Song, Z., & Zhao, R. (2019). Effects of high-voltage electric field process parameters on the water-holding capacity of frozen beef during thawing process. *Journal of Food Quality, 2019*, 1–11. https://doi.org/10.1155/2019/9140179
Zheng, X., Ji, H., Zhang, D., Zhang, Z., Liu, S., & Song, W. (2022). The identification of three phospholipid species roles on the aroma formation of hot-air-dried shrimp (litopenaeus vannamei) by gas chromatography–ion mobility spectrometry and gas chromatography-mass spectrometry. *Food Research International, 162*, Article 112191. https://doi.org/10.1016/j.foodres.2022.112191