Food Science of Animal Products

Research Article

Comparison of flavor quality of edible parts from green and white carapace strains of adult Chinese mitten crab (*Eriocheir sinensis*)

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Received: September 1, 2024; Revised: September 20, 2024; Accepted: November 18, 2024

Abstract: This study investigated the flavor quality differences between the edible parts from green and white carapace strains of adult *Eriocheir sinensis*. The comparison of odor and taste of edible parts, including muscles, ovaries, and hepatopancreas, was conducted through sensory evaluation and quantitative analysis of flavor compounds. The results indicated that the contents of glutamic acid ((0.56 ± 0.03) mg/g vs. (0.43 ± 0.01) mg/g) ($P < 0.01$), 5′-inosine monophosphate ((17.13 ± 1.36) mg/100 g vs. (12.37 ± 0.29) mg/100 g) ($P < 0.05$), and equivalent umami concentration ((4.34 ± 0.24) g monosodium glutamate (MSG)/100 g vs. (3.34 ± 0.09) g MSG/100 g) ($P < 0.01$) in the muscles of white carapace crabs were significantly higher than those of green carapace crabs, resulting in a stronger umami. In contrast, the ovaries showed opposite results. For the hepatopancreas, total bitter free amino acids ((4.28 ± 0.37) mg/g) and nucleotides (inosine and hypoxanthine) were significantly lower in the white carapace strains than in the green carapace strains crabs ($P < 0.05$). In addition, the content of characteristic aroma substances is higher in the muscles (2-octanone, 3-phenylpropanal) and ovaries (β-citronellol) of white carapace crabs, as well as in the hepatopancreas ((*E*,*E*)-2,4-nonadienal, benzoic acid ethyl ester, β-citronellol) of green carapace crabs. In summary, the white carapace crabs outperform the green carapace crabs in most flavor attributes, suggesting that the white carapace crabs have great promotional potentiality. The research results provide a theoretical basis for the evaluation of germplasm resources and further breeding of white carapace strains of *E. sinensis*.

Keywords: *Eriocheir sinensis*; white carapace strain; edible parts; flavor quality; sensory evaluation; headspace gas chromatography-ion mobility spectrometry; free amino acids; flavor nucleotides

Citation: R. Y. Zhang, L. Zhang, D. D. Zhang, et al., Comparison of flavor quality of edible parts from green and white carapace strains of adult Chinese mitten crab (*Eriocheir sinensis*), Food Sci. Anim. Prod. 3 (2025) 9240102. https://doi.org/10.26599/FSAP.2025.9240102.

1 Introduction

The Chinese mitten crab (*Eriocheir sinensis*) is favored by consumers for its unique flavor and excellent taste. According to the *China Fishery Statistical Yearbook 2024*, the production of *E. sinensis* were reached nearly 880 000 tons in 2023, and the market value exceeding 150 billion yuan. The color of the carapace is a crucial indicator of crustacean edible quality. In the wild, over 90% of adult *E. sinensis* have a green carapace, although some individuals also have purple, white, yellow or red carapace[1–2]. With the continuous improvement of living standards, more and more consumers are not only focusing on nutrition and flavor quality, but also pursuing differentiated characteristic qualities. The new strain of white carapace crabs (Haida Jade Crab) has attracted the attention of breeders and consumers due to its unique color, which can increase the diversity of the crab consumption market.

Previous studies have shown that the white carapace strain of *E. sinensis* has similar nutritional value to the green carapace strain, and white carapace crabs have the advantage of fast growth rate, which is important for artificial breeding and germplasm promotion[3–4]. The main edible parts of *E. sinensis* muscles, gonads and hepatopancreas significantly influence consumers' purchasing decisions due to their taste and odor. Most research on the flavor quality differences in *E. sinensis* has focused on the culture environment and feed[5–8]. However, there is limited information about the flavor quality variations among different carapace color strains of *E. sinensis*.

Therefore, the muscles, ovaries and hepatopancreas of green and white carapace crabs were used as research objects, and a sensory evaluation was carried out to compare the odor and taste quality. Chromatography technology was used to analyze the main flavor substances (free amino acids (FAAs), flavor nucleotides) of the edible parts of *E. sinensis*. A comprehensive analysis of the flavor contribution of the main flavor substances was performed by calculating the taste activity value (TAV) and the equivalent umami concentration (EUC). Headspace-gas chromatography-ion mobility spectrometry (HS-GC-IMS) technology was used for odorant analysis, combined with relative odor activity value (ROAV) for odor quality contribution analysis. The differences in sensory

evaluation and flavor compound content between green and white carapace crabs were explored to provide a theoretical basis and practical reference for diversified breeding of *E. sinensis* based on carapace color, and to provide consumers with valuable consumption guidance.

2 Material and methods

2.1 Crab materials

All samples in this study were obtained from Chongming Research Base of Shanghai Ocean University. A total of 24 crabs were randomly selected, including 12 white carapace crabs and 12 green carapace crabs, each weighing 150–175 g. The crabs were tied with cotton thread and transported alive to the laboratory within 2 h of harvesting in a styrofoam box with refrigeration (0–4 °C). To avoid the crab's struggle, anatomical needles were used to insert into the crab mouth and quickly cut off the nerves along the abdomen before steaming[8]. The crabs were steamed at 100 °C for 20 min, and the collection process of the crab edible parts was carried out at 4–7 °C. The carapace was first separated from the body, and then the ovaries, hepatopancreas, and abdomen muscles tissues are removed with tweezers. Each samples group was evenly mixed and packaged in sensory cups and polyethylene bags (Jiangyin Honghao Packaging Materials Co., Ltd., Jiangyin, China) for sensory evaluation, detection of FAAs, flavor nucleotides, and GC-IMS. The sampling groups are coded as follows: muscles of green carapace *E. sinensis* (MG); muscles of white carapace *E. sinensis* (MW); ovaries of green carapace *E. sinensis* (OG); ovaries of white carapace *E. sinensis* (OW); hepatopancreas of green carapace *E. sinensis* (HG); hepatopancreas of white carapace *E. sinensis* (HW).

2.2 Sensory evaluation

Following the method of Zhang et al.[9], 20 trained sensory assessors were selected, including 10 males and 10 females. Sensory evaluation was conducted on the abdomen muscles, ovaries and hepatopancreas of cooked crabs. Evaluators first scored the intensity of odors (meaty, fatty, green, oxidation, ammonia-like, and fishy), followed by scores for tastes (umami, sweet, bitter, and salty). The scoring system was as follows: score 0: not present; score 1: just recognizable; score 2: weak; score 3: moderate; score 4: strong; score 5: very strong.

2.3 Analysis of FAAs

Samples were processed according to the method of Shi et al.[10]. The procedure was performed in an ice bath with (0.500 0 ± 0.000 1) g of muscles, ovaries and hepatopancreas placed in a centrifuge tube. Then, 15 mL of 5 g/100 mL trichloroacetic acid was added in two aliquots, followed by 30 s of homogenization (HG-200, Hsiangtai Machinery Industry Co., Ltd., Taipei, China), repeated 3 times. The mixture was then sonicated (40 kHz, 4 °C) for 15 min and incubated in a refrigerator at 4 °C for 2 h. After centrifugation at 10 000 × *g* for 10 min (H2500R, Hunan Xiangyi Laboratory Instrument Development Co., Ltd., Changsha, China), 5 mL of the supernatant was extracted and the pH was adjusted to 2.00 ± 0.02 before diluting to a final volume of 10 mL with a 0.22 μm aqueous filtration membrane. A 5 mL portion of this solution was taken, the pH adjusted to 2.00 ± 0.02 with 1 and 6 mol/L NaOH, filtered through a 0.22 μm aqueous filter membrane and analyzed with an automatic amino acid analyzer (L-8800, Hitachi Co., Ltd., Tokyo, Japan).

2.4 TAV calculation

TAV was calculated according to the following formula (1):

$$\mathrm{TAV} = \frac{C}{T} \tag{1}$$

Where C represents the absolute concentration value of the taste substance (mg/100 g); T represents the threshold value of the taste substance (mg/100 g)[8].

2.5 Analysis of flavor nucleotides

The entire operation is carried out under ice bath conditions according to the previously described[6]. The sample ((1.500 0 ± 0.000 1) g) was weighed into a centrifuge tube and 7 mL of 10% (*V*/*V*) perchloric acid was added in two portions. The mixture was homogenized for 30 s and repeated 3 times (HG-200, Hsiangtai Machinery Industry Co., Ltd., Taipei, China). It was then sonicated (40 kHz, 4 °C) for 5 min and centrifuged at 4 °C and 12 000 × *g* for 10 min. The precipitate was washed with 5 mL of 5% (*V*/*V*) perchloric acid and centrifuged again to collect the supernatant. The above procedure was repeated twice and the supernatant was combined. The pH of the combined supernatant was adjusted to 5.75 ± 0.02 and it was placed in a refrigerator at 4 °C for 30 min. The supernatant was made up to 50 mL and filtered through a 0.22 μm aqueous phase filter membrane before liquid chromatography analysis (Waters Co., Ltd., Milford, USA). To achieve the nucleotide separations, high performance liquid chromatography conditions were set as follows: Inertsil ODS-3 C_{18} liquid chromatography column (4.6 × 250 mm, 5 μm, GL Sciences), column temperature: 30 °C; flow rate: 1 mL/min; injection volume: 10 μL; ultraviolet detector wavelength: 245 nm. Mobile phase A was methanol, while phase B was phosphate buffer solution.

2.6 EUC calculation

EUC was calculated according to the following formula (2):

$$\mathrm{EUC} = \sum_{i=1}^{n} a_i b_i + 1\,218\left(\sum_{i=1}^{n} a_i b_i\right)\left(\sum_{j=1}^{n} a_j b_j\right) \tag{2}$$

Where EUC was represented as g of monosodium glutamate (MSG) per 100 g of cooked edible parts. Here, a_i denotes the concentration of each umami amino acid (g/100 g cooked edible parts), while b_i refers to the relative umami concentration for each amino acid (with Glu valued at 1.0 and Asp at 0.077). Additionally, a_j indicates the concentration of 5′-nucleotides (g/100 g cooked edible parts), and b_j signifies the relative umami concentration for each 5′-nucleotide (with 5′-inosine monophosphate (IMP) valued at 1.0 and 5′-adenosine monophosphate (AMP) at 0.18). The number 1 218 serves as a synergistic constant[6].

2.7 HS-GC-IMS analysis

Volatile compound analysis was developed on a GC-IMS instrument (FlavourSpec® Sensitive Analyzer, G.A.S. Gesellschaft für analytische Sensorsysteme mbH, Dortmund, Germany). Each sample (1.50 g) was incubated in a 20 mL headspace vial at 100 °C for 15 min. The incubation speed was 500 r/min, the injection volume was 500 μL, and the injection needle temperature was 85 °C. An FS-SE-54-CB-1 column (15 m × 1 μm, 0.53 mm) was used, with column temperature at 60 °C, N_2 as the carrier gas, and an IMS temperature of 45 °C. The carrier gas flow rate was increased in a gradient: 2 mL/min for 2 min, 10 mL/min for 10 min, 100 mL/min for 20 min, and 150 mL/min for 30 min. The drift gas flow rate was 150 mL/min.

ROAV was calculated according to the following formula (3):

$$\mathrm{ROAV_i} = \frac{C_i}{C_{stan}} \times \frac{T_{stan}}{T_i} \times 100 \quad (3)$$

Where C_i and T_i are the relative content (%) and odor threshold (ng/g) of volatile substances, respectively; C_{stan} and T_{stan} are the relative content (%) and odor threshold (ng/g) of substances that contribute most to the flavor of the sample, respectively.

2.8 Statistical analysis

The experimental data were analyzed using *t*-test in SPSS 19.0 (SPSS Inc., Chicago, IL, USA) and presented as mean ± standard deviation (n = 3). The results were then graphed with OriginPro software (OriginLab, Northampton, MA, USA).

3 Results and discussion

3.1 Sensory evaluation

The digital photos of *E. sinensis* in two carapace colors were shown in Figure 1A. The Haida Jade Crab was white overall. The odor radar chart (Figures 1B$_1$–B$_3$) indicates significant differences in odor values between the edible parts of the green and white carapace *E. sinensis*. The ovaries and hepatopancreas had a predominantly fatty odor, while the muscles had a meaty odor. White carapace crabs had a more pronounced odor, with stronger meaty and grassy notes in the muscles. Green carapace crabs had a stronger oxidation flavor in the ovaries and a more intense fatty odor in the hepatopancreas.

The taste radar chart (Figures 1B$_4$–B$_6$) shows differences in taste values between the edible parts of the green and white carapace *E. sinensis*. The muscles of white carapace crab, as well as the hepatopancreas and ovaries of green carapace crabs, showed higher intensity of umami. The sweetness intensity of edible parts varies from high to low, including muscles, ovaries and hepatopancreas, but there is no difference in the color of the carapace. The intensity of saltiness in the muscles varied significantly, with white carapace crabs having a higher saltiness. Bitterness was more pronounced in the hepatopancreas of green carapace crabs.

The formation of crab flavor during steaming is a complex process. Metabolic pathways (protein degradation, energy metabolism, etc.) were affected by steaming, which ultimately affects the production of flavor compounds[9–10]. Further analysis of FAAs, flavor nucleotides, and GC-IMS are required to understand the sensory differences between green and white carapace crabs.

3.2 FAAs analysis and TAV results

As important flavoring substances, FAAs give aquatic products a rich taste[11]. Table 1 shows the changes in FAA content and TAV of edible parts of green and white carapace crabs. A total of 17 FAAs were detected, and there was no significant difference in the total number of FAAs between the edible parts of green and white carapace crabs.

UFAAs contents were higher in ovaries and significantly higher in OG than OW (P < 0.001). Asp content was significantly higher in MG (P < 0.01), while Glu content was significantly higher in MW (P < 0.01) and OG (P < 0.001). The total TAV of UFAAs was higher in MW and OG. Glu, with a TAV greater than 1.0 in all groups, likely contributes significantly to umami due to its low threshold value[12]. Glu is an intermediate product of other amino acids in the energy metabolism cycle, which may be the reason for its high content in UFAAs. Six SFAAs have been detected, found in muscles ovaries, and hepatopancreas, accounting for over 60% of the total. SFAAs were more abundant in muscles (16.68–17.17 mg/g) than in ovaries (5.67–5.73 mg/g) and hepatopancreas (8.71–9.45 mg/g), explaining the higher sweetness intensity in muscles. The total TAV of SFAAs differed significantly in muscles, with values being higher in MG. Thr and Ser contents were significantly different in edible parts but had thresholds larger than 1.0, resulting in a smaller sweetness contribution. Gly and Pro contents differed significantly in muscles (P < 0.001), with TAV being higher in muscle, explaining the greater sweetness intensity in muscles compared to ovaries and hepatopancreas. Ala and Arg had TAV greater than 1 in all parts, indicating their significant contribution to sweetness in all edible parts of *E. sinensis*.

BFAAs were found at high concentrations in the hepatopancreas (2.08–4.28 mg/g), with His having a TAV generally greater than 1, indicating its significant contribution to bitterness. His is known as a primary bitter amino acid in off-season crabs[13]. Despite its bitterness, the His can enhance the meaty flavor of aquatic

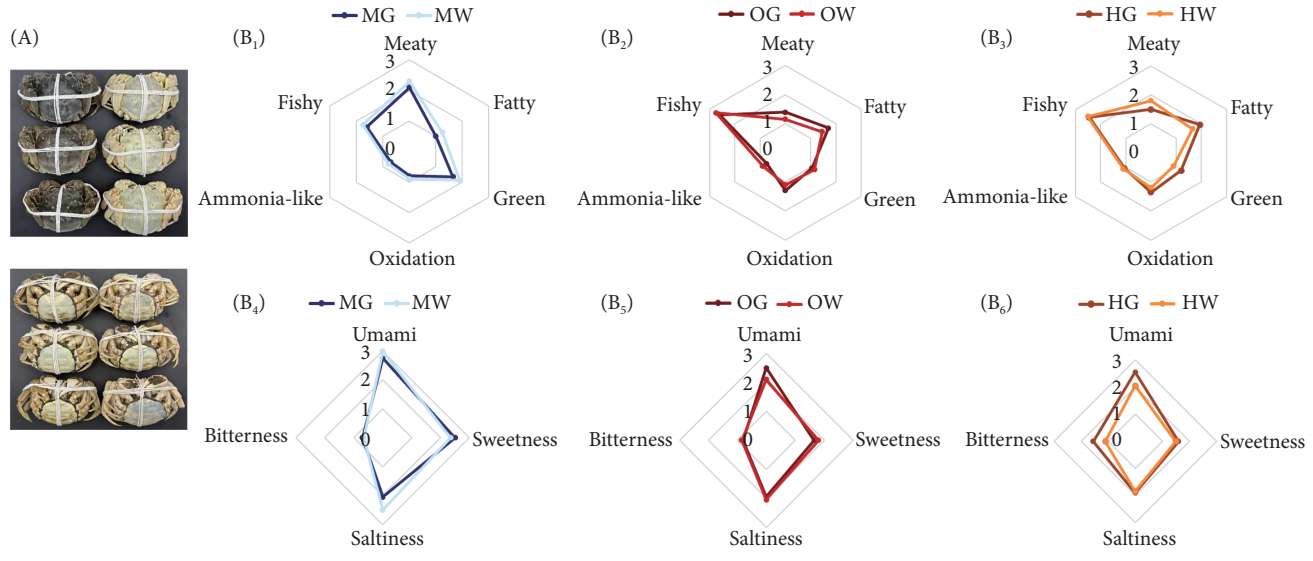

Figure 1 (A) The digital photos of white and green carapace of *E. sinensis* and (B) radar chart for sensory evaluation of edible parts. (B$_1$–B$_3$) Odor values; (B$_4$–B$_6$) taste values.

Table 1 The contents and TAVs of FAAs in the cooked muscles, ovaries, hepatopancreas from green and white carapace of *E. sinensis* ($n = 3$).

FAAs	Content (mg/g)										Taste attribute	Taste threshold (mg/100 g)	TAV					
	MG	MW		OG	OW		HG	HW					MG	MW	OG	OW	HG	HW
Asp	0.39 ± 0.01	0.30 ± 0.02	**	0.26 ± 0.01	0.28 ± 0.00		0.14 ± 0.01	0.28 ± 0.03			Umami (+)	100	0.39	0.30	0.26	0.28	0.14	0.28
Glu	0.43 ± 0.01	0.56 ± 0.03	**	1.18 ± 0.00	0.87 ± 0.06	***	0.60 ± 0.02	0.56 ± 0.03			Umami (+)	30	1.42	1.85	3.92	2.89	2.01	1.86
UFAAs	0.81 ± 0.01	0.86 ± 0.04		1.44 ± 0.00	1.14 ± 0.06	***	0.74 ± 0.02	0.84 ± 0.05			Umami (+)	–	1.80	2.16	4.19	3.16	2.14	2.15
Thr	0.69 ± 0.02	0.90 ± 0.03	***	0.26 ± 0.01	0.19 ± 0.00	***	0.60 ± 0.04	0.87 ± 0.04	**		Sweet (+)	260	0.27	0.35	0.10	0.07	0.23	0.33
Ser	0.30 ± 0.01	0.24 ± 0.02	**	0.06 ± 0.01	0.05 ± 0.00		0.34 ± 0.03	0.23 ± 0.02	*		Sweet (+)	150	0.20	0.16	0.04	0.03	0.23	0.16
Gly	5.35 ± 0.07	3.73 ± 0.20	***	0.12 ± 0.01	0.10 ± 0.00	*	0.73 ± 0.02	0.77 ± 0.02			Sweet (+)	130	4.11	2.87	0.09	0.08	0.56	0.59
Ala	2.28 ± 0.04	2.61 ± 0.16	*	1.34 ± 0.03	0.72 ± 0.01	***	1.97 ± 0.10	2.64 ± 0.15	**		Sweet (+)	60	3.80	4.34	2.23	1.20	3.28	4.41
Arg	4.71 ± 0.13	4.21 ± 0.31		1.58 ± 0.09	2.15 ± 0.05	***	2.46 ± 0.06	2.15 ± 0.17			Bitter/sweet (+)	50	9.41	8.43	3.17	4.30	4.91	4.30
Pro	3.35 ± 0.22	5.49 ± 0.39	***	2.30 ± 0.01	2.53 ± 0.17		2.60 ± 0.19	2.79 ± 0.10			Sweet/bitter (+)	300	1.12	1.83	0.77	0.84	0.87	0.93
SFAAs	16.68 ± 0.30	17.17 ± 1.09		5.67 ± 0.08	5.73 ± 0.11		8.71 ± 0.21	9.45 ± 0.46			Sweet (+)	–	18.91	17.97	6.40	6.53	10.09	10.71
Val	0.20 ± 0.01	0.32 ± 0.02	***	0.10 ± 0.01	0.08 ± 0.00	*	0.53 ± 0.03	0.33 ± 0.03	**		Sweet/bitter (–)	40	0.50	0.80	0.25	0.21	1.32	0.82
Met	0.26 ± 0.01	0.28 ± 0.02		0.06 ± 0.00	0.06 ± 0.00		0.28 ± 0.02	0.24 ± 0.00	**		Bitter/sweet/ sulfurous (–)	30	0.92	0.88	0.21	0.21	0.92	0.80
Ile	0.11 ± 0.01	0.18 ± 0.01	***	0.05 ± 0.01	0.06 ± 0.00		0.36 ± 0.03	0.16 ± 0.01	**		Bitter (–)	90	0.12	0.20	0.06	0.06	0.40	0.18
Leu	0.21 ± 0.01	0.30 ± 0.01	***	0.11 ± 0.01	0.12 ± 0.01		0.80 ± 0.06	0.27 ± 0.01	**		Bitter (–)	190	0.11	0.16	0.06	0.07	0.42	0.14
Tyr	0.13 ± 0.01	0.17 ± 0.01	**	0.05 ± 0.00	0.05 ± 0.00		0.54 ± 0.02	0.15 ± 0.00	**		Bitter (–)	–	–	–	–	–	–	–
Phe	0.10 ± 0.01	0.17 ± 0.01	***	0.12 ± 0.00	0.13 ± 0.00	***	0.64 ± 0.03	0.19 ± 0.00	***		Bitter (–)	90	0.11	0.19	0.14	0.13	0.71	0.21
Lys	0.31 ± 0.01	0.46 ± 0.03	***	0.74 ± 0.01	0.96 ± 0.01	***	0.86 ± 0.16	0.45 ± 0.00	*		Sweet/bitter (–)	–	–	–	–	–	–	–
His	0.27 ± 0.01	0.29 ± 0.02		0.22 ± 0.01	0.17 ± 0.00	**	0.26 ± 0.02	0.28 ± 0.02			Bitter (–)	20	1.36	1.44	1.08	0.84	1.30	1.41
BFAAs	1.60 ± 0.02	2.14 ± 0.11	***	1.46 ± 0.01	1.64 ± 0.01	***	4.28 ± 0.37	2.08 ± 0.06	**		Bitter (–)	–	3.13	3.66	1.81	1.51	5.09	3.57
Cys	0.04 ± 0.01	0.05 ± 0.00		0.02 ± 0.00	0.01 ± 0.00	**	0.11 ± 0.02	0.04 ± 0.01	*		Bitter/sweet/ sulfurous (–)	–	–	–	–	–	–	–
TFAAs	19.13 ± 0.31	20.23 ± 1.24		8.59 ± 0.08	8.52 ± 0.17		13.83 ± 0.57	12.42 ± 0.60			–	–	23.84	23.79	12.39	11.20	17.31	16.43

Note: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, green carapace *E. sinensis* (MG) vs. white carapace *E. sinensis*. (+), Pleasant; (–), unpleasant; –, not be determined. UFAAs, umami FAAs; SFAAs, sweet FAAs; BFAAs, bitter FAAs; Asp, aspartic acid; Glu, glutamic acid; Thr, threonine; Ser, serine; Gly, glycine; Ala, alanine; Arg, arginine; Pro, proline; Cys, cysteine; Val, valine; Met, methionine; Ile, isoleucine; Leu, leucine; Tyr, tyrosine; Phe, phenylalanine; Lys, lysine; His, histidine.

products[14]. Cys can degrade during heating to form 2-acetylthiazole, which may affect the odor of *E. sinensis*[15].

The difference in FAA content under the same rearing conditions is probably due to genetic factors in white carapace crabs[4]. FAAs also interact with each other. For example, Gly reduces bitterness and other undesirable flavors, while Glu and Ala inhibit sweetness[16–17]. FAAs interact with other flavor substances as well, such as NaCl, Glu and AMP, which reduce the bitter contribution of Arg in aquatic products. These complex interactions contribute to the unique overall flavor of aquatic products[18]. Amino acids can also act as flavor precursors, producing flavor compounds through degradation and the Maillard reaction[19]. Therefore, more research is necessary to determine the flavor of *E. sinensis* with two carapace colors.

3.3 Flavor nucleotides analysis and EUC results

Figure 2 shows the changes in the content of flavor nucleotide content in the edible parts of green and white carapace *E. sinensis*. The results suggested that the content of flavor nucleotides varied in different edible parts of *E. sinensis*, and there were significant differences between the green and white carapace in the same edible parts.

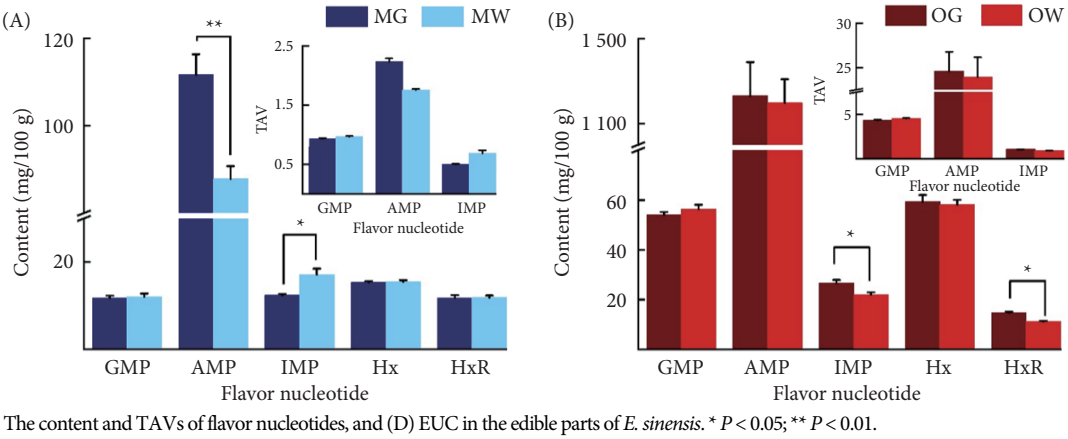

Figure 2 (A–C) The content and TAVs of flavor nucleotides, and (D) EUC in the edible parts of *E. sinensis*. * $P < 0.05$; ** $P < 0.01$.

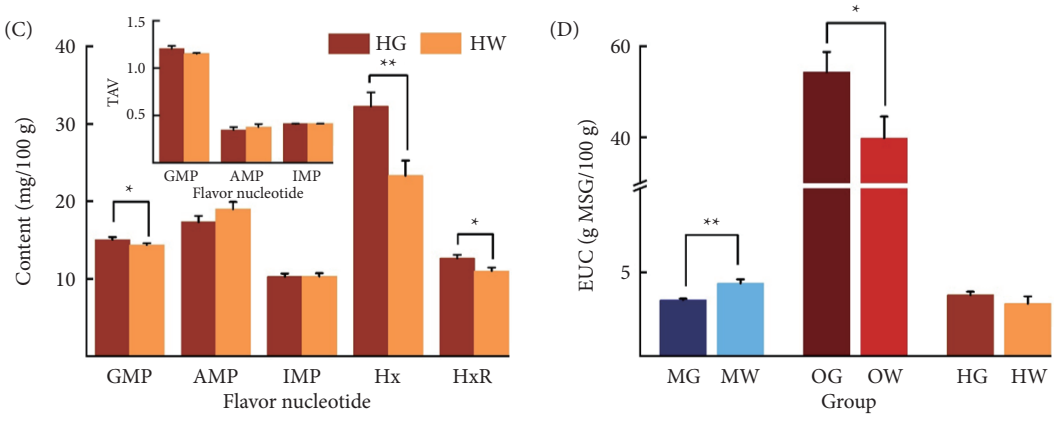

Figure 2 *(Continued)*

As shown in Figure 2, 5′-guanosine monophosphate (GMP) content was significantly different in hepatopancreas. HG ((15.06 ± 0.33) mg/100 g) was significantly higher than HW ((14.38 ± 0.11) mg/100 g) ($P < 0.05$). The TAV of GMP was above 1.0 in the ovaries and hepatopancreas. AMP was primarily found in the ovaries (1 196.93–1 230.14 mg/100 g), followed by muscles (87.80–111.66 mg/100 g), and hepatopancreas (17.33–18.98 mg/100 g). AMP was significantly different in ovaries and muscles. In addition, AMP not only inhibits bitterness, but also enhances the characteristic sweetness and saltiness of aquatic products. And it can combine with IMP to enhance the umami intensity. The AMP content affected flavor characteristics, providing a sweetness below 100 mg/100 g and enhancing umami while reducing sweetness above 100 mg/100 g[6]. The results showed that the AMP content in muscle was over than 100 mg/100 g in MG and less than 100 mg/100 g in MW, indicating stronger umami in MG and greater sweetness perception at MW can be concluded. In the ovaries, AMP contents were above 100 mg/100 g, indicating decreased sweetness and increased umami. In the hepatopancreas, AMP content was below 100 mg/100 g. The TAV of AMP was greater than 1 in muscle and ovaries. In the ovaries, the TAV were 23.94–24.60, indicating that AMP provides the main flavor perception for the ovaries. The results showed that IMP differed significantly in muscles and ovaries ($P < 0.05$). The higher content in MW and OG is likely to contribute to the stronger umami flavor perception. IMP alone did not enhance flavor but increased intensity when combined with monosodium glutamate[18]. Consistent with FAA results, higher IMP and Glu levels in MW and OG corresponded to greater umami perception. Inosine (HxR) and hypoxanthine (Hx), bitter substances produced during IMP degradation. The results showed that HxR was significantly different in ovaries and hepatopancreas ($P < 0.05$). Hx was significantly different in hepatopancreas ($P < 0.01$). The high content of HxR and Hx in green carapace crabs may cause bitterness. Genetic factors, edible part, feed composition, environment, transport, and storage can all influence flavor nucleotide content[6,20–21].

Synergistic umami enhancement between flavor nucleotides and FAAs[22]. MSG equivalents were used to evaluate the combined effect of UFAAs and flavor nucleotides on umami improvement. The results showed significant differences in EUC in the muscles and ovaries of *E. sinensis* with different carapace colors, with the ovaries having the highest EUC (39.84–54.39 g MSG/100 g). Since the MSG taste threshold was 0.03 g/100 g, the EUC in the ovaries was well above this threshold, suggesting a stronger umami perception in OG.

3.4 GC-IMS analysis and ROAV results

The volatile components and ROAV analysis in the edible parts of *E. sinensis* with green and white carapace crabs are shown in Figures 3 and 4. Volatile substances with ROAV ≥ 0.1 were considered contributors to the flavor, with those having ROAV ≥ 1.0 being the main aroma substances and those with 0.1 ≤ ROAV < 1.0 having a modifying effect on the overall flavor[23]. The results showed that the relative contents of volatile aroma substances differed between green and white carapace crabs. These variations contribute to the distinct flavors of each carapace crabs. Figure 3A(I) shows the substances with high content in MW. Including 2-ethylpyridine (green grass odor), *n*-octanal (fruity aroma), 2-octanone (sweet aroma), 2-phenylacetaldehyde (hyacinth odor), 3-(methylmercapto)propionaldehyde (onion, meat-like aroma), (*R*/*S*)-limonene (citrus, mint), (*E*,*E*)-2,4-heptadienal (fat, nut), 3-(methylthio)-1-propanol (cauliflower, cooked vegetable aroma), 2-cyclopenten-1-one, 2-hydroxy-3-methyl- (caramellic), 3-methylbutyl 2-methylbutanoate (fruity), dihydrolinalool (floral, fruity), 2,5-dimethyl-4-hydroxy-3(2*H*)-furanone (caramellic), 3-hydroxy-2-methyl-4-pyrone (creamy aroma), 3-phenylpropanal (sweetish, flowery), 2-propanone, 1-(acetyloxy)- (fruity buttery), 2-pentylfuran (vegetable-like), and cinnamaldehyde (spice)[24]. Thiophene has a strong, irritating odor similar to benzene. Substances with ROAV between 0.1 and 1 include (*R*/*S*)-limonene (citrus, mint), (*E*,*E*)-2,4-heptadienal (fat, nut), 2-pentylfuran (vegetable-like), and 3-phenylpropanal (sweetish, flowery). Main volatiles with ROAV greater than 1 were 2-octanone (sweet), *n*-octanal (fruity), and 3-(methylmercapto)propionaldehyde (onion, meat-like), which were the primary aroma substances in MW. *n*-Octanal was primarily formed through the oxidation of *n*-octanol. It can also be produced from the degradation of fatty acids or through the catalytic oxidation of octene[25]. 3-(Methylmercapto)propionaldehyde was formed through the degradation of methionine. Studies have shown that 3-(methylmercapto)propionaldehyde could enhance the umami taste[26]. This may also contribute to the strong umami taste intensity of MW.

Figure 3A(II) shows the substances with high content in MG. Including 2-ethyl-5-methylpyrazine (fruit, green), ethyl 2-hydroxypropanoate (rum), (*Z*)-3-hexen-1-ol (green, leafy), 2-methyldihydro-3(2*H*)-furanone, methylpyrazine (cocoa, green),

2-methoxyphenol (fried peanuts), benzaldehyde (bitter almonds), and (*E*,*E*)-2,4-hexadienal (irritating odor). Substances with ROAV between 0.1 and 1 include 2-ethyl-5-methylpyrazine (rum) and 2-methoxyphenol (fried peanuts). 2,5-Dimethyl-4-hydroxy-3(2*H*)-furanone (caramellic), found in both carapace colors, contributed the most. These results indicated that muscles contain more light savory and roasted meat flavors, aligning with the sensory evaluation that MW flavor was preferred.

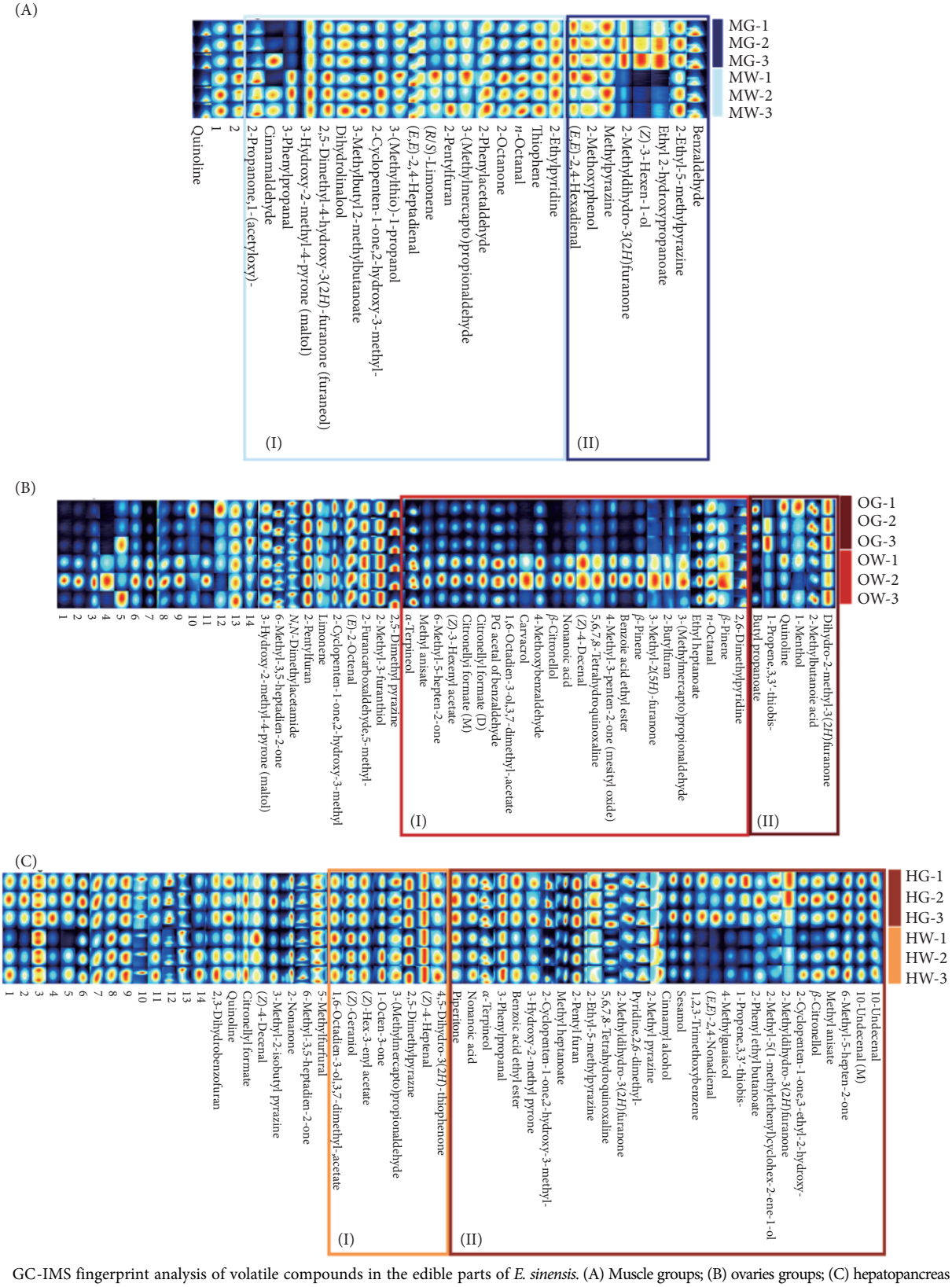

Figure 3 GC-IMS fingerprint analysis of volatile compounds in the edible parts of *E. sinensis*. (A) Muscle groups; (B) ovaries groups; (C) hepatopancreas groups. The Roman numeral regions represented the more abundant substances in a particular group.

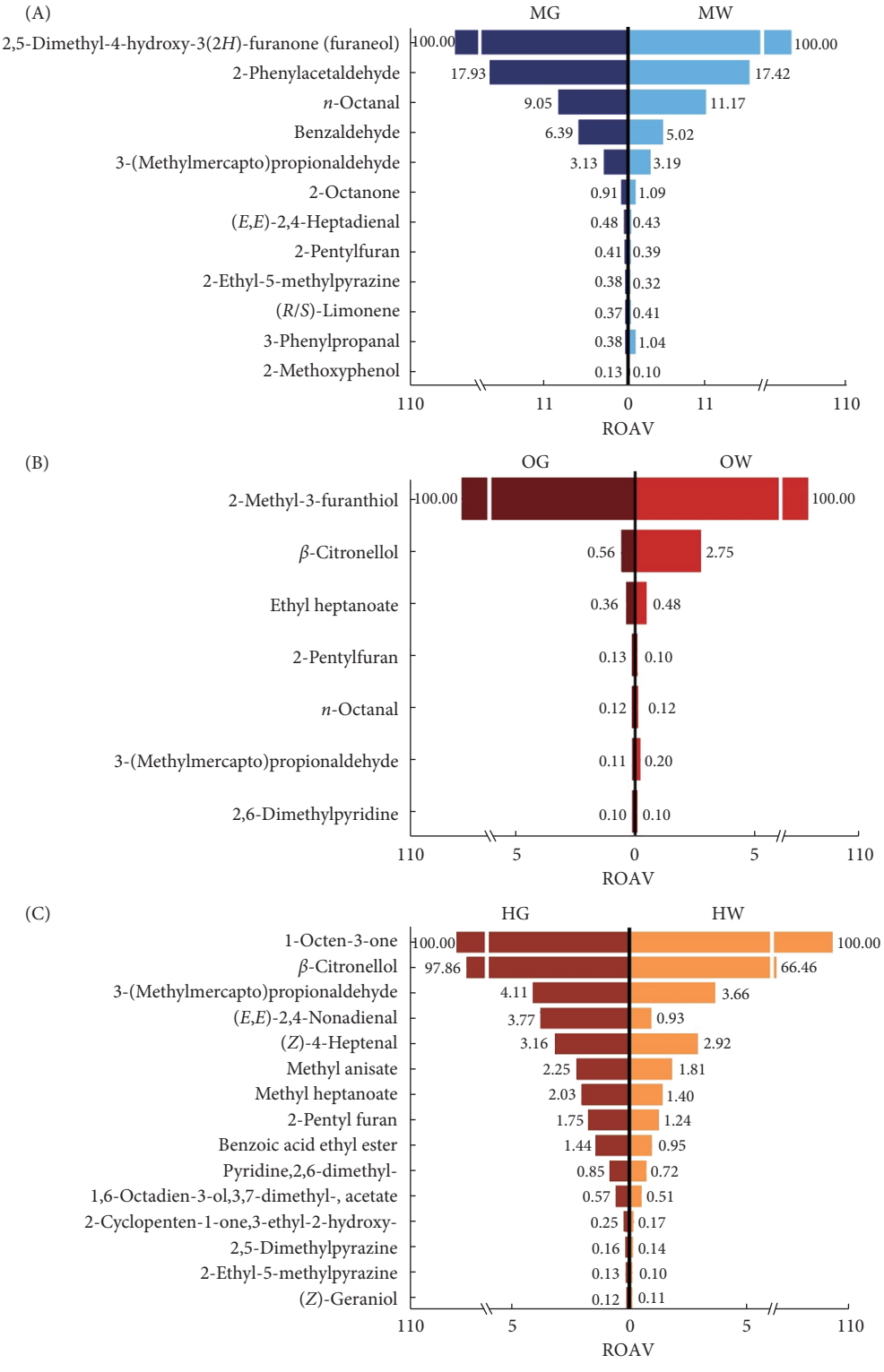

Figure 4 ROAV of volatile compounds in edible parts of *E. sinensis*. (A) Muscle groups; (B) ovaries groups; (C) hepatopancreas groups.

In the ovaries, the OW group had more high content volatile substances than the OG group. Figure 3B(I) shows substances with higher content in the OW group, including *n*-octanal (citrus, fat), ethyl heptanoate (fruit), 2,6-dimethylpyridine (savory), *β*-pinene (pine, wood), benzoic acid ethyl ester (prune, lettuce, herb, sweet), 4-methyl-3-penten-2-one (honey), 5,6,7,8-tetrahydroquinoxaline (savory), (*Z*)-4-decenal (fruit), *β*-citronellol (citrus, green, rose), 4-methoxybenzaldehyde (mint, sweet), carvacrol (caraway, spice, thyme), 1,6-octadien-3-ol,3,7-dimethyl-,acetate (flower, lavender), citronellyl formate (fruit), (*Z*)-3-hexenyl acetate (green fruit aroma), and 6-methyl-5-hepten-2-one (citrus, mushroom)[27]. *N*,*N*-Dimethylacetamide (slightly ammoniacal) and nonanoic acid (putrid odor) are undesirable. Among these, *n*-octanal (citrus, fat), ethyl heptanoate (fruit), 3-(methylmercapto)propionaldehyde (cooked potato, soy), and 2,6-dimethylpyridine (savory) had a ROAV between 0.1 and 1.0, while *β*-citronellol (citrus, green, rose)

had a ROAV greater than 1.0, contributing significantly to the OW odor.

1-Propene,3,3′-thiobis- (garlic, onion, capsicum), 1-menthol (peppermint), 2-methylbutanoic acid (cheese), and dihydro-2-methyl-3(2*H*)furanone (spice) were higher content substances in OG. 2-Methyl-3-furanthiol was the main contributor to the odor of both carapace color crab ovaries. Since Met could form 2-methyl-3-furanthiol[28] and there was no significant difference in Met content between OG and OW, this may explain the similar contribution to ovaries odor from both carapace colors.

The HG group contained more high content volatile substances than the HW. The major substances in the HG group included 10-undecenal (fruit), 6-methyl-5-hepten-2-one (citrus, mushroom), methyl anisate (floral, fruity), *β*-citronellol (citrus, green, rose), 2-cyclopenten-1-one (hyacinth), 2-methyldihydro-3(2*H*)furanone (maple, solanum-like aroma), 2-methyl-5(1-methylethenyl)cyclohex-2-ene-1-ol (minty spearmint), 2-phenyl ethyl butanoate (champagne, fruits), 1-propene,3,3′-thiobis- (garlic, onions, peppers), 4-methylguaiacol (marshmallow, campfire), (*E*,*E*)-2,4-nonadienal (fat, wax, green), 1,2,3-trimethoxybenzene (aroma), sesamol (bitter almond), cinnamyl alcohol (sweet balsamic, honey), piperitone (mint, cool), nonanoic acid (bitter almond), *α*-terpineol (anise, fresh, mint), 2-pentyl furan (green bean), and various benzene derivatives (fragrance). Substances with ROAV between 0.1 and 1.0 included pyridine, 2,6-dimethyl- (savory), 2-cyclopenten-1-one,3-ethyl-2-hydroxy and 2-ethyl-5-methylpyrazine (beany, nutty). Those with ROAV greater than 1 included *β*-citronellol (citrus, green, rose), (*E*,*E*)-2,4-nonadienal (fat, wax, green), methyl heptanoate (spice), 2-pentyl furan (green bean), and benzoic acid ethyl ester (prune, lettuce, herb, sweet). (*E*,*E*)-2,4-Nonadienal was produced through the oxidation of polyunsaturated fatty acids (linoleic acid)[29].

In the HW group, highly volatile substances included 1-octen-3-one (earth, mushroom), 3-(methylmercapto)propionaldehyde (cooked potato, soy), 4,5-dihydro-3(2*H*)-thiophenone (dairy), 1,6-octadien-3-ol,3,7-dimethyl-,acetate (flower, lavender), (*Z*)-hex-3-enyl acetate (banana, floral), (*Z*)-4-heptenal (savory), 2,5-dimethylpyrazine (cocoa, roast beef, roasted nut), and (*Z*)-geraniol (passion fruit, peach, rose). Substances with ROAV between 0.1 and 1.0 included 1,6-octadien-3-ol,3,7-dimethyl-,acetate (flower, lavender), 2,5-dimethylpyrazine (cocoa, roast beef, roasted nut), and (*Z*)-geraniol (passion fruit, peach, rose). Substances with ROAV greater than 1 included (*Z*)-4-heptenal (savory), 3-(methylmercapto)propionaldehyde (cooked potato, soy), and 1-octen-3-one (earth, mushroom). (*Z*)-4-Heptenal, known for its fatty and creamy odor, can be produced through the retroaldol condensation of 2,6-nonadienal[30]. The biosynthesis of 1-octen-3-one involves the oxidation of fatty acids, particularly from the linoleic acid pathway[31]. It has been shown that 3-(methylmercapto)propionaldehyde is a key odor compound in oil-rich and baking food[32–33]. In this study, 3-(methylmercapto)propionaldehyde was more prominent in the hepatopancreas with higher lipid content, which aligns with these findings. The removal of 3-(methylmercapto)propionaldehyde significantly reduced fat and baking odors in the hepatopancreas odor profile of *E. sinensis*, as shown by Lu et al.[34]. In this study, HG is likely to have more intense fat and baking odors compared to HW.

In summary, the three edible parts of *E. sinensis* each had different flavors. The hepatopancreas had the highest concentration of volatile flavor compounds, resulting in a richer flavor. The muscles and ovaries of the white carapace crabs contained more unique aroma substances, while the hepatopancreas of the green carapace crabs produced a higher quality aroma. The differences in the above odor are probably related to the content of carotenoids, fatty acids and FAAs in *E. sinensis*. The production of volatile compounds is influenced by carotenoids, fatty acids and FAAs[8,17]. Previous studies showed that there were differences in fatty acid composition between the white and green carapace crabs edible parts of *E. sinensis* ($P < 0.05$), but there was no significant difference in carotenoids[4]. And there were differences in FAAs in this study. The results indicated that most of the difference in the odor comes from the degradation of fatty acids and FAAs. The difference in FAAs and fatty acid content under the same rearing conditions is probably due to genetic factors in white carapace crabs[4].

4 Conclusion

The results indicate that both white and green carapace crabs have similar flavor compounds, but their different concentrations lead to variations in flavor quality. The white carapace crabs showed stronger umami in the muscles, while the ovaries of green carapace crabs had better taste. The white carapace crabs also had higher levels of aromatic volatiles in the muscles and ovaries, whereas the green carapace crabs had a better aroma from the hepatopancreas. Overall, the white carapace crab outperformed the green carapace strain in most flavor attributes. Genetic differences between the strains influence the composition of metabolites and flavor formation. Further research on the flavor quality of crabs at different growth stages is needed. This study provides valuable insights for the flavor formation of *E. sinensis* based on carapace color and supports the high-quality development of the *E. sinensis* industry.

Conflict of interest

The author declares no conflict of interests.

Acknowledgements

This study was supported by a general project from the National Natural Science Foundation of China (No. 32202211), an Industrial System Project for Chinese Mitten Crab (No. 202404), a Shanghai Agricultural Science and Technology Innovation Project from the Shanghai Municipal Commission of Agriculture and Rural Affairs (No. T2023329), and a plan of Science and Technology Innovation Action from Shanghai Science and Technology Commission (No. 23N71900100).

Authors contribution

Renyue Zhang: Data curation; methodology; writing-original draft. **Long Zhang:** Conceptualization; data curation; investigation; methodology; writing-original draft; writing-review and editing. **Dongdong Zhang:** Data curation. **Xugan Wu:** Investigation; supervision. **Xichang Wang:** Resources; supervision.

References

[1] Q. Li, L. Zu, Y. Cheng, et al., Carapace color affects carotenoid composition and nutritional quality of the Chinese mitten crab, *Eriochier sinensis*, LWT-Food Sci. Technol. 126 (2020) 109286. https://doi.org/10.1016/j.lwt.2020.109286.

[2] Y. Zhao, X. Zhu, Z. Han, et al., Comparative analysis of transcriptomes from different coloration of Chinese mitten crab *Eriocheir sinensis*, Fish Shellfish Immunol. 98 (2020) 515–521. https://doi.org/10.1016/j.fsi.2020.01.051.

[3] D. Zhang, C. Fan, X. Jiang, et al., Comparison of reproductive performance, embryo color and biochemical composition of white and green carapace strains of Chinese mitten crab (*Eriocheir sinensis*), South China Fish Sci. 18(3) (2022) 102–110. https://doi.org/10.12131/20210268.

[4] D. Zhang, C. Fan, X. Jiang, et al., Comparison of edible yield, carotenoid content and nutritional composition between the white carapace strain and green carapace strain of adult *Eriochier sinensis*, J. Fish China 47(9) (2023) 122–134. https://doi.org/10.11964/jfc.20210612886.

[5] L. Zhang, J. Wu, X. Jiang, et al., Different types of dietary carotenoids improve the color and odor quality of *Eriocheir sinensis* ovaries, Aquaculture Fish (2024) S2468550X24000017. https://doi.org/10.1016/j.aaf.2024.01.001.

[6] L. Zhang, Y. Yin, Y. Zheng, et al., Brackish water improves the taste quality in meat of adult male *Eriocheir sinensis* during the postharvest temporary rearing, Food Chem. 343 (2021) 128409. https://doi.org/10.1016/j.foodchem.2020.128409.

[7] J. Wu, L. Zhang, X. Jiang, et al., Effects of different dietary lipid levels on physiological metabolism and odor quality of hepatopancreas in adult female Chinese mitten crab (*Eriocheir sinensis*), Food Qual. Saf. 8 (2024) fyae013. https://doi.org/10.1093/fqsafe/fyae013.

[8] R. Zhang, L. Zhang, X. Jiang, et al., Effects of dietary *β*-carotene on color and flavor quality of ovaries in adult female Chinese mitten crab (*Eriocheir sinensis*), eFood 5(4) (2024) e169. https://doi.org/10.1002/efd2.169.

[9] L. Zhang, W. Wang, F. Zhou, et al., Tenderness and histochemistry of muscle tissues from *Eriocheir sinensis*, Food Biosci. 34 (2020) 100479. https://doi.org/10.1016/j.fbio.2019.100479.

[10] Y. Shi, Z. Qiu, M. Yin, et al., Key non-volatile taste components and characteristics in abdominal muscle of *Eriocheir sinensis* under various thermal processing methods, Food Chem. 464 (2025) 141902. https://doi.org/10.1016/j.foodchem.2024.141902.

[11] S. Shi, X. Wang, X. Wu, et al., Effects of four cooking methods on sensory and taste quality of *Portunus trituberculatus*, Food Sci. Nutr. 8 (2020) 1115–1124. https://doi.org/10.1002/fsn3.1398.

[12] Y. Yan, B. Xu. B. Yin, et al., Modulation of gut microbial community and metabolism by dietary glycyl-glutamine supplementation may favor weaning transition in piglets, Front. Microbiol. 10 (2020) 3125. https://doi.org/10.3389/fmicb.2019.03125.

[13] L. Zhang, N. Tao, X. Wu, et al., Metabolomics of the hepatopancreas in Chinese mitten crabs (*Eriocheir sinensis*), Food Res. Int. 152 (2022) 110914. https://doi.org/10.1016/j.foodres.2021.110914.

[14] J. Li, Z. Tu, X. Sha, et al., Effect of frying on fatty acid profile, free amino acids and volatile compounds of grass carp (*Ctenopharyngodon idellus*) fillets: effect of frying on composition of grass carp meat, J. Food Process. Preserv. 41(4) (2017) e13088. https://doi.org/10.1111/jfpp.13088.

[15] Q. Lu, W. Ding, X. Guo, et al., Drivers of consumer preference derived from active volatiles for cooked *Eriocheir sinensis*, Animals 13(3) (2023) 541. https://doi.org/10.3390/ani13030541.

[16] H. Wu, M. Ge, H. Chen, et al., Comparison between the nutritional qualities of wild-caught and rice-field male Chinese mitten crabs (*Eriocheir sinensis*), LWT-Food Sci. Technol. 117 (2020) 108663. https://doi.org/10.1016/j.lwt.2019.108663.

[17] L. Zhang, R. Zhang, X. Jiang, et al., Dietary supplementation with synthetic astaxanthin and DHA interactively regulates physiological metabolism to improve the color and odor quality of ovaries in adult female *Eriocheir sinensis*, Food Chem. 430 (2024) 137020. https://doi.org/10.1016/j.foodchem.2023.137020.

[18] M. Sarower, A. Hasanuzzaman, B. Biswas, et al., Taste producing components in fish and fisheries products: a review, Int. J. Food Ferment. 2(2) (2012) 113–121.

[19] N. Nasri, N. Beno, C. Septier, et al., Cross-modal interactions between taste and smell: odour-induced saltiness enhancement depends on salt level, Food Qual. Prefer. 22(7) (2011) 678–682. https://doi.org/10.1016/j.foodqual.2011.05.001.

[20] Y. Liu, C. Zhang, S. Chen, Comparison of active non-volatile taste components in the viscera and adductor muscles of oyster (*Ostrea rivularis* Gould), Food Sci. Technol. Res. 19(3) (2013) 417–424. https://doi.org/10.3136/fstr.19.417.

[21] L. Zhang, M. Yin, Y. Zheng, et al., Short-term rearing in brackish water regulates the taste-related metabolites of abdomen muscle for adult male *Eriocheir sinensis*, LWT-Food Sci. Technol. 142 (2021) 110898. https://doi.org/10.1016/j.lwt.2021.110898.

[22] H. Hong, J. M. Regenstein, Y. Luo, The importance of ATP-related compounds for the freshness and flavor of post-mortem fish and shellfish muscle: a review, Crit. Rev. Food Sci. Nutr. 57(9) (2017) 1787–1798. https://doi.org/10.1080/10408398.2014.1001489.

[23] X. Wu, Y. Hu, Q. Wang, et al., Study on the correlation between the dominant microflora and the main flavor substances in the fermentation process of cigar tobacco leaves, Front. Microbiol. 14 (2023) 1267447. https://doi.org/10.3389/fmicb.2023.1267447.

[24] Z. Yang, Y. He, G. Liao, et al., Comparative analysis of characteristic volatile compounds in five types of Yunnan dry-cured hams by HS-GC-IMS and HS-SPME-GC-MS. Food Sci. Anim. Prod. 1(2) (2023) 9240022. https://doi.org/10.26599/FSAP.2023.9240022.

[25] G. Reineccius, D. Peterson, 3-Principles of food flavor analysis, in: D. Kilcast (Eds.), Instrumental assessment of food sensory quality, Woodhead Publishing Series, UK, 2013, pp. 53–102.

[26] R. Andaleeba, Y. Zhua, N. Zhang, et al., Umami taste components in chicken-spices blends and potential effect of aroma on umami taste intensity, Food Sci. Hum. Wellness 13 (2024) 1220–1230. https://doi.org/10.26599/FSHW.2022.9250102.

[27] Y. Zhang, P. Gao, W. Zhang, et al., Free fatty acid hydrolyzed with lipases and their effects on enzyme-modified cheese flavor, Food Sci. Anim. Prod. 1(3) (2023) 9240031. https://doi.org/10.26599/FSAP.2023.9240031.

[28] J. Zhuang, Q. Xiao, T. Feng, et al., Comparative flavor profile analysis of four different varieties of *Boletus* mushrooms by instrumental and sensory techniques, Food Res. Int. 136 (2020) 109485. https://doi.org/10.1016/j.foodres.2020.109485.

[29] X. Hu, C. Fang, W. Zhang, et al., Change in volatiles, soluble sugars and fatty acids of glutinous rice, japonica rice and indica rice during storage, LWT-Food Sci. Technol. 174 (2023) 114416. https://doi.org/10.1016/j.lwt.2022.114416.

[30] N. Wu, S. Gu, N. Tao, et al., Characterization of important odorants in steamed male Chinese mitten crab (*Eriocheir sinensis*) using gas chromatography-mass spectrometry-olfactometry, J. Food Sci. 779 (2014) 1250–1259. https://doi.org/10.1111/1750-3841.12511.

[31] M. Li, R. Yang, H. Zhang, et al., Development of a flavor fingerprint by HS-GC-IMS with PCA for volatile compounds of *Tricholoma matsutake* Singer, Food Chem. 290 (2019) 32–39. https://doi.org/10.1016/j.foodchem.2019.03.124.

[32] A. Dach, P. Schieberle, Characterization of the key aroma compounds in a freshly prepared oat (*Avena sativa* L.) pastry by application of the sensomics approach, J. Agric. Food Chem. 69(5) (2021) 1578–1588. https://doi.org/10.1021/acs.jafc.0c07498.

[33] W. Du, M. Zhao, D. Zhen, et al., Key aroma compounds in Chinese fried food of youtiao, Flav. Fragra. J. 35(1) (2020) 88–98. https://doi.org/10.1002/ffj.359.

[34] Q. Lu, C. Qiu, J. Zhu, et al., Elucidation of key fatty aroma compound contributing to the hepatopancreas of *Eriocheir sinensis* using sensomics approach by GC-IMS and GC-MS-O, Food Chem. 455 (2024) 139904. https://doi.org/10.1016/j.foodchem.2024.139904.