Research article

Effects of the photovoltaic fishery culture model on muscle nutritional quality and volatile flavor compounds of *Litopenaeus vannamei*

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ABSTRACT

This study used *Litopenaeus vannamei* to compare the muscle nutritional quality and volatile flavor compounds of animals raised in the photovoltaic fishery culture model (PM) and the common pond breeding model (CM). Amino acids, fatty acids, and volatile flavor substances were identified and analyzed using an automatic amino acid analyzer and headspace solid phase microextraction(HS-SPME) combined with GC/MS. There were no significant differences between the two culture models in terms of general nutrients, mineral contents, and amino acid compositions in the muscles of *L. vannamei*. In the PM group, the proportion of flavor amino acids in total amino acids was higher. Based on the amino acid score (*AAS*) and chemical score (*CS*), it was found that methionine and cystine were the first limiting amino acids in the muscle samples. The essential amino acid index (*EAAI*) value was approximately 77 for both models, indicating high-quality proteins. The muscles contained nine types of fatty acids, with the PM group showing significantly higher levels of both monounsaturated and total fatty acids. A total of 23 volatile flavor compounds were identified in both models. The contents of 1-nonanal, n-tridecane, and alpha-terpineol were higher when cultured in the PM. Conversely, the contents of hexanal, 2-eth-ylhexanol, and dipentene were lower in the PM group. The photovoltaic fishery culture model has the potential to enhance income through photovoltaic power generation. In addition, this study found that the fatty acid composition of *L. vannamei* was improved in the PM, without compromising muscle composition or flavor. These results provide a theoretical basis for evaluating the meat quality of *L. vannamei* under different culture models and offer data to support and guide the promotion of the PM.

Key points

- The aim of this study was to investigate the impact of the photovoltaic fishery culture model on the nutritional quality and flavor of *L. vannamei*.

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• The photovoltaic fishery culture model did not reduce the muscle nutritional quality or flavor of *L. vannamei*, but it did increase its fatty acid content, proving that it is a reliable new green culture model.

1. Introduction

In recent years, freshwater aquaculture output in China has rapidly increased and it has become an important part of the development of China's fisheries [1]. Although pond aquaculture has improved and developed rapidly, some pond infrastructure facilities are still simple, economic foundations are weak, and the ecological environment of aquaculture waters are deteriorating due to excessive discharge from aquaculture. It is important to address these issues to ensure the sustainable development of pond aquaculture [2]. Future development will likely promote intelligent fisheries facilities, innovative traditional farming methods, and resource-saving and environment-friendly modern aquaculture [3]. The photovoltaic fishery culture model (PM) is a new and efficient production model that makes full use of land area by establishing photovoltaic power stations over ponds, allowing simultaneous fish farming and surface power generation, increasing the benefit [4]. This farming method improves land resource utilization and generates economic benefits through the addition of photovoltaic power generation. It is a new, environmentally-friendly farming method that maximizes benefits [5].

Aquaculture models can affect water environments, driving changes in temperature, pH, salinity, and dissolved oxygen levels [6]. These changes can affect the nutritional quality of aquatic products [7,8]. Research on the photovoltaic fishery culture model has indicated that it can lower water pH and temperature while increasing the nitrogen and phosphorus ratios. This has a positive impact on the growth of aquatic plants, which in turn affects the quality of cultured shrimp and crab [9]. Despite the potential benefits, the research on the photovoltaic fishery culture model is limited. Research to date has primarily focused on evaluating the effects of the photovoltaic fishery culture model on the growth of aquaculture products [10], pond water quality [9], and plankton [11]. However, there is a lack of research on the quality of aquatic products when using the photovoltaic fishery culture model.

The species *Litopenaeus vannamei* belongs to the phylum Arthropoda, family Penaeidae, and genus *Litopenaeus*, and is native to the tropical Pacific coast of western Latin America [12]. It was introduced into China in the late 1980s, and artificial breeding was achieved in the early 1990s. In recent years, national mariculture production of *L. vannamei* has shown a year-on-year increase, reaching 1.34 million tons in 2022 [1]. *L. vannamei* are not only delicious, but also rich in high-quality proteins, vitamins, minerals, omega-3 series polyunsaturated fatty acids, and astaxanthin, making them a favorite among consumers of aquatic products [13]. *L. vannamei* is one of the most commonly cultivated species in photovoltaic fishery breeding facilities in China. When purchasing *L. vannamei*, consumers are primarily concerned with its nutrition and flavor quality, as well as its odor, which is an important factor in evaluating its overall flavor. The taste and odor quality of *L. vannamei* can vary depending on the culture area and model. This study investigated the effects of the photovoltaic fishery culture model on the nutrition and flavor of *L. vannamei* by comparing it with the common pond breeding model (CM). The aim was to provide a theoretical basis and empirical data to support and guide the promotion of the photovoltaic fishery culture model.

2. Methods

2.1. Animal materials

The *L. vannamei* used in the experiment were sourced from Wencun Town, Taishan, Guangdong Province, China. The ponds in the photovoltaic fishery model (PM) were equipped with photovoltaic panels that covered 50 % of the light area, while the control group (CM) used the ordinary pond culture model with no artificial shading. The water source, stocking specifications, and shrimp seedling density were the same for both culture models. The *L. vannamei* seedlings used had a stocking specification of 2.5 ± 0.5 g. Feeding was conducted twice daily (at 09:00 and 18:00) throughout the breeding period using compound feed with 30 % protein content. The daily feed amount was 3 % of the total weight of the shrimp seedlings, with 70 % of the total feed amount given in the afternoon. Prior to each feeding, the feeding table was consulted to assess the feeding situation and adjust the amount as necessary. Pond water quality tests were conducted regularly throughout the experimental period. Additionally, 20 % of the breeding water in each pond was replaced on a weekly basis. Following a 50-day culture period, 30 *L. vannamei* were randomly selected from the ponds with different culture models. The selected shrimp exhibited robust body structures, intact appendages, and uniform sizes. In the PM group, *L. vannamei* had a body length of 10.54 ± 0.18 cm and a body weight of 19.23 ± 0.34 g. Meanwhile, the CM group had a body length of 11.03 ± 0.42 cm and a body weight of 22.07 ± 0.72 g. Ten *L. vannamei* from each group were preserved at -21 °C for subsequent body composition and mineral element analysis. The remaining 20 were used to extract muscle samples, which were collected using conventional methods and stored separately for subsequent analysis of amino acid and fatty acid composition and the determination of flavor substances.

2.2. Nutrients and mineral elements content determination

The nutrient composition of each of the 10 preserved *L. vannamei* from each group was analyzed separately. The determination method of general nutrients was referenced from Tang (2021) [14]. The moisture content in the muscle was determined following guideline GB 5009.3-2016. The muscle crude ash content was determined according to GB 5009.4-2016, while the muscle crude

protein content was determined following guideline GB 5009.5-2016. The crude fat content of the muscle was determined according to GB 5009.6-2016.

Simultaneously, the mineral elements in each muscle sample were analyzed. The determination method of general nutrients refer to Cui (2022) [15]. The muscle kalium and natrium content was determined according to GB 5009.91-2017, the muscle calcium content was determined according to GB 5009.92-2016, the muscle magnesium content was determined according to GB 5009.241-2017, the muscle iron element content was determined according to GB 5009.90-2016, the muscle copper content was determined according to GB 5009.13-2017, and the muscle zinc content was determined following guideline GB 5009.14-2017.

2.3. Amino acid content determination

The muscle samples were crushed using a mill, and 1 g of the sample was weighed and placed in a hydrolysis tube. Subsequently, 15 mL of a 6 mol/L hydrochloric acid solution was added to the hydrolysis tube, along with three drops of phenol. The hydrolysis tubes were then frozen for a period of 5 minutes, evacuated, and subsequently filled with nitrogen. This procedure was repeated three times before the tubes were sealed. Subsequently, the hydrolysis tube was subjected to a temperature range of 1 °C–110 °C, with hydrolysis occurring within the furnace. After a period of 22 h, hydrolysis was terminated, and the tube was cooled to room temperature. The hydrolysis tube was opened and the hydrolyzed contents were filtered into a 50 mL volumetric flask, with the volume adjusted with water to maintain a constant volume. The filtrate, amounting to 1.0 mL, was transferred to a 15-mL test tube and subjected to drying under reduced pressure in a heated environment of 50 °C. Subsequently, the solution was dissolved in 1.0 mL of sodium citrate buffer. Following filtration through a 0.22 μm membrane, the suction solution was employed as the sample determination solution for instrument determination. The mixed amino acid standard working solution was introduced to the amino acid automatic analyzer. Following the JG1064-2011 amino acid analyzer verification regulations and the instrument instructions and using the peak area of the external standard method, the concentrations of amino acids in the sample solutions were calculated.

2.4. Fatty acid content determination

Muscle samples were subjected to thorough mill grinding. A ground 1 g sample was placed into a 250 mL flat-bottom flask, which was then filled to a volume of 2.0 mL with a solution. Carbonic acid triglycerides were added as the internal standard solution. Subsequently, 100 mg of pyrogallic acid and zeolite were added, followed by 2 mL of 95 % ethanol and 4 mL of water to facilitate thorough mixing. Eight milliliters of a 2 % sodium hydroxide solution in methanol was added to the fat extract, which was then connected to a reflux condenser in a water bath at 80 °C until the oil droplets had disappeared. A further 7 mL of the 15 % boron trifluoride methanol solution was added, and the process continued for a further 2 minutes in the 80 °C water bath. The reflux condenser was rinsed. Next, heating was terminated and the flask was removed from the water bath and cooled rapidly to room temperature. Ten mL of n-heptane was added and the flask was shaken for 2 minutes, after which a saturated aqueous sodium chloride solution was added and the mixture was allowed to stratify. Approximately 5 mL of the upper n-heptane extraction solution was transferred to a 25 mL test tube, to which approximately 3 mL anhydrous sodium sulfate was added. The mixture was then shaken for 1 minute and left for 5 minutes. The upper solution was then transferred to an injection bottle for determination. A single methyl fatty acid methyl ester of a fatty acid standard solution was mixed with the solution and a qualitative chromatographic peak was observed. The fatty acid standard solution and the sample solution were injected into the gas chromatograph for determination and the peak areas of the chromatographs were quantified.

2.5. Nutritional quality evaluation

The amino acid score (*AAS*), chemical score (*CS*), and essential amino acid index (*EAAI*) were calculated for muscle samples of *L. vannamei* in different culture models. The results were compared to the FAO/WHO amino acid scoring model and the amino acid model of whole egg protein proposed by the Institute of Nutrition and Food Hygiene, Chinese Academy of Preventive Medical Sciences [16,17]. The calculation formula are as follows:

$$AAS = \frac{\text{Sample muscle protein amino acid content(mg/gN)}}{\underset{\text{model(mg/gN)}}{\text{Amino acid content in the FAO/WHO scoring}}}$$

$$CS = \frac{\text{Sample muscle protein amino acid content(mg/gN)}}{\text{Same amino acid content in whole egg protein(mg/gN)}}$$

$$EAAI = \sqrt[n]{\frac{100A}{AE} \times \frac{100B}{BE} \times \frac{100C}{CE} \cdots \times \frac{100F}{FE}}$$

The amino acid content (mg/g) was calculated as the percentage of amino acid content in fresh muscle divided by the percentage of crude protein content in fresh muscle, multiplied by 6250. The reference protein was whole egg protein, with essential amino acid contents (mg/gN) denoted AE and BE … FE. The *EAAI* formula compares the essential amino acid contents of sample to a reference protein. A and B⋯F represent the essential amino acid contents (mg/gN) of the proteins in the muscle sample. In addition, the *F*-number is the ratio of branched-chain amino acids to aromatic amino acids.

2.6. Determination of volatile flavor substances

For volatile flavor substance determination, 10 g of each sample was placed into a 40 mL bottle. To each bottle, 10 mL of water, 3 g of sodium chloride and rotor were added. The bottle was then held at a temperature of 80 °C for a duration of 15 minutes. The PDMS solid phase microextraction head was then inserted into the sample bottle for 40 minutes for adsorption. Then, the supernatant was inserted into the manual gas chromatograph inlet for desorption for 5 minutes. This process allowed for the volatile components adsorbed by the SPME fiber head coating film to be quickly thermally resolved at high temperature. Finally, the components were analyzed and identified using GC/MS.

2.7. Statistical analysis

Statistical analysis was conducted using the SPSS Statistics 17.0 software using independent T-tests. The experimental results were expressed as mean ± standard error. Differences in results were considered significant when $P < 0.05$. A computer-based search of the NIST 2011 MS database was conducted using the same temperature program and the standard reference of normal alkanes (C7–C30). The volatile flavor components present in the samples were obtained by area normalization (see Fig. 1).

3. Results

3.1. Comparative analysis of general nutrients and mineral elements

Table S1 shows nutrients and minerals in muscles of the *L. vannamei* in the two culture models. The conventional nutrient compositions showed that the differences between groups in terms of water content, crude protein, ash, and crude fat were not significant (Fig. 2A). In addition, the mineral element results indicated that the detected mineral elements did not show significant differences between the two groups (Fig. 2B and C).

3.2. Comparative analysis of amino acid compositions

In both groups, the muscles of the *L. vannamei* contained sixteen amino acids, including seven essential amino acids and four flavor amino acids (Fig. 3A). The essential amino acid with the highest content was lysine, while the flavor amino acid with the highest content was glutamic acid (Fig. 3A). In addition, the CM group had higher concentrations of total amino acids, total essential amino acids, total flavor amino acids, and total non-essential amino acids (Fig. 3C). Furthermore, the CM group exhibited a higher essential amino acids to total amino acids ratio and a higher essential amino acids to total essential amino acids ratio(Fig. 3B). Conversely, the PM group had a higher flavor amino acids to total amino acids ratio. Table S2 shows the contents of each amino acid under the two culture models.

3.3. Nutritional quality evaluation and analysis

The *L. vannamei* muscle samples were evaluated for their amino acid score (*ASS*) and chemical score (*CS*) under different culture
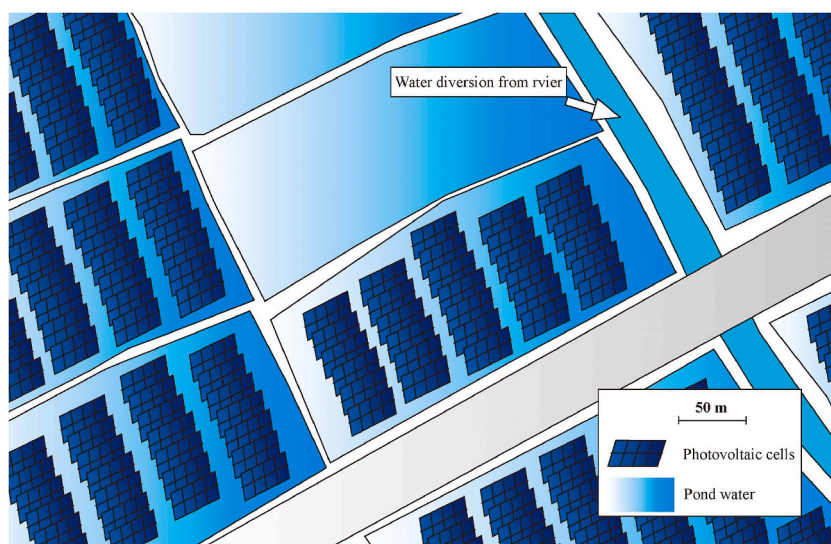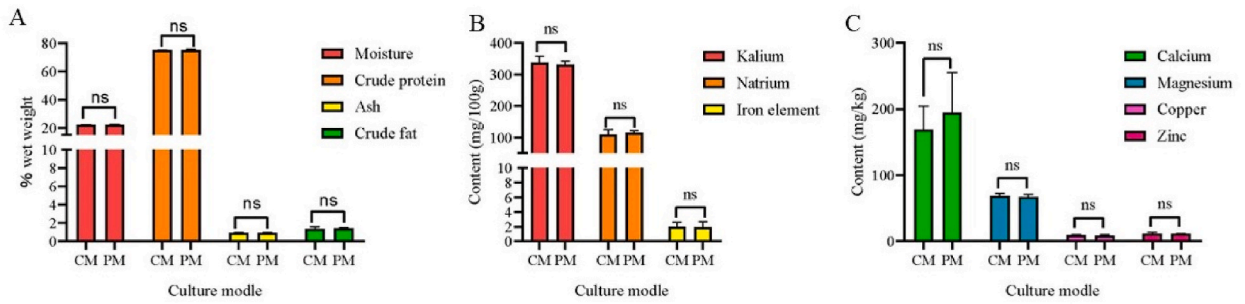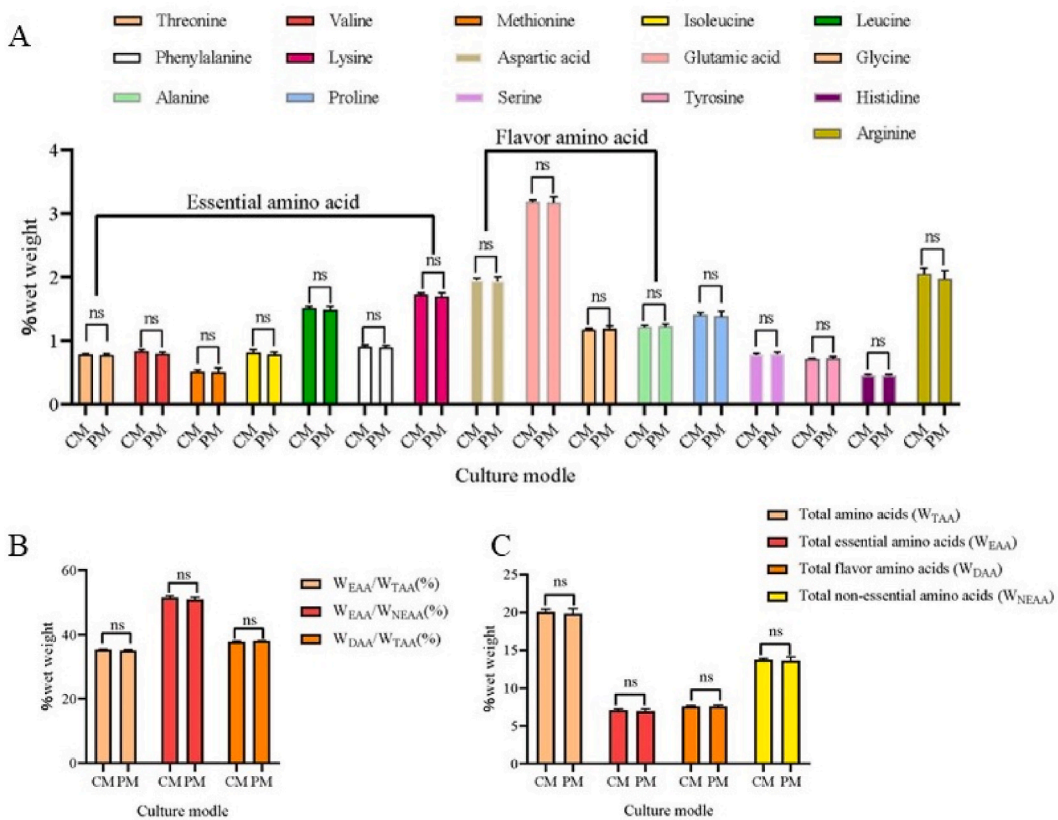

Fig. 1. Sample collection sites.

Fig. 2. Nutrients and minerals in muscles of the *L. vannamei* in two culture models. **CM** is the common pond breeding model. **PM** is the photovoltaic fishery model.

Fig. 3. Amino acids composition in muscles of the *L. vannamei* in two culture models. **CM** is the ordinary pond culture model. **PM** is the photovoltaic fishery model.

models (Table 1). The lowest *ASS* and *CS* values were observed for these two amino acids: methionine and cystine. With these two being the first limiting amino acids in the muscles of *L. vannamei* of both groups, the second limiting amino acid was valine. Furthermore, the *ASS* and *CS* values of other crucial amino acids in the muscles of both groups exceeded 0.73 and 0.41, respectively. Additionally, the CM group exhibited higher essential amino acid index (*EAAI*) values and ratios of branched-chain amino acids to aromatic amino acids.

3.4. Comparative analysis of fatty acid composition

Nine types of fatty acids were detected in the muscles of *L. vannamei* under different culture models. The samples contained two saturated fatty acids (SFA), two monounsaturated fatty acids (MUFA), and five polyunsaturated fatty acids (PUFA) (Fig. 4). The PM group had the highest total contents of saturated, monounsaturated, and polyunsaturated fatty acids. Palmitic acid was the saturated

Table 1

Comparative analysis of AAS and CS in muscles of *L. vannamei* from two culture models.

Essential amino acid types	PM group			CM group			The FAO score model	The egg score model
	Amino acid contents	AAS	CS	Amino acid contents	AAS	CS		
Leucine	470	1.07	0.88	471	1.07	0.88	440	534
Isoleucine	247	0.99	0.75	253	1.01	0.76	250	331
Lysine	536	1.58	1.21	537	1.58	1.22	340	441
Threonine	246	0.98	0.84	244	0.98	0.84	250	292
Valine	249	0.80[b]	0.61[b]	261	0.84[b]	0.64[b]	310	411
Phenylalanine	509	1.34	0.90	503	1.32	0.89	380	565
Methionine	160	0.73[a]	0.41[a]	161	0.73[a]	0.42[a]	220	386
Total	2418			2431			2190	2960
EAAI	76.45			77.12				
F-value	1.90			1.96				

Notes.

[a] Indicates the primary limiting amino acids.

[b] Indicates the secondary limiting amino acids.
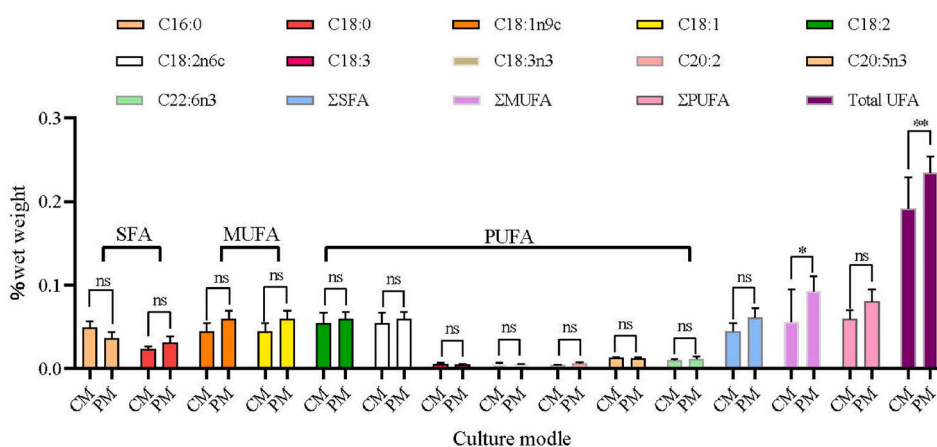
Fig. 4. Fatty acid compositions in muscles of the *L. vannamei* from two culture models.

fatty acid with the highest content, while *cis*-9, 12-octadecadienoic acid (C18:2n6c) was the polyunsaturated fatty acid with the highest content. Furthermore, the muscles in the PM group had significantly higher contents of monounsaturated fatty acids and total fatty acids compared to the CM group ($P < 0.05$) (Fig. 4). Table S3 shows the contents of each fatty acid under the two culture models.

3.5. Analysis of volatile flavor substances in muscle

The detected volatile compounds included 7 alkanes, 5 aldehydes, 5 alcohols, 2 ketones, 2 allenes, and 2 heterocyclic compounds. Table 2 shows the migration time and content percentage of the twenty-three volatile compounds found in the muscles of *L. vannamei* under different culture models. The volatile compounds found in *L. vannamei* were primarily aldehydes, followed by alkanes and alcohols. The muscles of *L. vannamei* in the PM group had higher levels of nonylaldehyde, tridecane, and α-terpinol compared to those in the CM group. Conversely, the hexaldehyde, 2-ethylhexyl alcohol, and D-limonene levels were lower in the PM group. The retention time of each volatile compound was consistent between the two culture models.

4. Discussion

The nutritional value of muscle is typically evaluated based on water content, ash content, crude fat, and crude protein. Of these, crude protein and crude fat are particularly important evaluation indices [18]. Proteins play crucial roles in both the compositions and basic activities of cells and tissues. While the amount of protein in a food does not solely determine its nutritional value, the protein content is an important factor to consider [19]. In this study, there was no significant difference in the crude protein content of *L. vannamei* grown under the two culture models. Compared with other shrimp, *L. vannamei* had higher crude protein contents than *Cherax quadricarinatus*, *Procambarus clarkii* [20], *Penaeus monodon* [15], *Macrobrachium nipponense* [14], *Penaeus chinensis* [21], and *Macrobrachium rosenbergii* [22]. Similarly important, fat serves various physiological functions in metabolic processes of fish and is an important source of energy. Furthermore, in addition to having high nutritional value, muscle with a fat content of over 3.5 % has a

Table 2

Volatile flavor compounds identified in the muscles of *L. vannamei* under different culture models.

Compounds	CAS number	Molecular formula	Relative molecule mass	PM group		CM group	
				Content percentage (%)	Retention time (min)	Content percentage (%)	Retention time (min)
Hexanal	66-25-1	$C_6H_{12}O$	100.16	8.41	0.313	14.86	0.34
Styrene	100-42-5	C_8H_8	104.15	0.7	3.97	3.48	4.002
Benzaldehyde	100-52-7	C_7H_6O	106.12	0.49	6.008	1.08	6.034
2-Amino-4-methylbenzoic acid	2305-36-4	$C_8H_9NO_2$	151.17	7.7	6.644	6.2	6.41
Phenylacetaldehyde	122-78-1	C_8H_8O	120.15	1.07	8.483	0.87	8.486
Octanal	124-13-0	$C_8H_{16}O$	128.20	0.29	9.987	0.23	9.879
(+)-Dipentene	5989-27-5	$C_{10}H_{16}$	136.23	13.44	10.741	24.23	10.752
2-Ethylhexanol	104-76-7	$C_8H_{18}O$	130.23	9.35	11.042	11.17	11.044
1-Octanol	111-87-5	$C_8H_{18}O$	130.23	0.6	12.669	0.18	12.696
1-Nonanal	124-19-6	$C_9H_{18}O$	142.24	28.68	13.724	11.63	13.738
alpha-Terpineol	98-55-5	C10H18O	154.25	1.06	16.628	0.13	16.704
n-Hendecane	1120-21-4	$C_{11}H_{24}$	156.31	9.51	16.919	9.01	16.917
Trans-2-dodecenol	69,064-36-4	$C_{12}H_{24}O$	184.32	0.95	17.149	0.52	17.181
4-Ethyloctane	15,869-86-0	$C_{10}H_{22}$	142.29	1.06	17.39	0.91	17.389
4-Methyldodecane	6117-97-1	$C_{13}H_{28}$	184.37	0.31	18.961	1.57	19.088
2, 2-Dimethylpentane	590-35-2	C_7H_{16}	100.21	0.87	19.36	0.56	19.446
3, 3-Dimethylhexane	563-16-6	C_8H_{18}	114.23	0.47	19.705	1.02	19.725
n-Tridecane	629-50-5	$C_{13}H_{28}$	184.41	8.92	20.441	5.6	20.439
2-Methyl-4- heptanone	626-33-5	$C_8H_{16}O$	128.21	0.46	21.384	0.43	21.375
1-Bromo-3-butene-2-ol	64,341-49-7	C_4H_7BrO	165.03	0.91	22.295	0.62	22.307
n-Hexadecane	544-76-3	$C_{16}H_{34}$	226.45	2.26	24.121	2.96	24.12
1,3,5-Triacetylbenzene	779-90-8	$C_{12}H_{12}O_3$	204.22	0.31	27.661	0.25	27.604
2,2,5-Trimethylhexane-3,4-dione	20,633-03-8	$C_9H_{16}O_2$	156.23	2.15	27.841	2.49	27.846

higher palatability [23]. Studies have found that the crude fat content of *L. vannamei* was higher than the contents of *C. quadricarinatus*, *P. clarkii* [20], *P. monodon* [15], and *M. rosenbergii* [22], but lower than that of *M. nipponense* [14]. Furthermore, one study revealed that crude fat and water content together made up approximately 80 % of the muscle's composition in *L. vannamei* [24]. Based on this observation, it was confirmed that *L. vannamei* has a high crude fat content but a low water content. A comparison of nutrient compositions revealed that the nutrients in the muscle of shrimp from the same genus, but different species, were closely related to their living environments, growth cycles, and food compositions [24]. Additionally, different genetic factors were found to have specific influences on nutrient compositions [25]. Mineral elements are essential for the human body and must be obtained through food [26]. This study found no significant differences in mineral elements in the muscles of *L. vannamei* under the two culture models. But the abundance of calcium and potassium in *L. vannamei* muscles in both culture models suggests that *L. vannamei* is a good source of easily absorbable calcium and potassium, making it a valuable addition to the diets of those seeking to supplement their mineral intakes.

Muscle nutritional quality is primarily influenced by the amino acids present in proteins. As per the FAO/WHO ideal model, the ratio of essential amino acids to total amino acids should be around 40 %, and the ratio of essential amino acids to non-essential amino acids should be more than 60 % [27,28]. In this study, the W_{EAA}/W_{TAA} and W_{EAA}/W_{NEAA} values of the muscle in the CM group were lower than those in the PM group, but the differences were not significant ($P > 0.05$), and both were close to the requirements of the FAO/WHO standard model representing good quality protein amino acid compositions, indicating these muscle samples contained high quality proteins. Of the essential amino acids, lysine had the highest content, followed by leucine. Lysine, as an important essential amino acid, can promote normal growth and development of the body and enhance immune function [29]. Leucine can reduce fat deposition and promote lipid metabolism [30]. In this study, the levels of lysine and leucine showed little difference and were higher than those of *C. quadricarinatus*, *P. clarkii* [20], *P. monodon* [15], *M. nipponense* [14], *P. chinensis* [21], and *M. rosenbergii* [22]. Therefore, consuming *L. vannamei* may compensate for any lysine and leucine deficiency in a cereal-based diet, thus improving protein utilization [31]. The freshness of protein depends mainly on the composition and content of glutamic acid and aspartic acid, which affect the umami flavor, and glycine and alanine, which influence the sweet flavor. Among these, glutamic acid has the strongest influence on umami taste and is also an important participant in the synthesis of physiologically active substances in the biochemical metabolism of brain tissue [32,33]. In this study, the contents of glutamic acid, aspartic acid, glycine and alanine in the muscle of *L. vannamei* were high under both culture models, indicating that they would have highly desirable flavor. Nevertheless, the proportion of flavor amino acids in total amino acids was higher in the PM environment, suggesting that muscle flavor was more pronounced in the PM environment.

The *AAS* and *CS* values showed that methionine and cystine were the first limiting amino acids in the muscle of *L. vannamei* under both culture models, indicating that supplementing methionine and cystine in the artificial feed during culture may enhance the growth and development of the shrimp. In addition, the *EAAI* of *L. vannamei* in both culture systems was 77 in this study. The *EAAI* value is a common index for evaluating nutritional value, with values higher than 90 indicating that the proteins have a high nutritional value, and values between 70 and 90 indicating that proteins have a good nutritional value [34]. Therefore, the nutritional values of the proteins in the *L. vannamei* were good under both culture models. In addition, studies have shown that the ratio of branched-chain amino acids (BCAA) to aromatic amino acids (*F*) in a normal healthy human body is 3.0–3.5, and *F* values in the 1.0–1.5 range indicate that the liver has been damaged, which is why supplementing with BCAA can improve the health of liver disease patients [35]. In this study, the muscle *F* value of *L. vannamei* was about 1.9 in both culture models, much higher than that of patients with liver damage, indicating that consumption of *Penaeus australis* may have a certain beneficial effect on patients with liver disease.

Fat plays an important role in the growth of animals and serves as the primary energy source for the body. Fatty acid compositions and contents in muscles are controlled by various factors, such as species, living environment, diet composition, and genetics [28]. The muscle tissue of *L. vannamei* in the PM group had significantly higher contents of unsaturated fatty acids (UFA) than saturated fatty acids (SFA). UFA plays an important role in the body, with numerous physiological functions. These include anti-oxidation, anti-aging, anti-tumor, improving immunity and reducing cardiovascular diseases. The muscle unsaturated fatty acid content of *L. vannamei* in the PM group was high, which indicates it is more beneficial for health [36]. Fatty acids such as oleic acid (C18: 1n9c), docosahexaenoic acid (C22:6n3, DHA), linoleic acid (C18:2n6c), and eicosapentaenoic acid (C20:5n3, EPA) were found in the muscle of *L. vannamei* in both culture models. Studies have shown that oleic acid can reduce the levels of total cholesterol and low-density lipoproteins in the blood, which reduces the incidence of coronary heart disease, so eating shrimp meat may contribute to the prevention of cardiovascular disease [37]. Docosahexaenoic acid, also known as 'brain gold', is an essential omega-3 polyunsaturated fatty acid. These are important in the growth and maintenance of cells in the nervous system and important components of brain and retinal fatty acids, they play important roles in promoting brain growth and development, improving vision, and so on [38]. Linoleic acid (C18:2n6c) can reduce blood cholesterol levels and improve blood circulation, which in turn inhibits atherosclerosis [39]. Eicosapentaenoic acid (C20:5n3, EPA) has many physiological functions such as improving immunity, combating tumors, and reducing cardiovascular disease [40]. The results showed that *L. vannamei* grown in both culture models are healthy foods.

Related studies have shown that lower molecular weight aldehydes (<150u) produce unpleasant odors, while higher molecular weight aldehydes produce sweet and fruity flavors [29]. Benzaldehyde has a bitter almond taste and is believed to be a product of the degradation of phenylalanine [41,42]. Both octanal and 1-nonanal are products of the oxidation of oleic acid. Octanal is typically associated with flavors of dry fish, grass, citrus fruit, and spice, while 1-nonanal is associated with flavors of raw fish, plastic, and fat [42]. The higher contents of octanal and 1-nonanal in the PM group were consistent with the higher content of oleic acid in muscle. Alcohols generally contribute relatively little to food flavor due to their high thresholds, they are generally undetected unless present in large quantities or in an unsaturated state [43]. In summary, the PM group exhibited reduced contents of some unpleasant volatile compounds, but increases in the content of other components, resulting in a minimal difference in flavor.

The nutritional and flavor profiles of *L. vannamei* muscle tissue exhibited differences between the photovoltaic fishery culture model and the common pond breeding model. These differences may be attributed to the differing light intensities and durations experienced by *L. vannamei* during their growth stage. Further investigation is required to elucidate the underlying mechanisms.

5. Conclusion

By comparing the differences of nutrients and flavor substances in *L. vannamei* muscle under the two culture models, we found that there was no significant difference in the contents of crude protein, ash, crude fat, calcium, potassium, magnesium, sodium, iron, copper, or zinc. Similarly, there were no significant differences in the contents of various amino acids. However, the contents of saturated monounsaturated fatty acids and total fatty acids were significantly higher in the PM group compared to the CM group, as was the *EAAI*. The volatile flavor substances in the muscles were consistent between the two culture models, but their relative contents differed significantly. Specifically, 1-nonanal, n-tridecane, and alpha-terpineol contents increased in the photovoltaic fishery culture model, while hexanal, 2-ethylhexanol, and dipentene contents decreased. On the whole, in addition to the photovoltaic fishery culture model having no negative effect on muscle nutritional quality or flavor of *L. vannamei*, it increased its fatty acid content, which proved that the photovoltaic fishery culture model is a reliable new green culture model. Concurrently, the photovoltaic fishery culture model has the potential to enhance income through photovoltaic power generation, which is worthy of further investigation and promotion. These results represent a strong theoretical basis and provide empirical data to support and guide the promotion of the photovoltaic fishery culture model.

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Data availability statement

All data generated or analyzed during this study are included in this published article.

Ethical approval

All animal handling procedures were approved by the Animal Care and Use Committee of the Fisheries Research Institute, Sichuan Academy of Agricultural Sciences (20220323002A), following the recommendations in the U.K. Animals (Scientific Procedures) Act, 1986. At the same time, all methods were carried out by relevant guidelines and regulations.

CRediT authorship contribution statement

Zhongmeng Zhao: Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Methodology, Formal analysis, Data curation. **Yongshuang Wang:** Methodology, Investigation, Data curation. **Qiang Li:** Validation, Software, Methodology, Investigation. **Han Zhao:** Methodology, Data curation. **Yuanliang Duan:** Methodology, Formal analysis, Data curation. **Xiaoping Wu:** Software, Investigation, Funding acquisition, Data curation. **Zhipeng Huang:** Software, Formal analysis, Data curation. **Huadong Li:** Software, Methodology. **Jian Zhou:** Methodology, Formal analysis. **Xingyu Chen:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e34797.

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