J. Ocean Univ. China (Oceanic and Coastal Sea Research) https://doi.org/10.1007/s11802-018-3550-6 ISN 1672-5182, 2018 17 (4): 697-904

Biochemical Composition and Nutritional Value of Different Shell Color Strains of Pacific Oyster *Crassostrea gigas*

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(Received May 12, 2017; revised August 20, 2017; accepted April 20, 2018) © Ocean University of China, Science Press and Springer-Verlag GmbH Germany 2018

Abstract The shell color of Pacific oyster (Like Like S is a desirable trait; but the nutritional studies on S with different shell colors have not been conducted. Through successive selective breeding, five shell color strains of black (B), purple (P), orange (O), golden (G) and white (W) anave been developed. The aim of this study was to evaluate the chemical composition and nutritional value of five shell color strains and one commercial population with a common color. The biochemical composition including moisture, total protein, glycogen, ash, total fat, fatty acids (FA), amino acids and minerals was detected. The results indicated that the protein (50.76%–56.57%) was the major component. The content of glycogen showed a significant difference between orange shell and golden shell strains, as well as between commercial population and golden shell strain. In addition, all shell color strains contained a large amount of essential amino acids (12.20–14.15g(100g)⁻¹), of them leucine (2.81–3.29g(100g)⁻¹) and lysine (2.79–3.28g(100g)⁻¹) were predominant. The oysters were rich in polyunsaturated fatty acids (42.26%–45.24% of total fatty acid) with high levels of DHA (18.53%–21.16% of total fatty acid) and EPA (17.23%–18.68% of total fatty acid). Significent differences of mineral contents (Mg, Zn, Fe and Cu) were identified among the six populations. These results indicated that the first of the study is useful for selective breeding of with different shell colors.

Key words USCHCHARS biochemical composition; nutrition value; shell color; selective breeding

1 Introduction

Pacific oyster (USCHCLES is currently the most widely farmed oyster in the world. The production increased at an annual average of 7.8% over the last 30 years as was stimulated by market requirement (FAO, 2016). In view of its importance, selective breeding programs have been initiated in some countries (Dégremont **U**, 2010; Langdon **U**, 2003). Recently, with the improvement of selective breeding, the visual perception traits of Pacific oyster, such as shell and mantle pigmentations, have attracted more and more attentions (Brake $\mathcal{U}_{\mathcal{G}}$, 2004). It has been shown that consumers are willing to pay more money for seafood with specific color, such as rich red salmon (Alfnes 2006). Similarly, consumers' preference for Pacific oyster may also be influenced by shell color. Shell color is a high-valued trait which is known to appeal to consumer preference, and therefore, affecting product value (Kahn and Wansink, 2004). The oysters with different shell colors are rarely seen in the market and are sold at much higher prices than others (Nell, 2001). Thus, selective breeding was implemented for the shell color of Card and five strains

* Corresponding author. Tel: 0086-532-82031622 E-mail: gili66@ouc.edu.cn characterized by black, purple, orange, golden and white shells were developed after successive five generations of selection.

The large-variation in shell color of the cultured populations of **Case** indicated that the shell color can be considered as a continuously distributed quantitative trait and can be stably inherited (Brake **CO**, 2004). The genetic analysis based on 133 single nucleotide polymorphism (SNP) markers demonstrated that there was sigIn present study, in order to provide useful information for selective breeding of shell color strains, biochemical

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while injector and detector with temperatures of 250 and respectively were used. The temperature program 260 was: initial temperature 50 , increasing up to 190 at per minute and then at 2 per minute to 240 40 and maintained at this temperature for 2 min. Methyl nonadecanoate (19:0) was used as internal standard. Each of the specific FAME peaks was identified by the retention time with reference to the known standard (Supelco, Inc., Bellefonte, Pennsylvania, USA). The relative amount of each fatty acid in each shell color oyster was expressed as the percentage of the specific fatty acid in the sum of total fatty acids.

2.5 Determination of Minerals

Calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), copper (Cu) and selenium (Se) contents of frozen-dried portions were determined by the inductively coupled plasma atomic emission spectrometer (ICP-AES, Model VISTA-MPX, VARIAN, USA) according to the method of AOAC (2000). The contents were expressed as g kg⁻¹ dry sample.

2.6 Statistical Analysis

All data were subjected to a one-way ANOVA and dif-

ferences between the means were tested by Tukey's multiple range test. The level of significance was set at $P_{<}^{2}$ 0.05. The results are presented as mean values with their standard errors (P_{4}^{2} 3), and all statistical analyses were performed using SPSS 21.0 (SPSS Inc., USA).

3 Results

3.1 Proximate Composition

Proximate composition of five shell color strains and control population of provide a sthe major component in all the samples (50.76%–56.57% dry weight), followed by glycogen (16.65%–22.09% dry weight) and fat (3.58%–5.15% dry weight). The protein content of golden shell strain was slightly higher than that of others. The analysis of variance revealed a significant effect of shell color on the content of glycogen. Orange shell strain showed significantly higher glycogen (1<0.05) but lower fat contents than golden shell strain. Between the shell color strains and commercial population, no obvious difference in the contents of moisture, protein, fat and ash was observed (1>0.05).

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Proximate compositions	Black shell	Purple shell	Orange shell	Golden shell	White shell	Commercial population	
Moisture	80.79 ± 0.87^{a}	80.80 ± 0.26^{a}	79.73 ± 0.82^{a}	80.28 ± 0.59^{a}	80.80 ± 0.23^{a}	79.92 ± 0.53^{a}	
Protein	50.76 ± 2.04^{a}	52.33 ± 1.68^{a}	51.98 ± 2.96^{a}	56.57 ± 6.10^{a}	52.42±1.91 ^a	52.76 ± 0.89^{a}	
Fat	4.96 ± 0.52^{a}	4.80 ± 0.44^{a}	3.58 ± 1.57^{a}	5.04 ± 1.85^{a}	5.15 ± 0.68^{a}	4.95 ± 0.62^{a}	
Glycogen	20.32 ± 3.66^{ab}	19.28±3.27 ^{ab}	22.09±0.59 ^b	16.65 ± 0.32^{a}	17.91 ± 2.01 ^{ab}	21.96 ± 1.16^{b}	
Ash	13.40 ± 2.59^{a}	11.73 ± 0.30^{a}	9.71 ± 2.06^{a}	10.67 191	.46 392.7203	Tm ()Tj -0	()T3

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concentration of 20:4 n-6 in the orange shell strain (2.89%) and commercial population (2.83%) was significantly higher than that in purple shell color strain (2.21%).

As a result, the ratio of total n-3 PUFA to total n-6 PUFA in golden shell strain was significantly lower than that in black, purple and white shell color strains (I < 0.05).

Table 3 A mino acid profiles of soft tissues of five shell color and commercial population of

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	Amino acid	Black shell	Purple shell	Orange shell	Golden shell	White shell	Commercial population
	Aspartic**	4.63±0.22	4.53±0.23	4.41±0.46	5.00±0.13	4.30±0.34	4.42±0.23
	Threonine*	1.71±0.04	1.71±0.07	1.69 ± 0.14	1.85±0.06	1.65±0.15	1.68 ± 0.08
	Serine	1.87±0.03	1.87±0.07	1.93±0.12	2.02 ± 0.06	1.84 ± 0.14	1.87±0.12
	Glutamic acid* *	6.57±0.17	6.75±0.34	6.60 ± 0.67	7.41±0.10	6.47 ± 0.53	6.99 ± 0.39
	Glycine**	3.03 ± 0.12	3.21±0.22	3.36 ± 0.29	2.97±0.19	3.04 ± 0.30	3.01 ± 0.09
	Alanine**	2.39 ± 0.01	2.47±0.10	2.49 ± 0.19	2.71±0.09	2.36 ± 0.20	2.48±0.16
	Cysteine	0.17 ± 0.05	0.17 ± 0.05	0.12 ± 0.05	0.09 ± 0.01	0.17 ± 0.02	0.12 ± 0.04
	Valine*	1.99 ± 0.04	1.96 ± 0.09	1.99±0.18	2.18±0.10	1.89±0.18	1.92 ± 0.08
	Methionine*	0.04 ± 0.01	0.08 ± 0.01	0.10 ± 0.02	0.09 ± 0.05	0.08 ± 0.01	0.06 ± 0.03
	Isoleucine*	1.82±0.06	1.79 ± 0.09	1.84±0.19	2.02±0.10	1.72±0.17	1.79 ± 0.08
	Leucine*	2.94 ± 0.09	2.97±0.18	2.95±0.27	3.29 ± 0.15	2.81±0.28	2.97±0.16
	Tyrosine	1.19 ± 0.03	1.18±0.05	1.18±0.08	1.30 ± 0.05	1.13±0.12	1.14 ± 0.04
	Phenylalanine*	1.33±0.04 ^{ab}	1.34±0.06 ^{ab}	1.35±0.11 ^{ab}	1.44 ± 0.06^{b}	1.27±0.12 ^{ab}	1.22 ± 0.03^{a}
	Histidine	1.34 ± 0.02	1.31 ± 0.05	1.34 ± 0.05	1.42±0.02	1.25 ± 0.13	1.27 ± 0.09
	Lysine*	2.94 ± 0.09	2.93±0.16	2.97±0.27	3.28±0.12	2.79±0.27	3.01 ± 0.19
	Arginine	2.80 ± 0.06	2.81±0.21	2.87±0.25	3.06 ± 0.12	2.59 ± 0.25	2.77±0.20
	Proline	1.83±0.06	1.72±0.12	1.83±0.08	1.95±0.07	1.78±0.16	1.76 ± 0.09
	Taurine	4.28 ± 0.03^{b}	4.08±1.10 ^{ab}	4.47 ± 0.09^{bc}	$4.87 \pm 0.20^{\circ}$	3.74 ± 0.27^{a}	4.45 ± 0.30^{bc}
	TAA	42.85±0.98	42.88±1.65	43.67±3.29	46.95±1.23	40.85 ± 3.55	42.97 ± 1.95
	TEAA	12.77±0.34	12.78±0.64	12.90±1.17	14.15 ± 0.53	12.20±1.16	12.64 ± 0.56
	E/T (%)	29.80 ± 0.15	29.79 ± 0.42	29.51 ± 0.54	30.13 ± 0.34	29.86 ± 0.25	29.43 ± 0.05
	E/N (%)	42.43+0.70	42.44 ± 0.85	42.10 ± 0.82	43.13 ± 0.32	42.54 ± 0.51	41.75+0.18

Notes: Date are mean \pm standard deviation (III 3, unit: (g(100 g dry weight)⁻¹)). Different letters in the same row indicate significant difference (I < 0.05). * Essential amino acids. ** Delicious amino acids. TAA, total amino acids; EAA, total essential amino acids. E/T means the ratio of EAA and TAA; E/N means the ratio of EAA and nonessential amino acid.

Table 4 Fatty acid profiles of soft tissues of five shell color and commercial population of Catalon (%) dry matter basis)

Fatty acid	Black shell	Purple shell	Orange shell	Golden shell	White shell	Commercial population
C14:0	3.02±0.31	3.22±0.14	2.73±0.89	2.79±0.48	3.26 ± 0.45	2.87±0.93
C15:0	0.90 ± 0.11	0.77±0.21	0.96 ± 0.04	0.83 ± 0.24	0.85 ± 0.12	0.77±0.12
C16:0	24.61 ± 2.14	25.51±1.62	24.43 ± 4.36	25.42 ± 3.24	25.40 ± 1.55	27.10±2.01
C17:0	2.21 ± 0.09	2.24 ± 0.16	2.23 ± 0.13	2.24 ± 0.41	2.06 ± 0.36	1.99 ± 0.04
C18:0	5.30 ± 1.61	5.49 ± 0.02	6.23±1.70	5.59 ± 0.84	4.96 ± 1.26	5.75±1.10
C20:0	2.80 ± 0.46^{ab}	2.22±0.21 ^a	3.85±1.14 ^b	2.48 ± 0.40^{ab}	2.25 ± 0.30^{a}	2.93±

Mg than the orange shell strain and control population (I < 0.05), whereas the content of Ca showed no significant difference between the shell color strains and commercial population (I > 0.05). When considering the micro-minerals, Fe content in the black shell strain (1.31 gkg⁻¹) was significantly higher than those in the orange shell strain (0.56 gkg⁻¹) and control population (0.58 gkg⁻¹) (I < 0.05). The observed Zn concentration ranged from 0.82 to 1.64g

kg⁻¹, and the highes Zn content was found in orange shell color strain (I < 0.05). In addition, the concentration of Cu were significantly higher in the orange shell (0.34g kg⁻¹), purple shell (0.27gkg⁻¹) and black shell color (0.26 gkg⁻¹) strains than in the commercial population (0.22g kg⁻¹) (I < 0.05). Between the cultured five shell color strains and the commercial population, norphytoious difference in the content of Se was observed (I > 0.05).

Table 5 Mineral contents of soft tissues of five shell color and commercial population of U	(dry weight)
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Minerals	Black shell	Purple shell	Orange shell	Golden shell	White shell	Commercial population		
Ca (gkg ⁻¹)	4.45 ± 0.59^{a}	4.11±1.35 ^a	3.94 ± 0.63^{a}	5.15 ± 0.58^{a}	4.36 ± 1.36^{a}	5.16 ± 2.63^{a}		
Mg (gkg ⁻¹)	3.71 ± 0.12^{b}	3.44 ± 0.39^{ab}	2.93 ± 0.02^{a}	3.57 ± 0.20^{b}	3.39 ± 0.13^{ab}	2.92 ± 0.03^{a}		
Zn (gkg⁻¹)	1.24 ± 0.06^{ab}	1.36±0.03 ^{bc}	$1.64 \pm 0.11^{\circ}$	1.20±0.06 ^{ab}	1.33±0.37 ^{bc}	0.82 ± 0.11^{a}		
Fe (g kg ⁻¹)	1.31 ± 0.30^{b}	0.88 ± 0.14^{ab}	0.56 ± 0.04^{a}	0.97 ± 0.58^{ab}	0.88 ± 0.20^{ab}	0.58 ± 0.05^{a}		
Cu (gkg ⁻¹)	0.26 ± 0.01^{bc}	$0.27 \pm 0.01^{\circ}$	0.34 ± 0.00^{d}	0.23 ± 0.02^{ab}	0.24 ± 0.03^{abc}	0.22 ± 0.02^{a}		
$Se(mgkg^{-1})$	11.05±1.6 ^{1a}	11.18±2.72 ^a	9.16 ± 0.94^{a}	9.74 ± 0.93^{a}	10.97 ± 5.03^{a}	$\mathbf{D}^{8.97 \pm 2.81^{a}}$		
Note: Data are many a standard deviation (n_{0}) Different latter in the same raw indicate similiar difference ($P_{0.05}$)								

Notes: Data are mean \pm standard deviation (II_{4}^{2} 3). Different letters in the same row indicate significant difference (I<0.05).

4 Discussion

In general, high protein content and low fat content have become symbolic of the ideal food $\mu_{\text{Hao}} \mathcal{A}_{\text{Hao}}$ 2015). In this study, the results showed that rich in protein and low in fat content, and with a high content of glycogen, which may be reflected in the quality and taste of oysters (Oliveira a, 2006). In similar studies, Karnjagapratum a (2013) reported that Asian hard clam IKENXILIOOC contained about 53.82% protein and 14.96% carbohydrate. From the results of this study, the content of glycogen in that in Asian hard clam; however, the protein content was similar to that of Asian hard clam. The contents in proximate compositions of oysters agreed with previous findrings reported for glycoger (Wang **2015**; Li **2006**), protein (Wang **2016**, 2015) and fat (Li **2016**, 2006). In addition, the data analyses revealed distinct differences in lipid and glycogen contents between the orange shell strain and golden shell strain. The orange shell strain exhibited a significantly higher glycogen content as compared to the golden shell strain, while fat dropped drastically. This may be explained by the conversion of energy (Pogoda *CU*, 2013), as the glycogen reserve may be used in the synthesis of lipids (De la Parra **UU**, 2005). The simultaneous glycogen decrease and fat increase may indicate the conversion of carbohydrates into lipids during ontogenesis ((De la Parra UU, 2005; Robinson, 1992). The variations in proximate compositions of marine seafood are closely related to biological factors, including species, diet, harvest area, catching season, seasonal and sexual variations (Karnjanapratum **EU**, 2013). Moreover, the differences in compositions between the studied populations may plate closely to the growth speed of oysters (Chi 2007). The results revealed A harvested from Rushan Bay can be a rich that 📞 source of nutrients, including protein, fat and glycogen.

The most abundant amino acid in five shell color strains and commercial population was glutamic acid, and this observation is in line with the finding reported by

C **1**<u>2</u>013) for Asian hard clam. In I WILLS ELEPTIMELES' Babarro ELE (2011) reported the soft tissue consisted of 3.09% glutanic acid and 1.01% aspartic. However, in this study, much higher compositions of glutanic and (6.47%) 7.41%) and aspartic (4.3%–5%) than **Automotion** From these results, the taste of oysters could be stronger than the mussels cultured on a raft system. Several recent studies reported that some amino acids especially histidine, proline, valine, methionine, cysteine, tyrosine, and phenylalanine play significant roles in the activities of antioxidative peptides (Bougater **20**, 2010; Samaranayaka and Li-chan, 2011). These seven amino acids accounted for approximately 18% of the total amino acids detected in this study, which suggests that there is strong antioxidant activity in these oysters. In general, taurine is found in breast milk, suggesting that it is particularly important at this stage. However, the capacity of endogenous synthesis of taurine is limited in humans (particularly in infants), therefore, the majority of body taurine usually are from ford sources especially seafood and meat (El Zahraa **20**, 2012). Additionally, some previous studies have indicated that tauring can decrease blood lipids (Pandya 40, 2010). Li 40 (2015) demonstrated that the contern of tauring tras $1.51 \text{ g} (100 \text{ g})^{-1}$ and $1.21 \text{ g} (100 \text{ g})^{-1}$ in **EVERGES (700 p)** and 1.21 m an UT Direspectively, from the east coast of Jiangsu Province. The taurine concentration in soft tissue of the two species was tess than half of that in Carestudied here. Therefore, Careston a good source of taurine, especially the golden shell color strain. Content and composition of total amino acids of 🕼 investigated in this study are somewhat in a with the values (42.8%-50.6%) provided for IVILIDIC harvested from the coast of Andaman Sea (Karnjanapratum **UU**, 2013). Difference in the content of total amino acids indicated the different protein nutritional value between the shell color strains and commercial population. Based on the amino acid profiles, TEAA content was higher in the golden shell color strain, indicating that its protein fraction was of higher nutritional value than that

of the other strains, especially the white shell color strain. The content of amino acids satisfy the suggested profile of essential amino acid requirements for adult humans, however, the mechanism of different shell color effects on amino acid content need to be elucidated in future studies.

Similar to our FAMEs results, Pogoda 400 (2013) reported palmitic (23.5%), EPA (16.4%), DHA (21.3%) were major fatty acids found in Calman acids found in Oca tober from the test site of Nordergründer Dridi **CA** (2007) reported the fatty acid profile of **CA** from the Bizert lagoon in winter, and found the three major fatty acids were DHA (20.4%), EPA (12.15%), and palmitic acid (19.77%). One of the most striking differences among the results of Pogoda (2013), Dridi (2007) and ours is in the level of EPA. This difference is likely a result of the environmental temperature in which the oysters resided prior to harvest. The PUFA levels are high when temperature is low, while the PUFA levels are low when temperature is high (Dridi *@a*, 2007). Moreover, the polyunsaturated fatty acid 20:5n-3 and 22:6n-3 are very important and conservative elements of bio-membranes. The amount of essential FA may sorve as an indicator for the preferred diet (Dalsgaard **UU**, 2003; Soudant **UU**, 1999). For example, high levels of n-3 PUFA (37.02%-40.27% of total fatty acids) is important in the human diet for platelet anti-aggregating and blood pressure-reducing properties (Orban UU, 2006; Karnig papratum UU, 2013). However, Karnjanapratum UU (2013), reported the levels of (n-3) PUFA was 28.70% in IVICENTin the viscera, and this value was much lower than that in The relatively high n-3/n-6 PUFA ratio indicated the high proportion of essential n-3 fatty acids. These aspects contribute to a positive evaluation of the lipid quality of Carterian Bay. In consideration of the high lipid quality, an increment of the consumption of LS s recommended by the current dietary guidelines (Simopoulos, 2003).

Like other bivalve mollusks, **Second** bivalve mo

erence Intakes (RDI) of Ca and Mg are 1000 and 400 mgk -079 0.0015 Tc .2.814 Tw -220006 -1.216 Td [verny)456()6(ay)708.4(,r)-5.2

provide useful information on selective breeding of different shell pigmentation and comprehensive utilization of

Acknowledgements

This study was supported by the grants from the National Natural Science Foundation of China (No. 31772 843), the Key Research and Development Program of Shandong Province (No. 2016ZDJS06A06), and the Industrial Development Project of Qingdao City (17-3-3-64-nsh).

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(Edited by Qiu Yantao)