

Received:
24 October 2018
Revised:
6 January 2019
Accepted:
11 February 2019

Cite as:
Madhusa
Mihirani Subasinghe,
Bedigama Kankanamge
Kolitha Kamal Jinadasa,
Ayanthi N. Navarathne,
Sevvandi Jayakody. Seasonal
variations in the total lipid
content and fatty acid
composition of cultured and
wild *Crassostrea madrasensis*
in Sri Lanka.
Heliyon 5 (2019) e01238.
doi: 10.1016/j.heliyon.2019.
e01238



Seasonal variations in the total lipid content and fatty acid composition of cultured and wild *Crassostrea madrasensis* in Sri Lanka

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Abstract

The marketplace contains a choice of both cultured and wild oysters, often subtle differences in taste and characteristics are observed between wild and cultured oysters. Therefore, seasonal variations of total lipid and total fatty acid compositions were studied in both, wild and cultured populations of *Crassostrea madrasensis* in Gangewadiya in Kala-Oya estuary and in cultured populations in the Puttalam lagoon in Sri Lanka over a 13 month period. The fatty acid profile was analyzed using Gas Chromatography. The average lipid percentage was $1.28 \pm 0.02\%$ and there was no significant difference between cultured and wild oysters ($p > 0.05$). A total of 17 fatty acids was detected. Significant monthly variations were seen in all fatty acids, except docosapentaenoic acid (DPA/

C22.5(n-3)) and docosahexaenoic acid C226(n-3). Significantly high concentrations ($p < 0.05$) of omega 3 fatty acids were recorded during October while significantly higher omega 6 concentrations were recorded during April ($p > 0.05$). Saturated fatty acids had the highest concentration followed by polyunsaturated fatty acids and monounsaturated fatty acids. Palmitic acid was the major saturated fatty acid and docosahexaenoic acid was the major polyunsaturated fatty acid. The ratio of total n-3 PUFA to total n-6 PUFA were 2.6, 2.9 and 3.0 in Gangewadiya wild, Gangewadiya cultured and Kandakuliya cultured oysters, respectively. Though there were no significant differences in omega 3 to omega 6 ratios in cultured and wild oysters in Gangewadiya, a significantly higher ratio was calculated for cultured oysters in Kandakuliya. Hence, a discriminant analysis indicated that in terms of the fatty acid composition, cultured *C. madrasensis* in Kandakuliya is distinct compared to wild and cultured populations from Gangewadiya. Since, both wild and cultured *C. madrasensis* shared the same waters in Gangewadiya, the lack of differences can be explained. However, in both sites and under wild and cultured conditions, fatty acid ratio confirms the importance of *C. madrasensis* as an ideal source of omega 3.

Keywords: Food science, Food analysis

1. Introduction

Oysters could be considered among the best known and most widely cultivated marine animals worldwide (Cruz-Romero et al., 2008; Asha et al., 2014). They play an important role in the national economies of many countries due to oyster culture being a highly developed industry and, oysters being a cheap source of protein. In developing countries, it is considered as a low-cost subsistence food for many coastal populations. In countries, such as the United States of America, Europe, Japan, etc., oysters are a highly esteemed seafood and are considered as a delicacy (Asha et al., 2014) and a significant percentage of animal protein in the food market is contributed by oysters (Korringa, 1976).

Shellfish such as oysters and mussels are known to be high in protein, low in fat and calories (Salaskar, 2008). They are also high in omega 3 fatty acids such as eicosapentaenoic acids (EPA) and docosahexaenoic acids (DHA), which can improve cardiovascular health (Mateos et al., 2010; Chen, 2011). Due to health consciousness, the modern society is interested in taking more seafood in view of its nutritional superiority (Srilatha et al., 2013).

Crassostrea madrasensis is one of the most widely cultivated oysters in the world. In addition, they are widely distributed in coastal and estuarine environments in India, Pakistan, Indonesia and Sri Lanka to which it is native (Indrasena and Wanninayake, 1994; Alam and Das, 1999; Ghazala and Muzammil, 2001). It is naturally found in

the estuary of Kala-Oya in Sri Lanka and oyster fishery is a major small-scale fishery carried out by Sri Lankan coastal communities. In recent years, they are cultured in racks in the same area by local communities. Additionally, *C. madrasensis* has been introduced to the nearby Puttalam lagoon since 2011 to expand the culture. Hence, at present, both wild and cultured oysters are found in the marketplace. Yet little attention has been paid to the differences in nutritional quality between various culture sites, and the influence of the seasons, on the qualities of oysters. Therefore, this study was carried out to determine the seasonal variations of total lipid and fatty acid composition in wild and cultured *C. madrasensis*.

2. Materials and methods

2.1. Sample collection and preparation

Both wild and cultured *C. madrasensis* were collected from Gangewadiya in Kala-Oya estuary (08° 19.219', 079° 50.218') however, only cultured *C. madrasensis* were collected from Kandakuliya in Puttalam lagoon (08° 12.608', 079° 41.888') located in the North Western Province of Sri Lanka. Cultured *C. madrasensis* were collected from the culture racks and wild oysters were collected from natural oyster beds. Monthly approximately 15–20 oysters were collected from each sampling location over a 13 month period from July 2014 to July 2015.

After collection, the samples were cleaned to remove exterior impurities and were transported to the laboratory in coolers chilled with ice. In the laboratory, samples were firstly allowed to thaw and then, were rinsed with deionized water and blotted with tissues to remove external water. Then the weight of the whole individual oyster and the weight of the oyster muscles were measured to the nearest milligram. Then they were chopped and homogenized. The fatty acid determination was carried out on fresh samples.

2.2. Total lipid extraction

The extraction of total lipid of oyster muscle was performed according to the method described by Bligh and Dyer (1959). All chemicals were of analytical grade or better. The extracted 10 mL of oil was pipetted into a pre-weighed dried and cooled beaker and placed in a fume cupboard till all chloroform evaporated. Then it was dried in an oven for 1 hour and cooled in a desiccator for 20 minutes and the weight was taken. Afterward, the total lipid percentage was calculated as follows.

$$\text{Total Lipid \%} = \frac{\text{Weight of oil (g)} \times \text{Volume chloroform extract made up (mL)} \times 100}{\text{Volume of oil extract brought to evaporation in (mL)} \times \text{Weight of oyster sample (g)}}$$

2.3. Fatty acid analysis

Fatty acid methyl esters (FAME) were prepared by saponification of approximately 50 mg of extracted oil, using 0.5 M methanolic sodium hydroxide, followed by esterification with boron trifluoride catalyzed reaction, with 1.0 ml (20.086 g m⁻³) of internal standard of heptadecanoic acid. Afterward, fatty acid methyl esters were extracted from the aqueous phase into n-heptane (Berner and Jensen, 1991). FAME was separated by Gas Chromatography (Shimadzu GC 2014, Kyoto, Japan) equipped with a Flame Ionization Detector (FID) and fitted with a fused silica DB wax capillary column (length 25 m × 0.25 mm ID × 0.25 μm film thickness). Helium was used as the carrier gas with a pressure of 14 psi. Injector and detector temperatures were programmed to be 240 °C and 270 °C, respectively. The temperature programme used in the oven was 160 °C–240 °C at 3 °C/min and was held isothermally at 240 °C for 15 min. Retention times of FAME standards were used to identify chromatographic peaks. The qualitative and quantitative determination was done using Qualmix fish S (89-5550) standard and internal standard; heptadecanoic acid. All the measurements were carried out in duplicate.

2.4. Statistical analysis

Monthly variations in fatty acid concentrations and total lipid between groups were analyzed using the General Linear Model and one-way ANOVA. The contributions of the fatty acids by percentage of total fatty acids were analyzed using area graphs. Discriminant analysis was done to analyze composition uniqueness in fatty acid concentrations within each treatment. Statistical analysis was performed using Microsoft Excel 2007 version and Minitab 18.

3. Results and discussion

3.1. Total lipid content

Percentage of lipids fluctuated between $0.94 \pm 0.09\%$ (March 2015) and $1.59 \pm 0.01\%$ (July 2014) in the Gangewadiya wild treatment, $0.88 \pm 0.01\%$ (March 2015) and $1.54 \pm 0.02\%$ (July 2015) in Gangewadiya cultured treatment, $0.10 \pm 0.00\%$ (January 2015) and $1.45 \pm 0.00\%$ (December 2015) in Kandakuliya cultured treatments (Fig. 1). The highest percentage of lipid ($1.59 \pm 0.01\%$) was recorded for wild oysters in Gangewadiya in December 2014. The lipid reserves of mollusk mainly depend on the environmental influences on metabolic activities, the nutritional value of the food supply and the stage of gonadal development (Su et al., 2006; Mateos et al., 2010). The results of the present study revealed the significant differences between monthly variations of lipid content. The mean percentage of lipid of July 2015 ($1.45 \pm 0.02\%$) was significantly higher than the mean

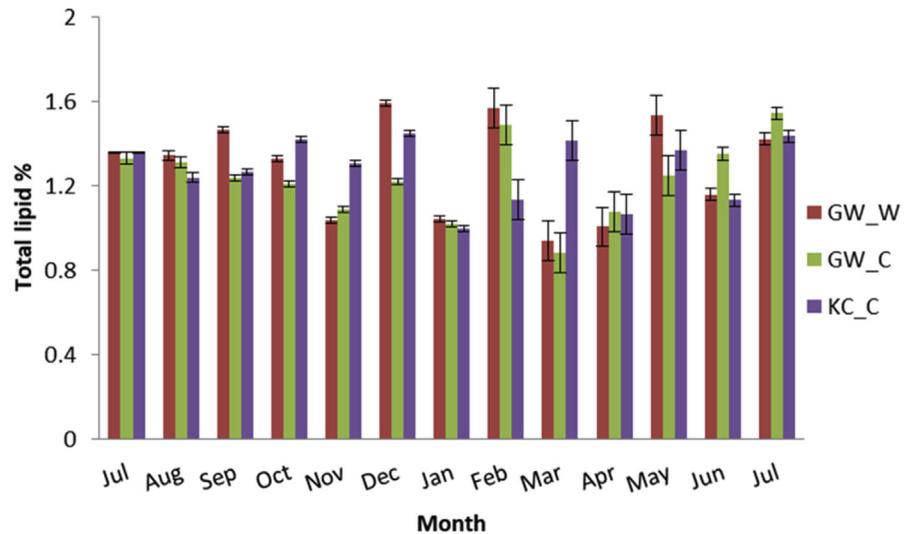


Fig. 1. Monthly variation of percentage of lipid (mean \pm S.E) in *C. madrasensis* in Gangewadiya cultured (GW_C), Kandakuliya cultured (KC_C) and Gangewadiya wild (GW_W) samples.

percentage of lipid in April of 2015 ($1.03 \pm 0.04\%$) (ANOVA, $df_{12,11}$, Tukey's mean separation, $p < 0.001$). Previous studies on *C. madrasensis* in Kali estuary in India have also shown monthly variations of lipid content (Salaskar and Nayak, 2011). However, there was no significant difference in lipid percentage between the three treatments ($p > 0.05$). This non-significant difference between treatments suggests the reduced or no impact of geographical variation on the lipid content of *C. madrasensis*.

3.2. Seasonal variation of fatty acids in cultured and wild oysters

The seasonal variation in fatty acids in *Crassostrea madrasensis* is shown in Table 1. A total of 17 fatty acids from myristic (C14:0) to docosahexaenoic (C22:6(n-3)) was observed. Palmitic acid (C16:0) was the most predominant saturated fatty acid whilst erucic acid (C22:1(n-9)) and docosahexaenoic acid (C22:6(n-3)) was dominant monounsaturated and polyunsaturated fatty acid respectively. The literature presents similar results (Linehan et al., 1999; Martino and da Cruz, 2004).

Significant monthly variations were seen in all fatty acids except docosapentaenoic acid (DPA/C22:5(n-3)) and docosahexaenoic acid C22:6(n-3). Most fatty acid compositions were high during October to November period while some fatty acid compositions were high from April to May. Significantly higher concentrations (ANOVA, $df_{12,39}$, Tukey's mean separation, $P < 0.05$) of saturated fatty acid, mono-unsaturated fatty acid and polyunsaturated fatty acids were recorded during October. Significantly higher concentrations (ANOVA, $df_{12,39}$, Tukey's mean separation, $P < 0.05$) of omega 3 fatty acids were recorded during October while significantly higher omega 6 concentrations was recorded during April.

Table 1. Monthly variations of fatty acid composition (mg/100g of oyster meat) in *C. madrasensis*.

| Fatty acid | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul |
|------------|-------------------------------|------------------------------|-------------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|
| C14.0 | 0.31 ± 0.02 ^{ABC} | 0.22 ± 0.03 ^{BC} | 0.27 ± 0.03 ^{ABC} | 0.36 ± 0.03 ^{AB} | 0.38 ± 0.03 ^A | 0.32 ± 0.03 ^{ABC} | 0.33 ± 0.02 ^{ABC} | 0.25 ± 0.05 ^{ABC} | 0.23 ± 0.04 ^{BC} | 0.22 ± 0.01 ^C | 0.23 ± 0.02 ^{ABC} | 0.31 ± 0.01 ^{ABC} | 0.30 ± 0.02 ^{ABC} |
| C15.0 | 0.08 ± 0.01 ^{BC} | 0.06 ± 0.01 ^C | 0.09 ± 0.01 ^{BC} | 0.15 ± 0.02 ^{AB} | 0.12 ± 0.01 ^{ABC} | 0.10 ± 0.02 ^{ABC} | 0.10 ± 0.03 ^{ABC} | 0.08 ± 0.02 ^{BC} | 0.07 ± 0.02 ^{BC} | 0.09 ± 0.01 ^{BC} | 0.10 ± 0.02 ^{BC} | 0.18 ± 0.02 ^A | 0.07 ± 0.01 ^{BC} |
| C16.0 | 2.17 ± 0.19 ^{AB} | 1.76 ± 0.18 ^B | 1.89 ± 0.26 ^C | 3.00 ± 0.24 ^A | 2.24 ± 0.11 ^{AB} | 2.02 ± 0.26 ^{AB} | 1.79 ± 0.16 ^B | 1.89 ± 0.14 ^B | 2.03 ± 0.35 ^{AB} | 2.03 ± 0.13 ^{AB} | 2.32 ± 0.35 ^{AB} | 2.27 ± 0.17 ^{AB} | 1.90 ± 0.09 ^B |
| C16.1 | 0.43 ± 0.05 ^{AB} | 0.34 ± 0.04 ^{BC} | 0.35 ± 0.05 ^{BC} | 0.54 ± 0.04 ^A | 0.36 ± 0.03 ^{ABC} | 0.32 ± 0.03 ^{BC} | 0.26 ± 0.02 ^{BC} | 0.21 ± 0.06 ^C | 0.27 ± 0.05 ^{BC} | 0.27 ± 0.03 ^{BC} | 0.26 ± 0.02 ^{BC} | 0.38 ± 0.03 ^{ABC} | 0.35 ± 0.01 ^{BC} |
| C18.0 | 0.56 ± 0.05 ^B | 0.45 ± 0.05 ^B | 0.55 ± 0.08 ^B | 0.84 ± 0.05 ^A | 0.66 ± 0.05 ^{AB} | 0.54 ± 0.05 ^B | 0.51 ± 0.04 ^B | 0.50 ± 0.03 ^B | 0.57 ± 0.11 ^{AB} | 0.61 ± 0.04 ^{AB} | 0.59 ± 0.08 ^{AB} | 0.58 ± 0.04 ^{AB} | 0.42 ± 0.01 ^B |
| C18.1(n-9) | 0.20 ± 0.01 ^{BC} | 0.13 ± 0.02 ^C | 0.15 ± 0.03 ^C | 0.35 ± 0.03 ^{AB} | 0.27 ± 0.02 ^{BC} | 0.32 ± 0.04 ^{BC} | 0.29 ± 0.04 ^{BC} | 0.29 ± 0.03 ^{BC} | 0.36 ± 0.08 ^{AB} | 0.38 ± 0.05 ^{AB} | 0.41 ± 0.08 ^A | 0.26 ± 0.03 ^{BC} | 0.19 ± 0.01 ^{BC} |
| C18.1(n-7) | 0.43 ± 0.02 ^{AB} | 0.35 ± 0.04 ^B | 0.34 ± 0.03 ^B | 0.56 ± 0.04 ^A | 0.38 ± 0.02 ^B | 0.34 ± 0.04 ^B | 0.30 ± 0.04 ^B | 0.31 ± 0.04 ^B | 0.29 ± 0.05 ^B | 0.38 ± 0.03 ^B | 0.35 ± 0.01 ^B | 0.44 ± 0.04 ^{AB} | 0.39 ± 0.02 ^{AB} |
| C18.2(n-6) | 0.12 ± 0.01 ^B | 0.11 ± 0.01 ^B | 0.12 ± 0.02 ^B | 0.18 ± 0.01 ^B | 0.12 ± 0.01 ^B | 0.20 ± 0.01 ^{AB} | 0.16 ± 0.02 ^B | 0.15 ± 0.01 ^B | 0.15 ± 0.03 ^B | 0.30 ± 0.05 ^A | 0.18 ± 0.03 ^B | 0.15 ± 0.01 ^B | 0.12 ± 0.01 ^B |
| C18.3(n-3) | 0.09 ± 0.01 ^C | 0.13 ± 0.02 ^C | 0.12 ± 0.03 ^C | 0.27 ± 0.04 ^A | 0.26 ± 0.01 ^{AB} | 0.15 ± 0.02 ^C | 0.16 ± 0.02 ^{BC} | 0.13 ± 0.01 ^C | 0.16 ± 0.03 ^{BC} | 0.13 ± 0.01 ^C | 0.18 ± 0.02 ^{ABC} | 0.17 ± 0.01 ^{ABC} | 0.13 ± 0.01 ^{ABC} |
| C18.4(n-4) | 0.23 ± 0.01 ^B | 0.19 ± 0.02 ^B | 0.21 ± 0.02 ^B | 0.34 ± 0.03 ^A | 0.25 ± 0.01 ^{AB} | 0.21 ± 0.02 ^B | 0.21 ± 0.02 ^B | 0.18 ± 0.02 ^B | 0.17 ± 0.02 ^B | 0.22 ± 0.02 ^B | 0.19 ± 0.02 ^B | 0.25 ± 0.01 ^{AB} | 0.20 ± 0.01 ^B |
| C20.1(n-9) | 0.13 ± 0.01 ^{AB} | 0.14 ± 0.02 ^{AB} | 0.14 ± 0.03 ^{AB} | 0.18 ± 0.02 ^{AB} | 0.12 ± 0.01 ^{AB} | 0.17 ± 0.03 ^{AB} | 0.17 ± 0.03 ^{AB} | 0.14 ± 0.01 ^{AB} | 0.13 ± 0.03 ^{AB} | 0.09 ± 0.01 ^B | 0.21 ± 0.04 ^A | 0.16 ± 0.02 ^{AB} | 0.14 ± 0.01 ^{AB} |

(continued on next page)

Table 1. (Continued)

| Fatty acid | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul |
|------------|-------------------------------|------------------------------|-------------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------------|-------------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|
| C20.4(n-6) | 0.34 ± 0.02 ^{ABC} | 0.26 ± 0.03 ^C | 0.31 ± 0.04 ^{BC} | 0.48 ± 0.04 ^A | 0.38 ± 0.03 ^{ABC} | 0.27 ± 0.04 ^C | 0.29 ± 0.03 ^{BC} | 0.30 ± 0.03 ^{BC} | 0.30 ± 0.05 ^{BC} | 0.43 ± 0.03 ^{AB} | 0.28 ± 0.03 ^{BC} | 0.37 ± 0.03 ^{ABC} | 0.28 ± 0.01 ^C |
| C20.5(n-3) | 0.31 ± 0.02 ^B | 0.26 ± 0.03 ^B | 0.33 ± 0.03 ^B | 0.52 ± 0.05 ^A | 0.40 ± 0.01 ^{AB} | 0.33 ± 0.03 ^B | 0.37 ± 0.03 ^B | 0.31 ± 0.03 ^B | 0.30 ± 0.04 ^B | 0.41 ± 0.03 ^{AB} | 0.29 ± 0.03 ^B | 0.37 ± 0.02 ^B | 0.29 ± 0.02 ^B |
| C22.1(n-9) | 1.16 ± 0.08 ^{AB} | 1.01 ± 0.14 ^{AB} | 1.01 ± 0.13 ^{AB} | 1.41 ± 0.10 ^A | 1.00 ± 0.06 | 0.87 ± 0.10 ^B | 0.86 ± 0.06 ^B | 0.80 ± 0.08 ^B | 0.79 ± 0.13 ^B | 0.80 ± 0.07 ^B | 1.04 ± 0.11 ^{AB} | 1.19 ± 0.10 ^{AB} | 1.08 ± 0.08 ^{AB} |
| C22.4(n-6) | 0.07 ± 0.01 ^{BC} | 0.05 ± 0.01 ^C | 0.08 ± 0.02 ^{ABC} | 0.14 ± 0.02 ^{AB} | 0.11 ± 0.12 ^{ABC} | 0.06 ± 0.01 ^{ABC} | 0.08 ± 0.01 ^{ABC} | 0.05 ± 0.01 ^C | 0.09 ± 0.01 ^{ABC} | 0.15 ± 0.01 ^A | 0.09 ± 0.01 ^{ABC} | 0.14 ± 0.02 ^{AB} | 0.08 ± 0.01 ^{ABC} |
| C22.5(n-3) | 0.12 ± 0.01 ^A | 0.13 ± 0.02 ^A | 0.18 ± 0.04 ^A | 0.27 ± 0.02 ^A | 0.18 ± 0.01 ^A | 0.11 ± 0.01 ^A | 0.13 ± 0.02 ^A | 0.12 ± 0.01 ^A | 0.12 ± 0.01 ^A | 0.27 ± 0.11 ^A | 0.13 ± 0.01 ^A | 0.22 ± 0.03 ^A | 0.17 ± 0.03 ^A |
| C22.6(n-3) | 0.91 ± 0.06 ^A | 0.67 ± 0.07 ^A | 0.75 ± 0.09 ^A | 1.07 ± 0.08 ^A | 1.00 ± 0.22 ^A | 1.00 ± 0.08 ^A | 1.23 ± 0.16 ^A | 1.18 ± 0.14 ^A | 0.91 ± 0.17 ^A | 0.76 ± 0.17 ^A | 1.37 ± 0.27 ^A | 1.15 ± 0.09 ^A | 0.77 ± 0.04 ^A |

*Months with significant differences are depicted by alphabetic letters A, B and C. *Results are presented as mean concentration (mg/100g) ±SE.

Saturated fatty acids constitute most of the fatty acid pool, followed by polyunsaturated fatty acids and monounsaturated fatty acids in cultured and wild oysters (Table 2). Significant differences were seen in cultured oysters in Gangewadiya, cultured oysters in Kandakuliya and wild oysters in Gangewadiya between gondoic acid (C20.1(n-9)) and eicosapentaenoic acid (EPA/C20.5(n-3)). Gondoic acid (C20.1(n-9)) concentration were high in cultured oysters in Kandakuliya while eicosapentaenoic acid (EPA/C20.5(n-3)) concentration was high in cultured oysters in Gangewadiya. The variations of fatty acid concentrations in each site may be due to the changes of environmental parameters such as salinity of the water, availability of

Table 2. Variation of fatty acid concentration (mg/100g of oyster meat) in *C. madrasensis* in Gangewadiya cultured (GW_C), Kandakuliya cultured (KC_C) and Gangewadiya wild (GW_W) treatments.

| Fatty acid | Group | | | P value |
|------------|--------------------------------|--------------------------------|--------------------------------|-------------|
| | GW_W | GW_C | KC_C | |
| C14.0 | 0.31 ± 0.02 ^A | 0.29 ± 0.01 ^A | 0.27 ± 0.01 ^A | 0.22 |
| C15.0 | 0.10 ± 0.01 ^A | 0.10 ± 0.01 ^A | 0.10 ± 0.02 ^A | 0.86 |
| C16.0 | 2.06 ± 0.13 ^A | 2.08 ± 0.12 ^A | 2.15 ± 0.10 ^A | 0.80 |
| C18.0 | 0.55 ± 0.03 ^A | 0.57 ± 0.03 ^A | 0.59 ± 0.03 ^A | 0.59 |
| ΣSFA | 3.01 ± 0.18^A | 3.04 ± 0.16^A | 3.11 ± 0.14^A | 0.87 |
| C16.1 | 0.35 ± 0.02 ^A | 0.34 ± 0.03 ^A | 0.31 ± 0.02 ^A | 0.26 |
| C18.1(n-9) | 0.27 ± 0.02 ^A | 0.27 ± 0.02 ^A | 0.28 ± 0.02 ^A | 0.79 |
| C18.1(n-7) | 0.39 ± 0.02 ^A | 0.39 ± 0.01 ^A | 0.35 ± 0.02 ^A | 0.21 |
| C20.1(n-9) | 0.12 ± 0.01 ^B | 0.13 ± 0.01 ^B | 0.19 ± 0.01 ^A | 0.00 |
| C22.1(n-9) | 1.00 ± 0.06 ^A | 1.00 ± 0.06 ^A | 1.02 ± 0.06 ^A | 0.80 |
| ΣMUFA | 2.14 ± 0.12^A | 2.11 ± 0.10^A | 2.15 ± 0.10^A | 0.93 |
| C18.2(n-6) | 0.16 ± 0.01 ^A | 0.17 ± 0.01 ^A | 0.15 ± 0.01 ^A | 0.44 |
| C18.3(n-3) | 0.14 ± 0.01 ^A | 0.17 ± 0.01 ^A | 0.17 ± 0.01 ^A | 0.08 |
| C18.4(n-4) | 0.23 ± 0.01 ^A | 0.23 ± 0.01 ^A | 0.20 ± 0.01 ^A | 0.09 |
| C20.4(n-6) | 0.35 ± 0.02 ^A | 0.35 ± 0.02 ^A | 0.30 ± 0.02 ^A | 0.09 |
| C20.5(n-3) | 0.35 ± 0.02 ^{AB} | 0.37 ± 0.01 ^A | 0.32 ± 0.01 ^B | 0.03 |
| C22.4(n-6) | 0.09 ± 0.01 ^A | 0.09 ± 0.01 ^A | 0.10 ± 0.01 ^A | 0.55 |
| C22.5(n-3) | 0.18 ± 0.03 ^A | 0.16 ± 0.01 ^A | 0.16 ± 0.01 ^A | 0.59 |
| C22.6(n-3) | 0.89 ± 0.07 ^A | 1.04 ± 0.07 ^A | 1.01 ± 0.07 ^A | 0.35 |
| ΣPUFA | 2.39 ± 0.14^A | 2.58 ± 0.14^A | 2.41 ± 0.11^A | 0.58 |
| n-3 | 1.57 ± 0.09^A | 1.74 ± 0.10^A | 1.66 ± 0.08^A | 0.46 |
| n-6 | 0.60 ± 0.04^A | 0.61 ± 0.04^A | 0.55 ± 0.03^A | 0.39 |
| n-3/n-6 | 2.6^B | 2.9^{AB} | 3.0^A | 0.03 |

Locations with significant differences are depicted by alphabetic letters A and B.

*ΣSFA = Total saturated fatty acids, ΣMUFA = Total monounsaturated fatty acids, ΣPUFA = Total polyunsaturated fatty acids, n-3 = omega 3 fatty acids, n-6 = omega six fatty acids, n-3/n-6 = omega 3 to omega 6 ratio *Results are presented as mean concentration (mg/100g) ±SE.

food and temperature (Sidwell et al., 1979). Total Omega-3 fatty acid composition in Gangewadiya wild, Gangewadiya cultured and Kandakuliya cultured oysters were 1.57 ± 0.09 , 1.74 ± 0.10 and 1.66 ± 0.08 mg/100g of the oyster meat respectively. Similarly, the total omega-6 fatty acid composition in Gangewadiya wild, Gangewadiya cultured and Kandakuliya cultured oysters were 0.60 ± 0.04 , 0.61 ± 0.04 and 0.55 ± 0.03 of mg/100g of the oyster meat respectively.

The ratio of total n-3 PUFA to total n-6 PUFA were 2.6, 2.9 and 3.0 in Gangewadiya wild, Gangewadiya cultured and Kandakuliya cultured oysters, respectively. There were no significant differences in omega 3 and omega 6 fatty acids in wild oysters and cultured oysters. But the omega 3 to omega 6 ratio was significantly higher in cultured oysters in Kandakkuliya. An appropriate ratio of n-3 to n-6 is very important to the production of eicosanoids at a balanced level. Omega 3 to omega 6 ratios of 2:1-3:1 have been recommended by some authors, to enable greater conversion of α -linolenic acid into DHA (Krauss, 2000; Simopoulos, 2003; Lira et al., 2013). In the present study ratios between n-3 to n-6 were within this range. The high ratio of n-3/n-6 ratio in oysters shows an occurrence of a high proportion of n-3 polyunsaturated fatty acids over n-6 polyunsaturated fatty acids. This ratio is very useful for comparing the nutritional value of fish lipids due to their human health effects in coronary heart diseases, cancer and autoimmune diseases (Wang et al., 1990; Simopoulos, 2002; Asha et al., 2014). The area graph of the fatty acid concentration variation of wild oysters in Gangewadiya (GW_W), cultured oysters in Gangewadiya (GW_C) and cultured oysters in Kandakuliya (KC_C) are shown in Fig. 2.

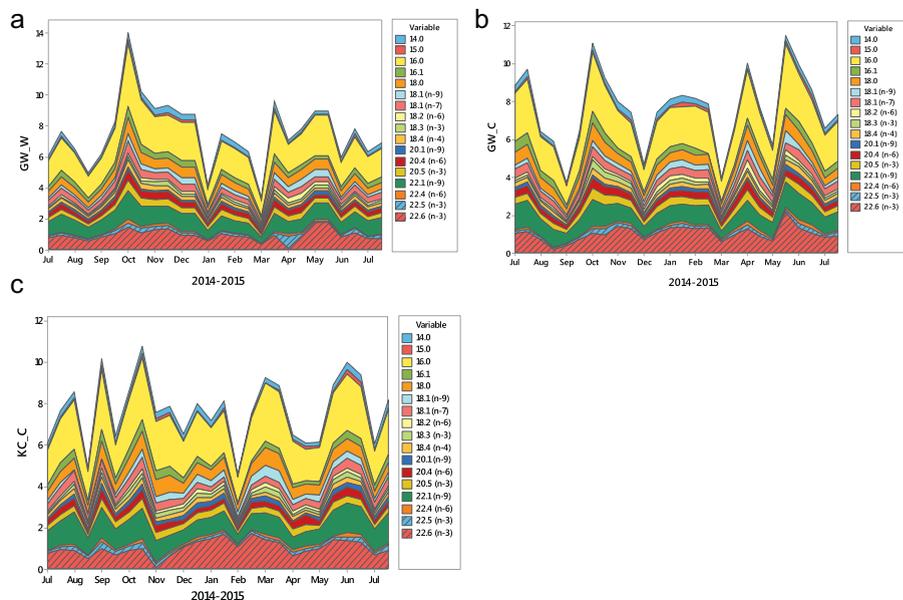


Fig. 2. Area graph of fatty acid composition (Fatty acid mg/100g) in *C. madrasensis* in (a): Gangewadiya wild oysters (GW_W), (b): Gangewadiya cultured oysters (GW_C) and (c): Kandakuliya cultured oysters (KC_C).

The discriminant analysis of three groups (Gangewadiya wild, Gangewadiya cultured and Kandakuliya cultured) in terms of fatty acid concentrations revealed when considering compositional uniqueness, the three groups were distinct. Discriminant analysis identified a true grouping of 80%, 80% and 84% for Gangewadiya cultured, Gangewadiya wild and Kandakuliya cultured populations, respectively. The squared distances between groups are given in Fig. 3. The differences of the fatty acid profile of two culture sites in the present study might be due to variations such as plankton and water quality in the food sources for oysters.

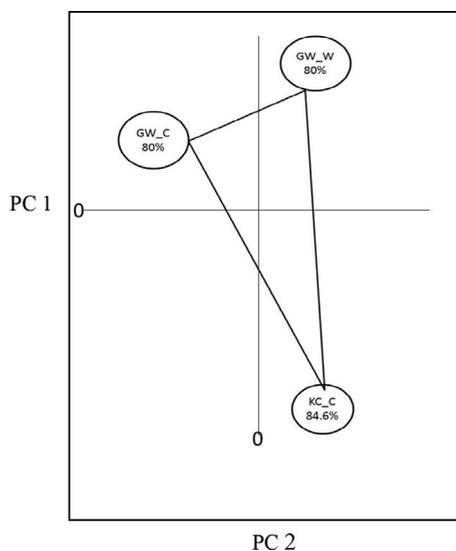


Fig. 3. Distances between groups in Gangewadiya cultured (GW_C), Gangewadiya wild (GW_W) and Kandakuliya cultured (KC_C) *C. madrasensis* given by Discriminant analysis for fatty acid concentrations.

4. Conclusion

A high monounsaturated and polyunsaturated fat ratio compared to saturated fatty acids revealed a possibility to market *C. madrasensis* as a food ideal for coronary heart diseases, cancer, autoimmune diseases and hypertension etc. The discriminant analysis revealed that the fatty acid composition of cultured oysters in Kandakuliya was more distinct than that of cultured and wild oysters in Gangewadiya. This could possibly be due to locational differences in water quality. Results conclude that except for significant differences in gondoic acid (C20.1(n-9)), eicosapentaenoic acid (EPA/C20.5(n-3)) and the omega 3/6 ratio, fatty acid content was similar in cultured and wild oysters. The omega 3 to omega 6 ratios also confirms the importance of *C. madrasensis* as an ideal source of omega 3. As per the results of the current study, the highest omega-3 fatty acid level was detected in October. Further studies incorporating monthly variations in nutritional

components such as protein, glycogen, mineral content and percentage edibility could be used to determine the optimal time for harvesting.

Declarations

Author contribution statement

Madhusa Mihirani Subasinghe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

B. K. Kolitha Kamal Jinadasa: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Ayanthi N. Navarathne, Sevvandi Jayakody: Analyzed and interpreted the data.

Funding statement

This work was supported by the National Aquatic Resources Research and Development Agency, Government of Sri Lanka.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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