Macroalga-associated bacterial endophyte bioactive secondary metabolites twinning: Cystoseira myrica and its associated Catenococcus thiocycli QCm as a model

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Abstract
Marine ecosystems represent the largest biome on the earth. Until now, the relationships between the marine microbial inhabitants and the macroalgal species unclear, and the previous studies are insufficient. So, more research is required to advance our understanding of macroalgal-microbial interactions. In this study, we tried to investigate the relationship between the brown marine macroalga, Cystoseira myrica and its associated bacterial endophyte, Catenococcus thiocycli, as the first study concerning the production of bioactive secondary metabolites from a macroalgal species comparing with its associated endophytic bacteria. Secondary metabolites were extracted from alga and its bacterial endophyte with ethyl acetate and methanol. All extracts contained significant quantities of phenolics, flavonoids, tannins, and saponins. Strikingly, extracts possess antioxidant, anti-inflammatory and antimicrobial activities which were significantly correlated to phenolic and flavonoid contents.

Keywords Marine · Macroalgae · Endophyte · Bacteria · Metabolites · Relationship

Introduction

Marine organisms that survive in extreme conditions possess potential to produce unique compounds that are not present in the terrestrial organisms. Over the past two decades, searching for bioactive natural products from the marine environment is of great interest to scientists due to their broad pharmaceutical benefits (Madkour et al. 2019).

Marine endophytic bacteria are living within the inner tissues of marine plants without causing any harmful effect to the host. Among the various marine organisms, macroalgae (seaweeds) that have wide diverse of bioactive compounds including flavonoids, terpenoids, alkaloids, quinones, sterols, tannins and polysaccharides are abundant sources of marine endophytic bacteria that attracting interest of biochemical research (Erbabley and Junianto 2020).

Although several studies focused on the relationships between epiphytic bacteria and their macroalgal hosts, reports about endophytic bacteria from macroalgae are still insufficient (Ameen et al. 2021). Consequently, there are many gaps in knowledge, and it is necessary to continue searching to achieve a better understanding of the relationship between macroalgae and associated bacteria (Soria-Mercado et al. 2012; Ameen et al. 2021). Due to, many species of marine algae have been reported as potential source for new drugs, the phytochemical screening of all marine algae and their associated microorganisms should become a priority, in order to determine which species can be exploited (Erbabley and Junianto 2020; Rashad and El-Chaghaby 2020). Wherefore, this study was carried out to investigate the relationship between the brown marine macroalga Cystoseira myrica (S.G.Gmelin) C. Agardh and the associated endophytic bacteria in regard to the production of bioactive secondary metabolites, in order to involve towards our understanding of macroalgae-bacteria relationships, and for exploration a new marine sources of potential therapeutic and pharmaceutical agents.

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Materials and methods

Collection of algal material

Samples were collected from Egyptian Red Sea, El Quseir (26°06'14"N 34°16'52"E) during April 2021, based on morphological characteristics like brown color, elongated main axis (about 50 cm long) bears spine-like appendages, air vesicles and distichous lateral branches followed the keys and descriptions adapted from Aleem (1993) and the website (http://www.seaweed.ie/descriptions/). Samples were transferred to the laboratory using cooling box for further study.

Isolation and identification of endophytic bacteria

Samples were carefully surface sterilized using ethyl alcohol (70%) and sterilized distilled water to remove epiphytic microorganisms. Filtered-autoclaved natural seawater, and synthetic seawater agar, contained (g/L: NaCl, 30; Na₂SO₄, 4; MgCl₂, 7H₂O, 1; KCl, 0.7; NH₄Cl, 0.5; NaHCO₃, 0.2; KH₂PO₄, 0.2; CaCl₂.2H₂O, 0.1; KBr, 0.1 and H₃BO₃, 0.025) were used for isolation and subculturing. The samples were aseptically crushed in 5 ml sterilized saline solution. 100 μl of tissue extract was spread on seawater agar plates. Plates were incubated at 25 °C for 72 h and observed daily for the appearance of colonies. The obtained isolate was commercially sent to SolGent Co., Ltd., South Korea for 16S rRNA gene sequencing. Alignment was performed between the obtained sequence and NCBI reference sequence database. The present sequence was introduced into NCBI to obtain an accession number.

Extraction of secondary metabolites

In Erlenmeyer flasks, 20 g of algal powder was extracted separately with methanol and ethyl acetate at a sample: solvent ratio of 1:5 (w/v) (Nurjanah et al. 2017). Flasks were tightly covered and shaking at 150 rpm for 24 h at 37 °C. Extracts were then filtered and solvents were evaporated at the room temperature. The obtained crude extracts were kept in the refrigerator for further study.

Bacterial extraction was carried out by inoculating strain QCm in 5 L nutrient broth and incubating at 37 °C under 150 rpm for 72 h. Then, the supernatant and the cell mass were extracted using methanol and ethyl acetate according to Noha et al. (2013).

Estimation of secondary metabolites contents

Stock concentrations of 1 mg/mL of algal and bacterial extracts were prepared. The contents of active secondary metabolites i.e., phenols, flavonoids, saponins and tannins were estimated in each extract according to Visweswari et al. (2013).

Assessment of in vitro antioxidant activity

Total antioxidant activity

The total antioxidant activity was estimated as µg ascorbic acid equivalents/mg extract using phosphomolybdenum assay (Prieto et al. 1999).

2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

The ability of the extracts to scavenge the stable free radical DPPH was measured according to the method of Brand-Williams et al. (1995). In brief, 2 mL of the DPPH solution (0.5 mmol/L) was added to 1 mL of the tested extract and incubated in darkness for 30 min at room temperature. After that, the absorbance was measured at 517 nm against control. The percentage of free radical scavenging was calculated as the following:

\[
DPPH \text{ radical scavenging (\%)} = \left( \frac{A_{\text{Control}} - A_{\text{Sample}}}{A_{\text{Control}}} \right) \times 100
\]

Ferric ion reducing power

The method of Ganesan and Kumar (2008) was followed to evaluate the reducing power of the extracts. Briefly, an aliquot of 50 µL extract was added to 0.1 mL of 1% potassium ferricyanide. The mixture was incubated at 50 °C for 30 min. Then, 0.1 mL of 1% trichloroacetic acid and 0.1 mL of 0.1% FeCl₃ were added to the mixture and left for 20 min. Absorbance was read at 700 nm. The reducing power of the extracts was calculated using ascorbic acid standard curve (Yen and Chen 1995).

Hydrogen peroxide (H₂O₂) radical scavenging activity

The ability of extracts to scavenge H₂O₂ radicals was estimated according to Ruch et al. (1989). 0.1 mL of each extract was transferred into the test tubes and was made up to 0.4 mL with phosphate buffer. After that, 0.6 mL of H₂O₂ solution (40 mM) was added and vortexed. The...
absorbance of the mixture was read at 230 nm against control. The percentage of H$_2$O$_2$ scavenging was calculated as follows:

$$\text{H}_2\text{O}_2\text{scavenging activity (\%)} = \left(\frac{A_{\text{Control}} - A_{\text{Sample}}}{A_{\text{Control}}}\right) \times 100$$

**Assessment of in vitro anti-inflammatory activity**

**Inhibition of protein denaturation**

The ability of the extracts to inhibit protein denaturation was determined using the method of Mizushima and Kobayashi (1968) with slight modifications. The reaction mixture which consisted of 1 mL of 1% aqueous solution of bovine serum albumin and 1 mL of the tested extract was adjusted to pH 6.3 using 1 N HCl, incubated for 20 min at 37 °C and then heated to 50 °C for 30 min. After cooling to room temperature, the turbidity of the sample was measured at 660 nm. Aspirin (100 μg/mL) was used as standard anti-inflammatory drug. The percentage inhibition of protein denaturation was calculated using the following equation:

$$\text{Percentage inhibition (\%)} = \left(\frac{A_{\text{Control}} - A_{\text{Sample}}}{A_{\text{Control}}}\right) \times 100$$

**Anti-proteinase activity**

The Anti-proteinase activity of the extracts was estimated according to Oyedapo and Famurewa (2008). 1 mL of the tested extract was added into the reaction mixture which contained 1 mL of (20 mM) Tris HCl buffer (pH 7.4) and 1 mL of (0.06 mg/mL) trypsin. The mixture was incubated for 5 min at 37 °C. Then, 1 mL of (0.7%, w/v) casein was added and incubated for 20 min at 37 °C. After that, the reaction was stopped by 2 mL of (70%, w/v) trichloroacetic acid. The reaction mixture was centrifuged, and the absorbance of the obtained supernatant was measured at 210 nm. The percentage inhibition of proteinase was calculated using the following equation:

$$\text{Percentage inhibition (\%)} = \left(\frac{A_{\text{Control}} - A_{\text{Sample}}}{A_{\text{Control}}}\right) \times 100$$

**Antimicrobial activity**

Antibacterial and antifungal activities of the extracts against *Escherichia coli*, *Salmonella typhi*, *Klebsiella pneumoniae*, *Micrococcus luteus*, *Proteus mirabilis*, *Aspergillus niger* and *Candida albicans* were investigated using well diffusion method according to the Clinical and Laboratory Standard Institute (2010). Briefly, Mueller Hinton gar plates were inoculated with the tested species. Wells of 6 mm were made using sterilized cork borer. The wells were filled with 50 μL of 1 mg/mL of the tested extract. Plates of bacteria were incubated at 37 °C for 48 h and plates of fungi were incubated at 28 °C for 7 days. Ampicillin and fluconazole (1 mg/mL) were used as antibacterial and antifungal standard drugs respectively.

The diameters of inhibition zones (mm) were recorded. The activity index (AI) was calculated according to Singh et al. (2002) equation:

$$\text{Activity index (AI)} = \frac{\text{Inhibition zone of extract}}{\text{Inhibition zone of standard drug}}$$

**Gas chromatography-mass spectrometry (GC–MS) analysis**

The GC–MS analysis of the extracts was performed in the chemistry department, faculty of science, Aswan university using GC/MS instrument (Agilent Technologies: 7890A GC/5977A MSD). The bioactive compounds were identified by comparing the mass spectrum of the unknown compounds with the spectrum of the known compounds using National Institute Standard and Technology (NIST11.L) mass spectral reference library (Marzoqi et al. 2015).

**Data analysis**

All data were recorded from three biological replicates (n = 3). Data were analyzed using the statistical software R project (v.3.2.2.). All values were represented as means ± standard errors (SEs). Tukey’s HSD- test was used to compare between extracts. The level (P ≤ 0.05) was considered as significant. Principal Component Analysis (PCA) was performed to achieve the multivariate analysis of the secondary metabolites in the host macroalga and the associated bacterial endophyte using XLSTAT software (v. 2020.1.3). Pearson’s correlation was run to determine the correlations among the different metabolites and their biological activities.

**Results**

**Identification of endophytic bacteria**

The comparative analysis of strain QCm 16S rRNA gene sequence with NCBI reference sequence database showed that strain QCm exhibited the highest similarity of 100% with *Catenococcus thiocycli* strain TG 5–3 (NR104870). The present sequence was deposited to NCBI database under the accession number (OK584768).

**Estimation of secondary metabolites**

The contents of phenolics, flavonoids, saponins and tannins in each of the ethyl acetate and methanol extracts of
the endophyte *C. thiocycli* strain QCm and its host alga *C. myrica* were evaluated (Fig. 1). It was found that the amounts of phenolics were significantly variable among different extracts (\(F\)-value = 35.938; \(p\)-value = 0.00001). It was observed that the ethyl acetate extracts of both alga and its endophyte contained the highest contents of phenolics.

Extracts were significantly different in their contents of flavonoids (\(F\)-value = 251.07; \(p\)-value = 0.00001). The highest quantities of flavonoids (2164.7 ± 5.5 and 1418.4 ± 7.71 µg quercetin equivalent/mg extract) were detected in the methanol extract of *C. myrica* and the ethyl acetate of *C. thiocycli* respectively.

The ethyl acetate extract of *C. myrica* was significantly contained a rich amount of saponins and tannins (778 ± 6.4 µg diosgenin equivalent/mg extract and 606 ± 1.4 µg catechol equivalent/mg extract respectively) comparing to other extracts (Fig. 1).

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Antioxidant activities

In this study, three complementary measurements i.e., total antioxidant activity, DPPH radical scavenging activity, \( \text{H}_2\text{O}_2 \) radical scavenging activity and Ferric ion reducing power were performed to evaluate the antioxidant activity of the different extracts (Fig. 2). Total antioxidant activity was significantly different (\( F \)-value = 1634.5; \( p \)-value = 0.00001) among different extracts (Fig. 2). Interestingly, the highest total antioxidant activities (4415.3 ± 7 and 3978.7 ± 7.1 \( \mu \text{g ascorbic acid equivalent/mg extract} \)) were assessed for the ethyl acetate extracts of \( C. \text{myrica} \) and \( C. \text{thiocycli} \) respectively.

The different extracts were significantly varied in their DPPH radical scavenging ability (\( F \)-value = 101.72; \( p \)-value = 0.00001). In general, the extracts of the endophyte \( C. \text{thiocycli} \) had higher DPPH radical scavenging activities than those of the host \( C. \text{myrica} \). Among the extracts, the methanolic extract of \( C. \text{thiocycli} \) was the most potent with a scavenging activity percentage of 92.7%.

Scavenging potential of \( \text{H}_2\text{O}_2 \) radicals by the different extracts was significantly different (\( F \)-value = 5.1; \( p \)-value = 0.009). The methanolic extracts of both the host and the endophyte revealed the highest percent of scavenging activity (71.6 ± 0.3 and 66.8 ± 1.6% respectively).

The extracts displayed significant different reducing power values (\( F \)-value = 217.3; \( p \)-value = 0.00001). The extracts of the host \( C. \text{myrica} \) were the most potent with reducing potential ranged from 1105.5 ± 5.2 to 1338 ± 5 \( \mu \text{g ascorbic acid equivalent/mg extract} \) compared to those of the endophyte \( C. \text{thiocycli} \).

**Anti-inflammatory activity**

In this study, the in vitro anti-inflammatory activity of extracts was determined by measuring their inhibitory action against protein denaturation and proteinase activity. Compared to the tested standard anti-inflammatory drug (aspirin), the highest inhibition percentage of albumin denaturation was observed in the ethyl acetate and methanolic extracts of the macroalga \( C. \text{myrica} \) (96.7 ± 0.5 and 89.9 ± 0.2% respectively). Whereas the anti-proteinase activity of the ethyl acetate extraction of the endophyte \( C. \text{thiocycli} \) was higher than those of the other tested extracts (Fig. 3).

**Antimicrobial activity**

The antibacterial and antifungal potential of extracts against \( \text{Escherichia coli} \), \( \text{Salmonella typhi} \), \( \text{Klebsiella pneumoniae} \), \( \text{Micrococcus luteus} \), \( \text{Proteus mirabilis} \), \( \text{Aspergillus niger} \) and \( \text{Candida albicans} \) was evaluated (Fig. 4). The different extracts had significant different effects on the tested bacteria (\( F \)-value = 7.07; \( p \)-value = 0.001). Interestingly, the methanolic extracts of both \( C. \text{thiocycli} \) and \( C. \text{myrica} \) showed the broadest antibacterial spectrum with activity index values of 0.81 ± 0.021 and 0.62 ± 0.035 respectively (Fig. 4). On the other hand, the ethyl acetate extract of \( C. \text{thiocycli} \) exhibited the most potent activity against the tested fungi with activity index value of 0.46 ± 0.028 (Fig. 4).

PCA was used to confirm these results. Interestingly, extracts were categorized into four groups (Fig. 5). The first group located in the upper left side of the plot included the ethyl acetate extract of \( C. \text{thiocycli} \) which contained the highest content of phenolics and was higher in total antioxidant, anti-proteinase, and antifungal activities than the other extracts. The second group included the ethyl acetate extract of \( C. \text{myrica} \) which was characterized by high contents of saponins and tannins and exhibited high percentage of protein denaturation inhibition and \( \text{Fe}^{3+} \) reducing power (aligned in the upper right side of the plot). The third group was aligned in the lower left side of the plot and included the methanolic extract of \( C. \text{thiocycli} \) which exhibited high DPPH scavenging and antibacterial activities. The fourth group at the lower right side of the plot contained the methanolic extract of \( C. \text{myrica} \) which characterized by high content of flavonoids and revealed higher \( \text{H}_2\text{O}_2 \) scavenging ability.

**GC–MS analysis of extracts**

In the present study, The GC–MS analysis of the ethyl acetate and methanolic crude extracts of \( C. \text{myrica} \) and \( C. \text{thiocycli} \) showed a mixture of various compounds. Seventeen peaks were detected for ethyl acetate extracts of both \( C. \text{myrica} \) and \( C. \text{thiocycli} \), while the total number of the
main peaks that were observed for methanolic extracts of both *C. myrica* and *C. thiocycli* were twenty-five. The major bioactive compounds that were characterized and identified in the ethyl acetate and methanolic extracts of *C. myrica* and *C. thiocycli* were shown in (Tables 1, 2).

**Discussion**

Algae are the main primary producers that represent the key elements of the aquatic environment (Harder 2009).
Bacteria are naturally inhabiting the environments of micro- and macroalgae, and they are dominant among the primary colonizers that associate with algal surfaces and tissues (Lachnit et al. 2011). Until now, there are many gaps in our understanding of the relationships and possible specific associations in aquatic environments. Although some studies have been recently concerned the interactions between marine organisms, there are

### Table 1
The major bioactive compounds identified in the ethyl acetate extracts of the macroalga *C. myrica* and its associated bacterial endophyte *C. thiocycli* by GC–MS analysis

| Extract    | Compounds                  | Retention time (min) | Molecular weight | Peak area (%) | Bioactivity as per literatures                  | Reference                  |
|------------|----------------------------|----------------------|------------------|---------------|------------------------------------------------|-----------------------------|
| *C. myrica*| Dibutyl phthalate (C₁₆H₂₂O₄) | 15.246               | 278              | 13.611        | Antimicrobial                                     | Roy and Laskar (2006)      |
|            | Heptadecane (C₁₇H₃₈)       | 9.089                | 240              | 11.097        | Anti-inflammatory                                  | Kim et al. (2013)          |
|            | Octacosane (C₂₈H₅₇)        | 11.378               | 394              | 9.953         | antimicrobial, antioxidant, anti-inflammatory     | Khatua et al. (2016)       |
|            | Tetracosane (C₂₄H₄₉)       | 9.496                | 338              | 8.969         | Antioxidant                                       | Paudel et al. (2019)       |
|            | Pentacosane (C₂₅H₅₉)       | 11.939               | 352              | 6.829         | Antimicrobial                                     | Marrufo et al. (2013)      |
| *C. thiocycli*| Dodecane, 2,6,11-trimethyl- (C₁₄H₂₃) | 9.089               | 212              | 12.991        | Antibacterial                                     | Rahbar et al. (2012)       |
|            | Dibutyl phthalate (C₁₆H₂₂O₄) | 15.241               | 278              | 11.619        | Antimicrobial                                     | Roy and Laskar (2006)      |
|            | Dodecane (C₁₂H₂₆)         | 9.496                | 170              | 11.388        | Antibacterial                                     | Padma et al. (2019)        |
|            | 2-Bromo dodecane (C₁₂H₂₅Br) | 11.378               | 248              | 10.371        | Antibacterial                                     | Aagboke and Aftama (2016)  |
|            | Octacosane (C₂₈H₅₇)        | 11.939               | 394              | 7.065         | Antimicrobial, antioxidant, anti-inflammatory     | Khatua et al. (2016)       |

### Table 2
The major bioactive compounds identified in the methanolic extracts of the macroalga *C. myrica* and its associated bacterial endophyte *C. thiocycli* by GC–MS analysis

| Extract    | Compounds                  | Retention time (min) | Molecular weight | Peak area (%) | Bioactivity as per literatures                  | Reference                  |
|------------|----------------------------|----------------------|------------------|---------------|------------------------------------------------|-----------------------------|
| *C. myrica*| Heneicosane (C₂₁H₄₄)       | 9.089                | 296              | 12.250        | Antimicrobial                                     | Vanitha et al. (2020)      |
|            | Eicosane (C₂₀H₄₂)          | 9.495                | 282              | 11.421        | Anti-inflammatory                                  | Okechukwu (2020)           |
|            | Pentadecane (C₁₅H₃₂)       | 11.378               | 212              | 9.493         | Antimicrobial                                     | Barretto and Vootla (2018) |
|            | Pentacosane (C₂₅H₅₉)       | 11.939               | 352              | 7.693         | Antimicrobial                                     | Marrufo et al. (2013)      |
|            | Octacosane (C₂₈H₅₇)        | 15.240               | 394              | 5.750         | antimicrobial, antioxidant, anti-inflammatory     | Khatua et al. (2016)       |
| *C. thiocycli*| Eicosane (C₂₀H₄₂)          | 9.089                | 282              | 12.393        | Anti-inflammatory                                  | Okechukwu (2020)           |
|            | Tetracosane (C₂₄H₄₁)       | 9.496                | 338              | 11.261        | Antioxidant                                       | Paudel et al. (2019)       |
|            | Heptacosane (C₂₇H₅₇)       | 11.384               | 380              | 11.152        | Antibacterial                                     | Duke (1992)                |
|            | Hentriacontane (C₃₁H₆₄)    | 11.939               | 436              | 9.048         | Anti-inflammatory                                  | Kim et al. (2011)          |
|            | 2-methyloctacosane (C₃₂H₆₀) | 14.531               | 408              | 6.899         | Antimicrobial                                     | Barretto and Vootla (2018) |
insufficient investigations on macroalgae–bacteria interactions (Goecke et al. 2010).

In recent years, it has been reported that secondary metabolites particularly play a significant role in regulating the macroalgae–bacteria relationships in marine ecosystems (Sneed and Pohnert 2011a). In the present study, the secondary metabolites produced by the marine brown macroalga Cystoseira myrica and its associated bacterial endophyte Catenococcus thiocycli strain QCm, and their biological activities were investigated.

Interestingly, it was found that C. myrica and associated C. thiocycli produce similar array of secondary metabolites including phenolics, flavonoids, saponins and tannins (Fig. 1). In the current study, the total antioxidant activity of the extracts was positively correlated with their contents of phenolics and flavonoids (Fig. 6). This agreed with the findings of the others who reported the presence of positive correlations between phenolic contents and antioxidant activities (Wang et al. 2010; Contreras-Calderón et al. 2011; Baharfar et al. 2015). Furthermore, linear proportional between total flavonoids and antioxidant activity was previously reported (Jayaprakasha et al. 2004; Ghasemzadeh et al. 2012).

During inflammatory reactions, proteinases significantly involve in tissue damage, so proteinase inhibitors like phenolics and flavonoids can provide a high level of protection (Leelaprakash and Mohan-Dass 2011). In the present study, the anti-inflammatory activity of the different extracts has been positively correlated with their phenolic and flavonoid contents (Fig. 6). This was in accordance with the findings of Diaz et al. (2012) and Naz et al. (2017) who reported the positive correlation between the levels of phenolic and flavonoid compounds in the extracts and their anti-inflammatory activities. Hence, the bioactive properties of the present extracts attributed to their high contents of phenolics and flavonoids.

On the other hand, there was a positive correlation between phenolic contents and antibacterial activity of the extracts (Fig. 6). This may attribute to the inhibitory effect of phenolics on nucleic acid biosynthesis and metabolic processes (Babaa and Malikb 2014; Naz et al. 2017). While antifungal activity of the extracts was attributed to flavonoids and tannins. It was previously reported that flavonoids effect on proteins and enzymes of the fungal cells and alter their configuration and activity (Kanwal et al. 2010), and tannins disrupt cell wall and plasma membrane (Zhu et al. 2019).

GC–MS analysis of C. myrica extracts revealed the presence of 17 constituents in the ethyl acetate extract and 25 constituents in the methanolic extract. Based on the peak area and retention time, the major identified compounds that were found in high amounts were dibutyl phthalate,

Fig. 6 Heatmap showing Pearson’s correlation analysis (correlation coefficient r) among the contents of secondary metabolites and the biological activities of the different extracts
heptadecane, octacosane, tetracosane, pentacosane, hecicosane, eicosane and pentadecane (Tables 1, 2). These chemical compounds have been reported to have antioxidant, antimicrobial, and anti-inflammatory potential (Roy and Laskar 2006; Kim et al. 2013; Marrufo et al. 2013; Khatua et al. 2016; Barretto and Vootla 2018; Paudel et al. 2019; Okechukwu 2020; Vanitha et al. 2020). On the other hand, 17 and 25 chemical compounds were identified in the ethyl acetate and methanolic extracts of C. thiocycli respectively (Tables 1, 2). The major peaks displayed by GC–MS chromatogram of the ethyl acetate extract were for dodecane, 2,6,11-trimethyl-, dibutyl phthalate, dodecane, 2-Bromo dodecane and octacosane compounds. While the major compounds detected in the methanolic extract were eicosane, tetracosane, heptacosane, hentriacontane and 2-methylloctacosane. Antioxidant, antimicrobial, and anti-inflammatory activity of these compounds were well previously documented (Duke 1992; Roy and Laskar 2006; Kim et al. 2011; Rahbar et al. 2012; Aagboke and Aftama 2016; Khatua et al. 2016; Barretto and Vootla 2018; Padma et al. 2019; Paudel et al. 2019; Okechukwu 2020).

Conclusion

The present study was carried out to contribute towards our understanding of relationships between macroalgae and their associated endophytic bacteria regarding the production of bioactive secondary metabolites. The output results of the study revealed that the brown marine macroalga C. myrica and associated bacterial endophage C. thiocycli strain QCm produce similar array of bioactive secondary metabolites which possess significant antioxidant, anti-inflammatory, and antimicrobial activities. This study suggests that C. myrica and associated C. thiocycli are promising source for pharmaceutical agents. Therefore, we recommend the separation and purification of active compounds and evaluating their activities using in vivo studies.

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Declarations

Conflict of interest The authors declare that they have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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