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# In-depth study of bio-oil and biochar production from macroalgae *Sargassum* sp. *via* slow-pyrolysis

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**Table S1**. Chemical constituent, proximate and ultimate analysis of *Sargassum* sp.

| **Chemical constituent (wt%)[a]** | |
|---|---|
| Carbohydrate | 53.23 ± 0.17 |
| Lipid | 2.05 ± 0.04 |
| Protein | 12.71 ± 0.14 |
| **Proximate analysis (wt%)[a]** | |
| Moisture content | 7.02 ± 0.02 |
| Ash content | 46.59 ± 0.04 |
| Fixed carbon | 3.84 ± 0.03 |
| Volatile matter | 49.57 ± 0.12 |
| **Ultimate analysis (wt%)[b]** | |
| C | 42.40 ± 0.38 |
| H | 5.86 ± 0.03 |
| N | 2.72 ± 0.01 |
| S | 2.78 ± 0.05 |
| O[c] | 46.24 ± 0.30 |
| **HHV (MJ kg$^{-1}$)** | 14.46 ± 0.08 |

[a] dry base
[b] dry ash-free
[c] calculated by difference, i.e.,O = 100% – C – H – N – S

**Table S2**. Chemical composition identified in *Sargassum* sp. bio-oil from GC/MS

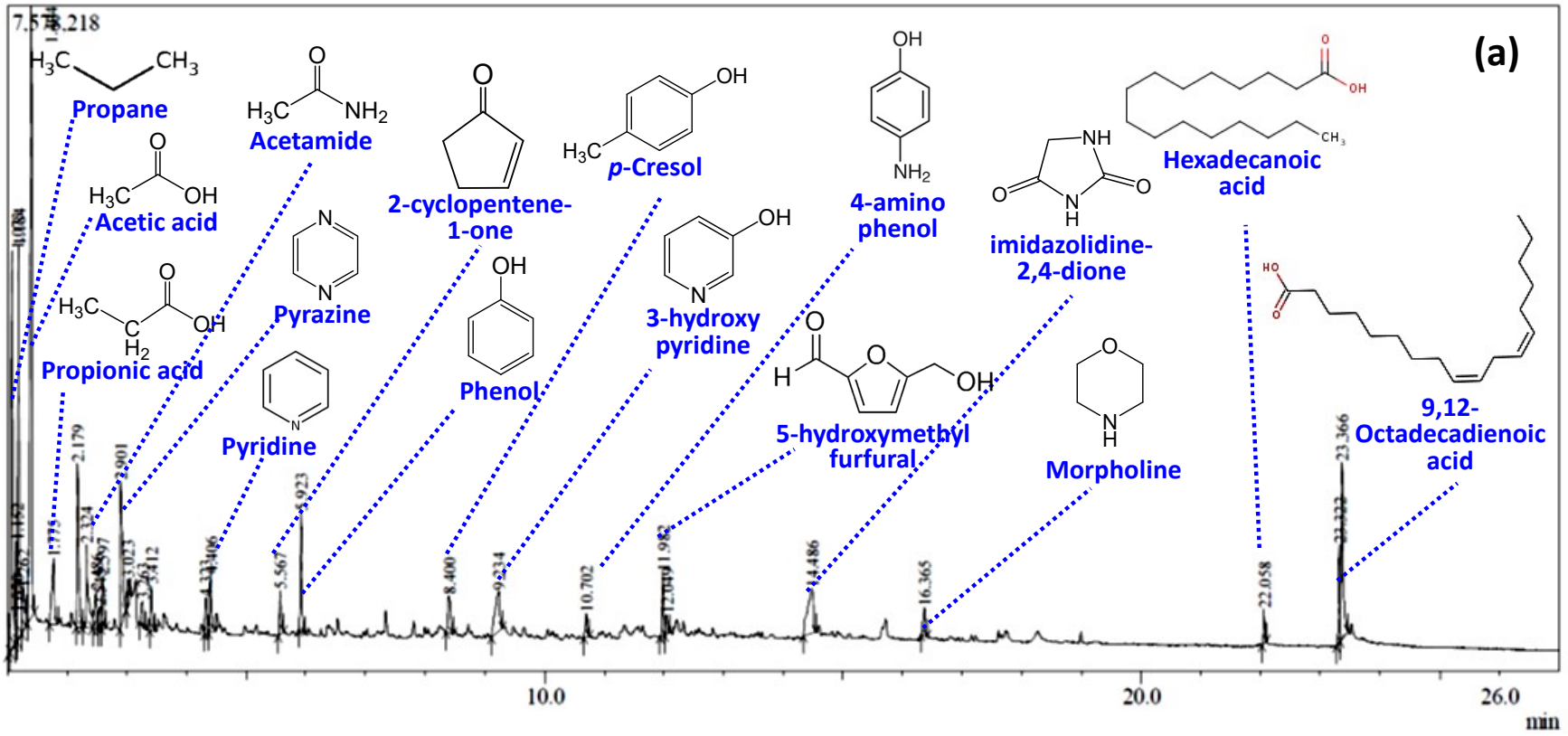
| No | Compounds | Molecular formula | Retention time [min] | Relative area (%) | | |
|---|---|---|---|---|---|---|
| | | | | 400 °C | 500 °C | 600 °C |
| 1 | Propane | $C_3H_8$ | 1.181 | 8.10 | 9.15 | 12.95 |
| 2 | Acetic acid | $C_2H_4O_2$ | 1.459 | 11.26 | 14.04 | 13.91 |
| 3 | Propionic acid | $C_3H_6O_2$ | 1.819 | 20.28 | 7.79 | 5.44 |
| 4 | 1-Butyne | $C_4H_6$ | 2.181 | 3.40 | 3.50 | 6.62 |
| 5 | Cyclopropane | $C_3H_6$ | 2.192 | n/a | 1.60 | 3.70 |
| 6 | Acetamide | $C_2H_5NO$ | 2.391 | 2.66 | 3.73 | 2.78 |
| 7 | Butylamine | $C_4H_{11}N$ | 2.547 | 0.13 | n/a | n/a |
| 8 | Cyclopentanone | $C_5H_8O$ | 2.615 | 0.46 | 1.01 | n/a |
| 9 | 4-Aminopyridine | $C_5H_6N_2$ | 2.917 | n/a | n/a | 4.40 |
| 10 | Pyrazine | $C_4H_4N_2$ | 2.921 | 4.60 | 5.47 | 0.52 |
| 11 | 2-Butenoic acid | $C_4H_6O_2$ | 3.248 | n/a | 8.75 | 4.86 |
| 12 | Isovaleric acid | $C_5H_{10}O_2$ | 3.266 | 0.71 | n/a | n/a |
| 13 | Butyric acid | $C_4H_8O_2$ | 3.350 | 0.75 | 1.10 | 0.86 |
| 14 | Furfuryl alcohol | $C_5H_6O_2$ | 3.413 | 10.52 | 1.27 | 10.66 |
| 15 | Pyridine | $C_5H_5N$ | 3.658 | n/a | n/a | 0.86 |
| 16 | 2-Cyclopenten-1-one | $C_5H_6O$ | 5.590 | 1.48 | 0.95 | 1.95 |
| 17 | Phenol | $C_6H_6O$ | 5.950 | 4.19 | 7.76 | 8.21 |
| 18 | 2,3-Dimethyl-2-cyclopente-1-one | $C_7H_{10}O$ | 7.359 | n/a | 0.81 | 0.56 |
| 19 | *o*-Cresol | $C_7H_8O$ | 7.835 | n/a | 0.57 | 1.32 |
| 20 | *p*-Cresol | $C_7H_8O$ | 8.427 | 0.77 | 1.18 | 1.87 |
| 21 | 3-Hydroxypyridine | $C_5H_5NO$ | 9.280 | 3.19 | 6.61 | 3.51 |
| 22 | Pentanamide | $C_5H_{11}NO$ | 9.506 | n/a | 0.82 | n/a |
| 23 | 2-aminophenol | $C_6H_7NO$ | 9.693 | n/a | 0.93 | 0.71 |
| 24 | 2,3,5-Trimethyl-6-ethylpyrazine | $C_9H_{14}N_2$ | 10.706 | 0.56 | n/a | n/a |
| 25 | 4-aminophenol | $C_6H_7NO$ | 10.716 | n/a | 0.97 | n/a |
| 26 | 5-Hydroxymehtylfurfural | $C_6H_6O3$ | 11.998 | 11.01 | 13.94 | 1.85 |
| 27 | Geraniol | $C_{10}H_{18}O$ | 12.053 | 0.58 | n/a | n/a |
| 28 | 2-Imidazolidinone | $C_3H_6N_2O$ | 12.347 | n/a | 0.54 | n/a |
| 29 | Imidazolidine-2,4-dione | $C_3H_4N_2O_2$ | 14.392 | 2.72 | 1.16 | 2.76 |
| 30 | Morpholine | $C_4H_9NO$ | 16.325 | 1.79 | 1.00 | 1.68 |
| 31 | Hexadecanoic acid | $C_{16}H_{32}O_2$ | 22.058 | 0.57 | n/a | n/a |
| 32 | 9,12-Octadecadienoic acid | $C_{18}H_{32}O_2$ | 23.322 | 1.44 | n/a | n/a |

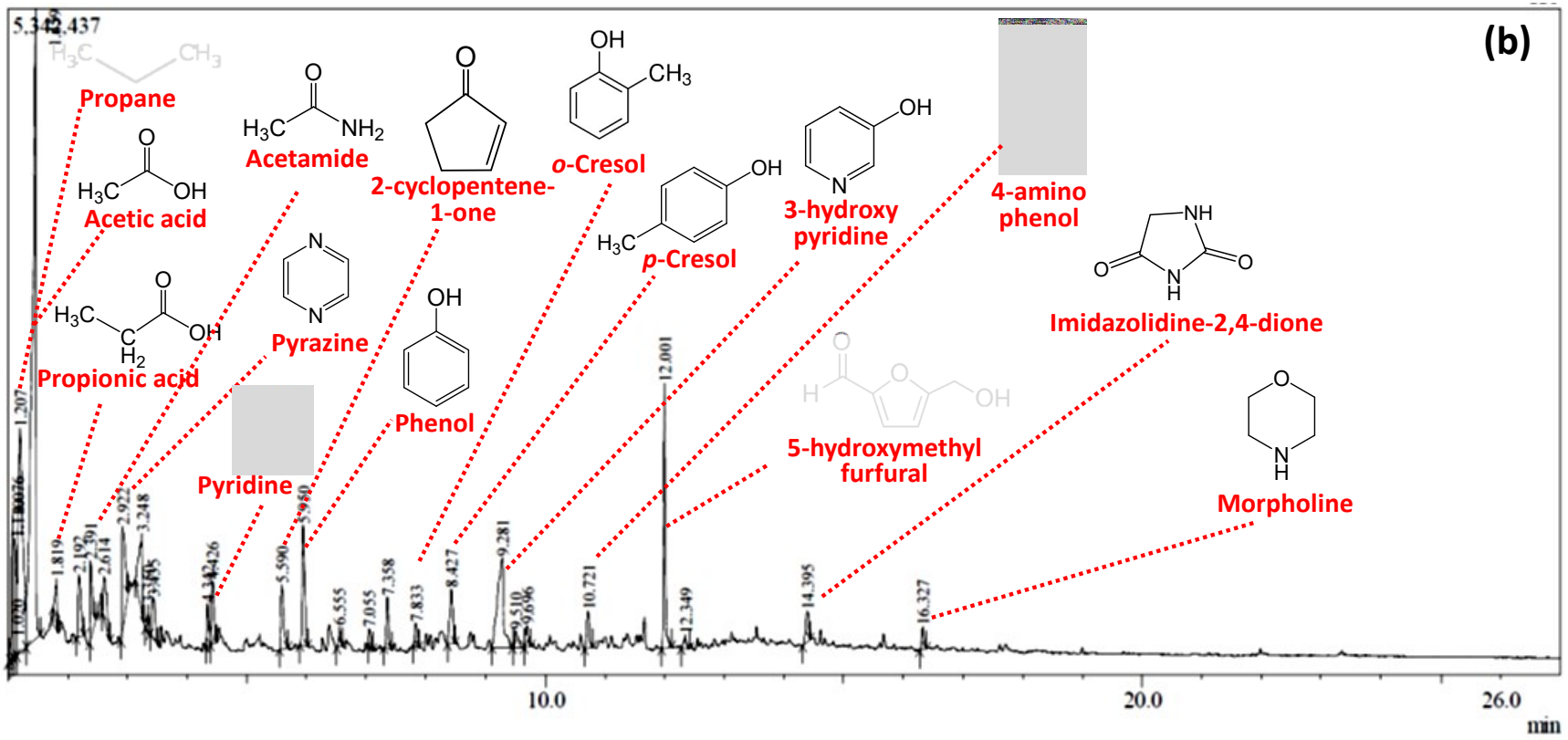
**Table S3** Band assignment of FTIR spectra of biochar

| Typical band assignment | Main peak ($cm^{-1}$) | | |
|---|---|---|---|
| | 400 °C | 500 °C | 600 °C |
| aliphatic C-H stretching | 2860 | 2835 | 2815 |
| C-C=C-C=C | 2251 | 2280 | 2286 |
| aromatic C=C stretching | 1592 | 1625 | n/a |
| aliphatic C-H bending | 1398 | 1420 | 1422 |
| aromatic C–H stretching | 1098 | 1095 | 1096 |

**Table S4** BET surface area and pore characteristics of macroalgal biochar

| Sample | BET surface area [$m^2\ g^{-1}$] | Total pore volume [$cm^3\ g^{-1}$] | Mean pore diameter [nm] |
|---|---|---|---|
| Biochar (400 ºC) | 4.28 | 0.023 | 12.20 |
| Biochar (500 ºC) | 5.43 | 0.026 | 11.44 |
| Biochar (600 ºC) | 5.68 | 0.029 | 10.83 |


(a)
Propane
Acetamide
Acetic acid
2-cyclopentene-1-one
p-Cresol
4-amino phenol
Hexadecanoic acid
Pyrazine
imidazolidine-2,4-dione
Propionic acid
3-hydroxy pyridine
Phenol
Pyridine
5-hydroxymethyl furfural
Morpholine
9,12-Octadecadienoic acid
10.0
20.0
26.0
min


(b)
Propane
Acetic acid
Propionic acid
Acetamide
Pyrazine
Pyridine
2-cyclopentene-1-one
Phenol
o-Cresol
p-Cresol
3-hydroxy pyridine
4-amino phenol
Imidazolidine-2,4-dione
5-hydroxymethyl furfural
Morpholine
10.0
20.0
26.0
min

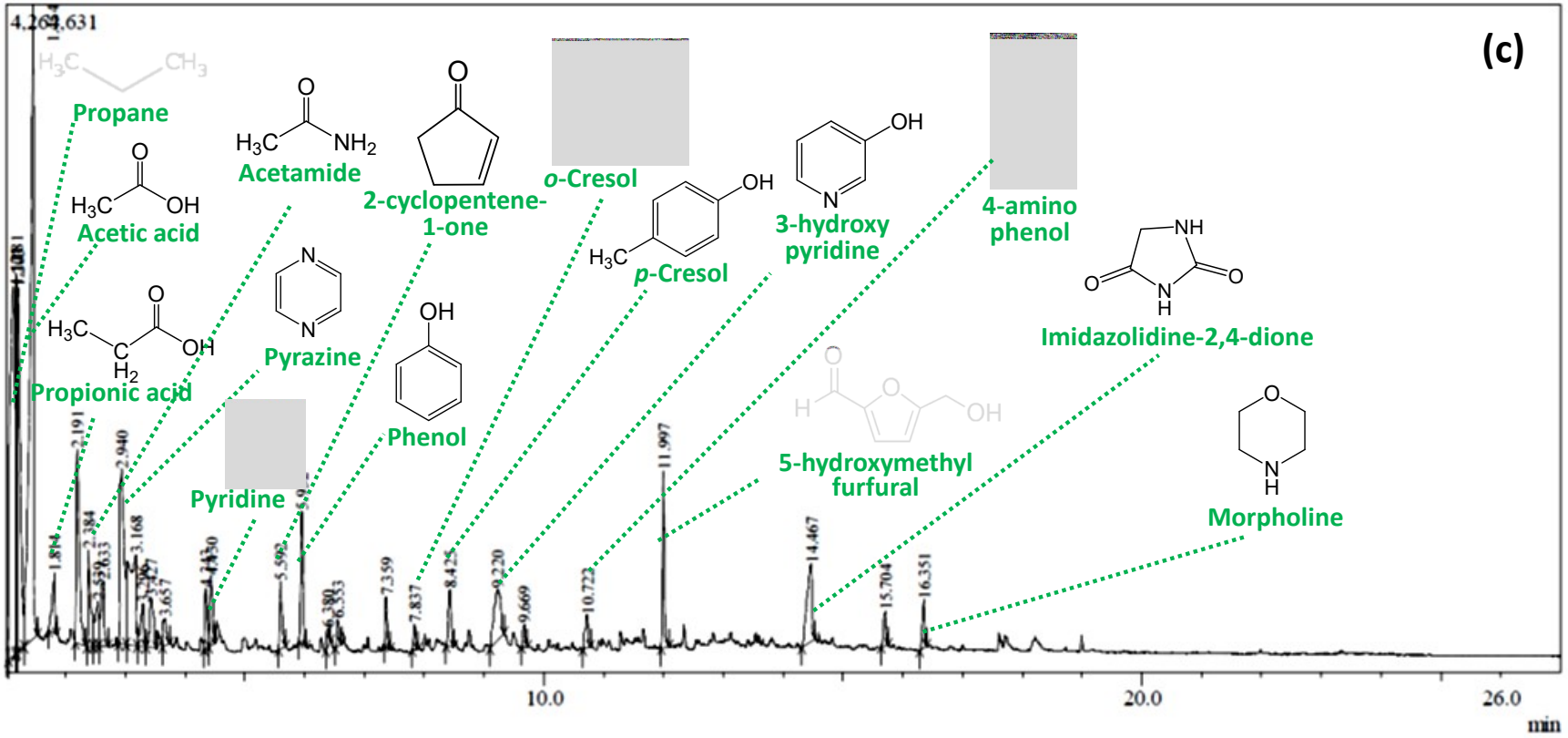



**Figure S1** Typical GC/MS chromatogram of *Sargassum* sp. bio-oil at (a) 400 °C, (b) 500 °C, and (c) 600 °C.

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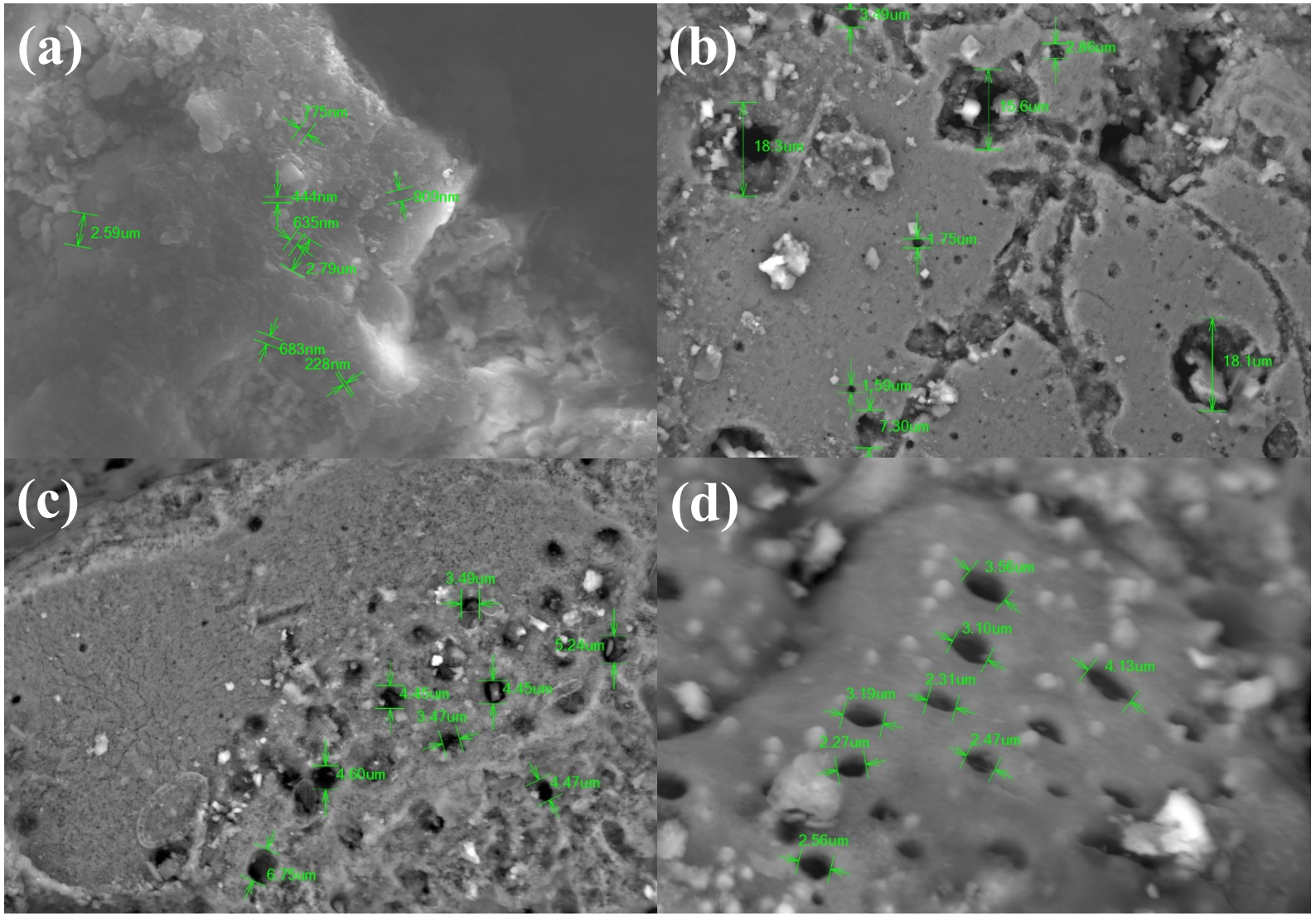


**Figure S2** The pore size of (a) untreated *Sargassum* sp.; (b) bio-char at 400 °C; (c) bio-char at 500 °C; and (d) bio-char at 600 °C.