Macroalgae cultivation in Korea/Asia with emphasis on emerging technology trends

Jang K. Kim¹,², Miseon Park³, Youngdae Kim³, Byunghwa Min³, Eun Kyoung Hwang³, Il Ki Hwang³, Eun-Jeong Park³, Hyun il Yoo³, Taejun Han¹, Chang-Hoon Kim⁴ and Charles Yarish²

¹Incheon National University, Korea; ²University of Connecticut, USA
³National Institute of Fisheries Science, Korea; ⁴Pukyong National University

(Photo: NASA)
Global Seaweed Production (MT) by Species (2013)

- Pyropia / Porphyra: 1,860,778
- Gracilaria: 3,538,655
- Kelp: 8,020,761
- Eucheuma / Kappaphycus: 10,155,714
- Other: 3,402,404

Economic Value (million dollar) by Species (2013)

- Pyropia / Porphyra: 1,185
- Kelp: 1,263
- Gracilaria: 1,002
- Eucheuma / Kappaphycus: 1,897
- Other: 1,354

(FAO 2016)
Global Seaweed Production (MT) by Country (2013)

- China: 50%
- Indonesia: 34%
- Philippines: 6%
- Korea: 4%
- Japan: 2%
- Other: 4%

Economic Value ($) by Country (2013)

- China: 45%
- Indonesia: 26%
- Japan: 16%
- Philippines: 3%
- Korea: 6%
- Other: 3%

(FAO 2016)
Seaweed Aquaculture in Korea

• Seaweed species reported in Korea: 753 (98 green, 166 brown, and 489 red) (Lee & Kang, 2002)

• The 4th country with the most seaweed production (FAO 2016)

• Exported >$340 million (34,470 MT) in 2014 (105% increase in comparison to 2010)

• >70% of total aquaculture production in Korea
# Seaweed Aquaculture in Korea

<table>
<thead>
<tr>
<th></th>
<th>Production (MT)</th>
<th>Economic value ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pyropia / Porphyra (Gim)</strong></td>
<td>419,024</td>
<td>269,447,654</td>
</tr>
<tr>
<td><strong>Saccharina / Laminaria</strong></td>
<td>372,311</td>
<td>67,515,494</td>
</tr>
<tr>
<td><strong>Undaria</strong></td>
<td>283,714</td>
<td>58,614,306</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>30,449</td>
<td>26,177,014</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,105,498</td>
<td>421,754,469</td>
</tr>
</tbody>
</table>

(Ministry of Oceans and Fisheries, 2015)
Seaweed Aquaculture in Korea (*Pyropia/Porphyra, Gim*)
Kelp species in Korea

- Saccharina japonica
- Kjellmaniella crassifolia
- Costaria costata
- Agarum cribrosum
- Undaria pinnatifida
- Ecklonia cava
- Ecklonia kurome
- Ecklonia stolonifera
- Eisenia bicyclis

(Photo: NFRDI Seaweed Research Center)
Kelp aquaculture in Korea
(Undaria pinnatifida)
Kelp aquaculture in Korea
(Saccharina japonica)

Yield: 24 – 45 kg m\(^{-1}\)
Selective Breeding

- Desirable strain development
- Fast growth
- Preferable morphology and flavor
- Disease and temperature tolerant strains
Selective Breeding

**Pyropia / Porphyra**
- 1950s: Strain/species selections
- 1962: *Pyropia tenera*
- 1967: *Pyropia yezoensis*
- 1980s ~ 1990s: intra-species selective breeding, color mutants
- 1990s: Inter-species selective breeding, protoplast fusion

**Undaria**
- 1970s: Strain selections (fast growth, large blade)
- Male and female gametophyte clone cultures ☞ selective breeding

**Saccharina / Laminaria**
- 1960s: Strain selections
- 1970s - : Gametophyte clone cultures
  - Intra-species selective breeding, X-ray treatment
  - Radiation treatment ☞ mutant
# Pyropia / Porphyra Strains

<table>
<thead>
<tr>
<th>Species</th>
<th>Pyropia tenera</th>
<th>Pyropia yezoensis</th>
<th>Hybridization</th>
<th>Mutation Breeding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>新品種選 (純種)</td>
<td>수과원 101호</td>
<td>수과원 107호 (잇바디)</td>
<td>전수 1호</td>
<td>속성장 교잡체</td>
</tr>
<tr>
<td></td>
<td>수과원 102호</td>
<td></td>
<td></td>
<td>속성장 방사무늬김</td>
</tr>
<tr>
<td></td>
<td>수과원 103호</td>
<td></td>
<td></td>
<td>속성장 방사무늬김</td>
</tr>
<tr>
<td></td>
<td>수과원 104호</td>
<td></td>
<td></td>
<td>고온내성 방사무늬김</td>
</tr>
<tr>
<td></td>
<td>수과원 105호</td>
<td></td>
<td></td>
<td>고온내성 방사무늬김</td>
</tr>
<tr>
<td></td>
<td>수과원 106호</td>
<td></td>
<td></td>
<td>고온내성 방사무늬김</td>
</tr>
<tr>
<td></td>
<td>수과원 107호 (잇바디)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>전수 1호</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>속성장 교잡체</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>속성장 방사무늬김</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>속성장 방사무늬김</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>고온내성 방사무늬김</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>고온내성 방사무늬김</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>고온내성 방사무늬김</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: NFRDI Seaweed Research Center)
Fast growth – high quality *P. yezoensis* strain

[♀] Fast growth
Japanese *P. yezoensis*

[♂] High quality
Korean *P. yezoensis*

= High quality + fast growth
Strain

[♀] Fast growth
Japanese *P. yezoensis*

[♂] High quality
Korean *P. yezoensis*

length: 124cm

width: 15cm

Hybridization (Source: NFRDI Seaweed Research Center)
Selective Breeding (Undaria pinnatifida)
Selective Breeding (*Saccharina japonica*)

(Photo: NFRDI Seaweed Research Center)
Selective Breeding (Kelp)

- 98% of the kelp culture overlaps the abalone culture
- Abalone feed
Selective Breeding (Kelp)

• 98% of the kelp culture overlaps the abalone culture
• Abalone feed
• Sept an Oct: NO seaweed to feed abalones
  → requires extended kelp growing season

_Kelp and Undaria_ harvest for Abalone feed
Global climate change

- Water temperature $\uparrow \rightarrow$ damage to kelp $\rightarrow$ yield $\downarrow$
- Water temperature $\uparrow \rightarrow$ shorter growing season $\rightarrow$ yield $\downarrow$
<Long term>
High temperature tolerant strain development

- During the early growing season, high temperature (22°C) is critical → decrease

<Short term>
Extend growing season

- Late outplanting → late harvest, providing kelp for abalone feed in Sept and Oct.
Seaweed aquaculture
- Nutrient limitation
- Chlorosis
- Low production

Fin- and shell-fish aquaculture
- Eutrophication
- HABs
- Shellfish contaminated by PSP producing *Alexandrium* spp.
- Fish kills
Open water
Integrated Multi-trophic Aquaculture (IMTA)
Open water Integrated Multi-trophic Aquaculture (IMTA)
Integrated Link System in Coastal Areas

- Land Based Culture
- Fisheries Cage Culture
- Artificial Polychaete Culture Ground
- Tides

(Intensive Recirculating Aquaculture)  Link System
IMTA (Integrated Multi-Trophic Aquaculture)
Tidal Flat & Bottom (Hanging) - Technical Applications
With rock worms

1.5 mos

0.5cm

3.0 mos

1.5cm

Without rock worms

10cm
Smart Aquaculture

Smart – Intelligent, ICT

Aquaculture Management

Sensors
CCTV
Automatic feeder
Disease monitoring

...
Acknowledgements

• Advanced Research Projects Agency - Energy (ARPA-E), US Dept. of Energy
• National Institute of Fisheries Science, Ministry of Oceans and Fisheries (MOF), Korea
• National Oceanic and Atmospheric Administration (NOAA)
• NOAA-MOF Joint Project Agreement, Joint Coordination Panel for Aquaculture Cooperation
• U.S. Department of Agriculture, National Institute of Food and Agriculture (NIFA)
• Incheon National University
• University of Connecticut