Identity

Undaria pinnatifida (Harvey) Suringar, 1873  [Alariaceae]

FAO Names: En - Wakame, Fr - Wakamé, Es - Abeto marino

Biological features

A brown seaweed. Thallus fixed by a ramified holdfast with numerous haptera, the origin of a flat stipe with denticulated margins (in young individuals); frond blade-like (lanceolated), extending from the tip of the plant for half to three-quarters the length of the plant, and reaching an overall length to about 60 cm or even up to 1m. It has a midrib with undulating wing-like pinnate blades at the base. The sporophyte is golden-brown in colour, with a lighter coloured stipe.

View FAO FishFinder Species fact sheet

Profile

Historical background
Cultivation of *U. pinnatifida* was first studied at Dalian, northeast China, by Youshiro Ohtsuki who patented cultivation techniques in 1943. After 1955, when several enterprising fishers began cultivating it on ropes, *U. pinnatifida* cultivation spread to various places in Japan, especially in the Sanriku and Naruto areas. Cultivation on a commercial scale began in China in the mid-1980s. Facilitated by the rising demand of the Japanese market, Liaoning province was the first area for commercial cultivation. Today, two northern provinces, Liaoning and Shandong, have become the main production areas for *U. pinnatifida*. Consumption of the macroalgae as a seafood is divided in two categories; the processed midribs are consumed inside China, while the sporophylls and blades are mainly exported to Japan and other Asian countries.

In Japan the first cultivation of this kelp began in 1953 in Onagawa Bay, Miyagi Prefecture, and since the mid-1960s there has been extensively cultivated at a commercial level. In the 1970s, the cultivation method shifted from the hanging method to the horizontal longline method, and the development of salting technology increased the annual production from 50 000 to 120 000 tonnes. The largest-scale cultivation of this species was carried out in Sanriku district and Tokushima Prefecture comprising about 90 percent of the total global production.

In the Republic of Korea, rope cultivation of *U. pinnatifida* began in 1964, and subsequently the cultivation was largely developed, promoted and industrialized in the 1970s. Thereafter, the annual production of *U. pinnatifida* steadily increased to 410 000 tonnes (wet weight) in 1994, and has since fluctuated between 200 000 and 400 000 tonnes. The 2013 harvest was 327 380 tonnes accounting for 29 percent of total seaweed farming production in Korea.

In 1983, *U. pinnatifida* was deliberately introduced into the North Atlantic in the coastal areas of Brittany by the French Research Institute for the Exploitation of the Sea (IFREMER) for commercial exploitation and initially cultivated at three sites: the island of Groix in the south, the Bay of Lampaul on the island of Ouessant west of Brest, and in the La Rance estuary near St. Malo.

In 2010, the New Zealand government approved commercial harvest and farming of *U. pinnatifida* under certain conditions.

Though it is now being cultivated on a small commercial-scale in waters off the French Brittany coast and the Spanish Galician coast, almost all commercial *U. pinnatifida* comes from extensive cultivation in China, Republic of Korea, and Japan. Currently, commercial cultivation of *U. pinnatifida* is being developed in Northwest Spain. New cultivars with properties such as high yield or high environmental adaptability have been developed by the traditionally crossbreeding method or through mutagenesis inducement in Asia countries China, Japan, and the Republic of Korea.

### Main producer countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>60%</td>
</tr>
<tr>
<td>Republic of Korea</td>
<td>20%</td>
</tr>
<tr>
<td>Japan</td>
<td>20%</td>
</tr>
</tbody>
</table>

FAO Fisheries and Aquaculture Department
Habitat and biology

*Undaria pinnatifida* can be found in low intertidal zones up to depth of 18 m, but is mainly found at depth between 1 to 3 m. It is able to grow on any hard surface to which it can attach, such as rocky reefs, mudstones, cobbles or even shells of abalone or bivalves. It often forms a thick, dense canopy that shades the sea life beneath it, and exhibits high tolerance to sunlight and wave exposure. However, *U. pinnatifida* is less likely to be found in areas of high level of freshwater influxes such as estuaries or mouths of rivers, owing to its preference for salinity levels of 27–33 ppt.

*U. pinnatifida* has an annual, heteromorphic life history characterised by two different life stages; the sporophyte stage (diploid, 2n) is macroscopic and visible to the naked eye, and the gametophyte stage (haploid, 1n) which is microscopic. In its natural distribution areas, the sporophyte generally appears between late October and early November (autumn), grows rapidly from December to March (winter-early spring), and reproduces in April (spring). However, this well-defined seasonal reproductive cycle does not appear consistently throughout its distribution range where the species has been introduced. Haploid spores, which give rise to filamentous female and male gametophytes, are formed following meiotic division of the initial diploid nucleus in unilocular sporangia that are grouped in fertile areas called sori. A mature sporophyll can releases up to 10 000 000 zoospores that germinate into dioecious gametophytes. Although the longevity of its sporophyte stage is only approximately six months, in its gametophyte stage, *U. pinnatifida* may remain viable for more than 24 months.

*U. pinnatifida* favours cold water, with a preference for temperature less than 12 °C. In Asia, the native habitat of *U. pinnatifida*, sporophytes grow quickly between 5 and 13 °C during winter and spring. The growth of *U. pinnatifida* sporophytes occurs in the meristematic zone between the stipe and blade while, its apical parts simultaneously degenerate. Its suitable temperature for growth is 5–15 °C, while at temperatures above 20 °C and 23 °C, sporophytes begin to degrade and die off, respectively. The optimal temperature for the growth and maturation of *U. pinnatifida* gametophytes is about 15–20 °C and optimal growth is positively correlated with an irradiance of 10–80 µmol photons m$^{-2}$ s$^{-1}$. In Asia, the release of zoospores occurs in water temperature between 17 and 20 °C, with germination taking place at approximately 20 °C. However, when water temperature is over 20 °C, longevity of zoospores decreases and less germination takes place.

Production

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Production cycle of Undaria pinnatifida

Production systems

Seed supply
Parental plants that are used for yearly sporeling production come from the farmed population. Parental plants are usually reserved on lone-lines until end of June after commercial harvest at the end of April. The plants are cultured under relatively deep water to elongate the time at sea until seeding process (hatchery) starts.

Nursery
At the end of June, when seawater temperature rises to 18–19 °C, well-matured sporophylls are cut off from the sporophytes, brought to land and dried in ambient temperature for 1–2 hours in a shaded place. Sporophylls are then put into filtered seawater for releasing spores, again at ambient temperature (16–18 °C). When the concentration of spores in the water reaches 100 000–150 000 per millilitre, the sporophylls are removed from the water, and collectors are inserted. Collectors are constructed by wrapping 2 mm thick nylon string around a plastic frame made of polyvinyl chloride (PVC) pipes. Collectors are removed from the seeding tank once the string are seeded with sufficient spores (50–100 spores within a 100× microscopic field), and are then transported in tanks of filtered seawater for the next step of the hatchery process. In the northern hemisphere, the hatchery starts in June when seeding spore onto collector is performed and ends in late of September when the seawater temperature drops to 22 °C, which is optimal for 200 µm long sporophytes to grow rapidly. The collectors are then transported to open sea and further grown at a water depth where the irradiance is about 200–300 µmol photons m$^{-2}$ s$^{-1}$. The sporeling string is cut into 5 cm long pieces for insertion onto the main cultivation ropes when open sea cultivation starts.

Ongrowing techniques
Cultivation of U. pinnatifida starts at sea by laying the longline horizontally and inserting sporeling strings at
Intervals of 35–40 cm. These strings will hang in the water, usually within 1 m of the surface. The interval between the horizontal longlines is 2 m. Each individual longline is 8 m in length. The initial sporeling is roughly 1 cm long. They will reach 2–3 m between outplanting in October and harvesting in April. Each individual longline can produce approximately 80–130 kg fresh Undaria biomass. The main variables to final production weight are the location, water current (strong current is favoured) and water depth where they are farmed.

Harvesting techniques

Harvesting starts in February when the sporophyte thalli reach approximately 1.5–2 m, and ends in late April. Plants are harvested manually by cutting the plants off the main cultivation rope. Sporophylls and thalli are packed separately and transported to the processing facility on the same day.

Handling and processing

Sporophylls are frozen immediately, while the remaining parts are bathed in hot water (85–95 °C) for approximately 20–60 seconds. The cooked plants are then thoroughly salted. The salted plants are packed in bags and pressed with heavy objects overnight to remove the excess salt water. Thereafter, the midribs and blades are separated manually by hand, packed into boxes and stored between -5 and -5 °C.

Production costs

Factors that impact the cost of production include labour, infrastructure to grow the plants in the sea (rafts, boat, ropes and floats), processing lines (with hot and cold seawater supply, transportation belts) and low temperature for storage of processed products. An approximate breakdown of the total cost for each of these factors is listed below.

- Labor: 30 percent
- Infrastructure for cultivation: 30 percent
- Processing: 20 percent
- Storage facilities: 10 percent

Diseases and control measures

In some cases antibiotics and other pharmaceuticals have been used in treatment but their inclusion in this table does not imply an FAO recommendation.

<table>
<thead>
<tr>
<th>DISEASE</th>
<th>AGENT</th>
<th>TYPE</th>
<th>SYNDROME</th>
<th>MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green-decay</td>
<td>Vibrio</td>
<td>Bacteria</td>
<td>Tip starts to burn into unhealthy green colour and decay, slowly spreading to the basal parts</td>
<td>Lower the cultivation density and apply fertiliser.</td>
</tr>
<tr>
<td>disease</td>
<td>harveyi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole-decay</td>
<td>Unknown</td>
<td>Bacteria</td>
<td>Green spots first appear on the blade, then decay into holes, and can also spread to the midrib.</td>
<td>Lower the density and apply fertiliser.</td>
</tr>
<tr>
<td>disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinhole</td>
<td>Amenophia</td>
<td>Harpacticoid</td>
<td>Small brown spots appear on the thallus blade near the midrib, and these spots and holes subsequently spread to the other pinnate blades. The disease becomes much more serious as the thalli age.</td>
<td>Lower the water temperature and harvest the plants early.</td>
</tr>
<tr>
<td>disease</td>
<td>orientalis and</td>
<td>copepod</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parathalestris</td>
<td>infestus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rot disease</td>
<td>Pseudomonas</td>
<td>Alginic acid</td>
<td>Decay of the holdfast, finally resulting in the detachment and loss of the sporelings. A serious disease, it can destroy virtually an entire crop.</td>
<td>Seawater should be renewed frequently and a certain amount of chloromycetin can be added in seawater, with its final concentration of 1 g L⁻¹.</td>
</tr>
<tr>
<td></td>
<td>decomposing</td>
<td>bacteria</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statistics

FAO Fisheries and Aquaculture Department
Production statistics

In China, the production of *Undaria* was not separately shown in official national statistics prior to 2003. However, information from alternative sources in China show that the annual production in the early 1990s was about 200 000 to 320 500 tonnes wet weight, which was two to three times of the pre-1980 level. From a total area of 7 693 hectares in 2014, China harvested 203 099 tonnes dry weight of *Undaria*, corresponding to 2 030 990 tonnes wet weight in FAO statistics (*). Most of the production is in Liaoning and Shandong provinces.

Republic of Korea: in 1994, the annual production of *U. pinnatifida* was 410 000 tonnes wet weight; in 2013, approximately 327 375 tonnes wet weight was harvested. Most of the production (91 percent) was produced from Wando County in Jeonnam Province south of the country.

Japan: Following the advances in *Undaria* culture technologies, the annual production reached a historical high of 153 762 tonnes wet weight in 1974. In 1976, about 20 000 tonnes wet weight were collected from natural habitats and 127 000 tonnes wet weight were cultivated. The annual production has been decreasing in recent years (104 000 tonnes wet weight in 1991, 82 000 tonnes wet weight in 1996, 66 800 tonnes wet weight in 2000 and 50 500 tonnes wet weight in 2014). Currently, the largest production areas are in the Miyagi, Iwate and Tokushima prefectures (80–90 percent of the domestic production). During 2001-2010 the annual output of this species was at or close to the level of 60 000 tonnes. When Japan was devastated by the tsunami in 2011, the production dropped drastically to less than 19 000 tonnes, but recovered to reach 48 350 tonnes in 2012. In 2014, the production was 43 900 tonnes.

(*) The volume of production of Undaria in “dry weight” reported by China has been converted back to wet weight or live weight equivalent by the factor “10”. The same factor is also used for converting several other farmed seaweed species reported by China except Japanese kelp.

Market and trade

Japan is the main market for *Undaria*, worldwide and marketed under the Japanese name, wakame. Aquaculture of *Undaria* in Japan is not sufficient to meet the domestic market, which has led to Japanese import of *Undaria* products from both the Republic of Korea and China for the past 30 years. The annual consumption of *Undaria* in Japan has reached 350 000–400 000 tonnes, of which 60 and 20 percent is imported from China and the Republic of Korea, respectively (Taira 2006). Increased cultivation of *Undaria* in China in the 1990s was driven by the demand of Japanese markets. As of 2014, nearly 50 percent of the
Chinese production of Undaria was exported to the Japanese markets. In the Republic of Korea, the English name “sea mustard” is used for Undaria. Apart from being a popular seaweed species for human consumption in the country, farmed Undaria is also used as feed for the cultivation of abalone, of which most production operations using marine cages occur in the Wando County, too.

**Products**
The quality of Undaria products is mainly valued on its thickness and hardness that is determined by cultivation and processing conditions (fresh green being the most preferable to people), storage quality (such as stability of pigment, elasticity and so on) and the absence of foreign materials. Undaria products can be classified as three main product forms, including the frozen sporophylls, cooked and salted blades and midribs. These three forms are further processed into many other kinds of instant foods.

In Japan, there are various kinds of commercial wakame products, including: dehydrated or dried, seasoned and instant wakame food. Most of the dehydrated products are of the traditional type, such as Suboshi and Haiboshi wakame. Compared with Suboshi wakame that is dried under the sun without ash treatment, Haiboshi wakame can keep its vivid green colour during storage at 35 °C for 50 days in the dark. Moreover, the dried products retain a nice fragrance with moderate elasticity for a long period during storage. Further techniques for wakame processing have been developed, including: salted, boiled-salted and dried-cut wakame products. Characterised by its good appearance (fresh green), low presence of foreign material and good storage quality, dried-cut wakame is prevalently consumed in market as an instant processed food.

**Status and trends**

Research (state of art-recent developments): There are three main lines of research regarding Undaria, including: evaluation of its potential as an invasive species in foreign waters; cultivation biology and techniques; and molecular biology.

Undaria pinnatifida has successfully invaded several areas of the world, including France, England, Netherlands, Belgium, Italy, western United States, New Zealand, Australia and Argentina. However, whether it will continue spreading to other parts of the world and to what extent it can make impact on the environments and other species is not clearly or fully understood.

Traditionally, mass sporelings used for cultivation were cultured through the zoospore collection method, and subsequently, a new method of culturing sporelings by the use of gametophyte clones was developed, which may meet the increasing demands of large-scale production of sporelings for commercial cultivation. In recent years, the crop yield of cultivated Undaria of Japan has not been able to meet commercial demand, and interestingly, the yield could be increased significantly by thallus excision, owing to a strong compensatory ability of the remaining tissues. In the future, “thallus excision” may be a potential cultivation technology to increase the production of Undaria. In addition, light intensity, temperature and the degree of water motion, are the main factors impacting the cultivated plants.

Molecular genetic markers, such as obtained by AFLP and SSR techniques, have been used in sporophytes and gametophytes to estimate the genetic diversity and relationships among various samples, which may be useful to species improvement through marker-assisted breeding and help to select indigenous genetic resources. Moreover, by use of molecular markers, more productive and healthy cultivars may be developed, which can greatly promote both the quality and quantity of the U. pinnatifida. In addition, genetic engineering may provide a powerful approach to improve the production and quality of U. pinnatifida, by introducing important gene(s) into its genome or chloroplast. Currently, an efficient transformation system for U. pinnatifida has been established and reporter genes such as lacZ have been successfully transferred into U. pinnatifida.

**Development prospective**
As a cheap seaweed, Undaria has been consumed as a seafood for many years in East Asia. Owing to the limited scale of the market, commercial cultivation is not expected to increase dramatically. The scale of...
commercial Undaria cultivation in China has been relatively stable with only slight fluctuations over the years, mainly controlled by the market in Japan. Breeding research in China is expecting to generate varieties that meet different requirements of the farming industry in the coming years.

**Market perspective**
The market for blade product is relatively stable. The demand for midrib product in China has been steadily increasing over the past five years.

**Recommendations**
*U. pinnatifida* is a tasty and healthy low-fat seafood, with a rich source of omega-3 fatty acids, protein, vitamins and dietary fiber. Its health benefits include a diverse set of algal polysaccharides and trace elements which may have anticancer properties. Moreover, it is rich in valuable compounds with pharmacological and biomedical activities, such as antiviral activities, maintaining cardiovascular health, and lowering blood pressure. Many micronutrients, including thiamine and niacin, which are found in this seafood are lacking in traditional land crops. The sporophyll contains a high content of fucoidan, of which the polysaccharide contained is believed to be effective in the prevention of certain cancers.

**Main issues**
There are two main issues with the cultivation of *U. pinnatifida*: the potential effect on environment and the economic impact on marine farms.

**Impact on the ecology and biodiversity beyond its native boundaries**
*U. pinnatifida* has been regarded as a noxious invasive alien species in countries other than its native distribution area. Its introduction to other waters was believed to be through the ballast water of cargo ships from Asia, which is possible because gametophytes contained in the water can survive the long-distance trip. Its further spread may be related to its natural dispersal and through transportation between locations. It can change the structure of ecosystems, especially in areas where native seaweeds are absent. By forming a dense canopy which shades the sub-canopy, it can impact the growth of the slow-growing native seaweed species by limiting the underwater solar irradiance and space, thus outcompeting and excluding these native species. For instance, in New Zealand the native coralline algae which are important for paua (edible marine snail) settlement were partially displaced by *U. pinnatifida*, resulting in decreased paua recruitment. Moreover, this seaweed can affect not only the biodiversity of flora, but also the fauna communities which are based on these phytogroups. *U. pinnatifida* can grow on reefs which offer refuges for fish, and gradually lead to habitat loss of fishes that dwell on the reefs. Study carried out in the Nuevo Gulf showed that its removal from invaded sites resulted in an increase in the biodiversity at those locations.

However, the spread of *U. pinnatifida* in Brittany was shown to be relatively non-aggressive to native species of that area. At this point, whether the impact on environment is negative varies from place to place. Meanwhile, owing to its quick growth rate, high fecundity (each mature individual can release millions of spores) and ability to withstand long-distance transportation, the *U. pinnatifida* indeed can distribute to other parts of the world.

**Impact on marine farms**
NIMPIS, 2002 states that *U. pinnatifida* has the potential to become a problem for marine farms by increasing labour and harvesting costs owing to fouling problems on fish cages, oyster racks, scallop bags and mussel ropes, which restricts water circulation through cages. The Department of Conservation of New Zealand in its brochure "Gorse of the Sea" state that *Undaria* could foul mussel farms, salmon farms and boats. Heavy infestations of *Undaria* may also clog marine farming machinery and heavy fouling of boats is thought to seriously decrease their efficiency.

The impacts of *U. pinnatifida* are not well understood and are likely to vary considerably depending on the location. Until now, there is no report to show that artificially removing the sporophytic plants (such as manual removal of *Undaria*, the use of brominated microbiocides and heat treatment) is effective at preventing its
spread, possibly owing to its powerful reproduction potential. Thus, the approach to Undaria management, such as the proper control of human mediated vectors; ballast water, attachment to hulls and marine equipment, would be to slow its spreading and reduce the chance of it reaching new locations. In addition, it is potentially possible to eradicate spores, gametophytes and sporophytes by use of UV light or high-pressure washing methods which eventually slow its rate of spread.

References


Related links

Aquafind
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Database on Introductions of Aquatic Species - DIAS
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FAO FishStatJ – Universal software for fishery statistical time series
Global Invasive Species Database
GLOBEFISH
GROWfish
World Aquaculture Society - WAS

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