

# Morphology and quality of cultivated *Laminaria japonica* Aresch. in the temperate waters of Naruto Straits, Japan

Masao OHNO<sup>\*1</sup>, Akinori DAN<sup>\*2</sup>,

Ryoko YOSHIMOTO<sup>\*3</sup>, Masayoshi MATSUOKA<sup>\*4</sup>

**Abstract** *Laminaria japonica* constitutes one of the main species of edible seaweeds in Japan. Due to its increasing demand for high quality konbu, expansion of its cultivation grounds has been carried out successfully by transplantation from its natural beds in northern Japan (Hokkaido, Aomori) to the warm waters of southern Japan (Naruto Straits, Tokushima Prefecture). The present study compared the morphological characteristics and nutritive contents of the cultivated *Laminaria* in warm waters with those from the cold waters in Japan. Results showed that frond size (length, weight, width, thickness) and contents of protein, carbohydrates, lipids, and ash have comparatively similar values between cultivated and natural harvests. Forced-cultivation of *Laminaria* should therefore be able to meet the increasing demand for the seaweed in the future. Not only the two areas are comparable in size and qualities of their harvests, force-cultivation reduces the waiting time for harvesting.

**Key words:** force-cultivation, Japan, konbu, *Laminaria japonica*, seaweed cultivation

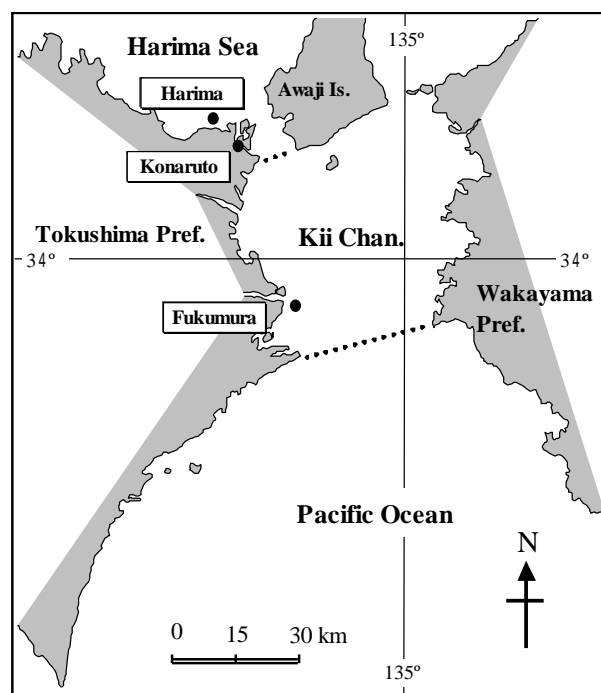
## Introduction

There are 18 species of *Laminaria* in Japan (Kawashima, 1984). The most valuable species, *Laminaria japonica*, occurs naturally in the cold waters of Japan. About 75 % (150,000 tons) of *Laminaria* are being harvested from the natural population while about 25 % comes from cultivation cold waters from cold to warm waters in Japan. It has been known that there are regional variations of the shape *L. japonica* fronds from different locations.

The first transplanting experiment on *L. japonica* outside of its natural habitat in cold waters was in 1966 in the Seto Inland Sea, off Hyogo Prefecture, West Osaka (Ii *et al.*, 1966). After then, Japanese fisheries researchers have carried out experimental cultivation of *Laminaria* in the warm waters. Much recently, the commercial cultivation of *Laminaria* is now being carried out in many warm water areas, but, so far, there are no reports of quality of harvests from these areas. In this paper, the morphology and qualities of cultivated *Laminaria* blades are compared among materials harvested from the new cultivation grounds in Naruto Strait and other fields

## Material and Methods

The seedlings of *Laminaria*, produced in the indoor cul-



**Fig. 1** The location of the study site in the coast of Tokushima Prefecture. Closed circles indicate three cultivation areas.

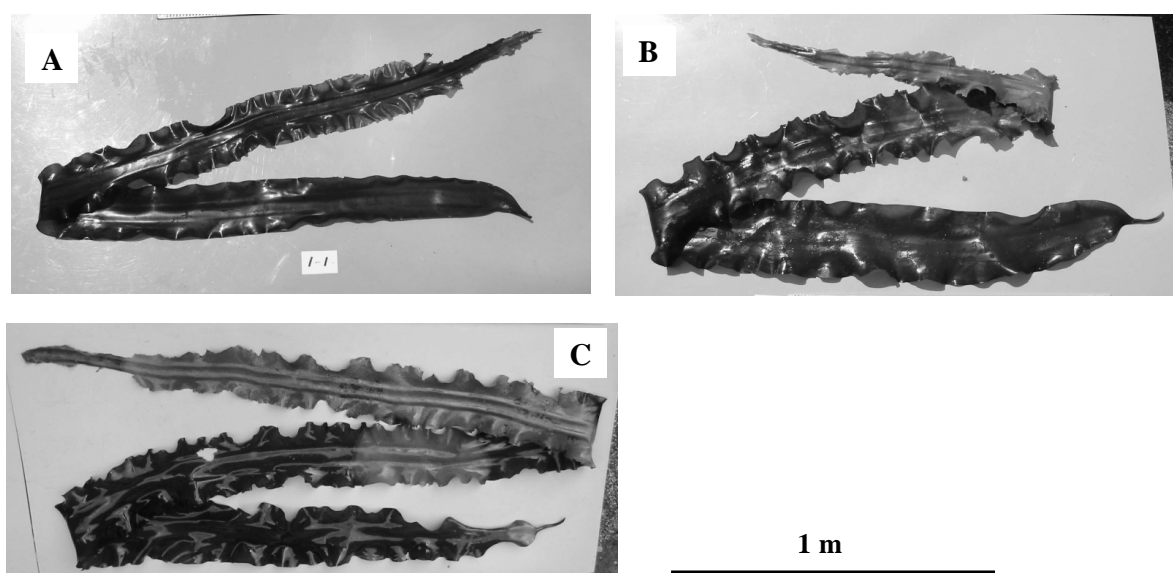
ture tanks of Iwate Seeding Center in northern Japan, were transferred to Naruto in November 2002, by air lift. The seeding strings were then cut into 5-cm segments, and inserted into the mother ropes at 50-cm interval. The mother ropes were then transplanted in the three cultivation fields in Naruto Strait, namely: Harima, Konaruto and Fukumura (Fig.1). Ten individuals having long frond lengths, which

\*1 Usa Marine Biological Institute, Kochi University, Usa-cho, Tosa, Kochi 781-1164, Japan

\*2 Fisheries Research Institute, Tokushima Agriculture, Forestry and Fisheries Technology Center, Seto-cho, Naruto, Tokushima 771-0361, Japan

\*3 Food Technology Division, Tokushima Prefectural Industrial Technology Center, 11-2, Nishibari, Saika-cho, Tokushima 770-8021, Japan

\*4 Kaiyo Doboku Co., Ltd Tokushima Branch, Nakano-cho-4, Tokushima, Tokushima 770-0932, Japan



**Fig. 2** The frond cultivated in the coast of Tokushima Prefecture. A, Harima; B, Konaruto; C, Fukumura.

**Table 1** Average ( $\pm$  SD) length and weight of blade and stipe vis a vis the percentage maturation rate of cultivated *Laminaria japonica* in Tokushima Prefecture at three cultivations sites (n = 10)

Cultivation area	Harima	Konaruto	Fukumura
Maturation rate (%)	0	10	30
Blade length (cm) $\pm$ SD	253.3 $\pm$ 89.7	377.3 $\pm$ 56.6	415.6 $\pm$ 59.2
Blade weight (g) $\pm$ SD	256.4 $\pm$ 163.8	703.1 $\pm$ 117.7	925.8 $\pm$ 267.7
Stipe length (cm) $\pm$ SD	5.5 $\pm$ 1.0	8.5 $\pm$ 1.2	7.4 $\pm$ 1.9
Stipe weight (g) $\pm$ SD	1.6 $\pm$ 0.4	3.8 $\pm$ 1.1	4.7 $\pm$ 1.5

were selected from materials on June 2004 harvesting season, were used for the morphological analysis.

Blade and stipe length, weight, width and thickness were measured in each material to find any possible morphological variants that may develop as a result of transplantation from cold to warm areas. The blade width and thickness were measured at 50-cm interval from 10 to 500-cm portion, i.e. from the base to the frond tip. Representative *Laminaria* fronds from the cultivation sites of Harima, Konaruto and Fukumura showing differences in morphology based on the above parameters were photodocumented.

Determination of physico-chemical factors that affect algal growth was made in the cultivation areas from November 2003 to May 2004: Water temperature was recorded automatically using a self-registering thermometer (MDS-T, ALEC Electronics Co. Ltd.) at the Fisheries Research Institute near the Konaruto cultivation site. For salinity and nutrient analysis water samples were collected from the surface at each site and measured in the laboratory with a salinometer (MODEL3-G, Turumi Seiki Co. Ltd.) and an autoanalyzer (TRAACS800, Bran Rube Co. Ltd.), respectively.

Moisture content of the fronds was determined as weight

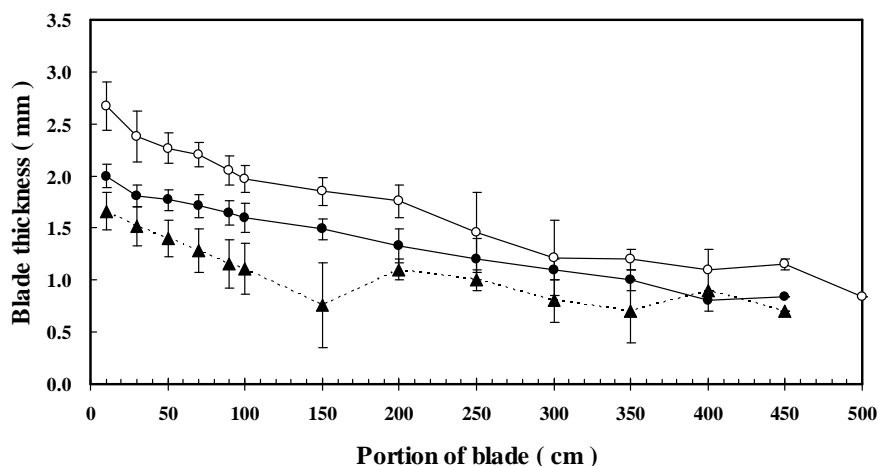
loss after drying the fronds to constant weight at 105 °C in an oven. Total nitrogen content was determined by the Kjeldahl method while crude protein was derived from the total nitrogen content multiplied by a factor of 6.25.

Lipid content of the dried fronds (at 100 °C) was extracted with a chloroform and methanol mixture (1:2) according to Southgate's method (Southgate, 1971). Ash content was estimated by heating the samples for 5 hrs in a temperature-controlled muffle furnace at 550 °C. The sum of the percentages of protein, moisture, fat (lipid) and ash was then subtracted from 100 g to obtain the percentage of carbohydrate in the sample.

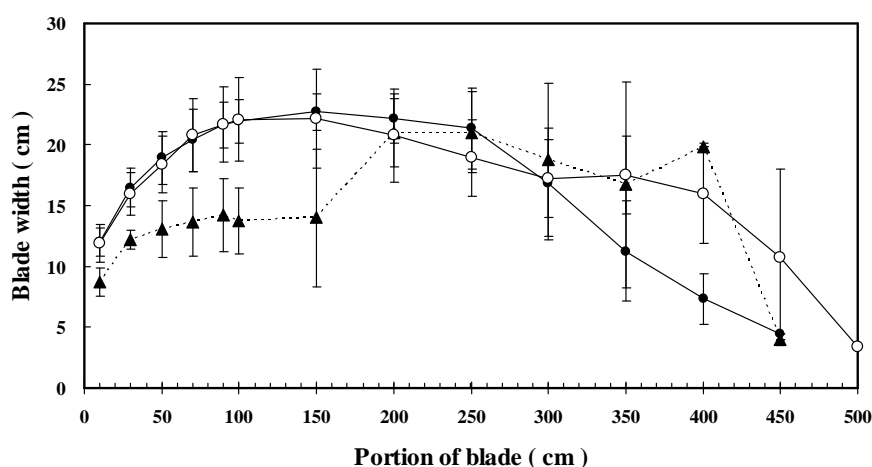
## Results and discussion

### *Cultivated Laminaria frond morphology*

*Laminaria* is characterized by its blade length, thickness and weight. The average blade length of the cultivated plants was lowest in Harima (253.3 cm), higher in Konaruto (377.3 cm) and highest in Fukumura (415.6 cm; Table 1). The average blade weight, likewise, was lowest in Harima (256.4 g), higher in Konaruto (703.1 g) and highest in Fukumura (925.8 g). The general appearance of the *Lami-*



**Fig. 3** The changes in blade thickness from root to tip of *Laminaria japonica*. , Harima; , Konaruto; , Fukumura.



**Fig. 4** The changes in blade width from root to tip of *Laminaria japonica*. , Harima; , Konaruto; , Fukumura.

*Laminaria* fronds from the three cultivation sites in Naruto, Tokushima Prefecture is shown in Fig. 2.

In terms of stipe measurements, stipe length had lowest value in Harima (5.5 cm), but unlike the blade length, highest value of stipe length was recorded in Konaruto (8.5 cm) instead of Fukumura (7.4 cm). Stipe weight, on the other hand, showed values from lowest to highest in Harima (1.6 g), Konaruto (3.8 g) and Fukumura (4.7 g; Table 1).

The change in width from holdfast to the tip of *L. japonica* frond varied among the three study areas, but the width at the center of the blade showed almost similar values among the three areas (Fig. 3).

*Laminaria* blades were at its thickest near the stipe-blade junction. Among the three cultivation areas in Naruto, those cultivated in Fukumura showed the highest values (2.7 mm) while those from Harima showed the lowest (1.5 mm) and those in Konaruto were of moderate thickness regardless of which portion of the blade the measurements were made, except for the 400-cm portion of the blade where the materials in Harima consisted of thicker blades than

those in Konaruto (Fig. 4).

#### *Environmental conditions in the cultivation ground*

The seasonal changes of water temperature in Naruto Strait from November 2003 to May 2004 showed values lower than 10 °C in February (winter season) but this increased gradually towards the spring-summer season (reaching to about 20 °C in May) - the growing period of *Laminaria* in southern Japan. Harvest season of *Laminaria* blades is normally done in early June (Fig. 5).

Dissolved inorganic nitrogen (DIN) in the surface water of *Laminaria* cultivation areas showed higher values from November to December, ranging from 4.0  $\mu\text{g-at L}^{-1}$  to 6.5  $\mu\text{g-at L}^{-1}$  in the three cultivation areas (Fig. 6). After this period, the DIN content decreased gradually during the growing season. The DIN contents in Harima showed highest concentration in the early growing season among the three cultivation areas.

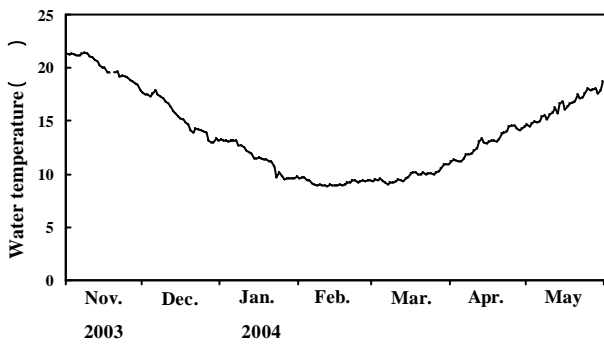


Fig. 5 Changes of water temperature in Konaruto area.

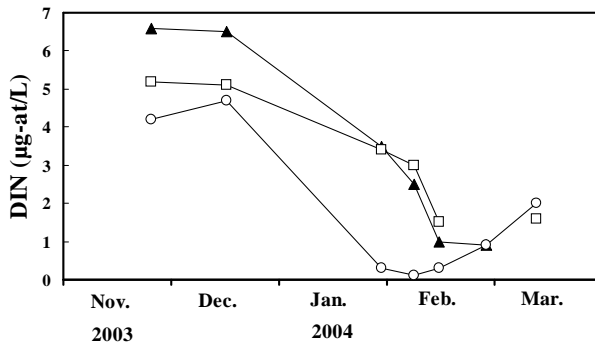


Fig. 6 Dissolved inorganic nitrogen (DIN) in the surface water near the cultivation grounds.  $\blacktriangle$ , Harima;  $\square$ , Konaruto;  $\circ$ , Fukumura.

*Laminaria* cultivation in each area was done off shore where the water current is very fast, brought about by the narrow Naruto Strait along the Seto Inland Sea. The cultivation area in Fukumura, has relatively faster water current observed among the three cultivation areas.

The transplanted *Laminaria* were growing healthily at each commercial cultivation ground where in blade length increased with the increase in water temperature towards the spring season.

The relative percentage (%) appearance of mature *Laminaria* harvested at the three cultivation areas is shown in Table 1. All of the blades harvested in Harima, did not mature as expected based on the absence of sori. Harvested blades showed maturation of 10 % and 30 % at Konaruto and Fukumura, respectively. As normally practiced, *Laminaria* fronds are harvested commercially before it reaches mature stage to avoid attachment of benthic animals.

#### Chemical composition

The *Laminaria* fronds collected from the three study sites differed in terms of the amounts of general nutritive composition, namely: protein, lipid, carbohydrate and ash of dry weight (Table 2). Relative amount, expressed as percentage (%), of water content did not show great differ-

Table 2 General nutritive composition of *L. japonica* cultivated in three sites along Naruto Strait, Tokushima Prefecture. Values are based on proximate analysis of 100 g dry weight sample

Cultivation area	Harima	Konaruto	Fukumura
Water (%)	9.8	11	9.3
Protein (%)	5.2	6.7	8.7
Lipid (%)	0.5	0.5	0.1
Carbohydrate (%)	61.2	54.3	49.1
Ash (%)	23.3	27.5	32.8

ence among materials collected from the three sites. The materials from Fukumura, however, contained highest protein value (8.7 %) than those from Harima (5.2%) and Konaruto (6.7%). Lipid content also did not vary much among materials collected from the three sites, which ranged from 0.1-0.5 %.

Carbohydrate contents, on the other hand, showed an opposite observation by comparison with protein content among the three sources. The content of carbohydrate in materials coming from Harima showed the highest value of 61.2% while those from Konaruto and Fukumura showed lower values of 54.3% and 49.1 %, respectively. The ash content of the analyzed materials had narrow range of 23.3-32.8 %.

Transplanting of *Laminaria* from its cold water origin of northern Japan to the warm water of southern Japan did not result to variation in thalli morphologies from those of its mother strain in the seed-farming center in Iwate. Thus, the results indicate that these characters, as stipe and blade length, weight, width and thickness in *L. japonica* are stable and are unchangeable by transplanting. Although blades of *Laminaria* harvested from Fukumura had fronds longer than those from Konaruto and Harima, despite the fact that nutrient contents in the cultivation areas were not so different, the longer fronds in Fukumura could be more of a result from the influence of stronger water current, promoting faster nutrient uptake in this area than with the other two areas in Naruto. The bigger blades grown in Naruto Strait might also be the effect of water temperature (8-20 °C) during longer growing period from January to June.

Comparison of morphological characteristics between the natural population of *Laminaria* in the cold waters of Hokkaido and Aomori and the fronds of cultivated *Laminaria* in Naruto (this survey) is shown in Table 3. The natural fronds of *Laminaria* in the fisheries grounds of Hokkaido and Aomori are normally harvested after two years (Sanbonsuga, 1984; Kirihara et al., 1989). The cultivated fronds in Naruto, in contrast, are harvested 7 - 8

**Table 3** Comparison of morphological characteristics among natural and cultivated *Laminaria* fronds in three areas of Japan

Origin	Blade length (cm)	Blade width (cm)	Blade fresh weight (g)
* Hokkaido (natural)	443 - 466	28.7 - 25.9	828 - 1298
**Aomori (natural)	308 - 446	18.0 - 22.4	344 - 842
Naruto (cultivated)	253 - 416	23.0 - 24.0	256 - 925

\*Sanbonsuga (1984), \*\* Kirihara *et al.* (1989)

months after transplanting. These cultivated materials are called the forced-cultivated *Laminaria*. The frond size of the cultivated *Laminaria* in Fukumura is similar to those naturally grown in Hokkaido and Aomori; the width of the blades of the Naruto fronds was similar to the width of natural *Laminaria* blades in Hokkaido (Kawasima, 1984; Sanbonsuga, 1984).

The most important quality of *Laminaria* products is their thickness. The natural fronds from Hokkaido has blade less than one mm thick in one year time and that range increases to between 3 and 4 mm in two years time (Kawasima, 1984). The blade thickness of cultivated fronds from Naruto (2.7 mm in Fukumura, 2.0 mm in Konaruto, and 1.7 mm in Harima) were relatively thin compared to those of the natural fronds growing in Hokkaido. But recently, their way of utilization differs between the 'northern' and the 'southern' types. The 'southern' (cultivated) *Laminaria*

growing in Naruto Strait has soft texture compared to the 'northern' (natural) type growing in the cold waters. The latter is a preferred material over the former for preparing "oden" - a popular Japanese dish.

The cultivation areas for *Laminaria* in warm waters in Japan have expanded quite recently where natural *Laminaria* population is absent. It is now possible to transfer by air lift the seeding string of *Laminaria* from the cold water seeding center in northern Japan to the warm water cultivation areas in southern Japan within 1-2 days.

The data of blade length and water temperatures during cultivation period in several *Laminaria* cultivation areas in Japan are shown in Table 4. The size of cultivated blades is fairly different among cultivation areas. From these results, it can be concluded that the optimum water temperature of growing *Laminaria* could range from 7 - 23 °C. In addition, Kawashima (1984) reported that the optimum water temperature of naturally growing *Laminaria* in the cold waters of Hokkaido ranges from 5 to 20 °C. It is interesting to note that the forced *Laminaria* cultivation is recently being tried in the subtropical waters of Okinawa, Japan, as the water temperature in subtropical waters could also range from 16-25 °C for half a year.

From these results, *Laminaria* cultivation can therefore

**Table 4** Comparison of blade length of *Laminaria* fronds in relation to temperature among the cultivation grounds during cultivation season

Cultivation area	Blade of length	Lower water temperature	High water temperature	Reference
Sado	180	9	21	Sakai (1968)
Yokosuka	420	9	15	Torkko <i>et al.</i> (1987)
Hyogo	250	8	20	Ii <i>et al.</i> (1966)
Naruto	350-400	7-8	25	Matsuoka <i>et al.</i> (1991)
Tosa	240	15	20	Ohno & Matsuoka (1992)
Ariake	150	8	23.7	Yotusi & Nishikawa (1968)
Ise	175	8	18	Achiha & Nakamura (1988)

**Table 5** General nutritive composition (per 100 dry wt.) of *L. japonica* from natural beds in Hokkaido

	Harvesting area		
	Osatube (Hokkaido)	Nisitoi (Hokkaido)	Ohma (Aomori)
Seawater (%)	10.3	10.1	11.2
Protein (%)	5.3	5.6	7.4
Lipid (%)	1.6	1.4	2
Carbohydrate (%)	65.1	63.8	64.9
Ash (%)	17.7	19.1	19.2

be carried out in all coastal areas of Japan, i.e. from cold waters to warm waters. The quality of harvests based on frond characteristics, especially thickness, texture and taste could be used as basis in preparing different Japanese dishes. The natural *L. japonica* harvested in Hokkaido is considered of highest quality as it contains high protein and amino acids. From such commercial point of view, it is therefore important to know if the forced cultivated *Laminaria* include protein content comparable to that of natural blades.

The nutritive composition of dried *Laminaria* blades cultivated from different areas in Japan shows the different values among three sites. The larger blades cultivated in Fukumura shows the highest values of proteins and the best qualities among the three sites.

Based on the relative percentage nutritive composition of the natural *Laminaria* fronds shown in Table 5 the Naruto *Laminaria* fronds are therefore good harvesting grounds comparable in quality with those of natural harvests. The relative percentages of protein and carbohydrate among cultivated blades show similar values with those of the natural *Laminaria* (Sanbonsuga, 1984). Although the lipid content of the Naruto *Laminaria* fronds was lower than those of natural *Laminaria* its ash content from the same material was higher than that of natural fronds (Sanbonsuga, 1984).

In conclusion, the results of size and nutritive contents of *Laminaria* show comparable results of forced-cultivated fronds with those from the natural grounds in the cold waters of Japan. Therefore force cultivation should be expanded to be able to meet the increasing demand for high quality *Laminaria* in Japan.

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