Cultivation of *Laminaria japonica* in Udo Coast, Jeju

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제주도 우도해역
다시마 양식시

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제주도 우도해역에서의 다시마 양식시험

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초 록

제주도에서 전복먹이인 참다시마의 생산을 위하여, 백령도산과 완도산 두 품종을 우도 어장에서 2003년 1월부터 7월까지 재배시험을 하였다. 한 달에 한번씩 수질환경과 10형질을 조사하였다. 수온은 12.9-23.5℃, 염분농도는 31.3-36.8‰, 용존산소는 5.40-9.86ppm, pH는 7.82-9.61, 아질산성 질소는 0.02-0.15㎍-at/ℓ, 질산성 질소는 2.27-3.49㎍-at/ℓ, 암모니아성 질소는 0.15-0.56㎍-at/ℓ, 인산성 인은 0.07-0.99㎍-at/ℓ였다. 실험종료 시 백령도산과 완도산의 전장, 엽폭, 경장, 엽장, 중대부길이, 엽두께, 전중량과 비대도는 각각 173.83과 153.76㎝, 14.61과 13.05㎝, 3.94와 3.02㎝, 169.88과 150.65㎝, 155.81과 137.10㎝, 1.01과 0.96㎝, 258.04와 200.96㎝로 백령도산이 조금 높았다. 반면 중대부폭, 줄기두께와 중대부두께는 완도산이 약간 높았다. 각 형질의 상대성장율은 두 품종에서 거의 비슷하였다. 분산분석 결과, 전장과 엽폭, 엽폭과 전중량간에는 유의차가 있었으나 전장과 전중량간에는 유의차가 없었다. 일반적으로는, 우도어장에서는 백령도산이 완도산보다 형질면에서 우수한 것 같으나, 참다시마의 재배생리생태학과 육종학에 관한 많은 연구가 필요하다.

Abstract

To produce *Laminaria japonica* as a abalones' feed in Jeju, the cultivation experiment of the Baekryungdo and the Wanddo cultivars of *L. japonica* was performed at the Udo aquafarm from January to July 2003. Eight water conditions of the aquafarm and ten characters of the two cultivars were measured once a month. The water temperature ranged from 12.9℃ to 23.5℃. The salinity was 31.3-36.8‰; the DO was 5.40-9.86*ppm* ; the pH was 7.82-9.61. Concentrations of NO_2-N, NO_3-N, NH_4-N and PO_4-P were 0.02-0.15㎍-at/ℓ, 2.27-3.49 ㎍-at/ℓ, 0.16-0.56㎍-at/ℓ and 0.07-0.99㎍-at/ℓ. The total blade length of the Baekryungdo and the Wando ones was 173.84 and 153.67 ㎝ at the close fo the growing test. The blade width, stipe length, blade length, fascia length, blade thickness, total weight and substantiality of the Baekryungdo and the Wando ones were 14.61 and 13.05㎝, 3.94 and 3.02㎝, 169.88 and 150.65㎝, 155.81 and 137.10㎝, 1.01 and 0.96㎝, 258.04 and 200.96㎝, and 101.56 and 94.62 when the experiment was finished in July; the values of the Baekryungdo one was slightly higher than those of the Wando one. The fascia width, stipe thickness and fascia thickness of the wando one were slightly higher than those of the Baekryungdo one. The relative growth rate of these characters of these two cultivars during the whole growing test was almost the same. The result of the ANOVA between total blade length and blade width, and blade width and total weight were significant, but the result of the ANOVA between total blade length and total weight was met significant. Generally, the performance of the Baekryungdo cultivar seems to be higher than that of the Wando one at the Udo aquafarm, a lot of studies on physiological ecology for cultivation and breeding, however, are needed in the future.

Ⅰ. Introduction

The brown algal genus *Laminaria*, with about 30 species (Kain 1991), is native to cold-temperature waters of the northern hemisphere. They are, however, known from warm temperate regions off the Philippines and Brazil (Joly and Oliveira Filho 1967; Petrov *et al.* 1973). *L. japonica* f. *membranacea*, *L. ochotensis, L. cichorioides*, and *L. saccharina* f. *linearis* are naturally distributed in the northern east coast of Korea (Kang. 1996), and *L. ochotensis, L. cichorioides* and *L. sacchrina* f. *linearis* are also reported as indigenous species by Kawashima(1993). For the cultivation, *L. religiosa*(Chang and Geon 1970; Chang and Chung 1971) and *L. japonica* (Baik and Pyen 1973; Chang *et al.* 1973) were transplanted from Hokkaido, Japan, to Ilsan Bay and Ilkwang Bay on the south-east coast and Jumunjin on the central east coast in Korea. Since then the aquafarm have expanded to the south and west coast due to successful retransplanting from the east coast.

Nowadays, natural populations of *Laminaria*s have been found in east (Nam *et al.* 1985; Sohn 1987), south (Sohn 1996; Seo 2001) and west (Seo 2001) coast maybe due to attachment of spores from aquafarms. Moreover, entities have been introduced from China to Geumil, Wando (Seo pers. communication) and was introduced from China to Haenam by National Fisheries Research and Development Institute in 2001.

Studies on cultivation (Chang and Geon 1970; Chang 1971; Chang and Chung 1971; Chang *et al.* 1973; Baik and park 1979), seed culture (Baik 1977), growth and morphological variation (Gong 1993), gametogensis and early sporophyte development (Lee 1992), fine structure (Chung 1990), germination, growth and production (Kang 1999) and molecular phylogeny (Boo *et al.* 1999; Yoon 1999; Boo and

Yoon 2000; Yoon and Boo 1999) morphological and RAPD-analytical study(Seo 2001) of *Laminaria*s in Korea were reported, study on *Laminaria* cultivation in Jeju, however, could not be found.

Only a few species of *Laminaria* have been mainly cultivated as a sea-vegetable for humanbeings' food or foodstuffs and a feed for abalones which is the basis for one of the largest aquaculture industries in China, Japan and Korea and it is known as "Haidai" in China, "Komu" in Japan and "Dasima " in Korea. (Ohno and Largo 1998; Sohn 1998; Wu 1998). Therefore, to manifest morphological, ecological, physiological, biochemical, genetical and food scientific characteristics of *Laminaria* cultivars and local varieties, or both are important in establishing well-defined breeding objective, i. e., making obvious breeding strategy and tactics, and advancing rational breeding management and operation in breeding program. They give also basic information to selection the best cultivar for cultivation objective and to reveal the best cultivation condition for the cultivar in cultivation program.

For the ecological breeding of *Laminaria*s, the study on ecomorphology, adaptability, and quantitative-genetical analysis of this marine crop are needed because these are closely related one another, in a word, breeding is artificial evolution, and the taxon has broad morphological variation(Kawashima and Yotsukura, 2000. pers. communication)

In Jeju, although the abalone aquaculture has been increasing, feeds for abalones such as *Laminaria* has been purchased from other places such as Jeollanamdo. Therefore, this study have been performing the cultivation experiment of two local cultivars , the Baekryungdo and the Wando ones at the Udo aquafarm in Jeju area from January to July 2003 for a abalones' feed, and as a part of ecological breeding studies of *Laminaria*s.

Ⅱ. Materials and Methods

Seed collectors introduced from Baekryungdo and Wando aquafarms were cultivated in the Udo aquafarm, Jeju, where the sporelings were allowed to grow to about 2 – 3 cm long . The seeded strings cut into 3 – 4 cm long were inserted at 30 cm intervals into intermediate slender ropes, and the ropes were wound around the main cultivation ropes at 1 m underwater.

The provisional outplanting was started at October 6, 2002, when the water temperature was 21.5℃ and the specific gravity was 1.0220. The regular cultivation was started at December 15, 2000, when the water temperature 11℃ and the specific gravity 1.0240.

The experimental site for the growing test and the external feature of the thallus of *Laminaria* were shown in Figure 1 and 2. The strip-plot design was used for the growing test in two aquafarms. Ten subcharacters such as total blade length, stipe length, blade length, fascia length, blade width, fascia width, stipe thickness, fascia thickness, blade thickness, total weight and substantiality of the two cultivars were measured once a month when plants were collected, and of them five subcharacters were used for the statistical analysis.

Water temperature and salinity were measured by DO meter(YSI, Model 85/10 FT). Waters were sampled by 1.8ℓ portable midlayer water samplers with water temperature meter (Wildlife Supply Company, Model 1920-H60-0896.) and these waters were used for determinating nitrite-nitrogen(NO_2-N) by the method of N-(1-Naphthyl) -ethylenedimine dihydrochloride (Bendschneider and Robinson 1952), nitrate-nitrogen (NO_3-N) by cadmium-copper reduction (Wood *et el.* 1967), ammonia-nitrogen(NH_4-N) by phenolhypochlorite (Solòrzano 1969), and phosphate- phosphorus (PO_4-P) by ascorbic acid(Murphy and Riley 1962) in laboratory.

Calculations using measurements followed Gomez and Gomez(1984), Sokal and Rohlf (1995), Kempton and Fox(1997) and Lynch and Walsh(1998).

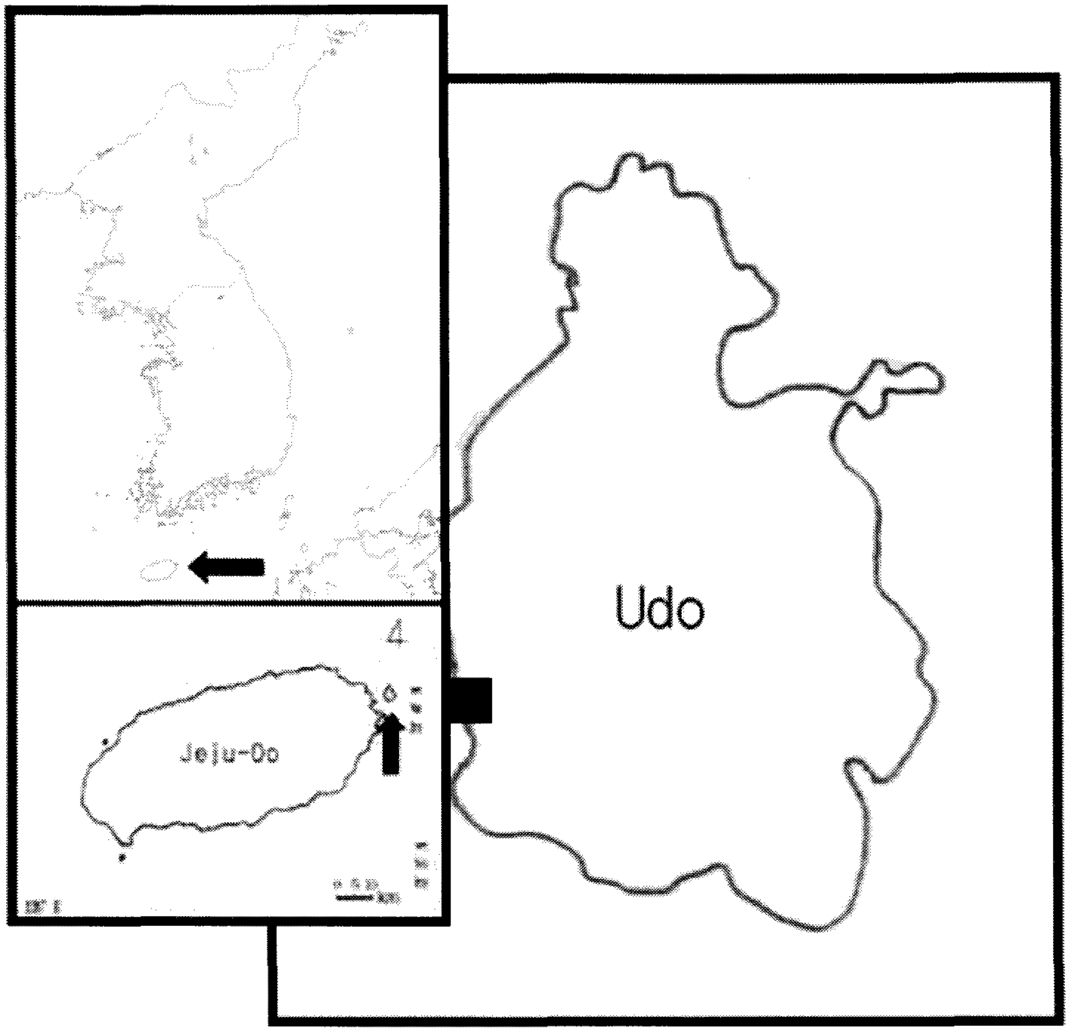


Fig. 1. The experimental sites for the growing test

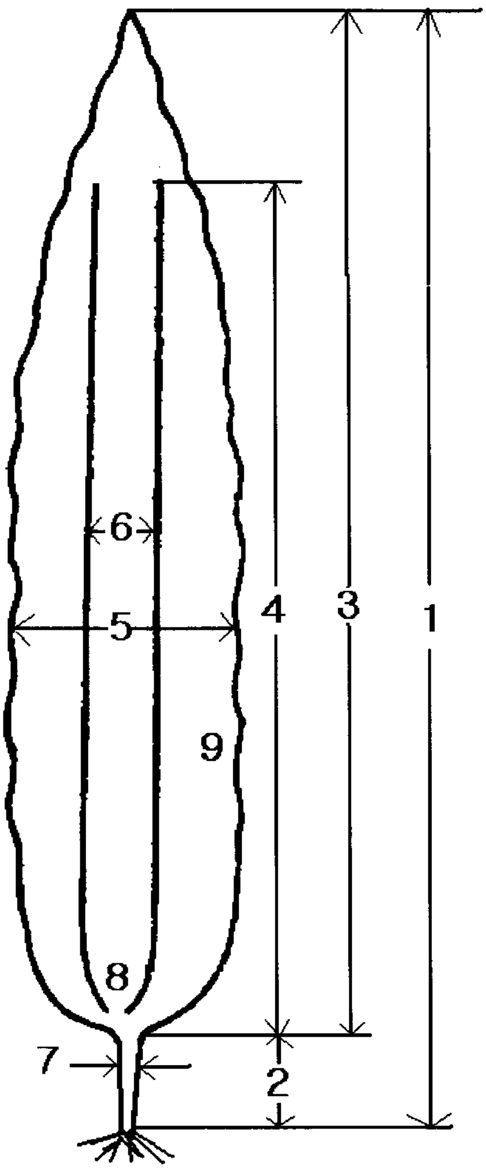


Fig. 2. External feature of the thallus of *Laminarias*.

1, total blade length; 2, stipe length; 3, blade length, 4, fascia length; 5, blade width; 6, fascia width, 7, stipe thickness; 8, fascia thickness; 9, blade thickness.

Substantiality was not showed in the illustration.

Ⅲ. Results and Discussion

Figure 3 shows the variation of water temperature, water salinity, dissolved oxygen and pH at the Udo aquafarm from January to July, 2003. The water temperature ranged from 12.9℃ to 23.5℃ ; the water temperature was the lowest in March and the highest in July. The salinity was fluctuated from 31.3‰ in July to 36.8‰ in April. The DO changed from 5.40 ppm in July to 9.86 ppm in February. The pH was altered from 7.82 in May to 9.61 in March.

Figure 4 shows the variation of NO_2-N, NO_3-N, NH_4-N and PO_4-P from February to July, 2003. The NO_2-N was 0.15 μg-at/ℓ from February to May and July, but was 0.02μg-at/ℓ in June. The NO_3-N ranged from 2.27μg-at/ℓ in June to 3.49μg-at/ℓ in March. The NH_4-N was fluctuated from 0.16μg-at/ℓ in April to 0.56μg-at/ℓ in May ; the NH_4-N has increased suddenly in May. The PO_4-P was varied from 0.07μg-at/ℓ in May to 0.99μg-at/ℓ in March ; the PO_4-P has dropped abruptly in May.

Figure 5 shows the monthly comparison of total blade of the Baekryungdo and Wando cultivars of *L. japonica*. The Baekryungdo cultivars was higher than the Wando one. The relative growth rate of the Baekryungdo one during the growing test was 0.013 (Table 1). The length of the two cultivars shortened in July ; this seems to be falling off of the large individuals due to the typhoon.

Figure 6 shows the monthly comparison of the blade width of the two cultivars. The blade width of the Baekryungdo one was higher than that of the Wando one. The relative growth rate of the Baekryungdo and Wando ones during the growing test was 0.010 and 0.009, respectively(Table 2).

Figure 7 shows the monthly comparison of the stipe length of the two cultivars. The stipe length of the Wando one was shorter than that of the Baekryungdo one from June. The stipe length of the two cultivars abruptly shortened in July ; this seems to be falling off of the large individuals due to the typhoon. The relative growth rate the Baekryungdo and Wando one during the growing test was 0.006 and 0.005(Table 3).

Figure 8 shows the monthly comparison of the blade length of the two cultivars. The blade length of the Baekryungdo one was longer than that of the Wando one. The length of the two cultivars decreased in July. The relative growth rate of the Baekryungdo and the Wando one during the test was 0.014 and 0.013(Table 4).

Figure 9 shows the monthly comparison of the fascia length of the two cultivars. The fascia length of the Baekryungdo one was longer than that of the Wando one. The length of the Baekryungdo one decreased after May, and that of the Wando one decreased after June. The relative growth rate of the Baekryungdo and the Wando one during the test was 0.016 and 0.015(Table 5).

Figure 10 shows the monthly comparison of the fascia width of the two cultivars. Generally, the fascia width of the two cultivars increased during the growing test, and that of the Wando one was wider than that of the Baekryungdo one after May. The relative growth rate of the Baekryungdo and the Wando one was 0.010 and 0.011, respectively(Table 6).

Figure 11 shows the monthly comparison of the stipe thickness of the two cultivars. The stipe thickness of the Wando was thicker than that of the Baekryungdo one after June, and that of the two cultivars decreased in July. The relative growth rate of the Baekryungdo and the Wando one during the growing test was 0.006 and 0.007(Table 7).

Figure 12 shows the monthly comparison of the fascia thickness of the two cultivars. The fascia thickness of the Wando one was slightly thicker than that of the Baekryungdo one in February, June and July, and that of the two cultivars decreased after June. The relative growth rate of the Baekryungdo and the Wando one during the growing test was 0.016 and 0.017(Table 8).

Figure 13 shows the monthly comparison of the blade thickness of the two cultivars. The blade thickness of the Baekryungdo one was thicker than that of the Wando one, and that of the two cultivars decreased in July. The relative growth rate of the Baekryungdo and the Wando one during the growing test was 0.014 and 0.013(Table 9).

Figure 14 shows the monthly comparition of the total weight of the two cultivars. Generally, the total weight of the Baekryungdo one was heavier than that of the Wando one, and that of the two cultivars decreased in July. The relative growth rate of the Baekryungdo and the Wando one during the growing test was 0.034 and 0.032(Table 10).

Figure 15 shows the monthly comparison of the substantiality of the two cultivars. Generally, the substantiality of the Baekryungdo one was higher than that of the Wando one except that in May and June, and that of the two cultivars decreased after June. The relative growth rate of the Baekryungdo and the Wando one during the growing test was the same, 0.010(Table 11).

Figure 16 shows the relationship between total blade length and blade width of the two cultivars. The coefficient of determination was high. The result of ANOVA test was significant at 1 and 5% level(Table 12).

Figure 17 shows the relationship between total blade length and total weight of the two cultivars. The regression was curve, and the coefficient of determination was very high. The result of ANOVA test was not significant(Table 13).

Figure 18 shows the relationship between total blade width and total weight of the two cultivars. The regression was curve, and the coefficient of determination was very high. The result of ANOVA test was significant(Table 14).

Characters that are studied by biologists are of three types: meristic, metric and all-or-none(or binary) characters. Of the threes, the metric character of interested is a continuously distributed variable, and this quantity is described by the probability density function which is the probability that a variable lies within a specific range of values. The amount of variation is measured and expressed as the variance: when values are expressed as deviations from the population mean the variance is simply the mean of squared values. The components into which the variance is partitioned are the same as the components of values, i.e. the genotypic variance is the variance of genotypic values, environmental variance is the variance of environmental deviations, and total variance is the phenotypic variance, or the variance of phenotypic values.

The variance of the response variable y has two components: the amount of variance accounted for by the linear model(the regression variance) and the remaining variance not accountable by the regression(the residual variance). The elliptical shape of scattergrams of correlated variables is not usually very clear unless either large samples have been taken or the parametric correlation is high. The squared correlation coefficient, coefficient of determination, r^2, measures the proportion of the variance in y that is explained by assuming that the conditional density is linear. This ratio is a proportion between zero and one. The explained sum of squares of any variable must be smaller than its total sum of squares. If all the variation of a variable has been explained, its explained sum of squares can be as great as the total sum of squares, but no greater. When none of the variance can be explained by the other variable with which the covariance has been computed, the explained sum of squares is at its lowest value, zero. Thus, an important measure of the proportion of the variation of one variable determined by the variation of the other was obtained. It range from 0 to 1 and must be positive regardless of whether r is negative or positive. The r^2 is useful when one is considering the relative importance of correlations of different magnitudes, and may be useful in regression analysis(*cf.* Snedecor and Cochran 1982; Zar 1984; Sokal and Rohlf 1995; Falconer and Mackay 1996; Kearsey and Pooni 1996; Kempton and Fox 1997; Lynch and Walsh 1998).

Considering characters, which are controlled by several genes, the probability of finding the best genotype at all loci is extremely small. Since only phenotypes can be observed, the best genotype may be overlooked, even if it is in the population. The phenotypes show continuous variation and statistical parameters like means and variance are used to measure the response to selection. This response depends not only on the genetic variance, but also on the nongenetic variance and interaction of the genetic effects with the environment.

Only one year-performance test does not lead to judgement on which cultivar the superior lies, thus various performance test over a long term of years to improve cultivability and marketability including high yielding ability, high quality-produceableness, high stability, wide adaptability, broad- spectrum resistance, *etc.*, — these are characteristics which are desired by consumers, tradespeople and farmers.

The *Laminaria* cultivation in Jeju proved successful for the first time, therefore, laminarian plants for a feed of abalones can be supplied in Jeju.

Plant breeding can be defined as the art and science of changing and improving the genetic pattern of plants in relation to their economic use, or as controlled evolution of wild(economically usable) or cultivated plants, *Laminaria* in this case, based on selection and combination or recombination of genetic properties, therefore, the creation of the best cultivar needs working in a complex system.

THE WHY, WHEN, WHERE, WHAT AND HOW OF DOMESTICATION

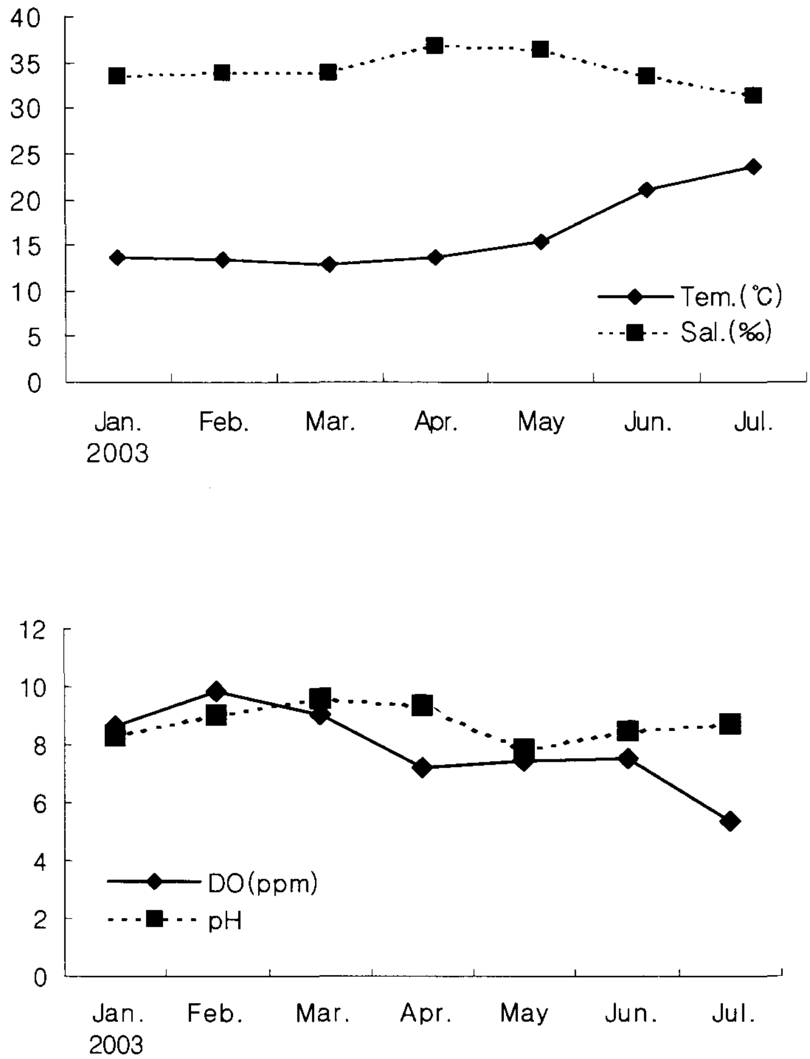
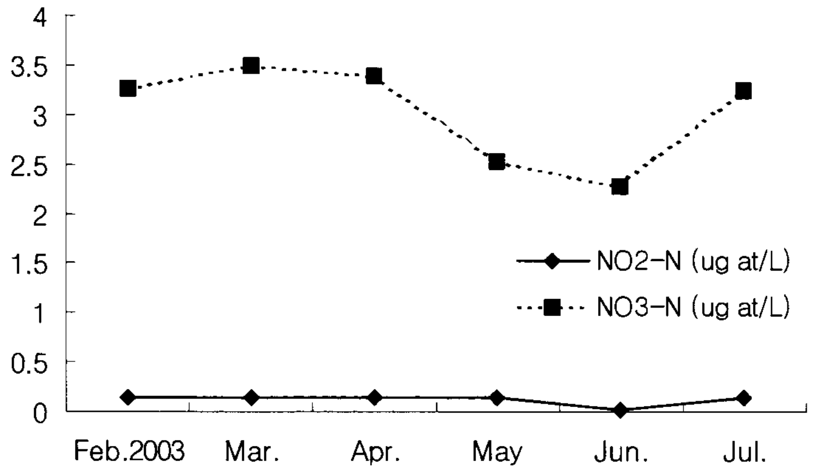


Fig. 3. Variation of water temperature, water salinity, dissolved oxygen and pH at the Udo aquafarm.



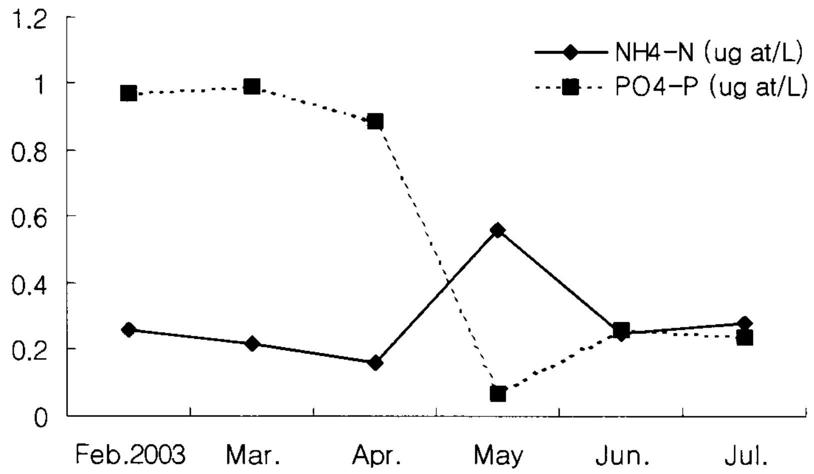


Fig. 4. Variation of nitrite-nitrogen(NO_2-N), nitrate-nitrogen(NO_3-N), ammonia-nitrogen(NH_4-N) and phosphate-phosphorus(PO_4-P) at the Udo aquafarm.

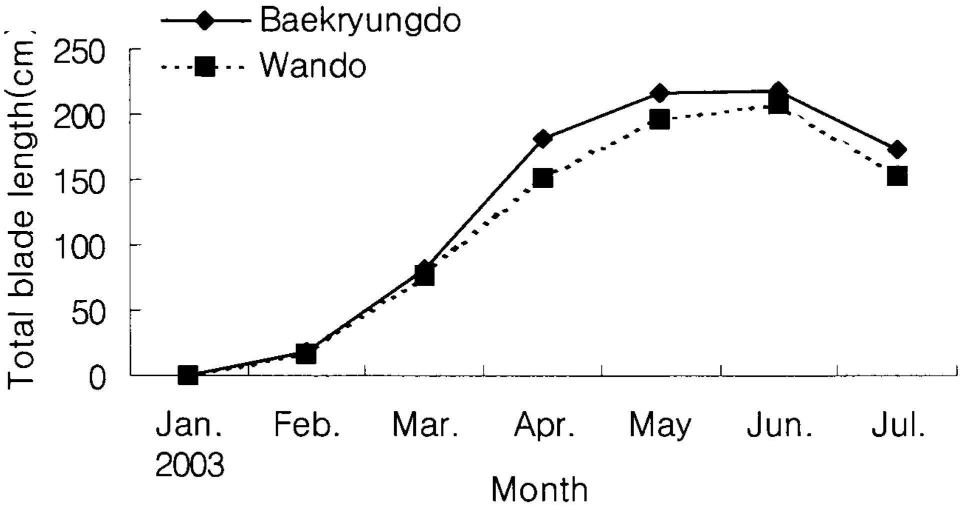


Fig. 5. Comparison of total blade length of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 1. Mean total blade length and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean total blade length(cm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.56	18.61	81.15	180.91	215.9	218.88	173.83
Wando	0.34	16.65	76.18	152.29	197.2	207.53	153.67
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.125	0.046	0.027	0.006	0.000	-0.007	0.013
Wando	0.139	0.048	0.023	0.008	0.001	-0.010	0.012

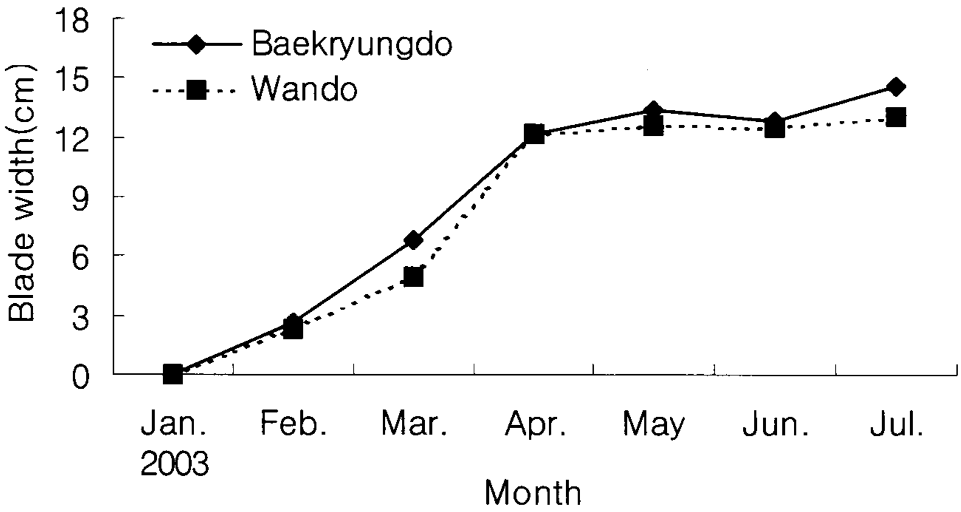


Fig. 6. Comparison of blade width of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 2. Mean blade width and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean blade width(cm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.1	2.68	6.85	12.23	13.4	12.84	14.61
Wando	0.1	2.35	4.95	12.16	12.57	12.53	13.05
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.117	0.029	0.019	0.003	-0.001	0.004	0.010
Wando	0.113	0.023	0.030	0.001	0.000	0.001	0.009

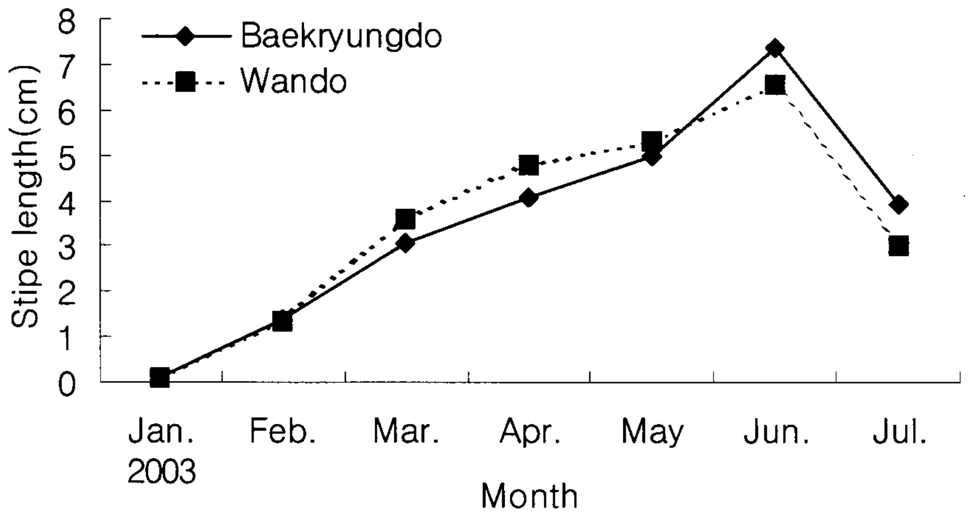


Fig. 7. Comparison of stipe length of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 3. Mean stipe length and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean stipe length(cm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.1	1.38	3.08	4.07	5.23	7.37	3.94
Wando	0.1	1.36	3.61	4.79	5	6.54	3.02
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.094	0.025	0.009	0.008	0.008	-0.020	0.006
Wando	0.093	0.031	0.009	0.001	0.006	-0.025	0.005

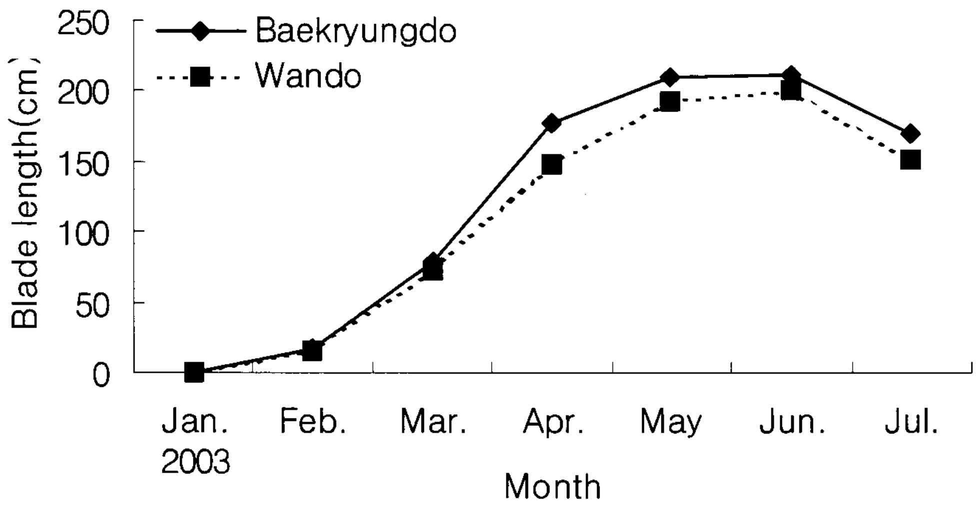


Fig. 8. Comparison of blade length of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 4. Mean blade length and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean blade length(cm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.5	16.96	78.06	176.84	209.83	210.97	169.88
Wando	0.3	15.01	71.82	147.5	192.23	200.99	150.65
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.122	0.048	0.027	0.005	0.000	-0.007	0.014
Wando	0.135	0.049	0.024	0.008	0.001	-0.009	0.013

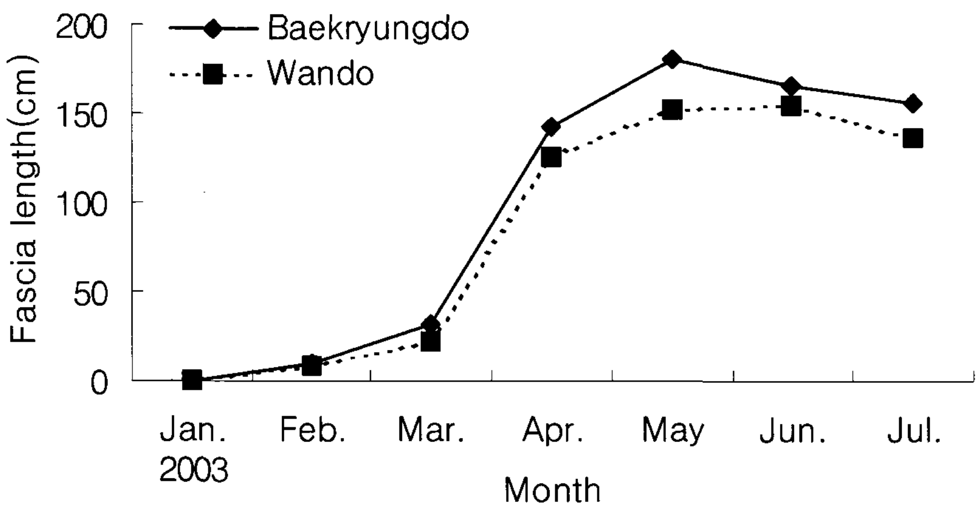


Fig. 9. Comparison of fascia length of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 5. Mean fascia length and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean fascia length(cm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.2	9.98	31.17	142.53	180.63	166.00	155.81
Wando	0.1	7.7	22.13	125.92	152.53	154.55	137.1
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.103	0.036	0.051	0.007	-0.002	-0.002	0.016
Wando	0.111	0.033	0.058	0.006	0.000	-0.004	0.015

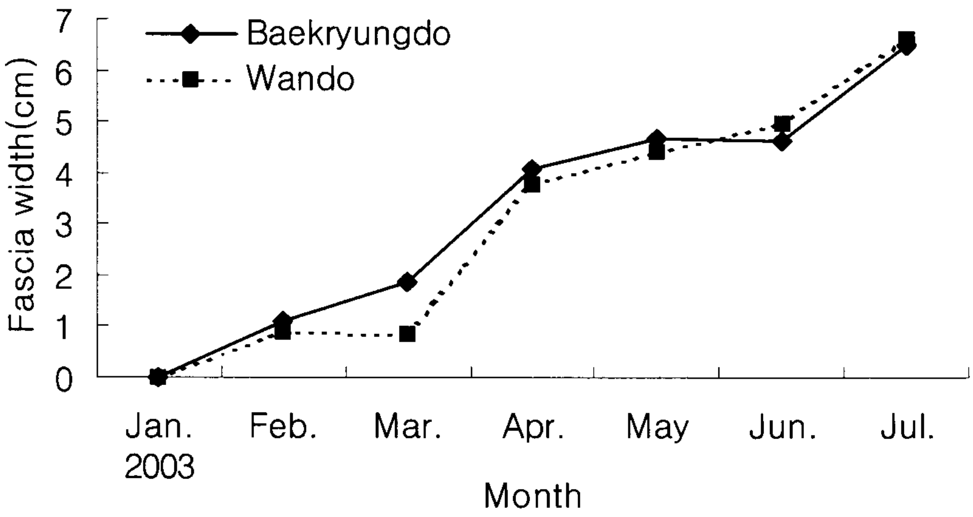


Fig. 10. Comparison of fascia width of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 6. Mean fascia width and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean fascia width(cm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.05	1.1	1.87	4.08	4.68	4.61	6.49
Wando	0.03	0.89	0.87	3.76	4.43	4.96	6.62
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.024	0.017	0.026	0.004	0.000	0.011	0.010
Wando	0.034	-0.001	0.049	0.005	0.003	0.009	0.011

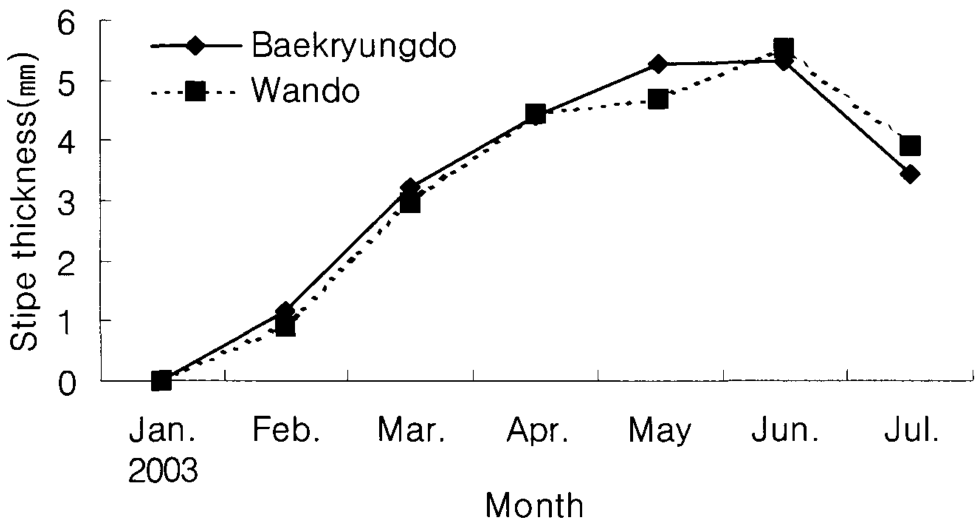


Fig. 11. Comparison of stipe thickness of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 7. Mean stipe thickness and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean stipe thickness(㎜)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.1	1.14	3.24	4.42	5.27	5.3	3.43
Wando	0.1	0.9	2.95	4.46	4.7	5.52	3.92
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.251	0.033	0.010	0.005	0.000	-0.014	0.006
Wando	0.243	0.037	0.014	0.002	0.004	-0.011	0.007

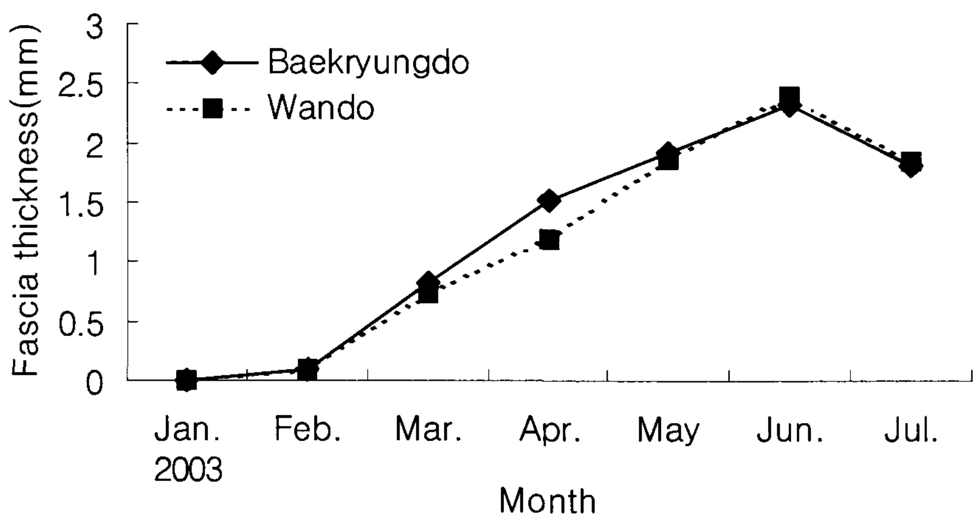


Fig. 12. Comparison of fascia thickness of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 8. Mean fascia thickness and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean fascia thickness(㎜)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.01	0.11	0.84	1.52	1.98	2.32	1.81
Wando	0.01	0.16	0.75	1.18	1.86	2.39	1.84
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.068	0.064	0.020	0.008	0.004	-0.008	0.016
Wando	0.081	0.048	0.015	0.014	0.006	-0.008	0.017

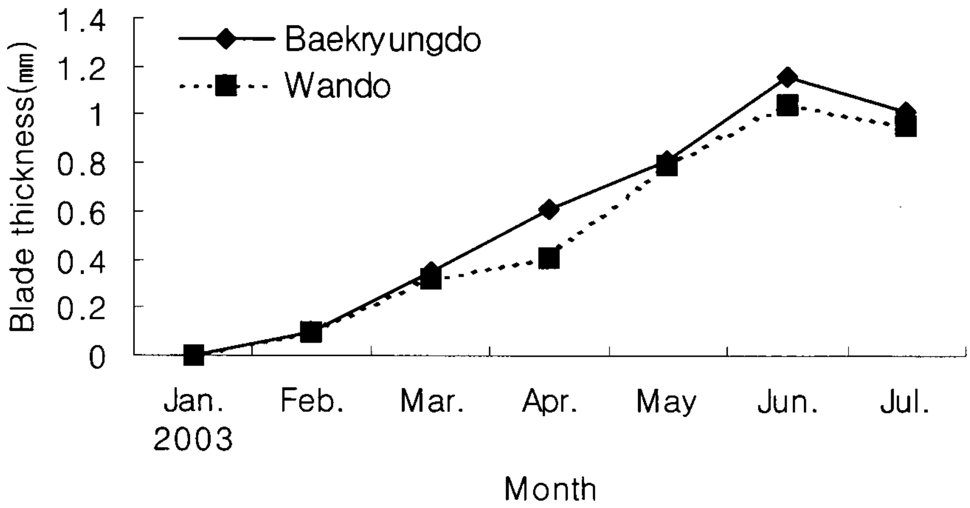


Fig. 13. Comparison of blade thickness of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 9. Mean blade thickness and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean blade thickness(mm)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.01	0.1	0.35	0.61	0.81	1.16	1.01
Wando	0.01	0.1	0.32	0.41	0.79	1.04	0.96
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.064	0.039	0.019	0.009	0.008	-0.004	0.014
Wando	0.064	0.036	0.008	0.020	0.006	-0.003	0.013

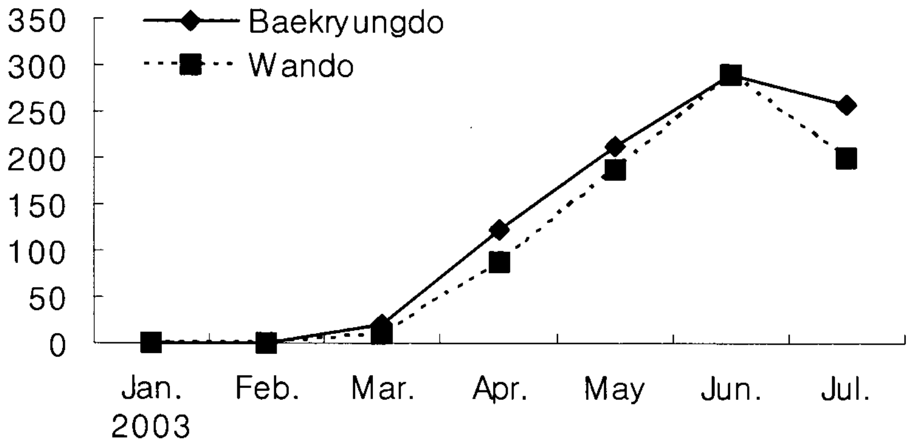


Fig. 14. Comparison of total weight of the two cultivars of *Laminaria japonica* at the Udo aquafarm.

Table 10. Mean total weight and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean total weight(g)						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.01	0.82	20.15	121.7	212.7	289.5	258.04
Wando	0.01	0.45	10.4	87.73	186.47	290.87	200.96
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.157	0.100	0.060	0.017	0.007	-0.004	0.034
Wando	0.136	0.098	0.071	0.024	0.010	-0.012	0.032

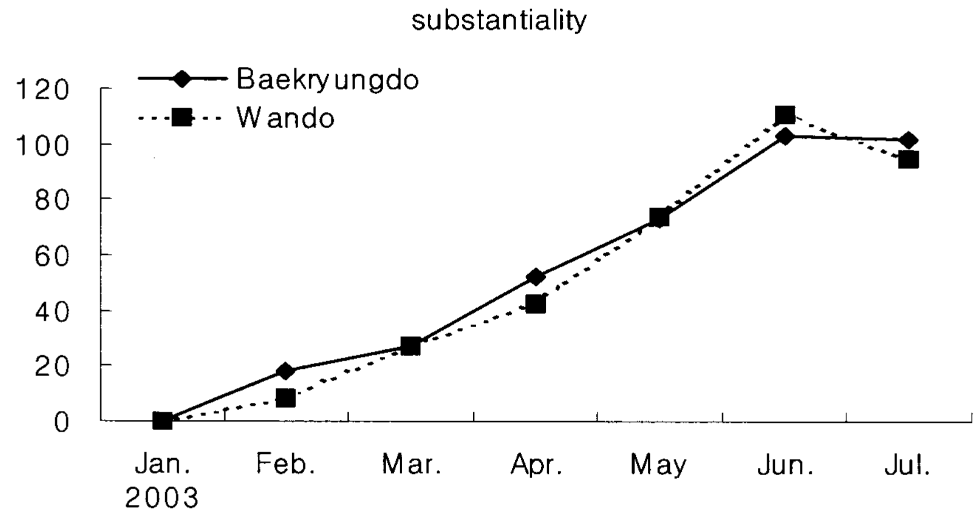


Fig. 15. Comparison of substantiality of the two cultivars of *Laminaria japonica.* at the Udo aquafarm.

Table 11. Mean substantiality and relative growth rate of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivars	Mean substantiality						
	10, Jan (0)	07, Feb (28)	11, Mar (60)	10, Apr (90)	12, May (122)	26, Jun (167)	27, Jul (198)
Baekryungdo	0.1	18.04	27.15	52.14	73.1	103.54	101.56
Wando	0.4	8.61	27.09	42.31	73.9	110.83	94.62
Cultivars	Relative growth rate						
	0-28	28-60	60-90	90-122	122-167	167-198	0-198
Baekryungdo	0.186	0.013	0.022	0.011	0.008	-0.001	0.010
Wando	0.110	0.036	0.015	0.017	0.009	-0.005	0.010

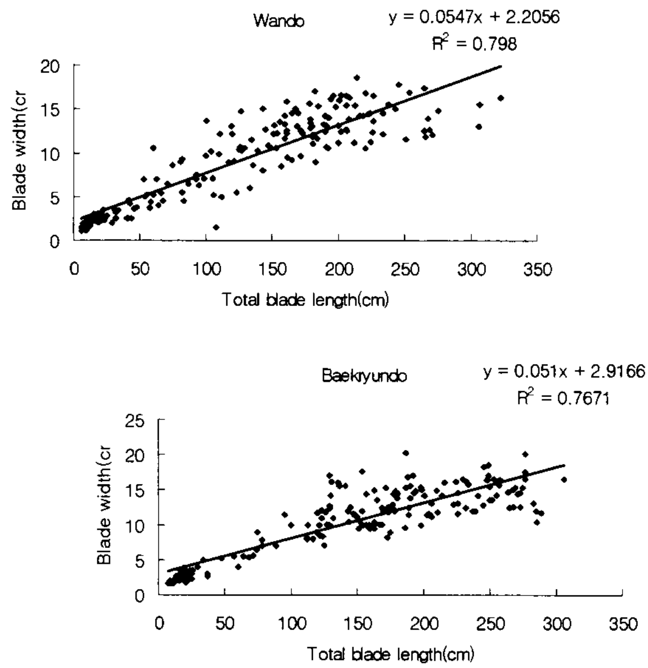
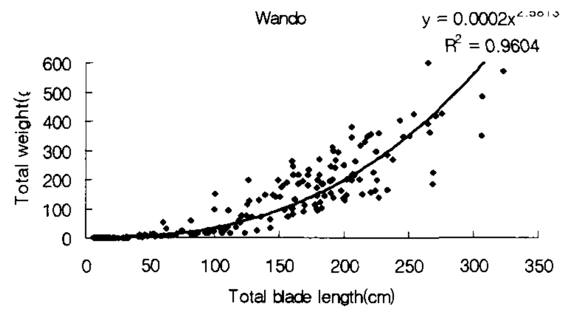


Fig. 16. Relationship between total blade length and blade width of two cultivars in *Laminaria japonica* at the Udo aquafarm.

Table 12. Analysis of variance between total blade length and blade width of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivar	Source of variation	Sum of squares	Degree of freedom	Mean of squares	F_0	$F_{(a)}$	
						5%	1%
	Regression	1328991.33	1	1328991.33			
Wando	Residual	1196711.59	358	3342.77	397.57	3.86	6.7
	Total	2525702.92	359				
	Regression	1689114.10	1	1689114.10			
Baekryungdo	Residual	1307672.78	358	3652.72	462.43	3.86	6.7
	Total	2996786.88	359				



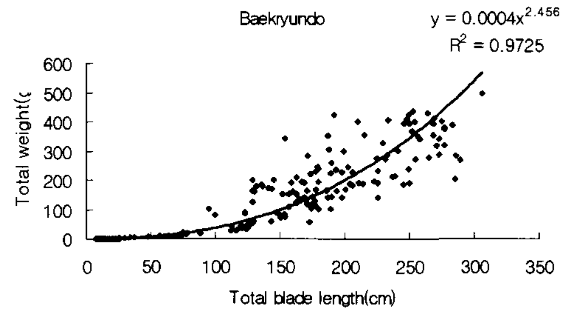


Fig. 17. Relationship between total blade length and total weight of two cultivars in *Laminaria japonica* at the Udo aquafarm.

Table 13. Analysis of variance between total blade length and total weight of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivar	Source of variation	Sum of squares	Degree of freedom	Mean of squares	F_0	$F_{(a)}$	
						5%	1%
Wando	Regression	3087.11	1	3087.11			
	Residual	4259100.16	358	11896.93	0.26	3.86	6.7
	Total	4262187.27	359				
Baekryungdo	Regression	1046.46	1	1046.46			
	Residual	4528813.22	358	12650.32	0.08	3.86	6.7
	Total	4529859.68	359				

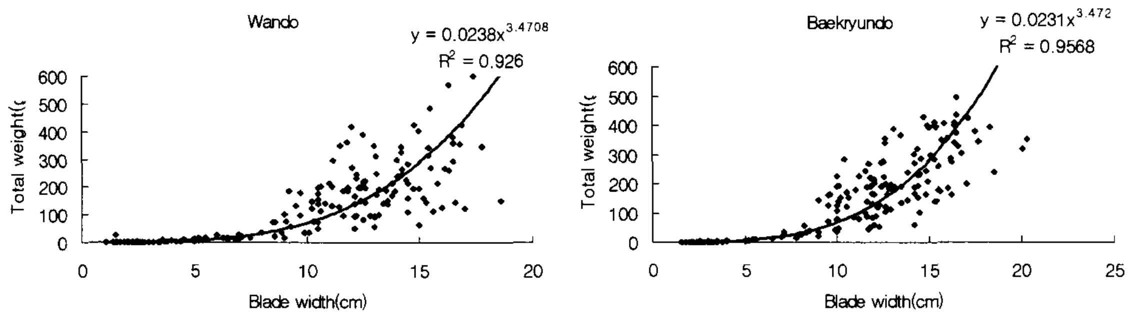


Fig. 18. Relationship between blade width and total weight of two cultivars in *Laminaria japonica* at the Udo aquafarm.

Table 14. Analysis of variance between blade width and total weight of the two cultivars of *Laminaria japonica* at the Udo aquafarm

Cultivar	Source of variation	Sum of squares	Degree of freedom	Mean of squares	F_0	$F_{(a)}$	
						5%	1%
	Regression	1203973.18	1	1203973.18			
Wando	Residual	3071325.61	358	8579.12	140.34	3.86	6.7
	Total	4275298.78	359				
	Regression	1774246.04	1	1774246.04			
Baekryungdo	Residual	3229978.46	358	9022.29	196.65	3.86	6.7
	Total	5004224.49	359				

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대학원 생활에 있어 항상 힘이 되어준 최성제, 전영호, 김용민, 김용만, 주용석, 박기호, 김희철등 저희 학번 친구에게 감사드리며, 학업에 바쁜 가운데 큰 도움을 준 서태호, 곽종욱, 최문성 등 해조재배학·유전육종학 실험실의 후배에게 감사를 드립니다.

끝으로 항상 제 가슴속에서 산으로 자리잡아 믿음으로 지켜주신 부모님과 장인, 장모님께도 고마움을 전하며, 바다보다 더 넓은 사랑으로 저를 믿고 따라준 아내와 혜민이 그리고 올해에 태어날 둘째에게 이 논문을 바칩니다

2004년 2월

이 정 호 올림