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Inheritance Mode of Some Characters of *Porphyra yezoensis* (Bangiales, Rhodophyta) II. Yield, Photosynthetic Pigments Content, Red Rot Disease-Resistance, Color, Luster and Volatile Sulfur Compounds Concentration

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Two recombinant wild-types, the ZGRW and the ZRGW were bred by reciprocal crosses of the green-type and the red-type pigmentation mutants of *Porphyra yezoensis*. They were cultivated to test the inheritance mode of yield and to measure the photosynthetic pigments content, red rot disease-resistance, color, luster and volatile sulfur compounds concentration. Standing crops and photosynthetic pigments content of gametothalli and color and luster of dried sheets were similar between the ZGRW and the ZRGW; therefore, these characters were governed by the nuclear inheritance mode. On the other hand, the resistance to red rot disease of gametothalli and dimethyl sulfide content of dried sheets were significantly different between the ZGRW and the ZRGW, so these characters were transmitted by the cytoplasmic inheritance mode.

Key Words: color, inheritance mode, luster, photosynthetic pigment content, pigmentation mutant, *Porphyra yezoensis*, reciprocal crosses, recombinant wild-type, red rot disease resistance, volatile compound concentration, yield.

INTRODUCTION

Studies on the genetics of pigmentation mutants in *Porphyra yezoensis* has been developed by Miura and others (Miura 1985; Ohme *et al.* 1986; Ohme and Miura 1988; Niwa *et al.* 1993; Hamada *et al.* 1994; Miura and Ohme-Takagi 1994; Shin and Miura 1997; Shin *et al.* 1997; Shin 1999). They also have conducted the breeding study on *Porphyra* by crossing between pigmentation mutants (Miura and Shin 1989; Shin and Miura 1995; Shin *et al.* 1996).

In crossbreeding, the inheritance mode of the characters of cultivars is important in the establishment of the well-defined breeding objective. This is also important because it gives the basic information for the cultivar selection and the control of cultivation practice. The inheritance mode of the characters has not been reported except the mode of crispness and free amino acid content (Shin and Miura 1997). This study was conducted to describe the inheritance mode of some characters of the two recombinant wild-types bred by the reciprocal crosses between a green-type and a red-type pigmentation mutant of *P. yezoensis*.

MATERIALS AND METHODS

Two recombinant wild-types of *Porphyra yezoensis*, ZGRW and ZRGW, were used in this study. The green-type (C-O giant) and the red-type (H-25) pigmentation mutant of *P. yezoensis* were used as the parental lines for crossbreeding to create the ZGRW (C-O giant × H-25) and the ZRGW (H-25 × C-O giant). These mutants are monogenic and recessive to the wild-type. Their genes are non-allelic belonging to the same linkage group (Ohme *et al.* 1986; Ohme and Miura 1988; Shin 1991; Hamada *et al.* 1994; Miura and Ohme-Takagi 1994).

As meiosis of *P. yezoensis* occurs at the time of conchospore germination (Ma and Miura 1984; Ohme and Miura 1988; Tseng and Sun 1989), the non-parental wild-type dihybrid sporothalli (choncelis), which are derived from the reciprocal crosses between the green-type and

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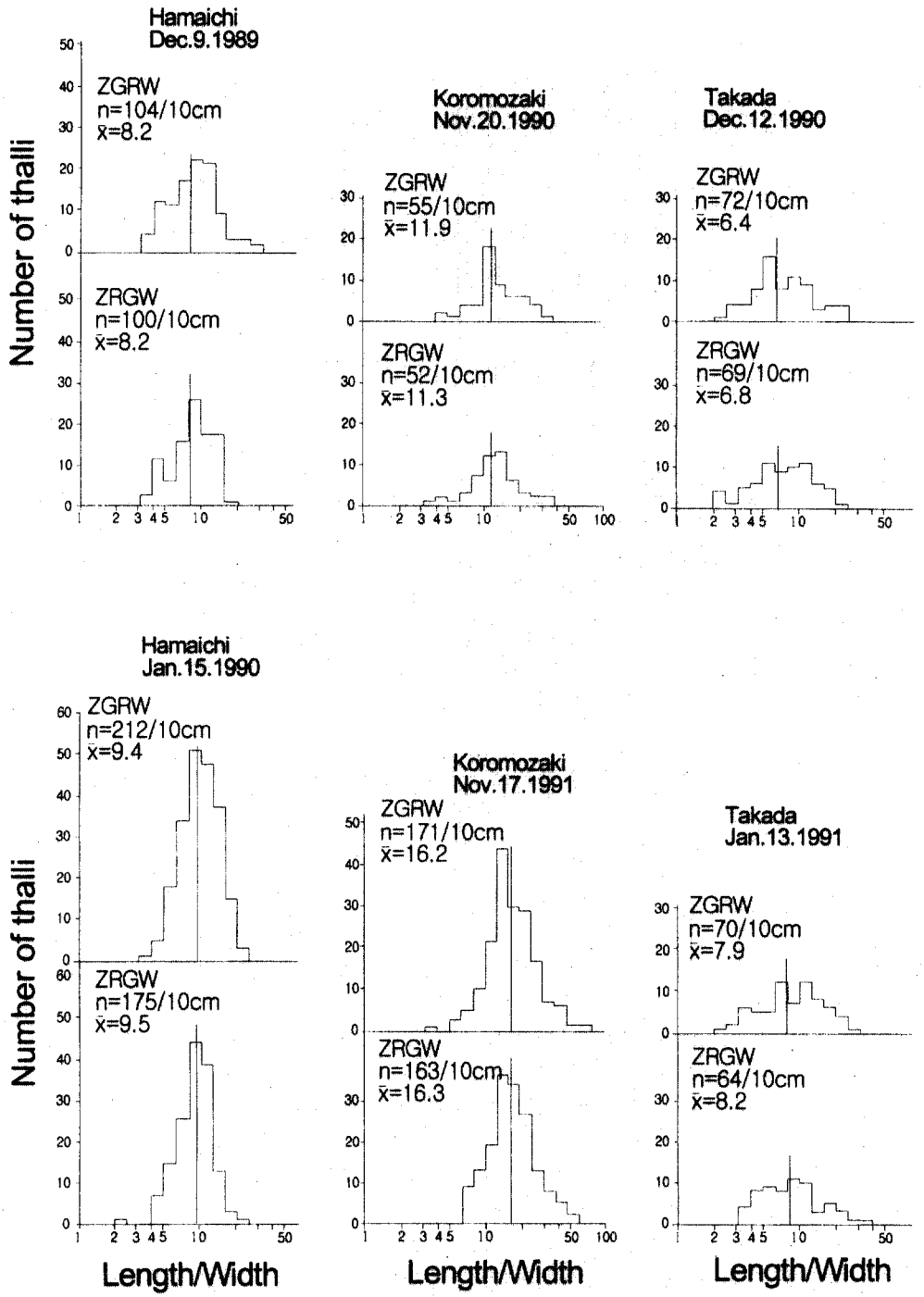

Fig. 1. Comparison of the ratio of length to width of gametothalli longer than 5 cm per 10 cm long netting twine between the ZGRW and the ZRGW of *Porphyra yezoensis* in 1989 and 1990 *Porphyra* years, autumn and spring harvesting seasons and three farming sites: Hamaichi aquafarm in Ishinomaki Bay, Koromozaki in Mikawa Bay and Takada in Ariakekai Bay. Upper histograms show the ZGRW and lower the ZRGW. The vertical bars in histograms are mean values of ratio of length to width.

the red-type mutant, produce respective dihybrid conchospores. They germinate into sectorially variegated chimeral gametothalli and single uniformly phenotypic gametothalli of parental ditype, non-parental ditype and tetrad type in color. The pattern of gametothalli development is similar to the ordered tetrad types found in fungi *Neurospora* (Ohme and Miura 1988; Shin 1991; Miura and Ohme-Takagi 1994).

Each of the ZGRW and the ZRGW is an autozygous and homozygous pure line that was bred from one sin-

Table 1. Comparison of contents ($\mu g/cm^2$, % of D.W.) of chlorophyll a (Chl. *a*), phycoerythrin (PE) and phycocyanin (PC), and their ratios between the recombinant wild-types of the ZGRW and the ZRGW resulting from the reciprocal crossings between the green-type and the red-type mutants in *Porphyra yezoensis*

Cultivar	Chl. *a*	PE ($\mu g/cm^2$)	PC	Chl. *a*	PE (% of D.W.)	PC	PE / Chl. *a*	PC / Chl. *a*	PE / PC
Autumn harvest of growing test									
Ishinomaki Bay, Hamaichi, Dec.09, 1989									
ZGRW	4.18	36.5	15.4	0.596	5.21	2.20	8.73	3.68	2.37
ZRGW	4.16	36.9	14.0	0.584	5.18	1.97	8.87	3.37	2.64
Mikawa Bay, Koromozaki, Nov. 20, 1990									
ZGRW	3.97	39.7	20.3	0.227	2.27	1.16	10.0	5.11	1.96
ZRGW	3.95	40.2	20.3	0.246	2.50	1.26	10.2	5.14	1.98
Ariakekai Bay, Takada, Dec. 12, 1990									
ZGRW	4.44	45.0	19.6	0.306	3.10	1.35	10.1	4.41	2.30
ZRGW	4.50	46.2	21.2	0.319	3.28	1.50	10.3	4.71	2.18
Spring harvest of growing test									
Ishinomaki Bay, Hamaichi, Jan. 15, 1990									
ZGRW	3.54	32.8	16.8	0.603	5.59	2.86	9.27	4.75	1.95
ZRGW	3.53	32.7	16.5	0.605	5.61	2.83	9.26	4.67	1.98
Mikawa Bay, Koromozaki, Jan. 17, 1991									
ZGRW	1.49	10.1	5.7	0.861	5.84	3.30	6.78	3.83	1.77
ZRGW	1.40	10.4	5.5	0.932	6.92	3.66	7.43	3.93	1.89
Ariakekai Bay, Takada, Jan. 13, 1991									
ZGRW	3.86	33.7	15.9	0.219	1.91	0.903	8.73	4.12	2.12
ZRGW	3.88	34.2	16.0	0.209	1.85	0.863	8.81	4.12	2.14

gle carpospore. The carpospore was fixed by intragametophytic selfing of one specific individual, selected from many single uniformly colored gametothalli of non-parental wild-types.

The gametothalli of the ZGRW and the ZRGW were cultivated to identify the inheritance mode of yield, photosynthetic pigments content, red rot disease-resistance, color and luster, and volatile sulfur compounds concentration at different farm sites and years in Japan. The population of the ZGRW and the ZRGW were cohort seedlings from their respective seed pools. They were always cultivated on the neighboring nets to each other in the same farm sites by same way, harvested on the same day, then processed to make dried sheet using the same processing machine and procedure by a *Porphyra* farmer. The measurements of the yield, photosynthetic pigment content, red rot disease-resistance, color and luster (Murakami Color Institute SG-102 Color-checkman for the Hamaichi sample and SG-103R for the others), and volatile compounds concentration were described in the previous studies (Shin 2003 a, 2003 b). The color and luster on both sides folding in two of a bundle of ten dried sheets of *Porphyra* were measured by turning the other side using the SG-103R Color-checkman. The ratio of the color and luster was set up at 0.95:0.05.

RESULTS AND DISCUSSION

Fig. 1 shows the comparison of the ratio of length to width of gametothalli longer than 5 cm long gametothalli per 10 cm long netting twine between the ZGRW and the ZRGW of *P. yezoensis*.

The ratio of length to width of gametothalli of the ZRGW to the ZGRW was similar, ranging from 94 to 106%. The difference of the standing crops as a marker of yield was not significant; therefore, the standing crop (yield) might be governed by the nuclear inheritance mode.

The green-type mutant showed slower growth rate at the early stage and much rapid rate at the later stage compared to those found in the wild-type and the red-type mutant. The overall relative growth rates of the green-type were somewhat higher than the wild-type and the red-type mutant. The number of sterile green-type mutants was higher than the other two types

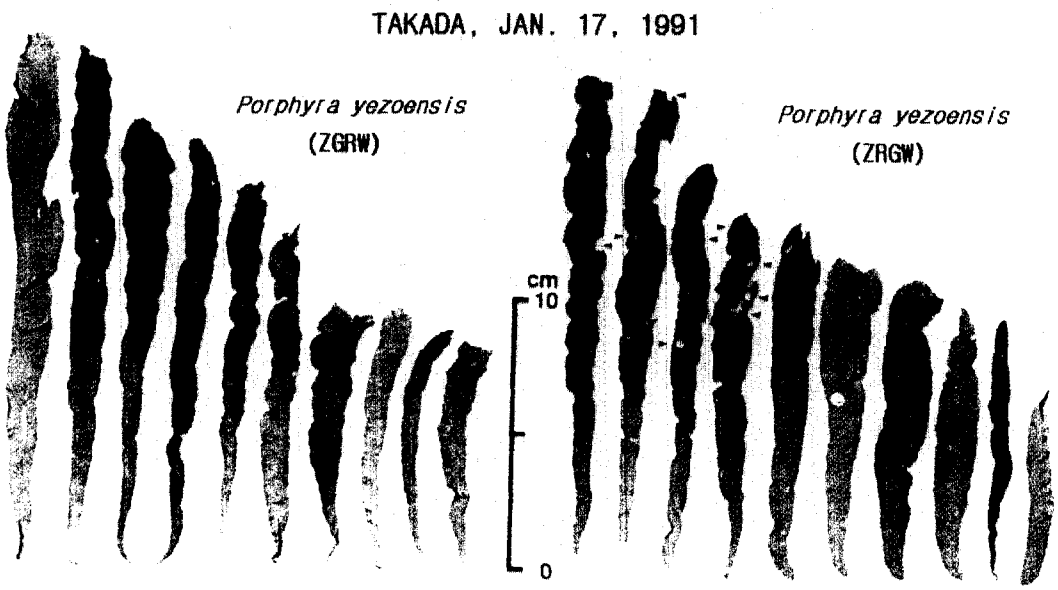

Fig. 2. Herbarium specimens showing the difference of resistance to red rot disease between the ZGRW and the ZRGW of *Porphyra yezoensis* collected at the Takada aquafarm, Ariakekai Bay on Jan.17, 1991. Ten specimens on the left are the ZGRW and on the right the ZRGW. Arrowheads show lesions of red rot infected by *Pythium porphyrae*.

Table 2. Comparison of the color and luster in dried sheets of *Porphyra* between the recombinant wild-types of the ZGRW and ZRGW resulting from the reciprocal crossings between the green-type and the red-type mutants in *Porphyra yezoensis*

(grade/mark)

Farm site*	Harvesting date	Cultivar	Color	Luster	Total
Hamaichi	Jan.08,1990	ZGRW	3/167	8/104	4/158
		ZRGW	3/172	6/122	3/165
Koromozaki	Nov.25,1990	ZGRW	1/183	3/66	1/177
		ZRGW	6/137	4/59	6/133
Takada	Nov.13,1990	ZGRW	6/133	4/50	6/129
		ZRGW	6/138	4/55	6/134
Koromozaki	Dec.24,1990	ZGRW	1/187	1/85	1/182
		ZRGW	1/187	3/69	1/181
Takada	Jan.06,1991	ZGRW	3/164	3/69	3/159
		ZRGW	4/158	3/65	4/153

*Hamaichi : Ishinomaki Bay; Koromozaki: Mikawa Bay; Takada: Ariakekai Bay.

(Migita and Fujita 1983; Kato and Aruga 1984). The mean value of ratio of length to width of gametothalli is high (Migita and Fujita 1983). Therefore, the characters such as the delay of early growth stage and higher sterility need further investigation on the point of the maternal inheritance view.

Table 1 shows the comparison of contents of chlorophyll *a* (Chl. *a*), phycoerythrin (PE) and phycocyanin (PC), normalized by area and dry weight, between the ZGRW and ZRGW of *P. yezoensis*. Area-based ratios of Chl. *a*, PE and PC of the ZRGW to the ZGRW were 94-101, 100-103 and 91-108%, respectively. Dry weight-based ratios of Chl. *a*, PE and PC of the ZRGW to the ZGRW were 95-108, 97-119 and 90-111%, respectively. Ratios of PE/Chl. *a*, PC/Chl. *a* and PE/PC of the ZRGW to those of the ZGRW were 100-110, 92-107 and 95-111%, respectively. The differences of the content of photosynthetic pigments between the ZRGW and the ZGRW were not significant; therefore, the photosynthetic pigments contents might be governed by the nuclear inheritance mode.

Fig. 2 shows herbarium specimens representing the

Table 3. Comparison of concentration of volatile sulfur compounds in dried sheets of *Porphyra* between recombinant wild-types of ZGRW and the ZRGW resulting from the reciprocal crossings between the green-type and the red-type mutants in *Porphyra yezoensis* (ppb)

Farm site*	Harvesting date	Cultivar	Dimethyl sulfide	Hydrogen sulfide	Methyl mercataptan
Hamaichi	Jan. 08, 1990	ZGRW	9428	1449	69
		ZRGW	5000	1260	50
Koromozaki	Nov. 25, 1990	ZGRW	282122	874	15
		ZRGW	91707	964	40
Takada	Nov. 13, 1990	ZGRW	246506	2855	103
		ZRGW	40501	450	17
Koromozaki	Dec. 24, 1990	ZGRW	6319	1020	23
		ZRGW	2361	846	22
Takada	Jan. 06, 1991	ZGRW	643	389	37
		ZRGW	474	333	28

*Hamaichi : Ishinomaki Bay; Koromozaki: Mikawa Bay; Takada: Ariakekai Bay.

difference of resistance to the red rot disease between the ZGRW and the ZRGW. The number of lesions on 100 randomly collected gametothalli of the ZGRW and the ZRGW of visually infected with the red rot disease were 18 and 75. The notable resistance to the red rot disease of the green-type mutant of *P. yezoensis* has been reported (Miura 1979, 1985; Migita and Fujita 1983). Therefore, the inheritance mode of this character might be cytoplasmic.

Table 2 shows the comparison of the color and luster in dried sheets of the ZGRW and the ZRGW. The grades and marks of color, luster and total varied widely depending on the farming seasons and farm sites. The results of one Koromozaki products were significantly different. Generally, the above properties were similar between the ZGRW and the ZRGW. The color and luster might be controlled by the nuclear inheritance mode.

Table 3 shows the comparison of concentration of volatile compounds in dried sheets of *Porphyra* between the ZGRW and the ZRGW. The concentration of dimethyl sulfide of the ZGRW was higher than that of the ZRGW in the range of 136-609%. The concentrations of hydrogen sulfide and methylmercaptan of the ZGRW were slightly higher than those of the ZRGW except one case. The concentration control mechanism of dimethyl sulfide might be transmitted by the cytoplasmic inheritance mode.

It is very important to manifest morphological, ecological, physiological, biochemical, physicochemical, and genetic characteristics of cultivars in (1) making the breeding strategy and tactics, (2) improving the rational breeding management, and (3) practicing the operation of the breeding program. Therefore, the further study of genetics including qualitative and quantitative traits is needed for growing these new cultivars.

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