Jap. J. Phycol. (Sôrui) 33: 312-316. December 10, 1985

Effect of growth temperature on photosynthesis-temperature relationships of a tide pool alga *Cladophora rudolphiana* (Chlorophyceae)*

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KATAYAMA, N., TOKUNAGA, Y. and YOKOHAMA, Y. 1985. Effect of growth temperature on photosynthesis-temperature relationships of a tide pool alga *Cladophora rudolphiana* (Chlorophyceae). Jap. J. Phycol. 33: 312-316.

Fronds of *Cladophora rudolphiana* (AGARDH) HARVEY were collected from a tide pool at the higher intertidal zone in summer where the water temperature exceeded 40°C and they were cultured at 15, 25, 30 and 35°C for two months. The growth rate was highest at 30°C. The optimum temperature for photosynthesis was 35°C in the frond grown at 35°C, while it was slightly higher than 30°C in that grown at 15°C, and was intermediate in those grown at 25 and 30°C. The maximum photosynthetic rate was observed in the frond grown at 35°C, and it was about three times higher than that observed in the frond grown at 15°C.

The heat resistance, however, apparently decreased in the frond grown at 15°C. It's photosynthetic activity was completely lost with one hour exposure at 40°C and could not be restored with incubation at 30°C, but the frond grown at 35°C retained it's photosynthetic activity under the same condition. The fronds grown at 25 and 30°C lost their photosynthetic activity to some extent with one hour exposure at 40°C, but they could recovered their activity with incubation at 30°C.

These results indicate that *Cladophora rudolphiana* is a species which is well adapted to high temperatures.

Key Index Words: Cladophora rudolphiana; *heat resistance*; *photosynthesis*; *Productmeter*; *seaweed*; *temperature*; *tide pool.*

Photosynthesis-temperature relationships in photosynthetic organisms are considered to be closely related to the temperature regimes of their habitats. YOKOHAMA and his colleagues confirmed this hypothesis for many seaweeds by comparing the photosynthetic characteristics of their fronds collected from different habitats or in different seasons (YOKOHAMA 1971, 1973, HATA and YOKOHAMA 1976, MIZUSAWA *et al.* 1978).

There seemed to be a general tendency for algal species distributed in the warmer sea area or found in summer, to be more heat resistant than those distributed in the colder sea area or found in seasons other than summer. Physiological differences found among the fronds collected from natural habitats, however, cannot be considered as purely genetic, since the characteristics of an organism are variable and are affected by environmental factors. Therefore, a genetic character of a species should be determined by comparing the physiological characteristics of the same species from different environments.

* Contribution from the Shimoda Marine Research Center, No. 456.

The present study was planned to compare the photosynthesis-temperature relationships in the fronds of a seaweed cultured at different temperatures. The species used as the material was *Cladophora rudolphiana*, which seems to be extremely heat resistant because it is abundant in tide pools at the higher intertidal zone in summer, where the water temperature often exceeds 40°C.

Materials and Methods

The algal fronds were collected in July, 1983, from a tide pool at the higher intertidal zone in Nabeta Bay near the Shimoda Marine Research Center, the University of Tsukuba. The fronds were cultured in 90 ×100 mm culture dish containing 400 m*l* sterilized Jamarin artificial seawater, Jamarin Laboratory Co. Ltd., Osaka, at 30°C for three months to increase the fronds, and then at 15, 25, 30 and 35°C for two months under a light intensity of 7 klux provided with 12 : 12 hr L : D cycles by white fluorescent light. The seawater was replaced every seven days during culture.

Growth rate of the alga was estimated from increment in fresh weight every week. Prior to the measurement of fresh weight, the algal fronds were transferred to centrifuge tubes into which cotton wool was packed, and the residual seawater was removed by centrifugation.

The rate of algal photosynthesis and respiration were measured with a Productmeter, a differential gas-volumeter, devised by YOKOHAMA and ICHIMURA (1969) and subsequently improved by YOKOHAMA *et al.* (1985). The reaction and compensation vessels were of Warburg type and of about 40 m*l* capacity. About 0.3 g fresh weight of frond was placed in the reaction vessel with 10 m*l* of the artificial seawater. When the photosynthetic rate was measured, the frond was irradiated with light of 30 klux, regarded to be sufficiently intense to saturate the photosynthesis of the frond under ordinary conditions.

Results

Table 1 shows the growth rates of the fronds of *Cladophora rudolphiana* at different temperatures. They were examined during the last one month in the culture period of two months. The growth rate was highest at 30°C among the temperatures examined.

After the fronds had been cultured at various temperatures for two months, photosynthesis-temperature relationships were determined in each frond. Fig. 1 shows the net photosynthesis- and respiration-temperature curves obtained from the fronds grown at 15, 25, 30 and 35°C. As can be seen in the figure, the photosynthetic property of this alga was changed slightly by the growth temperature. The optimum temperature for photosynthesis was 35°C in the frond grown at 35°C, while it was a little higher than 30°C in the frond grown at 15°C. The optimum temperatures in the fronds grown at 25 and 30°C seemed to be intermediate. The maximum photosynthetic rate increased with increase in growth temperature within the range examined (15–35°C). That rate of the frond grown at 35°C was about three times higher than that of the frond grown at 15°C.

Heat resistance was apparently different among the fronds cultured at different temperatures. The frond grown at 15°C lost not only photosynthetic activity but also respiratory activity with exposure at 40°C for several minutes, while the fronds grown at

Table 1. Growth rates of the fronds of *Cladophora rudolphiana* during culture at 15, 25, 30 and 35°C in an artificial seawater, Jamarin S, under a light intensity of 7 klux provided with 12 : 12 hr L : D cycles by white fluorescent light.

Growth temperature (°C)	Percent increase in fresh weight per month (%)
15	175
25	280
30	470
35	200

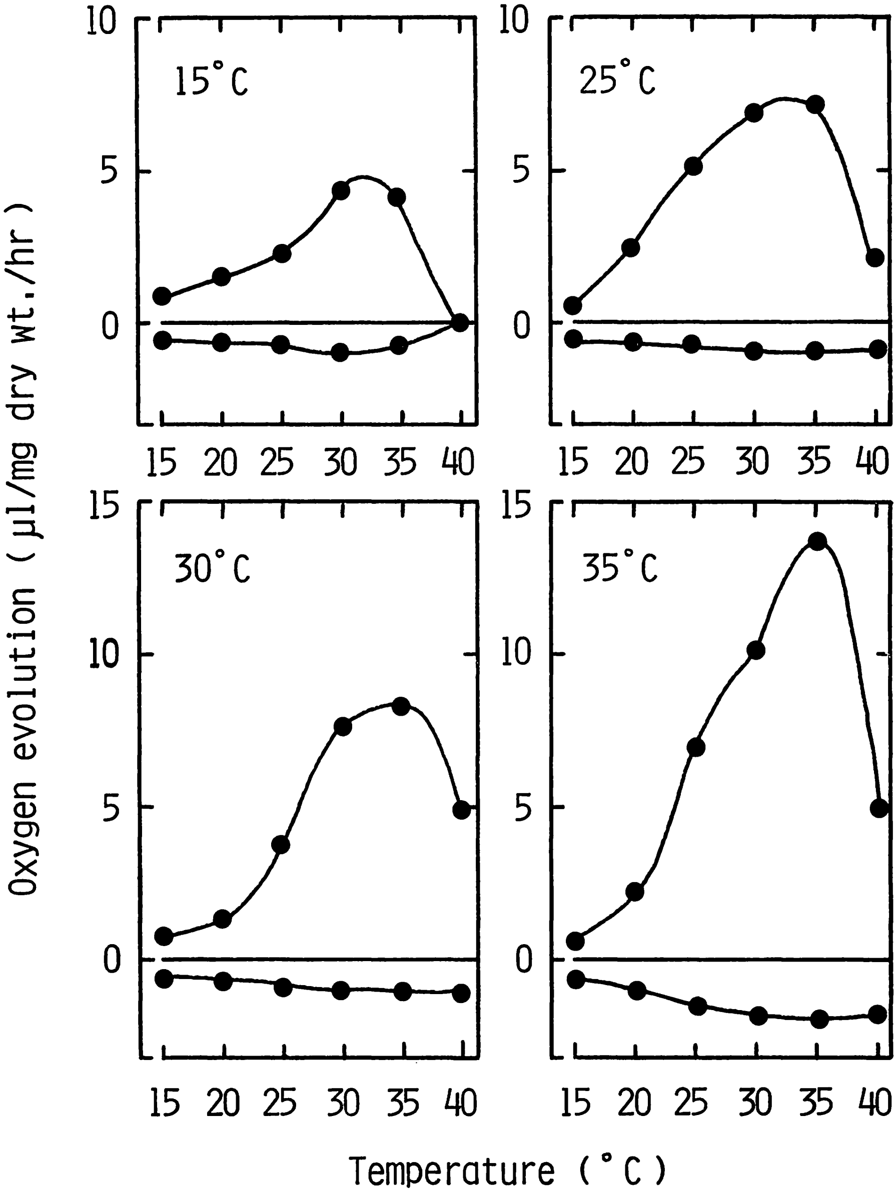

Fig. 1. Net photosynthesis- and respiration-temperature curves in the fronds cultured at 15, 25, 30 and 35°C. Light intensity was 30 klux.

25, 30 and 35°C retained both activities under the same heat exposure (Fig. 1). The photosynthetic machinery of the fronds grown at 25 and 30°C seemed, however, to be more or less injured at 40°C. Restoration of the photosynthetic activity after exposure at 40°C for one hour was examined at 30°C for each frond. As shown in Fig. 2, neither the photosynthetic nor respiratory activity of the frond grown at 15°C was recovered, while the photosynthetic activities of the fronds grown at 25 and 30°C were completely recovered after 20 hr and 3 hr, respectively.

Discussion

From the result that the growth rate of

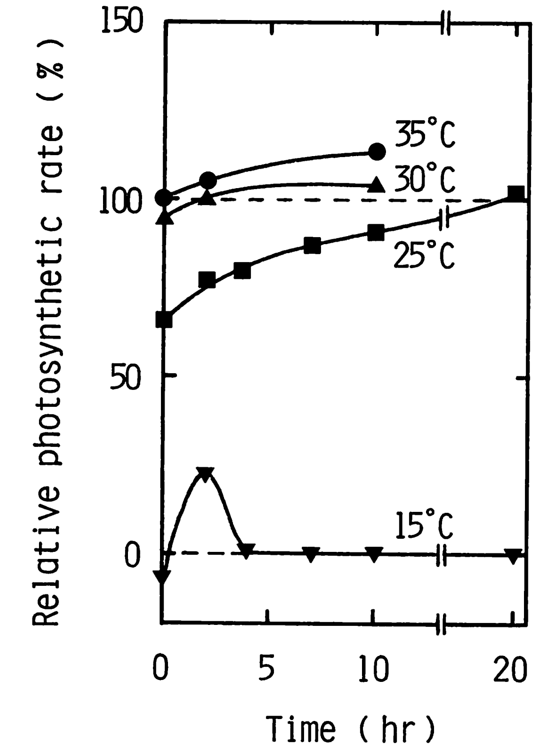

Fig. 2. Time courses of restoration of photosynthetic activity of the fronds at 30°C after they were exposed at 40°C for one hour. The temperatures in the figure are those at which each frond was cultured. 100% represents the photosynthetic rate in each frond before the heat treatment.

Cladophora rudolphiana was highest at 30°C among the temperatures examined, this alga can be regarded as a species which is well adapted to a high temperature. Actually this alga is abundant in summer in tide pools where the water temperature often exceeds 40°C.

It is remarkable that the optimum temperature for photosynthesis was higher than 30°C even in the frond of this alga grown at 15°C, while it was reported to be about 15°C in most of green algae collected from the other habitats in Nabeta Bay in winter where the water temperature was about 15°C (YOKOHAMA 1971, 1973). The adaptive property to a high temperature in this alga is also indicated by the result that the maximum photosynthetic rate in the frond grown at 35°C was about three times higher than that in the frond grown at 15°C.

The variation in the optimum temperature for photosynthesis was rather small among the fronds grown at different temperatures. Even between the fronds grown at 15°C and 35°C, the difference in the optimum temperature was only a few degrees Celsius. On the contrary, the heat resistance varied remarkably among those fronds. The frond grown at 15°C completely lost not only the photosynthetic activity but also respiratory activity with exposure at 40°C for one hour. However, the photosynthetic activity of the frond grown at 35°C was not affected with the same heat exposure at all.

The shift in the optimum temperature for photosynthesis and the variation in heat resistance according to difference in growth temperature, seem to be caused by different mechanisms. The former is likely to be caused by modification of the enzymic systems in the dark reaction of photosynthesis, and the latter is likely to be closely related to the change in fatty acid composition of lipids or lipid phases of membranes (cf. SATO and MURATA 1980, MURATA *et al.* 1984).

Acknowledgment

The authors express their deep gratitude to Prof. Y. SAKAI of the Institute of Algological Research, Faculty of Science, Hokkaido University for his kind identification of the material.

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片山舒康*・徳永裕子*・横浜康継: タイドプールより得たタマリシオグサ（緑藻）の光合成温度特性に及ぼす培養温度の影響**

夏季には水温が 40°C を超えることの多い潮干帯上部のタイドプールから，タマリシオグサの藻体を採集した。この藻体を 15, 25, 30, 35°C で培養したところ，30°C で培養したものが最もよく成長した。光合成の最適温度は，35°C で培養した藻体では 35°C であったが，15°C で培養したものでは 30°C よりやや高い温度，25°C と 30°C 培養のものでは，それらの中間であった。最大光合成速度は，35°C 培養の藻体では 15°C 培養のものの約 3 倍であった。これらの結果は，タマリシオグサが高温に適応した種であることを示唆している。

ところが，15°C で培養した藻体の耐熱性は著しく低下していた。15°C 培養の藻体は，40°C では光合成と呼吸のどちらの活性も示さず，40°C に一時間置いたのち 30°C にもどしても活性は回復しなかった。それに対して，25, 30, 35°C で培養した藻体は 40°C でも活性が完全には失われず，30°C にもどした時には活性の回復が認められた。(*184 小金井市貫井北町 4-1-1，東京学芸大学生物学教室，**415 静岡県下田市 5-10-1，筑波大学下田臨海実験センター)