Journal of Applied Phycology **10:** 51–53, 1998.

Light dependency of the photosynthetic recovery of *Nostoc flagelliforme*

Kunshan Gao[1,2,*], Baosheng Qiu[1], Jianrong Xia[2] & Aijun Yu[1]
[1] *Institute of Hydrobiology, The Chinese Academy of Sciences, Wuchang, Wuhan, Hubei, 430072 China*
[2] *Institute of Energy and Environmental Sciences, Science Center, Shantou University, Shantou, Guangdong, 515063 China*

[*] Author for correspondence; e-mail ksgao@public.wh.hb.cn

Received 9 December 1997; revised 14 January 1998; accepted 15 January 1998

Key words: blue-green alga, cyanobacterium, F_v/F_m light, *Nostoc flagelliforme*, photosynthesis, rewetting

Abstract

PS II photochemical efficiency (F_v/F_m) of *Nostoc flagelliforme* was examined after rewetting in order to investigate the light-dependency of its photosynthetic recovery. F_v/F_m was not detected in the dark, but was immediately recognized in the light. Different levels of light irradiation (4, 40 and 400 μmol photon m^2 s^{-1}) displayed different effects on the recovery process of photosynthesis. The intermediate level led to the best recovery of photochemical efficiency; the low light required longer and the high light inhibited the extent of the recovered efficiency. It was concluded that the photosynthetic recovery of *N. flagelliforme* is both light-dependent and influenced by photon flux density.

Nostoc flagelliforme, a terrestrial blue-green alga in arid areas of N. and N-W China, is of great economic value in China and biological studies have been carried out for some decades in order to develop its cultivation technology (Gao, 1998). *N. flagelliforme* is known to be drought tolerant, heat-resistant (Mei & Cheng, 1990), and photosynthetically productive even under extremely dry conditions *in situ* (Sheng et al., 1984; Cui, 1985). However, physiological activities, like respiration and nitrogen fixation, could only be detected when the alga was wet (Mei & Cheng, 1989). Rewetting retrieves or enhances the physiological activities of the alga. For long-stored samples (>2 yr), physiological activities following rewetting were found to recover in the sequence, respiration, photosynthesis and then nitrogen fixation (Scherer et al., 1984). The time required for the recovery appears to be correlated with the length of storage period (Gao, 1998). However, environmental factors may influence the process of physiological recovery and thus the time span required.

Light is one factor which would seem likely to influence the physiological recovery of the alga but little has been documented on this. The aim of the present study is to investigate whether the photosynthetic recovery of *N. flagelliforme* is a light-dependent process.

Materials and methods

Nostoc flagelliforme (Berk. & Curtis) Born & Flah. was collected at Siziwangqi, Inner Mongolia, in 1995 and stored under dry conditions until used for experiments in 1997. Samples were wetted with distilled water and maintained in the dark or exposed to light at 20 °C. In the case of light, photosynthetically active radiation was measured with a quantum sensor (SKP 200, ELE International); the alga was exposed to three levels of fluorescent irradiation (4, 40, 400 μmol photon m^2 s^{-1}). These levels are here termed low, intermediate and high, although even the last is well below the maximum values found under fully exposed conditions in nature.

The ratio of variable to maximal fluorescence (F_v/F_m) of the dark adapted samples was used as a measure of photosynthetic efficiency, which has been demonstrated in various plants to be proportional to the

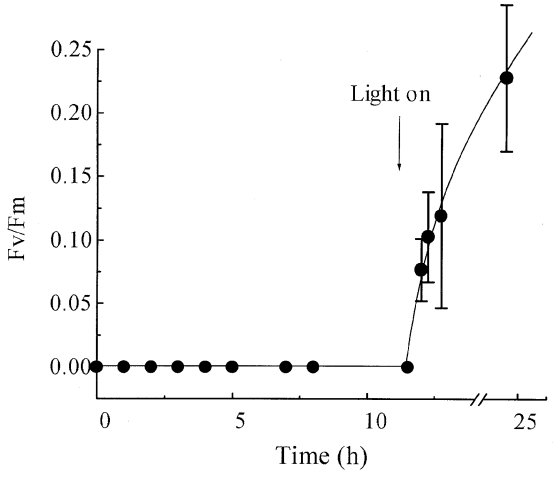

Figure 1. Change of F_v/F_m with time in *Nostoc flagelliforme* after rewetting in the dark and light (40 μmol m^2 s^{-1}). Mean of 15 samples ± SD.

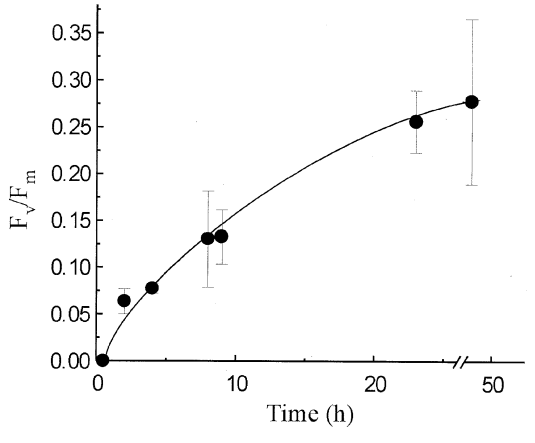

Figure 2. Change of F_v/F_m with time in *Nostoc flagelliforme* after rewetting in the low light (4 μmol m^2 s^{-1}). Mean of 15 samples ± SD.

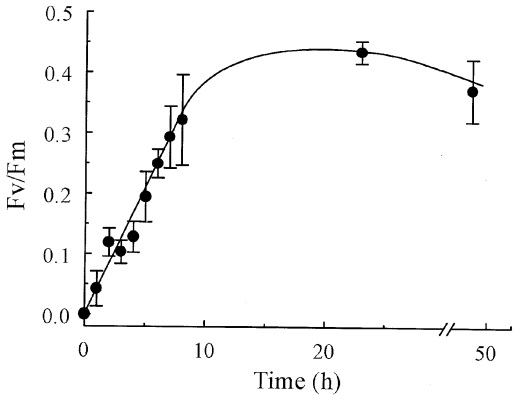

Figure 3. Change of F_v/F_m with time in *Nostoc flagelliforme* after rewetting in intermediate light level (40 μmol m^2 s^{-1}). Mean of 15 samples ± SD.

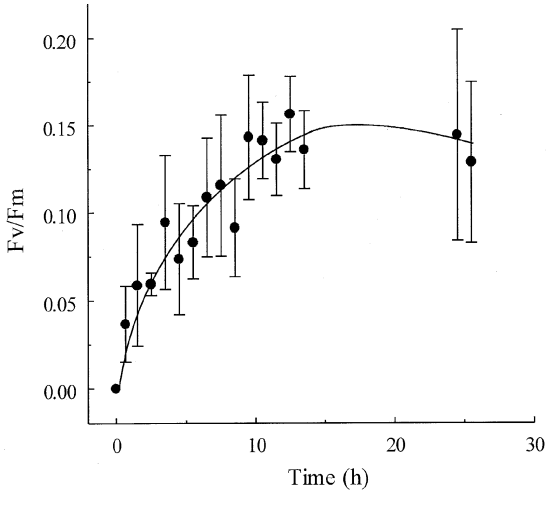

Figure 4. Change of F_v/F_m with time in *Nostoc flagelliforme* after rewetting in the high light (400 μmol m^2 s^{-1}). Mean of 15 samples ± SD.

quantum yield of photochemistry (Bjorkman, 1987; Somersalo & Krause, 1989; Krause & Weis, 1991; Hanelt, 1992). $F_v = F_m - F_o$ in which F_o is the initial fluorescence observed when all reaction centers of PSII are 'open', and F_m is the maximal fluorescence when all reaction centers are 'closed'. F_v/F_m was determined by using a Plant Efficiency Analyzer (PEA MK2, Hansatech Instrument LTD, German). Three segments (1–2 cm long) cut from different filaments of *N. flagelliforme* were mounted in each leaf-clip for 15 min dark adaptation before the fluorescence was measured. Each measurement was repeated five times.

Results

When *N. flagelliforme* was rewetted and maintained in the dark, *in vivo* fluorescence remained undetectable; however, when light was shed on, it was recognized immediately, and F_v/F_m increased with time (Figure 1). *In vivo* fluorescence was not detectable in dry samples. The result shows that the photosynthetic recovery of *N. flagelliforme* after rewetting requires light.

Light irradiation also affects the extent and pace of photosynthetic recovery. When *N. flagelliforme* was rewetted and exposed to low, intermediate and high light (4, 40, 400 μm m^2 s^{-1}), F_v/F_m increased with

time under all condition (Figures 2, 3, 4); however, it reached its maximum faster at the intermediate and high levels of light than at the low level. F_v/F_m ratio reached the maximum in about 11 h at the intermediate and the high regimes of light; beyond 50 h at the low level. The half-time of recovery (K_m) is about 10, 5 and 3.5 h for the low, intermediate and high light regimes, respectively. This indicates that higher light irradiation results in faster pace of the photosynthetic recovery. Nevertheless, the average maximal values of F_v/F_m were highest (0.44) at the intermediate level of light, median (0.29) at the low and lowest (0.15) at the highest level of light, indicating that high light irradiation negatively affected the recovery of photosynthetic efficiency.

Discussion

In the present study, the alga had been stored for about two years before its use for the experiment; the maximal photosynthetic efficiency was reached in about 11 h under moderate light irradiation. Scherer et al. (1984) reported that rewetted *N. flagelliforme* after storage for two years attained its maximal rates of photosynthesis in about 9 h. The time required for full photosynthetic recovery in the present study thus agrees well with that reported by Scherer et al.

This study made it clear that the photosynthetic recovery of the alga after rewetting is light-dependent: light intensity affects the recovery process. The photosynthetic recovery process of *N. flagelliforme* may be PS II protein synthesis-dependent and/or chlorophyll complex activation- dependent; and light may be essential to activating phycobiliproteins and/or chlorophyll protein complexes of *N. flagelliforme* after rewetting. At least six kinds of chlorophyll protein complexes are known in plants (Horton et al., 1994). Light is known to stimulate the turnover rate of the D_1 protein of PS II reaction center that carries several of the primary components of the photochemical reaction (Demmig-Adams & Adams, 1992). This study showed that higher light irradiation resulted in faster photosynthetic recovery. It is possible that activation or synthesis of PS II reaction center proteins is light-intensity-dependent. However, high light inhibited the extent of recovered photosynthetic efficiency. It seems likely that this is due to photodamage of the photosynthetic apparatus triggered by high light during the period of recovery, when the alga was not yet capable of dissipating excessive excitation energy.

Acknowledgements

This study was funded by the National Natural Science Foundation of China ('GUO JIA JIE CHU QING NIAN JI JIN', No. 39625002) and, by The Chinese Academy of Sciences ('BAIREN' plan).

References

Bjokman O (1987) Low-temperature chlorophyll fluorescence in leaves and its relationship to photon yield of photosynthesis in photoinhibition. In Kyle DJ, Osmond CB, Arntzen CJ (eds), Photoinhibition. Elsevier, Amsterdam: 123–144.

Cui Z (1985) The distribution of *Nostoc flagelliforme* in Siziwangqi county, Inner Mongolia. Acta Phytoecologica et Geobotanica Sinica 9: 223–230 (in Chinese with English summary).

Demmig-Adams B, Adams WW (1992) Photoprotection and other responses of plants to high light stress. Annu. Rev. Plant Physiol. Plant Mol. Biol. 43: 599–626.

Gao K (1998) Chinese studies on the edible blue-green alga, *Nostoc flagelliforme*: a review. J. appl. Phycol. 10: 37–49.

Hanelt D (1992) Photoinhibition of photosynthesis in marine macrophytes of the South Chinese Sea. Mar. Ecol. Progr. Ser. 82: 199–206.

Horton P, Ruban AV, Walters RG. (1994) Regulation of light harvesting in green plants. Indication by nonphotochemical quenching of chlorophyll fluorescence. Plant Physiol. 106: 415–420.

Krause GH, Weis E. (1991) Chlorophyll fluorescence and photosynthesis: the basics. Annu. Rev. Plant Physiol. Plant mol. Biol. 42: 313–349.

Mei JX, Cheng ZJ (1989) Effects of water supplying and illumination on the physiological activity of *Nostoc flagelliforme* Born. et Flah. J. Western-north Normal Univ. 1: 63–68 (in Chinese with English summary).

Mei JX, Cheng ZJ (1990) Effects of temperature on physiological activities of *Nostoc flagelliforme* Born. et Flah. J. Western-north Normal Univ. 1: 75–85 (in Chinese with English summary).

Scherer S, Ernst A, Chen TW, Böger P (1984) Rewetting of drought-resistant blue-green algae: time course of water uptake and reappearance of respiration, photosynthesis, and nitrogen fixation. Oecologia 62: 418–423.

Scherer S, Ernst A, Chen TW, Boger P (1986) Recovery of adenine-nucleotide pools in terrestrial blue-green algae after prolonged drought periods. Oecologia 68: 585–588.

Sheng XW, Jiang X, Cui ZY (1984) Preliminary studies on the photosynthetic characteristics of *Nostoc flagelliforme in situ*. Steppe Ecosystem Research 4: 66–70 (in Chinese).

Somersalo S, Krause GH (1989) Photoinhibition at chilling temperature. Fluorescence characteristics of unhardened and cold-acclimated spinach leaves. Planta 177: 409–416.