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UV-B radiation suppresses chlorophyll fluorescence, photosynthetic pigment and antioxidant systems of two key species in soil crusts from the Tengger Desert, China

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ABSTRACT

Field studies were conducted to investigate the influence of ultraviolet-B (UV-B) radiation on the moss *Bryum argenteum* and cyanobacterium *Microcoleus vaginatus* isolated from biological soil crusts (BSC) from the southeastern fringe of the Tengger Desert, China. UV-B supplementation with 0.33, 0.50, and 0.66 W m^{-2} was achieved using fluorescence tube systems for 40 days. We investigated Chl fluorescence parameters as well as photosynthetic pigment contents. We also measured lipid peroxidative production, malondialdehyde (MDA), superoxide dismutase (SOD) and catalase (CAT) which quench free radicals and prevent oxidative stress. We found that higher UV-B radiation significantly decreased ($p < 0.05$) the Chl fluorescence parameters, Chl and carotenoid (Car) contents, and antioxidative enzymes activities. In addition, higher intensities of UV-B radiation induced dramatic increases in MDA content of *B. argenteum* and *M. vaginatus*. The results of this study showed that increased levels of UV-B radiation caused detrimental effects on chlorophyll (Chl) fluorescence, photosynthetic pigment and antioxidant systems of *B. argenteum* and *M. vaginatus*. *B. argenteum* was more sensitive to enhanced UV-B radiation than *M. vaginatus*. Increased UV-B intensity causes changes in the composition and structure of BSC that could impair their protective ecological functions in desert areas.

1. Introduction

Biological soil crusts (BSC) are highly specialized soil-surface consortia of cyanobacteria, green algae, lichens, mosses and other organisms (Belnap and Lange, 2003). They have extraordinary capability to survive desiccation and extreme temperatures, thereby becoming the dominant biological surface feature of arid and semi-arid regions which occupy more than 40% of the terrestrial surface (Bowker et al., 2005). Ecological roles and ecosystem services of BSC have been clearly documented by recent studies, and include maintaining soil stability and fertility (Li et al., 2005), alleviating water and wind erosion (Barger et al., 2006), creating habitats for the germination and establishment of plants (Li et al., 2004), and providing habitat for soil animals and insects (Li et al., 2006). Given these important functions, a comprehensive understanding of the responses of BSC to changes in environmental factors is essential for their assessment and the protection of desert ecosystems (Jia et al., 2008). Many studies have discovered that the establishment and development of BSC are affected by a series of abiotic and environmental factors including UV-B radiation (Lud et al., 2002), wind erosion and sand burial (Jia et al., 2012), topsoil moisture (Eldridge and Tozer, 1997), soil pH (Ponzetti and McCune, 2001), and other soil physicochemical properties (Greene and Darnall, 1990).

Depletion of ozone in the stratosphere has been caused mainly by the emissions of chlorofluorocarbons, methane, and nitrous oxide (Molina and Rowlands, 1974). Atmospheric ozone concentrations have been 6–9% lower than historical averages and have continued at low levels in the early summers of northern mid-latitudes until the 1980s, and has remained relatively constant over the past few years. Reductions in the emissions of gaseous pollutants are predicted to lead to reductions in ozone depletion, but it will take many years

Abbreviations: BSC, biological soil crusts; Car, carotenoid; CAT, catalase; Chl, Chlorophyll; *ETR*, relative electron transport rate; F_0, the minimal fluorescence level; F_m, the maximal fluorescence level; F_v/F_m, the maximal quantum yield of PSII photochemistry; MDA, malondialdehyde; PSII, photosystem II; *qP*, photochemical quenching; SOD, superoxide dismutase; UV-B, ultraviolet-B; *Y*, the actual quantum yield of PSII photochemistry.

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before the stratospheric ozone concentrations drop to the levels that existed 50 years, and it is likely that we will have depleted ozone concentrations for many decades (Solomon, 1999). A 1% decrease in the stratospheric ozone concentrations results in a 2% increase in the flux of ultraviolet-B (UV-B, 280–315 nm; C.I.E. definition) reaching the earth's surface. UV-B is absorbed by proteins and nucleic acids and causes photo damage and conformational changes that can disturb physiological and biochemical processes such as growth, survival, functions of photosystem II (PSII), and biological molecules such as DNA (Germ et al., 2005).

UV-B radiation has a negative impact on terrestrial ecosystems through its actions on plants, microbes and animals. Ecosystem functions may be affected, including impacts on plant biomass, seed production, disease incidence or mortality of plants and animals, and changes in species composition and mineral nutrient cycling (Caldwell et al., 1998). It has been well established that increased UV-B radiation has harmful effects on the rate of photosynthesis of many plants (Urban et al., 2006). The efficiency and stability of PSII is important for the functioning of the photosynthetic apparatus. UV-B induced PSII damage can decrease rates of photosynthesis. Decreased photosynthetic rates are preceded by decreases in the photochemical efficiency of PSII (Haapala et al., 2010). The functioning of PSII can be evaluated by measuring chlorophyll (Chl) fluorescence. The growth inhibition observed in many plants subjected to increased UV-B is often combined with a decrease in their photosynthetic capacity. Chla concentration is a useful quantitative indicator of BSC development (Castle et al., 2011). Day et al. (2001) demonstrated reductions in the growth and biomass production of Antarctic vascular plants by current levels of UV-B. In addition, when photosynthetic organisms are subjected to UV-B radiation, they cannot avoid oxidative stresses due to the generation of reactive oxygen species (Kumari et al., 2010). In order to minimize oxidative injury, including lipid peroxidation, protein degradation and DNA damage, plants have developed a number of antioxidant defense systems, including the induction of enzymes such as superoxide dismutase (SOD) and catalase (CAT) (Singh et al., 2009). SOD can convert superoxide into H_2O_2 and O_2, and act as a first-line defender against oxidative stress caused by reactive oxygen species (Møller, 2001). In addition, CAT catalyzes H_2O_2 decomposition (Wang et al., 2010). The defense mechanisms play important roles in improving antioxidant capacity, by scavenging free oxygen radicals and resisting oxidative stress.

In the Shapotou region of the Tengger Desert in northwestern China, mobile sand dunes have been stabilized by re-vegetation of a 16 × 0.7 km green corridor to protect the Baotou-Lanzhou railway line (Li et al., 2004). Over the past 55 years the stability of the mobile sand dunes surface has increased because of the development and establishment of BSC (Li et al., 2002). The BSC of stabilized sand dunes of the Tengger Desert change over time and pioneer cyanobacteria are gradually substituted by desert algae, lichens and mosses (Li et al., 2002). The common BSC in the region are dominated by cyanobacteria, algae, mosses and lichens, or any combination of these organisms (Li et al., 2010). *Bryum argenteum* Hedw. and *Microcoleus vaginatus* (Vauch) Gom. were the first crust moss and cyanobacteria species to develop on the soil surface.

The purpose of this study was to evaluate how long-term exposure to supplementary UV-B radiation levels affect Chl fluorescence, photosynthetic pigment and antioxidant systems of two desert organisms isolated from BSCs - a moss and a cyanobacteria, *B. argenteum* and *M. vaginatus*. Samples of the two species were exposed to elevated UV-B levels for up to 40 days in field conditions. Our objectives were firstly to determine whether elevating UV-B radiation affects Chl fluorescence, the contents of Chl and carotenoid (Car), membrane lipid peroxidation, and the activities of antioxidative enzymes in both *B. argenteum* and *M. vaginatus*. Secondly, we compared the responses of the variables mentioned above in the two BSC species. We hypothesized that exposure to supplementary UV-B radiation would cause damage to the Chl fluorescence, photosynthetic pigment and antioxidant systems of both species, and that *B. argenteum* may be more sensitive to enhanced UV-B radiation than *M. vaginatus*. Damage to these biochemical systems in these species may result in decreased photosynthesis, leading to reduced growth, composition, and stability of BSC, thereby increasing the potential for water and wind erosion of the soil and decreasing the potential for colonization of deserts by higher plants.

2. Materials and methods

2.1. Plant materials and treatments

The research was conducted outdoors at the Shapotou Desert Research and Experiment Station, Ningxia, China, during early June to late July 2011. In September 2010, *B. argenteum* as well as *M. vaginatus* crusts were collected from Shapotou (37°32′–37°36′N, 105°02′-104°30′E). The altitude range of the collecting areas is 1300–1350 m above mean sea level that is typical of transitional desert steppe to steppified desert (Li et al., 2003). The mean annual precipitation is 186 mm, approximately 80% of which falls between May and September. The mean daily temperature in January is −6.9 °C, while the mean daily temperature in July is 24.3 °C. The cumulative sum of UV-B intensity per year has been increasing in this area. We selected sampling locations from the interspaces between shrubs in the re-vegetated ozone, and used cylindrical plastic containers (10 cm in diameter and 5 cm in height) to collect 48 samples of intact BSC dominated by the moss *B. argenteum* or by the cyanobacteria *M. vaginatus*. All samples were air dried and stored in the containers until the experiments began.

A square-wave UV-B system was used to provide supplementation (Ryan and Hunt, 2005). Eight 40 W fluorescent tubes (UV-B 313, Chenchen Lighting and Electronics Company, Shanghai, China) were installed above crusts dominated *B. argenteum* or *M. vaginatus*. Cellulose diacetate film (0.13 mm thick, Courtaulds Chemicals, Derby, UK) was used to filter out UV-C, and it was replaced every 5 days to ensure uniformly of UV-B transmission. The supplemental UV-B doses were 0.33, 0.50, and 0.66 W m^{-2}, simulating stratospheric ozone depletion of 6, 9, and 12% of stratospheric ozone at Shapotou, on a clear summer solstice day (2.75 W m^{-2}, control). The exposures of ambient and supplemental UV-B radiation were equivalent to 3.08, 3.25 and 3.41 W m^{-2}, and the spectral irradiance values were recorded using a UV digital spectroradiometer (Photoelectric Instrument Factory, Beijing Normal University, Beijing, China). The photosynthetically active radiation (400–700 nm) ranged between 800 and 1200 μmol m^{-2} s^{-1} measured by a quantum sensor (LI-COR, Lincoln, NE, USA). Samples were irradiated for 8 h (9:00 to 17:00) during 40 days, except on rainy days. During the entire experiment all crusts were moistened with 10 mL distilled water per day. Each radiation regime was replicated three times. Samples of irradiated *B. argenteum* and *M. vaginatus* were isolated from BSC, frozen in liquid nitrogen and stored at −80 °C before analysis. Prior to isolation, the Chl fluorescence parameters of *B. argenteum* and *M. vaginatus* crusts were determined. Three replicate samples of *B. argenteum* and *M. vaginatus* were taken for analyses every 10 days over a period of 40 days.

2.2. Chl fluorescence parameters determination

Chl fluorescence parameters were determined in situ by the method of Zhao and Wang (2002), with a pulse amplitude modulation 2000 fluorometer (MFMS-2, Hansatech, Kings Lynn, UK) at