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Research article

Exclusion of solar UV radiation improves photosynthetic performance and yield of wheat varieties

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ABSTRACT

Field studies were conducted to determine the potential for alterations in photosynthetic performance and grain yield of four wheat (*Triticum aestivum*) varieties of India- Vidisha, Purna, Swarna and Naveen Chandausi by ambient ultraviolet radiation (UV). The plants were grown in specially designed UV exclusion chambers, wrapped with filters that excluded UV-B (<315 nm), UV-A/B (<400 nm) or transmitted ambient UV or lacked filters. The results indicated that solar UV exclusion increased the leaf mass per area ratio, leaf weight ratio and chlorophylls per unit area of flag leaves in all the four varieties of wheat. Polyphasic chlorophyll *a* fluorescence transients from the flag leaves of UV excluded wheat plants gave a higher fluorescence yield. Exclusion of solar UV significantly enhanced photosynthetic performance as a consequence of increased efficiency of PS II, performance index (PI_{ABS}) and rate of photosynthesis in the flag leaves of wheat varieties along with a remarkable increase in carbonic anhydrase, Rubisco and nitrate reductase activities. This additional fixation of carbon and nitrogen by exclusion of UV was channelized towards the improvement in grain yield of wheat varieties as there was a decrease in the UV-B absorbing substances and an increase in soluble protein content in flag leaves of all the four varieties of wheat. The magnitude of response for UV exclusion for all the measured parameters was higher in two varieties of wheat Vidisha and Purna as compared to Swarna and Naveen Chandausi. Cumulative stress response index (CSRI) for each variety was developed from the cumulative sum of physiological and yield parameters such as leaf mass area ratio of flag leaf, total chlorophyll content, performance index at absorption basis, rate of photosynthesis and grain yield. All the varieties had a negative CSRI, demonstrating a negative impact of ambient UV radiation. Naveen Chandausi and Swarna are less sensitive to ambient UV radiation; Vidisha is more sensitive to both UV-A and UV-B and Purna is more sensitive to ambient UV-B radiation.

1. Introduction

Plants are inevitably exposed to solar UV (280–400 nm) radiation, since they require sunlight to perform photosynthesis. The global depletion of the stratospheric ozone layer, largely due to the release of chlorofluorocarbons (CFCs) caused by human activities, has resulted in an increase of solar UV-B radiation at the Earth's surface (Ballaré et al., 2011). The solar UV-B background level is often high and poses an environmental challenge in most of the tropical regions of the world including, India. The amount of UV-B radiation reaching tropical latitudes is higher than in temperate because the lower solar zenith angle leads to a less atmospheric UV-B absorption in tropics. A substantial part of India lies in the low ozone belt (Sahoo et al., 2005) suggesting the potential vulnerability of plants to increased UV-B under field conditions.

Although UV-B only represents a fraction of the solar spectrum, it may exert substantial photobiological effects when absorbed by important macromolecules, such as proteins and nucleic acids (Nawkar et al., 2013). Numerous studies have shown that enhanced UV-B radiation can affect physiological and biochemical processes of many plant species, including altered plant photosynthesis (Tossi et al., 2011), changes in the carbon partitioning from growth pools to secondary metabolic pathways (Bassman, 2004) and thus changes in crop morphology, crop reproductive organ abortion and yield reduction (Mohammed and Tarpley, 2010).

At particular latitudes, experiments using UV-B exclusion by specific filters to remove the UV-B radiation (280–315 nm) from solar spectrum are most appropriate to evaluate the effects of

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ambient UV-B radiation (Rousseaux et al., 2004). Different laboratories which have carried out the studies by using UV exclusion (280–400 nm) approach have generally focused on UV-B impacts on plant growth and morphology with varying results. At temperate locations many species often fail to respond to UV-B exclusion (Cybulski and Peterjohn, 1999). Solar UV-B exclusion does not cause any significant effect on the naturally occurring plants of alpine plant community (Caldwell, 1968). By excluding solar UV-B in field experiments carried out in Japan, a transient reduction in biomass accumulation in tomato plants was obtained (Tezuka et al., 1993).

On the other hand, more recent studies conducted on exclusion of solar UV radiation in tropical countries including India, have reported that the ambient solar UV-B radiation have significantly deleterious effects on terrestrial plants (Kataria et al., 2013; Kataria and Guruprasad, 2014; Zhu and Yang, 2015). The level of ambient UV-B radiation in sunlight varies with reference to latitude and is relatively higher in tropical regions than in temperate regions. The impact of the ambient UV radiation is especially higher under tropical climate where the plants are exposed to longer duration of sunlight (Sahoo et al., 2005). The presence of ambient UV components caused reduction in biomass accumulation, photosynthesis, growth and yield of many plants species (Kataria and Guruprasad, 2012a,b; Kataria et al., 2013; Kataria and Guruprasad, 2014). These studies suggested that sensitivity to ambient UV radiation however varies considerably both within and between plant species (Kataria and Guruprasad, 2012a,b; Kataria et al., 2013; Kataria and Guruprasad, 2014).

Wheat is one of the major world food crops and potentially sensitive to ambient UV-B (Kataria and Guruprasad, 2012a). The effects of enhanced UV-B radiation on intraspecific differences in the responses of wheat has been extensively studied on physiology and yield but with the majority of studies considering the effect of enhanced UV-B radiation with lamp supplementation on the physiological and biochemical aspects (Li et al., 2000) in growth chambers and greenhouses. The reports on the adverse effect of ambient UV on wheat plants are very limited (Kataria and Guruprasad, 2012a; Kataria et al., 2013). In our previous study, we have identified intraspecific differences in responses to ambient UV radiation in terms of growth, morphology and the yield among four varieties of wheat (*Triticum aestivum*) (Kataria and Guruprasad, 2012a) by the exclusion of solar UV components. However, the effects of ambient UV on intraspecific responses in terms of photosynthetic parameters like chlorophyll fluorescence, gas exchange parameters and the enzymes involved in carbon and nitrogen metabolism like carbonic anhydrase (CA), ribulose-1,5-bisphosphate carboxylase (Rubisco) and nitrate reductase (NR) in wheat varieties have not been investigated yet.

In this study, we grew the four varieties of wheat in fields under ambient and exclusion of solar UV with an objective to (1) determine the solar UV radiation effects on wheat physiology under field conditions; (2) assessment of the intraspecific differences in physiological response of wheat varieties to UV-B and UV-A radiation and (3) also to calculate the cumulative stress response index (CSRI) to evaluate the physiological responses of wheat varieties to ambient solar UV radiation by the exclusion of solar UV wavelengths at Indore (Latitude $22^0$43′N), India under field conditions.

We hypothesized that exclusion of solar UV components will increases the leaf mass per area ratio and chlorophyll content, and affect other physiological processes, i.e. increased efficiency of Photosystem II (PS II) and reducing power as well as the increased activity of CA, Rubisco and nitrate reductase activity which will ultimately increase the yield of wheat varieties. These changes will result in intraspecific differences in the physiological responses of wheat varieties to ambient UV radiation under field conditions.

2. Materials and methods

2.1. Study site and experimental design

Seeds of Indian wheat (*T. aestivum* L.) varieties; Naveen Chandausi (HI 1418), Swarna (HI 1479), Vidisha (DL 788-2) and Purna (HI 1544) were collected from Regional Wheat Research Station, Indian Agriculture Research Institute, Indore. The field experiments were conducted in the Botanical Garden of School of Life Sciences, Indore (22°43′N, 75°50′ E), Madhya Pradesh, India. The experiments were carried out during November 2011 to February 2012. Soil of the study site was medium loam in texture (sand 40%, silt 30% and clay 20%). During the experimental period, average temperature ranged 25°C to 27°C, relative humidity ranged from 55 to 75% and photosynthetically active radiation (PAR) averaged 1450 μmol m^{-2} s^{-1} at midday. Seeds were sown in the field area of 1.6 m × 1.6 m in 1.20 m rows planted 0.23 m apart with 0.05 m plant spacing within the row under iron cages of dimensions [1.22 mL × 1.22 mW × 1.52 mH]. The recommended doses of nitrogen, phosphorus and potassium (120 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 40 kg K_2O ha^{-1}) were applied through urea, single super phosphate and muriate of potash respectively to all plots before sowing.

The iron cages were wrapped with UV cut-off Polyester filters (Garware Polyester Ltd., Mumbai) that selectively cut-off UV-B (<315 nm) and UV-A/B (<400 nm) radiation. For the present study, two types of controls were taken; plants were grown either in the cages covered with polythene filter that transmits all the ambient solar radiation (filter control FC) or in open field without any filters, exposed to natural solar radiation (open control OC). The transmission characteristics of these filters measured by Shimadzu Spectrophotometer (UV-1601) is shown in Fig. 1. From the time of germination the filters were erected and were maintained until maturity. Because of solarization, the filters were replaced every 2 weeks as they became brittle. The bottom sides of all the cages (0.35 m above ground) were left uncovered, to allow normal ventilation. The frames received full solar radiation for most of the day without any shading. Both inside and outside each enclosure, temperatures were monitored daily using max/min thermometers. The temperature inside the cages never differed more than 2°C from the ambient air temperature due to the passive ventilation system. The UV exclusion treatments did not affect the leaf or soil temperatures. Irrigation was given as and when required for optimal growth of the crop. The experiments were conducted in a randomized block design with three replicates; it refers to independent UV-treatment set-ups for each filter (FC, −UV-B and −UV-A/B) and for open control (OC).

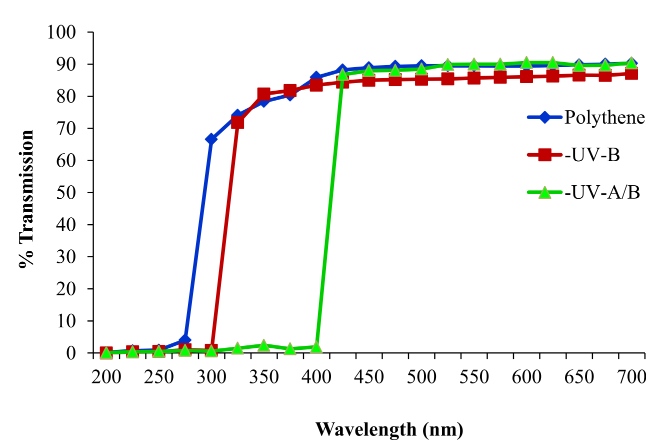

Fig. 1. Transmission spectra of UV cut off filters and polythene filter used in growth chambers for raising wheat varieties under field conditions.