



# Morphological and physiological responses of nine southern U.S. rice cultivars differing in their tolerance to enhanced ultraviolet-B radiation

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## ABSTRACT

The impact of climatic change on crop production is a major global concern. One of the climatic factors, ultraviolet-B radiation (UV-B; 280–320 nm), which is increasing as a result of depletion of the global stratospheric ozone layer, can alter crop productivity. As the initial step in development of UV-B tolerant rice cultivars for the southern U.S., in this study we screened popular southern U.S. rice cultivars for variation in tolerance to elevated UV-B radiation with respect to morphological, phenological and physiological parameters. Plants grown in the greenhouse at the Texas AgriLife Research and Extension Center in Beaumont, Texas, U.S. were exposed to 0, 8 or 16  $\text{kJ m}^{-2} \text{day}^{-1}$  UV-B radiation for 90 days. Our results showed differences among southern US rice cultivars in response to UV-B treatments with respect to leaf photosynthetic rate ( $P_n$ ), leaf phenolic concentration, pollen germination (PG), spikelet fertility (SF), leaf number, leaf area, and yield. For most of the cultivars, plants exposed to enhanced UV-B radiation showed decreased  $P_n$ , PG, SF and yield and increased spikelet abortion and leaf phenolic concentration compared to the plants grown in a UV-B-free environment. In this study, cultivar 'Clearfield XL729' performed better than the other cultivars under enhanced UV-B radiation.

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## 1. Introduction

Rice (*Oryza sativa* L.) and all other crops cultivated between 40°N and 40°S latitudes are already experiencing UV-B doses of 2–10  $\text{kJ m}^{-2} \text{day}^{-1}$  depending on the season and location (NASA, 2008, [http://www.toms.gsfc.nasa.gov/ery\\_uv/ery\\_uvl.html](http://www.toms.gsfc.nasa.gov/ery_uv/ery_uvl.html)). Chlorofluorocarbons, which can deplete the stratospheric ozone layer, can remain in the upper atmosphere for 40–150 years (Dentener et al., 2001); hence, the global UV-B radiation will not recover to the levels of the pre-industrialization era by 2050, even if all the nations implement the Montreal Protocol and its Amendments and Adjustments (World Meteorological Organization, 2007). The potentially excessive UV-B levels of the near future could reduce rice yields at multiple locations around the world, including the U.S., which accounts for 12% of global rice trade, thereby having a pronounced effect on the economics of global rice trade (Food and Agricultural Organization, 2008, <ftp://ftp.fao.org/docrep/fao/010/ai760e/ai760e00.pdf>). Most U.S. rice is grown in the southern U.S.

The UV-B radiation effects on plants range from the molecular level to the ecosystem level (Caldwell et al., 1998). Reduction in plant function due to enhanced UV-B radiation is primarily associated with damage to DNA, proteins and membranes (Middleton

and Teramura, 1994). Recent reviews of the effects of UV-B radiation on the major agricultural and non-agricultural species have concluded that the sensitivity of crop plants to UV-B radiation varies depending on species and cultivar, growth conditions, and other stress conditions (Kakani et al., 2003). The differences in sensitivity to enhanced UV-B radiation among species or cultivars is due to differential effects of UV-B radiation on DNA, proteins, membranes, photosynthesis, pollen germination, and biomass production (Caldwell et al., 1998; Feng et al., 2000). Several studies have reported differences among rice cultivars in sensitivity to enhanced UV-B radiation (Teramura et al., 1991; Dai et al., 1992; Hidema et al., 1996; Kumagai et al., 2001). However, knowledge of the effects of enhanced UV-B radiation on southern U.S. rice cultivars is minimal.

Morphological, physiological and biochemical changes in plants, including inhibition of photosynthesis, have been reported to occur due to enhanced UV-B radiation (Bornman and Teramura, 1993; Mohammed, 2002). The decrease in photosynthesis due to enhanced UV-B radiation has been reported for several crops including rice cultivars (Teramura et al., 1991; Ziska and Teramura, 1992; Zhao et al., 2004), and is primarily associated with reduced levels of leaf chlorophyll (He et al., 1993; Huang et al., 1993), stomatal conductance (Dai et al., 1992), leaf Rubisco (ribulose-1,5-bisphosphate carboxylase/oxygenase) content (Ziska and Teramura, 1992), leaf nitrogen and leaf soluble protein (Hidema et al., 1996), LHClI (light-harvesting chlorophyll *a/b*-binding protein of photosystem II) content, and/or altered

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photosynthesis-related gene expression (Strid et al., 1996a,b). The decrease in  $P_n$  due to enhanced UV-B radiation decreased cotton (*Gossypium hirsutum* L.) yields (Zhao et al., 2004).

Protective plant responses against enhanced UV-B radiation include increased production of UV-B absorbing compounds: flavonoids and phenylpropanoids, carotenoids (Middleton and Teramura, 1994), and phenolic compounds in the leaves (Beggs et al., 1986; Mohammed, 2002). The UV-B absorbing compounds act as screening pigments by absorbing UV-B radiation, thereby protecting photosynthetic tissues. The carotenoids and phenolic compounds are highly correlated with the UV-B-absorbing capacity of the leaves (Middleton and Teramura, 1994; Levizou and Manetas, 2002). Hence, an increase in carotenoid or phenolic concentration can render protection to photosynthetic tissues from enhanced UV-B radiation.

Rice yield is highly correlated with the number of productive tillers per unit area and the number of spikelets per panicle, both of which vary with the genotype and environment (Yoshida et al., 2006). However, only the fertile spikelets, and not the degenerated (aborted) or the sterile spikelets, contribute to the yield. Spikelet fertility (SF) is highly correlated with pollen germination (PG), whereas spikelet degeneration (abortion) is correlated with availability of soluble carbohydrates to the spikelets at the meiosis stage (Kobayashi et al., 2001). Previous studies have reported decreased pollen germination (Feng et al., 2000; Koti et al., 2005) and decreased leaf soluble carbohydrates (Zhao et al., 2004) at enhanced UV-B radiation, thereby affecting spikelet fertility and degeneration, hence profoundly affecting the yield.

Enhanced UV-B radiation decreases plant height and seedling length (Sullivan and Teramura, 1989). Barnes et al. (1993) reported reduction in rice plant height and decreased dry matter production at enhanced UV-B radiation, simulating 5% ozone depletion, due to decreased leaf and canopy photosynthesis. Low carbohydrate availability due to enhanced UV-B radiation can reduce the chance of a bud developing into a viable tiller, thus affecting tiller production (Bos and Neuteboom, 1998). Tiller production in rice is an important agronomical trait (Li et al., 2003), and tiller number in small grains is highly correlated with yield (Paulsen, 1987). Teramura et al. (1991) reported variability among rice cultivars with respect to tiller production,  $P_n$ , chlorophyll, UV-B absorbing compounds, morphological characteristics and biomass production in response to enhanced UV-B radiation. Moreover, Teramura et al. (1991) reported that UV-B tolerance among the rice cultivars ranged from very sensitive to relatively resistant, including many with intermediate sensitivity. However, knowledge of the effects of enhanced UV-B radiation on southern U.S. rice cultivars is minimal.

The screening of more southern U.S. rice cultivars for UV-B resistance would be accelerated if the physiological traits related to UV-B stress tolerance could be identified for southern U.S. rice cultivars. With this background, we hypothesize that the magnitude of cultivar tolerance to enhanced UV-B radiation will differ among southern U.S. cultivars with respect to morphological, phenological and physiological traits. Therefore, the objectives of the present study were (1) to examine the effects of enhanced UV-B radiation on growth, morphological, phenological and physiological traits of southern U.S. rice cultivars; and (2) to determine which screening trait might be a useful tool in future breeding efforts to enhance UV-B tolerance.

## 2. Materials and methods

### 2.1. Experimental conditions and plant culture

A study was conducted in the greenhouse at the Texas AgriLife Research and Extension Center at Beaumont, Texas, U.S. (Longi-

tude: 94° 16' 59" W; Latitude: 30° 4' 0" N) over 2 years. Across years, the experiment was laid out in a completely randomized design (CRD). Because of high similarity ( $P \geq 0.5$ ) between years, this design was more efficient than a blocked design (Snedecor and Cochran, 1980). Under each UV-B regime, there were nine cultivars, six plants per cultivar. In the mid-south region of the U.S., 'Cheniere' ('Newbonnet'/'Katy'/'L-202'/'Lemont'/'L-202'), 'CL161' (Mutation of 'Cypress'), 'Cocodrie' ('Cypress'/'L-202'/'Tebonnet'), 'Cypress' ('L-202'/'Lemont'), 'Sierra' ('Dellmont'/'B8462T3-710') 'Basmati370'/'CI9881'/'PI331581'/'3'/'Rexmont'), 'Presidio' ('Jefferson'/'Maybelle'/'Rosemont'), (United States Department of Agriculture, Agricultural Research Service, National Plant Germplasm System, 2010) 'XL8', 'XL723' and 'Clearfield XL729' ('CLXL729') accounted for 70% of the land area planted to rice in 2006. Among the above cultivars, 'Cheniere' 'CL-161', 'Cocodrie', 'Cypress', 'Sierra', and 'Presidio' are inbred cultivars and 'XL8', 'XL723' and 'CLXL729' are hybrid cultivars (RiceTec Seed Co., Alvin, TX, USA). All the above cultivars used in the present study are tropical japonica type (with the possible exception of the hybrids whose origins are undisclosed) and are semi dwarf cultivars. Plants were grown in 3L pots, which were placed in a square wooden box (0.84 m<sup>2</sup>). The boxes were lined with black plastic that served as a water reservoir. Pots were filled with a clay soil (fine montmorillonite and thermic Entic Pelludert) that is common to rice farms in the area. Five seeds were sown per pot and plants were thinned to one plant per pot after seedling emergence. The day/night temperatures and absolute humidity in the greenhouse ranged between 27–35 °C/19–25 °C and 13–14 g/m<sup>3</sup>, respectively. In both years, the light intensity in the greenhouse during the day was up to 800  $\mu\text{mol m}^{-2} \text{s}^{-1}$  (Quantum Meter, Apogee Instruments, Logan, UT, U.S.).

A three-way split application of nitrogen was provided as described by Mohammed et al. (2007) in each experiment. Nitrogen was applied in the form of urea and ammonium sulfate, and phosphorus in the form of P<sub>2</sub>O<sub>5</sub>. Urea-N was applied at the rate of 112.3 kg N ha<sup>-1</sup> along with 45.4 kg P ha<sup>-1</sup> of phosphorus (P<sub>2</sub>O<sub>5</sub>) at planting. The remaining nitrogen fertilizations (both 44.9 kg N ha<sup>-1</sup> in the form of ammonium sulfate) were applied 20 days after emergence (DAE) and at the panicle-differentiation stage. The boxes were filled with water to approximately 3 cm above the top of the soil in each pot, 20 DAE. The plants were uniform in terms of development, as indicated by tiller development, at the beginning of the UV-B radiation treatments described below.

### 2.2. UV-B radiation treatments

The greenhouse roof material (polycarbonate) was opaque to incoming natural UV-B radiation. All of the UV-B radiation was artificially supplied by supplemental UV-B lighting using UV-313 lamps (Q-Panel Company, Cleveland, OH, U.S.) driven by dimming ballasts in a square-wave fashion. Although the square-wave UV-B supplementation system in controlled environments can provide disproportionate spectral conditions on cloudy days, square-wave UV-B supplementation systems are useful in quantifying, modeling and screening studies (Reddy et al., 2003). The UV-B radiation provided by these fluorescent sun-lamps was delivered to plants for eight hours each day from 0800 to 1600 h. To filter out UV-C radiation (<280 nm), the lamps were wrapped with solarized 0.07-mm cellulose diacetate film (JCS Industries Inc., La Mirada, CA, U.S.), which was changed at regular intervals (4–5 days) to account for the degradation of its absorptive properties. Rice plants were exposed to three biologically effective UV-B doses of 0, 8 (moderate), or 16 (enhanced)  $\text{kJ m}^{-2} \text{day}^{-1}$  (0, 8, and 16 kJ, respectively) from 20 DAE until harvest. The biologically effective UV-B doses imposed in the present study simulate 0, 10 and 30% depletion of stratospheric ozone (Madronich et al., 1998). Each UV-B regime

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