Photosynthetic characteristics of *Amaranthus tricolor*, a C₄ tropical leafy vegetable

Z.F. LIN¹ and J. EHLERINGER

Department of Biology, University of Utah, Salt Lake City, UT 84112, USA

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Abstract. The gas exchange characteristics are reported for *Amaranthus tricolor*, a C₄ vegetable amaranth of southeastern Asia. Maximum photosynthetic capacity was 48.3 ± 1.0 μmol CO₂ m⁻² s⁻¹ and the temperature optimum was 35°C. The calculated intercellular CO₂ concentration at this leaf temperature and an incident photon flux (400–700 nm) of 2 mmol m⁻² s⁻¹ averaged 208 ± 14 μl l⁻¹, abnormally high for a C₄ species. The photosynthetic rate, intercellular CO₂ concentration, and leaf conductance all decreased with an increase in water vapor pressure deficit. However, the decrease in leaf conductance which resulted in a decrease in intercellular CO₂ concentration accounted for only one fourth of the observed decrease in photosynthetic rate as water vapor pressure deficit was increased. Subsequent measurements indicated that the dependence of net photosynthesis on intercellular CO₂ concentration changed with water vapor pressure deficit.

Introduction

*Amaranthus*, a relatively large genus of C₄ photosynthetic pathway plants, found in diverse habitats, includes both weedy and agronomically useful species [10, 18, 19]. The agronomic species consist of both grain types and leafy vegetable types, and both forms are valued for their high protein content and balanced amino acid composition [7, 10, 20]. Amaranths are known to have high lysine (5.0%) and sulfur-containing amino (4.4%) contents, especially in comparison with other plant protein sources [7, 12]. Protein contents of the dry matter of leaves are reported to be greater than 27% [3, 5, 14].

Associated with the high leaf protein contents, one would expect to observe high intrinsic photosynthetic capacities since a large fraction of the leaf proteins are associated with the photosynthetic process. The gas exchange characteristics of the grain and weedy amaranth species measured thus far support this prediction [4, 8, 15, 21]. In fact, Singh et al. [21] showed a linear relationship between protein content and photosynthesis in *A. retroflexus* up to rates of 40 μmol CO₂ m⁻² s⁻¹.

¹ Permanent address: South China Institute of Botany, Guangchou, People's Republic of China
Little is known, however, about the productivity characteristics of the leafy vegetable amaranths, although they are an important component in the diets in many subtropical countries [12]. The data which do exist suggest that vegetable amaranths are highly productive. Deutsch [3] conducted trials on six species and found that one species, *A. tricolor*, yielded 20 metric tons per hectare of leaf material in 25–30 days. Leafy vegetable yields of 26 metric tons per hectare in *A. caudatus* have been reported by Oke [16]. These plants are frequently ratooned for multiple harvests over a 2–3 month period.

The purpose of the current study was to investigate the basic photosynthetic gas exchange characteristics of a common leafy vegetable amaranth. The species used in this study was *A. tricolor*, which is commonly grown throughout the southeastern Asia and western Pacific regions.

Materials and methods

Seeds of *Amaranthus tricolor* were collected from Guangchou, People's Republic of China and were greenhouse grown in Salt Lake City, Utah, during the winter and spring of 1982. Plants were grown individually in 10x pots in a mixture of potting soil and perlite. They were watered daily and fertilized weekly. In the greenhouse natural sunlight was supplemented by metal halide and sodium vapor high intensity discharge lamps to create midday irradiances of approximately 1.6–1.8 mmol m$^{-2}$ s$^{-1}$ (400–700 nm). Daily incident quantum flux in the 400–700 nm waveband averaged near 40 mol m$^{-2}$ during the 14 h/10 h day/night cycle. The daily greenhouse temperature cycle was approximately 25/15°C and the midday relative humidity 25%.

Simultaneous measurements of photosynthesis and transpiration were made with an open gas exchange system described previously by Ehleringer [4], in which irradiance, leaf temperature, ambient CO$_2$ concentrations, and water vapor pressure deficit could be controlled. Single attached leaves were initially exposed to an irradiance of 2 mmol m$^{-2}$ s$^{-1}$ (400–700 nm), a leaf temperature of 35°C, an ambient CO$_2$ concentration of 330 μl l$^{-1}$, and a water vapor pressure deficit of 1.5 kPa. The boundary layer conductance to water vapor in the chamber was approximately 50 mm s$^{-1}$. Three to five replicates were run for each analysis.

Carbon isotope ratios were determined on leaves at Brigham Young University using standard techniques as described by Smith and Brown [22].

Results and discussion

The temperature dependence of net photosynthesis was measured at high irradiances and under normal atmospheric conditions on recently matured leaves (approximately 10–15 days old) (Figure 1). At an irradiance of