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Characteristics of Photosynthetic Behaviors and Chlorophyll Fluorescence in Different Vegetable Species

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Abstract: This study investigated the variability in various physiological characteristics of seven popular commercial vegetable seedlings such as cabbage, spinach, Chinese cabbage, eggplant, cucumber, tomato and Chinese radish. The photosynthetic rate (Pn) was highest in cabbage seedlings followed by eggplant seedlings. Cucumber and cabbage seedlings showed higher stomatal conductance (CS) than other vegetables studied. Cucumber seedlings had higher respiration rate followed by tomato, eggplant, and Chinese radish. In the case of internal CO₂ concentration, all the species studied showed significant differences. Chinese cabbage seedlings exhibited the highest transpiration rate (Tr) and Chinese radish had the lowest. There was little decrease in photochemical efficiency of PS II i.e., Fv/Fm value of chlorophyll fluorescence in all species, however cabbage and spinach seedlings had the highest Fv/Fm value followed by cucumber, tomato, and eggplant seedlings. Among all the physiological parameters, Pn was highly correlated with Fv/Fm value. The results may be useful in formulating efficient selection and breeding programs in improving desired quality characteristics of plant species.

Key words: Photosynthesis, chlorophyll fluorescence, vegetables, physiological functions

INTRODUCTION

Physiological characters such as photosynthesis (Pn), transpiration (Tr) and stomatal conductance (CS) affect growth and yield in crop plants. Photosynthesis ultimately controls crop productivity. Many factors interact to get quality seedlings of vegetables and one of the most important is Pn. It is now well established that, the photosynthetic characteristics vary in many fold among species in normal sunlight. Photosynthesis at 1.0 cm⁻² min⁻¹ and 300 ppm CO₂, was shown to vary from 7 to 49 μg CO₂ cm⁻² h⁻¹. Theoretical causes were analyzed by Rabinowitch (1951) his equation predict that the maximum Pn may be determined by chlorophyll content or the proportionality between absorbed quanta and Pn. Until now several authors supported the theory. Regarding this aspect (i) it is now well known that fluorescence emission provides a non-destructive probe to examine the photochemical events of Pn and (ii) chlorophyll fluorescence has the potential of providing valuable information on Pn.

Chlorophyll fluorescence analysis is a relatively new technology that in recent years has become one of the most powerful and widely used techniques available to plant physiologists and ecophysiologists. It is often used as a very sensitive and intrinsic probe of photosynthetic reactions (Papageorgiou, 1975) and it is increasingly applied in various fields of plant physiology (Smilie and Nott, 1979; Artus et al., 1996; Yamada et al., 1996; Meyer and Gentzly, 1998; Griffiths and Maxwell, 1999; Maxwell and Johnson, 2000). Recently, Fv/Fm (ratio of variable to maximum fluorescence—the quantum efficiency of open photosystem II centers) value of chlorophyll fluorescence has been used widely for the measurement of the stress conditions of crop plants (Genty et al., 1989; Somersalo and Krause, 1989; Sasaki and Oda, 1994). Maxwell and Johnson (2000) reported that the Fv/Fm value correlated linearly with the quantum of photosynthesis. The prime objectives of this study are (i) to evaluate the variation of different physiological process especially Pn, Tr, CS and chlorophyll fluorescence of different vegetable species and (ii) selection of physiologically active vegetable species for further studies on details of physiological mechanisms.

MATERIALS AND METHODS

Plant materials and cultural condition: Seedlings of seven vegetables were chosen to compare the characteristics of Pn and chlorophyll fluorescence.
Table 1: List of the vegetable species used in this study

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific/Botanical name</th>
<th>Sowing date</th>
<th>Measuring date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td><em>Brassica oleracea</em> L. <em>Capitata</em></td>
<td>April 19</td>
<td>May 28</td>
</tr>
<tr>
<td>Spinach</td>
<td><em>Spinacea oleracea</em> L.</td>
<td>April 21</td>
<td>May 30</td>
</tr>
<tr>
<td>Chinese cabbage</td>
<td><em>Brassica rapa</em> L. <em>Pakhinsis</em></td>
<td>June 16</td>
<td>July 27</td>
</tr>
<tr>
<td>Eggplant</td>
<td><em>Solanum melongena</em> L.</td>
<td>August 06</td>
<td>September 30</td>
</tr>
<tr>
<td>Cucumber</td>
<td><em>Cucumis sativus</em> L.</td>
<td>August 06</td>
<td>September 22</td>
</tr>
<tr>
<td>Tomato</td>
<td><em>Lycopersicon esculentum</em> Mill.</td>
<td>April 01</td>
<td>May 02</td>
</tr>
<tr>
<td>Chinese radish</td>
<td><em>Raphanus sativus</em> L. <em>var. Longipinnatus</em></td>
<td>June 16</td>
<td>July 25</td>
</tr>
</tbody>
</table>

Information on the vegetable species used in the study is shown in Table 1. The experiment was conducted at the Department of Agroindustrial Sciences, Kagawa University, Japan during 1997. The seedlings of all the species were grown from seeds in black plastic trays having 128 cells filled with 3 peat and 1 rockwool media (v/v) in a vinyl house (25±3°C) under natural photoperiod. Cabbage (cv. Okina) and spinach (cv. Bunchlu Paruku) seedlings were grown in April-May, Chinese cabbage (cv. Muso) in June-July, eggplants (cv. Senryo twogo), cucumber (cv. Sharp 1) in August-September, tomato (cv. Momotaro) in April-May and Chinese radish in June-July. Three seeds were sown in each cell and thinned to one seedling about 4 days after emergence. When the seedlings were about 15 days old, they were transplanted to 12 cm diameter polyethylene pots filled with the same media. A 100 mL of modified Hoagland's nutrient solution (Khan and Yoshida, 1996) was supplied 3 times/week/seedling. When the seedlings developed approximately 7-8 leaves, 10 uniform plants of each species were selected and used for the measurements described later.

**Determination of photosynthetic characteristics:** Photosynthetic characteristics were measured as per the methods described by Khan and Yoshida (1996) using a LI-6200 portable Photosynthetic System (LI-COR, Inc., Lincoln, NE, USA). The measurements were done at room temperature (20-25°C), with 300-400 ppm CO₂ and under natural photoperiod. These measured values were linearly calibrated to the values at 350 ppm. The fourth leaf of each seedling was used for the measurement of the physiological characteristics.

**Determination of chlorophyll fluorescence:** The chlorophyll fluorescence measurements were analyzed as described by Genty *et al.* (1989) with slight modification. After finishing the measurement of photosynthetic characteristics those leaves were settled with black cuvettes for dark adaptation for 3-4 h. After the seedlings became adapted to darkness at room temperature, chlorophyll fluorescence was measured from photosystem II using actinic light intensity 300 μmol/m²/s for 150 sec by a fluorometer (CF-1000, P. K. Morgan instrument, Sandoval, MA, USA). The center of the leaf was used for the measurement except for the midrib. Stress is measured as a ratio of Fv (variable fluorescence) to Fm (maximum fluorescence). Fv was calculated as Fm-Fo (minimal fluorescence).

**Data analysis:** Data for the different parameters were analyzed by analysis of variance (ANOVA) procedure and the level of significance was calculated from the F value of ANOVA using the Excel Statistics 2000 program package for Windows (Social Information Service Co. Ltd, Tokyo, Japan). The means were separated at p = 0.05 by least significant test. The relationships among various physiological parameters were described with linear and quadratic correlation analysis using the above statistical program.

**RESULTS AND DISCUSSION**

For selection and comparative purposes among the seven vegetable species in relation to photosynthetic characteristics at 350 ppm and chlorophyll fluorescence (CF), the data collected during the experiment are presented in Fig. 1. These include photosynthetic rate (Pn), stomatal conductance (Cs), stomatal resistance (Rs), transpiration rate (Tr), internal CO₂ concentration and Fv/Fm values of chlorophyll fluorescence. All the parameters showed highly significant differences among the species studied. Among the seven species, the seedlings of cabbage had the maximum rate of Pn followed by eggplant. There were no significant difference among the other five species i.e., Chinese cabbage, cucumber and spinach. Chinese cabbage and cabbage seedlings showed higher Cs followed by cucumber, Chinese radish, spinach, tomato and eggplant seedlings. Cucumber had the highest Rs followed by eggplant, tomato and Chinese radish. There are conflicting reports as to the importance of Rs and Cs during leaf development. In sugar beet, no change was found in the number of stomata per unit leaf area over a week period (Brown and Rosenburg, 1970). In contrast several authors (Davis *et al.*, 1977; Davis and McCree, 1978; Maxwell and Johnson, 2000) reported that changes in these parameters due to environmental factors...
Fig. 1: Comparison in photosynthetic rate (Pn), stomatal conductance (CS), stomatal resistance (RS), internal CO₂ concentration, in transpiration rate (Tr) and Fv/Fm value of chlorophyll fluorescence in eggplant (EP), cucumber (CU), cabbage (CAB), spinach (SP), Chinese cabbage (CC), Tomato (TO) and Chinese radish (CR) seedlings. Bars represent the standard error which, when absent, is concealed by the symbol.
are common in different other crop species. In case of the internal CO₂ concentration, Chinese cabbage showed highest rate followed by spinach. Chinese radish exhibited the lowest internal CO₂ concentration followed by cucumber. The transpiration rate (Tr) among the species also differed widely and Chinese cabbage seedlings had highest Tr rate followed by spinach, cabbage and tomato. The Chinese radish seedlings showed lowest rate of Tr followed by cucumber and eggplant. In general, where water availability limits crop growth, maximum productivity can be expected from species which use water in the most efficient manner. Efficiency depends on the relationship between Pn and Tr and increases with an increase in Pn/Tr (Downe, 1969; Khan and Yoshida, 1996).

Figure 1 also shows the relation of variable to maximum fluorescence (Fv/Fm) emitted from photosystem II (PS II). It may serve as a quantitative indicator of the efficiency of the photochemistry of PS II. Among the seven species, the seedlings of cabbage and spinach had the highest Fv/Fm value followed by cucumber, tomato and eggplant. The Chinese radish and Chinese cabbage seedlings showed lowest values. There was relatively little difference in the photochemical efficiency of PS II i.e., Fv/Fm value in all the species compared to other parameters studied. Table 2 shows the relationship among the physiological characters studied. Photosynthetic rate of the species had a highly significant positive relationship with only the Fv/Fm value of chlorophyll fluorescence. These data indicated that efficiency of photosynthetic activities was associated with Fv/Fm value and vise versa. Tr, CS and internal CO₂ were highly significantly correlated with each other. Stomatal conductance also showed significant association with Tr and internal CO₂ concentration. The findings of the results suggests that Tr depends on the opening and closing of the stomata. The differences in Pn have been associated with a number of different factors in different species, including stomatal and mesophyll resistance, RuDP carboxylase activitandy mesophyll cell size (Evan, 1973; Schreiber et al., 1995), as well as chlorophyll content and chloroplast numbers (Ojinya, 1974 Bueberry and Buzzell, 1977; Schreiber et al., 1995). Using seven different vegetable species grown in the glasshouses and with Pn rate measured at room temperature, we have demonstrate a close association between Pn and Fv/Fm value of chlorophyll fluorescence. The cabbage seedlings had highest Pn rate which was associated with highest Fv/Fm value. Therefore the relation Fv/Fm can be used as characteristic of photosynthesical activity of phytoplankton. Since the measurements are non-intrusive, fast and reliable, these make chlorophyll fluorescence an attractive tool for physiological research and for breeding purposes.

Based on the results of the physiological characteristics namely performance of the photosynthetic rate and chlorophyll fluorescence of the vegetables species, cabbage, spinach and eggplant seedlings were chosen for further physiological and biochemical studies under different stress conditions. Furthermore, the results of the studies provide information on the seedling quality evaluation of vegetable species that may be helpful to plant breeder and plant physiologist.

REFERENCES


