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Assessment of durum wheat yield and carbon isotope discrimination by reflectance indices WI and PRI

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SUMMARY – Relationships between grain yield, carbon isotope discrimination against $^{13}\text{C}$ ($\Delta$), and the spectral reflectance indices water index (WI) and photochemical reflectance index (PRI) were explored under Mediterranean conditions. Twenty-five durum wheat genotypes were grown in four environments in NE Spain, with a range of drought events that resulted in yield levels from low to high. Environment had a strong influence on all the traits studied, the genotype being also significant. WI proved to be a good indicator of yield when drought occurred during grain filling. PRI was also strongly related to yield, except in the driest environment. Relationship between these spectral reflectance indices and $\Delta$ were inconsistent.

Introduction

Durum wheat ($Triticum turgidum$ L. var $durum$) is extensively grown in the Mediterranean region, where drought and high radiation levels have negative effects on yield (Loss and Siddique, 1994). In this context, the water use efficiency (WUE) and radiation use efficiency (RUE) are key traits to achieve high grain yields. To estimate WUE during grain filling, carbon isotope discrimination against $^{13}\text{C}$ ($\Delta$) may be used (Farquhar and Richards, 1984). Spectral reflectance indices may be a useful tool to estimate several physiological plant traits. Water Index (WI) was formulated to infer plant water content (Peñuelas et al., 1996) while the Photochemical Reflectance Index (PRI) has demonstrated to be related with RUE (Gamon et al., 1992).

The objective of this work was to study the relationships among WI and PRI with $\Delta$ and grain yield in durum wheat under contrasting Mediterranean conditions.

Materials and methods

Four field experiments (further referred to as environments) were performed in 1998 and 1999 under irrigated and rainfed conditions in NE Spain. In each experiment 25 durum wheat genotypes were grown in randomised complete block designs with 4 replicates and plots of 12 m².

Canopy reflectance was recorded with a narrow-bandwidth visible/near infrared portable field spectroradiometer (Fieldspec UV/VNIR, Analytical Spectral Devices, Boulder, CO, USA). Spectra were captured at milk grain stage, and two spectral reflectance indices were computed as: $\text{WI} = \frac{R_{\text{970}}}{R_{\text{900}}}$, and $\text{PRI} = \frac{R_{\text{531}} - R_{\text{570}}}{R_{\text{531}} + R_{\text{570}}}$, were $R_n$ is the reflectance at the wavelength (in nm) indicated by the subscript.

Plots were harvested at ripening and grain yield (kg/ha) was determined and expressed at 10% moisture level. In mature grains, $\delta^{13}\text{C}$ was determined for each plot and carbon isotope discrimination ($\Delta$) was further calculated according to Farquhar et al. (1989).

Combined analyses of variance (ANOVA) were performed over years and water regimes. Pearson correlation coefficients between traits were calculated by experiment. Stepwise regression analyses were carried out to explain relationships between the spectral reflectance indices and grain yield or $\Delta$. Analyses were performed with the SAS-STAT package (SAS Institute Inc., 2000).
Results and discussion

Table 1 shows the amount of water received by the crop from sowing to anthesis and during grain filling, and the mean grain yield and ∆ values. These results indicate that the crop experienced dissimilar drought levels before and after anthesis which resulted in a wide range of yield and ∆ values. The environments were ranked according to the yield level as high, medium-high, medium-low and low, being yield levels mainly associated with scarcity in water input during grain filling (Table 1).

Table 1. Grain yield, carbon isotope discrimination (Δ) and water input before and after anthesis in experiments carried out in NE Spain during 1998 and 1999 under irrigated and rainfed water regimes. Each experiment involved 25 durum wheat genotypes

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Water input (rainfall + irrigation, mm)</th>
<th>Water limitation†</th>
<th>Grain yield (t/ha)</th>
<th>Environment (yield level)</th>
<th>∆ (‰)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sowing-anthesis</td>
<td>Anthesis-maturity</td>
<td>Sowing-anthesis</td>
<td>Anthesis-maturity</td>
<td></td>
</tr>
<tr>
<td>Irrigated 1999</td>
<td>240</td>
<td>165</td>
<td>+</td>
<td>-</td>
<td>7009</td>
</tr>
<tr>
<td>Irrigated 1998</td>
<td>312</td>
<td>73</td>
<td>-</td>
<td>+</td>
<td>5192</td>
</tr>
<tr>
<td>Rainfed 1999</td>
<td>201</td>
<td>55</td>
<td>+</td>
<td>++</td>
<td>3820</td>
</tr>
<tr>
<td>Rainfed 1998</td>
<td>156</td>
<td>27</td>
<td>++</td>
<td>+++</td>
<td>2531</td>
</tr>
</tbody>
</table>

†Levels of water limitation: -no limitation; +light limitation; ++moderate limitation; +++severe limitation.

The results of the ANOVA (Table 2) indicate that the environment was the main factor explaining variations in all traits. The genotype was also a significant source of variation, even if it explained between 2.6 and 5.2% of variability. These results highlight the importance of the environmental conditions on grain yield, ∆ and the studied spectral reflectance indices, but also the opportunity for genotype selection for these traits.

Table 2. Percentages of the ANOVA’s sum of squares for 25 durum wheat genotypes grown in NE Spain during 1998 and 1999 under irrigated and rainfed water regimes

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Grain yield</th>
<th>∆†</th>
<th>PRI‡‡</th>
<th>WI‡‡‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment (E)</td>
<td>3</td>
<td>83.0***</td>
<td>91.0***</td>
<td>90.4***</td>
<td>72.5***</td>
</tr>
<tr>
<td>Genotype (G)</td>
<td>24</td>
<td>5.2***</td>
<td>2.6***</td>
<td>3.3**</td>
<td>4.9*</td>
</tr>
<tr>
<td>G x E</td>
<td>72</td>
<td>6.4</td>
<td>3.1</td>
<td>4.4</td>
<td>9.4</td>
</tr>
<tr>
<td>Block (environment)</td>
<td>12</td>
<td>5.3***</td>
<td>3.3***</td>
<td>1.9*</td>
<td>13.2***</td>
</tr>
</tbody>
</table>

†Δ: Carbon isotope discrimination against 13C in mature grains. ‡‡PRI: Photochemical reflectance index. ‡‡‡WI: Water index.

Water index was negatively correlated with grain yield in all experiments except the highest yielding one (Table 3). In this environment, water supply was not limiting during grain filling (Table 1), causing the water status to be similar for all genotypes and WI was not suitable to detect genotype differences.

Grain yield was correlated with PRI in all environments except the lowest yielding one. In that environment, water supply was severely restricted during the whole growth cycle, thus causing premature senescence of plants and a lack of relationship between grain yield and PRI. These results indicate that the radiation use efficiency is a key trait under Mediterranean conditions, where radiation is available in excess (Loss and Siddique 1994), and the photo-protection mechanisms are necessary to prevent cell damage and to allow plant metabolism to continue normally (Gamon et al., 1992).
Table 3. Pearson correlation coefficients between grain yield, carbon isotope discrimination against $^{13}$C in mature grains ($\Delta$), photochemical reflectance index (PRI) and water index (WI) for 25 durum wheat genotypes grown in NE Spain in four environments

<table>
<thead>
<tr>
<th>Environment (yield level)</th>
<th>High</th>
<th>Medium-high</th>
<th>Medium-low</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield – WI</td>
<td>-0.37</td>
<td>-0.72***</td>
<td>-0.51**</td>
<td>-0.52**</td>
</tr>
<tr>
<td>Grain yield – PRI</td>
<td>0.46*</td>
<td>0.68***</td>
<td>0.56**</td>
<td>-0.02</td>
</tr>
<tr>
<td>$\Delta$ – WI</td>
<td>-0.17</td>
<td>-0.56**</td>
<td>-0.30</td>
<td>-0.38</td>
</tr>
<tr>
<td>$\Delta$ – PRI</td>
<td>-0.01</td>
<td>0.51**</td>
<td>0.50*</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

*Significant at $0.01 < P < 0.05$, **significant at $0.001 < P < 0.01$; ***significant at $P < 0.001$.

The correlation coefficients between WI or PRI and $\Delta$ were less consistent than for grain yield. It has been postulated that $\Delta$ is the result of the balance between water transpired and carbon intake over the time (Farquhar et al., 1989), thus indicating that WI solely may not explain $\Delta$. Since WI is expected to be related to water transpired and PRI to carbon intake, it would be likely that WI and PRI together are related to $\Delta$. In our experiments, these two spectral indices were poor indicators of $\Delta$, probably because the $\Delta$ in the mature grains would be the integration of transpiration and carbon intake during the whole grain filling period, which may not be quantified with the spectral indices measured in a specific day.

Our results indicate that WI and PRI may be used to estimate grain yield under Mediterranean conditions, but WI usefulness may be restricted in the absence of drought, while severe drought during grain filling would limit the usefulness of PRI. The significance of the genotypic variation suggests opportunity for selecting for WI and PRI in order to increase yield.

References


