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

D. Villegas*, N. Aparicio and C. Royo***
*IRTA (Institute for Food and Agricultural Research and Technology), Cereal Breeding, Centre UdL-IRTA, Rovira Roure 191, 25198 Lleida, Spain
**Instituto Tecnológico Agrario de Castilla y León, Subdirección de Investigación y Tecnología, Carretera de Burgos km. 119 - "Finca Zamadueñas", 47071 Valladolid, Spain

SUMMARY – Relationships between grain yield, carbon isotope discrimination against ^{13}C (Δ), 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 Δ 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}C (Δ) 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 Δ and grain yield in durum wheat under contrasting Mediterranean conditions.

Matherials 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 m^2.

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: $WI = R_{970}/R_{900}$, and $PRI = (R_{531}-R_{570})/(R_{531}+R_{570})$, 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, $\delta^{13}C$ was determined for each plot and carbon isotope discrimination (Δ) 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 Δ. 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 Δ values. These results indicate that the crop experienced dissimilar drought levels before and after anthesis which resulted in a wide range of yield and Δ 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

Experiment	Water input (rainfall + irrigation, mm)		Water limitation†		Grain yield (t/ha)	Environment (yield level)	Δ (‰)
	Sowing-anthesis	Anthesis-maturity	Sowing-anthesis	Anthesis-maturity			
Irrigated 1999	240	165	+	-	7009	High	18.7
Irrigated 1998	312	73	-	+	5192	Medium-high	16.7
Rainfed 1999	201	55	+	++	3820	Medium-low	17.1
Rainfed 1998	156	27	++	+++	2531	Low	14.6

†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, Δ 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

Source of variation	df	Grain yield	Δ†	PRI††	WI†††
Environment (E)	3	83.0***	91.0***	90.4***	72.5***
Genotype (G)	24	5.2***	2.6***	3.3**	4.9*
G × E	72	6.4	3.1	4.4	9.4
Block (environment)	12	5.3***	3.3***	1.9*	13.2***

†Δ: Carbon isotope discrimination against ^{13}C in mature grains.
††PRI: Photochemical reflectance index.
†††WI: Water index.
*Significant at $0.01 < P < 0.05$; **significant at $0.001 < P < 0.01$; ***significant at $P < 0.001$.

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 (Δ), photochemical reflectance index (PRI) and water index (WI) for 25 durum wheat genotypes grown in NE Spain in four environments

	Environment (yield level)			
	High	Medium-high	Medium-low	Low
Grain yield – WI	-0.37	-0.72***	-0.51**	-0.52**
Grain yield – PRI	0.46*	0.68***	0.56**	-0.02
Δ - WI	-0.17	-0.56**	-0.30	-0.38
Δ - PRI	-0.01	0.51**	0.50*	-0.10

*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 Δ were less consistent than for grain yield. It has been postulated that Δ 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 Δ. 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 Δ. In our experiments, these two spectral indices were poor indicators of Δ, probably because the Δ 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.

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