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WHEAT BREEDING IN A WATER STRESSED ENVIRONMENT V. CARBON ISOTOPE DISCRIMINATION AS A SELECTION CRITERION

M.Siddique Sadiq, C.R.Arain* and A.R.Azmi.
Nuclear Institute for Agriculture and Biology (NIAB)
P.O. Box 128, Faisalabad, Pakistan.
*Department of Botany, Sindh University, Jamshoro, Pakistan.

Summary

To assess the potential of carbon isotope discrimination as a selection criterion for enhancing stress yield, simulated water deficit field studies were undertaken to measure its genetic variation and association with yield and yield related traits. Discrimination was significantly reduced in terminal stress compared to well watered conditions.Carbon isotope discrimination was significantly correlated with grain yield, biological yield, harvest index, and productive tillers under terminal and preanthesis stress.

Index words; Carbon isotope discrimination, selection criterion, harvest index, stress yield

Introduction

In recent years, the use of stable carbon (C) isotopes in agricultural and ecological research has become more frequent (Tiezen and Boutton, 1989). The stable isotopes of C are ^{12}C and ^{13}C, which comprise 98.89% and 1.11%, respectively, of all C in nature (Ehleringer and Rundel, 1989). Photosynthetic processes in plants discriminate against the heavier C isotope (^{13}C) over the lighter, more abundant atmospheric form (^{12}C) at the carboxylation step. This has resulted in the grouping of plants into either C_3 or C_4 types depending upon their photosynthetic pathways. Breadwheat utilizes the C_3 pathway.

Carbon isotope discrimination (Δ) has been proposed to indirectly select for improved seed yield and water use efficiency (WUE) in wheat (Farquhar and Richards, 1984). The relationship between Δ and seed yield varies with the pattern of stress (Ehleringer et al. 1990) whereas the relation of Δ and WUE to plant productivity is less clear. It is not certain that high WUE will necessarily confer increased yield or drought resistance in a given environment (Condon and Richards, 1993; Johnson and Tiezen, 1994). A positive association between dry matter production and Δ indicated that high productivity and high WUE were not always compatible (Condon and Richards, 1993). A negative correlation of dry matter production with Δ suggested that high WUE might be important for increased productivity (Johnson and Bassett, 1991). Increased WUE may result in reduced dry matter partitioning to grain (Ehdaie and Waines, 1993).

The objectives of this study were (i) to examine genetic variation in carbon isotope discrimination and (ii) to measure its association with grain yield and yield related traits in order to assess the potential of Δ as an indirect selection criterion for grain yield in wheat.

Materials and Methods

The research was conducted at the Atomic Energy Agricultural Research Centre's Farm, Tandojam, Pakistan. The experimental site was divided into twelve plots which were separated by a 3 m buffer zone on each side to prevent seepage. Prior to planting, plots were precision levelled to ensure even distribution of irrigation water. The soil was of clay loam in the upper layer (0-15 cm) and sandy clay loam in the lower layers (16-30 cm & 30-60 cm) having in each case a bulk density of 1.42 g cm^{-3}. The soil moisture content by volume at field capacity (-0.05 M Pa) was 28% and at wilting point (-1.5 M Pa) was 13.5%. Ec and pH values were 2.2 dSm^{-1} and 7.33, respectively. There was no significant interannual variation for precipitation, evaporation, maximum/miminum temperature and relative humidity. The amount of precipitation during the cropping seasons was negligible.

Seven spring breadwheat genotypes identified as drought tolerant and susceptible (Sadiq et al. 1994) were included. The experiment was set out as a three replicate split plot design with water regimes in main plots and genotypes in the subplots. The preplanting irrigation (75 mm equivalent) was applied on Nov. 8 every year, with the subsequent irrigations (75 mm equivalent) at the different developmental stages of growth i.e. T_o, No irrigation during the entire crop growth; T_1, Irrigation at tillering stage; T_2, Irrigation at anthesis stage, and T_3, Normal recommended irrigation (375 mm). The land was well prepared and fertilizer was applied at the rate of 70:35 N:P kg ha^{-1}. Seeds were hand drilled in excess on Nov.15 1989 and Nov. 16, 1990 and later thinned to the required population of 320 seedlings m^{-2}. Each genotype consisted of four rows, each 5 m long, spaced 0.25 m apart. Disease incidence and lodging were not limiting factors for crop growth and yield.

Twelve aluminium access tubes, each 5 cm in diameter and 1 m long, were installed in the center of each plot at planting. A neutron moisture meter (Model 2601, Scaler No.419 Troxlar Lab, North Carolina, USA) was used to measure soil moisture content. Changes in the moisture content in the 0.75 m soil profile in each plot were measured weekly at 0.15, 0.30, 0.45, 0.60 and 0.75 m depth. These values were periodically checked gravimetrically. A drop over time below field capacity in the soil water content at a particular depth was taken as the soil water deficit for that depth and time. Volumetric soil water content was calculated as soil water content x bulk density x depth of soil layer.

Leaf samples at harvest were collected, dried at 70°C, ground to particle size of less than 100 um in a Wiley mill and analysed for $^{13}C/^{12}C$ ratio on a mass spectrometer (VARIAN MAT GD 150 USA). The carbon isotope discrimination was calculated assuming a value of -8‰ for the isotope composition of the air relative to the standard Pee Dee Formation of belemnite (Sajjad et al. 1989). Data were collected on dry matter yield, grain yield, harvest index, spike yield and spikes bearing tillers. Analysis of variance was carried out to test the significance of differences among the treatments and genotypes by Duncan's Multiple Range Test and correlation coefficients were calculated (Steel and Torrie, 1980).

Results

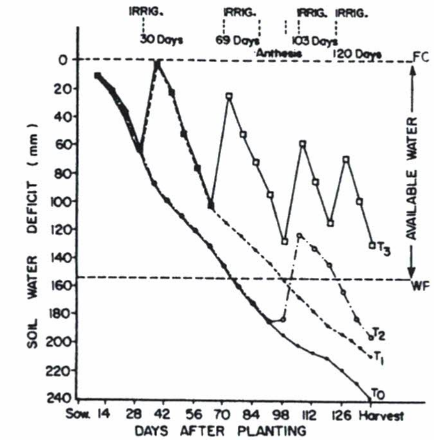

Fig. 1 . SOIL MOISTURE DEPLETION FROM FIELD CAPACITY FOR THE WHOLE PROFILE FOR ALL TREATMENTS DURING THE GROWING SEASON

In To and T2, the entire soil profile fell below wilting point (WP) at 71 days after planting and continued up to maturity in To (Fig. 1) whereas water content in T2 remained within available limits for 19 days(days 103-122). The soil moisture content in T1 dropped below wilting point immediately after anthesis and continued until maturity. At maturity, soil water extraction was the highest in To followed by T1 and T2. Plants in To extracted 30 mm and 45 mm more water than those in T1 and T2, respectively.

The stress treatments significantly reduced grain yield (Table 1). The highest reduction occurred in To (46.2%), followed by T2, (34.8%) and T1 (32.9%). Significant genotype x treatment interaction was observed. Significant maximum reduction in grain yield due to water stress was observed in AZS-17 and Pavon and the minimum in AZS-4. Carbon isotope discrimination varied significantly among treatments; the highest value was found in T3 and the lowest in To.Significant genotype x treatment interaction was observed. Water stress significantly reduced Δ in Pavon and AZS-17.

A positive significant correlation between Δ and grain yield, biological yield, harvest index, and productive tillers was found in To (Table 2). Nonsignificant associations between Δ and other traits were observed in T1 and T3.

Discussion

For drought tolerance studies, it is essential to quantify the growing environment. Under terminal stress (To), the highest soil moisture extraction from deeper layers seemed to support the plant growth producing a reasonable grain yield (Fig.1; Table 1). Other stress treatments showed similar responses. In general, plants under stress extracted more soil water and from deeper layers than those grown in non-stress conditions. The trend in soil moisture extraction patterns in the present study is in agreement with earlier results (Talukder et al. 1989; Cutforth et al. 1991).

Table 1. Grain yield and carbon isotope discrimination of seven genotypes grown under different water regimes

Genotype	T3	T2	T1	To	Mean
		Grain yield (kg ha^{-1})			
	c**	i	k	p	
AZS-3	6313c*	4513b	4288c	3563c	4668c
	a	g	f	j	
AZS-4	7000a	4875a	5113a	4375a	5340a
	b	i	h	m	
AZS-11	6558b	4500b	4775b	4080b	4978b
	g	v	u	x	
AZS-17	4875f	2500f	2618g	1625g	2903g
	e	t	r	r	
Pavon	5500e	2918e	3125e	2125f	3415e
	n	r	s	u	
C-228	4025g	3125d	3000f	2625e	3193f
	d	o	l	q	
Chakwal-86	6038d	3850o	4125d	3313d	4330d
Mean	5758A	3755C	3863B	3100D	
		Carbon isotope discrimination (‰)			
	c**	i	h	i	
AZS-3	20.05b*	18.91c	19.05c	18.91b	19.23c
	c	h	k	i	
AZS-4	20.06b	19.12b	18.72d	18.51c	19.10d
	a	f	g	ij	
AZS-11	20.63a	19.45a	19.23b	18.84b	19.54b
	d	lm	j	n	
AZS-17	19.95b	18.45d	18.80d	18.16d	18.84e
	e	o	n	o	
Pavon	19.65c	17.66f	18.42e	17.61e	18.34f
	b	g	c	h	
C-228	20.27b	19.20b	20.07a	19.11a	19.66a
	g	lm	g	n	
Chakwal-86	19.28d	18.48e	19.21b	18.17c	18.79e
Mean:	19.98A	18.75C	19.07B	18.47D	

* Comparison of genotypes within treatment, ** GxT interaction

Table 2. Phenotypic correlation co-efficients between carbon isotope discrimination and grain yield-related traits

Trait	T3	T2	T1	To
Grain yield	0.153	0.566**	-0.142	0.517*
Biological yield	0.211	0.612**	0.295	0.538**
Harvest index	0.054	0.190	0.276	0.469*
Spike yield	0.142	0.522*	-0.292	0.160
Productive tillers	0.194	0.585**	0.120	0.419*

** P>0.01 * P>0.05

Water stress significantly reduced grain yield and Δ. AZS-4 and AZS-17 had consistently the highest and the lowest yields in stress treatments. The genotypes, i.e. AZS-4, AZS-11 and AZS-3 had intermediate Δ values but had significantly higher yields. AZS-17 and Pavon had low yield and low Δ in stress treatments. Lower mean values of Δ in stress compared to those of nonstress conditions in the present study is in agreement with earlier findings (Condon et al., 1992; Ehdaie and Waines 1994). Low Δ has been associated with low yield and water stress susceptibility in wheat (Morgan et al. 1993). It seems important to establish what values of Δ are appropriate in particular environments and for particular species. The co-occurrence of low Δ and low productivity could suggest that the genotypic ranking for Δ was determined predominantly by stomatal conductance.

Genotype x environment interactons are of two types; crossover and noncrossover (Baker 1988). Genotype x water regime interactions for grain yield and Δ were significant and were the noncrossover type in the present study. Crossover interactions in spring wheat cultivars for grain yield (Blum and Pnuel 1990) and noncrossover interaction for Δ (Matus et al. 1995) were reported earlier. The absence of crossover interaction in the present study indicates that the ranking of genotypes did not change across water regimes. Selecting genotypes with consistent Δ values in both nonstress and drought stress environments seems to be the best way to obviate the potential interactions of Δ with drought stress resistance mechanisms.

The present study confirmed earlier reports of positive association between Δ and grain yield, biological yield and harvest index under terminal and preanthesis stress (Condon et al. 1987; Ehdaie et al. 1991; Morgan et al. 1993; Ehdaie 1995). One of our objectives was to assess the relationship between Δ and grain yield in the context of the use of Δ as an indirect selection criterion. It will depend upon the magnitude of the correlation between Δ and seed yield under field conditions. Low but significant positive association under terminal and preanthesis stress was observed. Low Δ seems to be indicative of low yield potential under stess environments. Selection for intermediate Δ combined with important productivity traits should be practiced in wheat breeding programmes in water limited environments. In the present study only a small fraction of germplasm was sampled for Δ . It may be possible to uncover hidden genetic diversity if a large number of accessions are evaluated. More studies are needed to determine how selection for water use efficiency through Δ will affect biological yield, grain yield, and harvest index.

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