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Durum wheat variety testing
under high and low input cultivation

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Summary

In Arizona, durum wheat cultivation will need to shift from abundant water and nitrogen inputs to a more sustainable low input management in the near future. Screening old and new durum wheat varieties for their grain yield and quality, and for their metabolic status, under limited input cultivation will help directing future studies and breeding efforts aimed at developing new low input varieties adapted to the arid conditions of the Arizona low desert. This study represents the first large screening of durum wheat varieties under low input management and includes the assessment of their grain yield and quality performance and their leaf biochemical status. Several site-years combinations are necessary to adequately characterize the potential of durum wheat varieties to low input environments and this study would be mostly beneficial if part of annual routine evaluation.

Introduction

Durum wheat is an important crop for Arizona with an average of ~57,000 acres harvested per year during the last five years (USDA, www.nass.usda.gov, 2020-2024). In the Arizona low desert, durum wheat cultivation requires abundant irrigation (more than 30 inches of water per acre per season). Such a high-water requirement is not a sustainable option for the future especially considering the ongoing drought of the Colorado River basin which makes it necessary to use groundwater resources for supplemental irrigation. Relying on groundwater for durum wheat irrigation represents a high cost for farmers (up to ~$50/acre per irrigation treatment) that leads to a substantial decrease in their profitability for this crop. Apart from water availability, the exceptional grain quality (high gluten index, protein, and yellow color) and high yield of the durum wheat varieties grown in Arizona, collectively named Desert Durum®, strongly relies on frequent and abundant applications of nitrogen (N) fertilizer, particularly near anthesis. After planting, N fertilizer is mostly applied in the irrigation water as liquid (e.g., UAN-32). In the future, shifting to a more sustainable low input durum wheat production in Arizona will require a reduction of the irrigation treatments and of the overall water quantity applied to the crop. This reduction will also impact on the application schedule and overall seasonal quantity of N fertilizer, thus negatively affecting grain yield and quality of durum wheat varieties grown in Arizona. Mechanisms of crop adaptation to limited inputs involve morphological, physiological, and molecular responses that lead to changes in plant biochemistry and metabolism which ultimately affect plant performance.

For these reasons, evaluating the impact of reduced irrigation and application of N fertilizer on grain yield and quality, and flag leaf biochemical status, of an expanded set of old and new durum wheat varieties is critical to (1) assess the need for new varieties resilient to low agronomic inputs and, (2) identify possible parents for a breeding program aimed at creating new low input varieties for arid environments, and (3) understand the main biochemical changes induced by low input cultivation in relation to the source (leaf) to sink (grain) system.

Procedure

A trial testing high and low water and nitrogen rates on grain yield and quality performance of durum wheat varieties was conducted at the Maricopa Agricultural Center (MAC) of the University of Arizona, Maricopa, AZ. Sudan grass was the crop planted the previous year at the field used for the trial. The field soil texture was sandy loam and soil chemical properties for samples taken before planting at different depth are listed in **Table 1**. Ammonium phosphate (16-20-0) was applied preplant at a rate of 470 lbs/acre providing ~75 lbs/acre of nitrogen (N) and ~95 lbs/acre of phosphorous (P). A list of the irrigations and applications of N fertilizer (UAN-32) during the growing season are provided in **Table 2**. On December 19th, 2023, seeds of eighteen between discontinued and commercially available durum wheat varieties (**Table 3**) were planted in the dry field with a cone planter (7 rows spaced 6 inches apart) in 5×20 ft. plots. The experimental design considered two neighboring fields (high and low input) each one comprising four replicated randomized complete blocks of the varieties. The seeding rate for the high input field was ~96 lbs/acre while this rate was reduced to ~58 lbs/acre (~40% reduction) for the low input field. On February 6th, 2024, 16 (eight per field) soil moisture probes (GS1, Decagon Devices, Pullman, WA, USA) were installed at two depths (10 and 20 inches) on eight randomly selected plots and connected to data loggers (Em50, Meter, Pullman, WA, USA) to control the levels of soil volumetric water content (%) during the entire season and plan irrigations accordingly. On April 12th, at the grain filling stage, between 10am and 12pm, 8 flag leaves were collected from each plot and immediately frozen in liquid nitrogen on field before being stored in a -80ºC freezer and later analyzed by colorimetric assays to measure: total chlorophyll (Chl), total non-enzymatic antioxidant capacity (TAC), total proteins (Prot), total free amino acids (AA), starch, sucrose (Suc), glucose (Glu), and fructose (Fru). During the same day and sampling window, 3 more flag leaves were collected from each plot to determine the leaf relative water content (RWC). On May 16th and 17th, 2024, a 1 m^2 (10.76 sq. ft.) area that included 5 out of the 7 rows (the 2 external rows were excluded) in the middle of each plot was manually harvested to determine grain yield and quality parameters. Grain yield (lbs/acre), seed weight (grams, based on 250 seeds), and test weight (lbs/bu, based on 1 pint of grain) were measured from samples of all the harvested plots. For all the other grain quality parameters, replicates of each variety under the same input were pooled to generate single samples. The pooled samples were then used to measure grain vitreousness (%, based on visual score of 100 seeds), and, after milling, their flour was used to measure protein (%, normalized at 14% moisture) and gluten index (%) by near-infrared (NIR) spectroscopy.

Results and Discussion

The low input (LI) field received ~47% less irrigation water (4 irrigations, 19 inches in total) than the high input (HI) field (8 irrigations, 36 inches in total) and ~57% less N fertilizer (HI: 245 lbs/acre; LI: 105 lbs/acre) with only one N application (at anthesis, mid-March), after planting (**Table 2**). From anthesis until harvest (mid-March to mid-May), the total precipitation at MAC was minimal (less than one inch of rain) with maximum daily temperatures between 30ºC and 40 ºC from mid-April to harvest (**Figure 1**). The combined effect of the weather conditions and limited inputs exposed the durum varieties in the LI field to strong environmental stress. This stress resulted in 43% mean grain yield reduction of the 18 durum varieties (mean±SD: HI=7,079±525 lbs/acre; LI=4,030±44 lbs/acre), ranging from a minimum of 33% for the variety Sky to a maximum of 56% for the variety Ocotillo (**Table 3**). Interestingly, the variety with the highest grain yield under both HI and LI (8,050 lbs/acre and 4,799 lbs/acre, respectively) was Dorato. Considering grain and flour quality (**Table 4**), the LI treatment strongly reduced mean vitrousness (mean±SD: HI=92±7%; LI=58±22%) and gluten index (mean±SD: HI=79±21; LI=44±23). The effect of the LI treatment on protein was opposite with an increase in all the varieties compared with the HI treatment (mean±SD: HI=9.7±0.6%; LI=12.6±0.6%). Under LI conditions, the only two varieties that displayed a gluten index higher than 80 were Sky and Dorato (85 and 81, respectively), with Sky also showing that highest vitrousness (85%) and above average protein content (13.1%) under the same condition.

Overall, the results of the agronomic field trial conducted at MAC in 2024 highlighted the need of new durum varieties for low input cultivation in the arid conditions of the Arizona low desert. Interestingly, older varieties from the 1970s, 1980s, and 1990s (e.g., Yavaros 79, Mexicali 75, Ocotillo, Kronos) did not show more resiliency for grain yield and quality traits under LI than more modern varieties. This suggests that breeding efforts during the last 40 years have generated new materials that are overall more robust and resilient to environmental stresses than older germplasm. The only exception found in this study is Sky, released in 1999, that displayed the best quality values under LI treatment and, thus, represents a possible parental line to use in future breeding programs aimed at developing new low input durum wheat varieties for arid environments. Despite the interesting findings of this study, we acknowledge the need of several locations and years of field trials to assess variety performance, particularly under suboptimal conditions, such as under LI conditions. The results of this trial will be most useful if part of a future routine evaluation under limited inputs of the commercially available durum wheat germplasm.

The biochemical profiling of the flag leaf tissue samples collected at the grain filling stage highlighted how the LI treatment produced a significant and marked alteration of the physiological and metabolic status of the durum wheat varieties (**Figure 2**). Under LI, reduced irrigation induced a strong decrease in the flag leaf relative water content (RWC) of all the varieties. This state of leaf dehydration was matched by a general reduction of total leaf chlorophyll (Chl), proteins (Prot), and free amino acids (AA), indicating an overall reduced biosynthetic activity under LI treatment. The reduction in Prot and AA might be also associated the low N availability under LI conditions. Conversely, the LI treatment was matched by a strong and general increase in sucrose (Suc), starch, and, to a lesser extent, of fructose (Fru) and non-enzymatic total antioxidant capacity (TAC). These increases are suggesting that under the stressful LI conditions, the flag leaves of the durum varieties reduced their main source function of transferring carbohydrates to the developing grain sink. In addition, a higher TAC under LI conditions suggests active antioxidative actions in response to the pro-oxidative conditions generated by water limitation. Principal component analysis (PCA) based on RWC and the other biochemical variables displayed an almost perfect separation of HI and LI leaf tissues on PC1, that alone explained ~50% of the sample variance (**Figure 3**). PCA loadings of the variables showed that RWC, AA (both higher in HI samples), and Suc (higher in LI samples) were the main ones to drive HI and LI sample separation on PC1.

Overall, the results of the flag leaf biochemical profiling suggest that the source-to-sink function was deeply altered by the LI treatment and that the quantitative evaluation of this variation is a promising phenotyping strategy for understanding the basis of durum wheat performance under LI cultivation. For these reasons, we suggest that in the future crop molecular phenotyping must be always matched to variety testing in durum wheat under LI cultivation.

Acknowledgements

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Table 1. Soil chemical analysis from samples taken before planting at the field site at MAC (0-8 in.: composite of 24 cores; 0-1, 1-2, and 2-3 ft.: composite of 6 cores).

Chemical measurement	Unit	0-8 in.	0-1 ft.	1-2 ft.	2-3 ft.
pH	(pH)	8.7	8.5	8.6	8.6
Soluble salts	(mmho/cm)	0.29	0.26	0.26	0.27
Excess lime rating	(estimate)	HIGH	HIGH	HIGH	HIGH
Organic matter (LOI)	(%)	1.0	1.1	1.1	0.9
Nitrate (2N KCl)	(ppm; lbs/acre)	2.84; 7	3.41; 12	2.15; 8	1.06; 4
Ammonium (KCl)	(ppm; lbs/acre)	0.99; 2	2.93; 11	0.62; 2	0.29; 1
Phosphorous (Olsen)	(ppm)	8.9	12.2	9.5	8.6
Potassium (NH_4OAc)	(ppm)	285	303	300	215
Sulfate (M-3)	(ppm)	36.8	41.6	41.9	40.6
Zinc (DTPA)	(ppm)	1.7	1.1	0.6	0.4
Iron (DTPA)	(ppm)	3.3	4.7	3.8	4.1
Manganese (DTPA)	(ppm)	3.3	4.1	2.8	2.0
Copper (DTPA)	(ppm)	1.4	1.4	1.3	0.8
Calcium (NH_4OAc)	(ppm)	4,389	4,233	4,402	4,423
Magnesium (NH_4OAc)	(ppm)	263	267	271	240
Sodium (NH_4OAc)	(ppm)	325	323	349	323
Sum of cations	(me/100g)	26.3	25.6	26.6	26.1
Soil texture	(% of sand-silt-clay)	n.d.	57-13-30	58-12-30	60-12-28
Field capacity	(% of volume)	n.d.	28.3	28.1	26.4
Permanent wilting point	(% of volume)	n.d.	13.9	13.8	13.0

Table 2. Cultural practices for the high and low input durum wheat trial conducted at MAC, 2024.

Cultural information	High input	Low input
Previous crop	Sudan grass	Sudan grass
Planting date	12/19/2023	12/19/2023
Irrigation dates and amounts	12/20: 6.5 in. 01/08: 3.2 in. 02/21: 3.9 in. 03/14: 5.9 in. 03/28: 3.9 in. 04/08: 3.8 in. 04/17: 2.9 in. 04/29: 5.9 in. SUM = 36.0 in.	12/20: 6.5 in 01/08: 3.2 in. 02/21: --- 03/14: 5.9 in. 03/28: --- 04/08: --- 04/17: 3.4 in. 04/29: --- SUM = 19.0 in.
Nitrogen application dates and amounts	12/15: 75 lbs/acre 02/21: 50 lbs/acre 03/14: 60 lbs/acre 03/28: 40 lbs/acre 04/08: 20 lbs/acre SUM = 245 lbs/acre	12/15: 75 lbs/acre 02/21: --- 03/14: 30 lbs/acre 03/28: --- 04/08: --- SUM = 105 lbs/acre
Phosphorous application dates and amounts	12/15: 95 lbs/acre	12/15: 95 lbs/acre

Table 3. Grain yield performance of the durum wheat varieties (in alphabetical order) used in the field trial conducted at MAC, 2024. Values (best linear unbiased estimators, BLUEs) of each variety under each input were determined using a linear mixed model that considered the variety and input as fixed effects and blocks as random effects.

Variety	**Year released**	**Source**	**Input**	**Grain yield** (lbs/acre)	**Test weight** (lbs/bu)	**Seed weight** (grams)	**Grain yield loss** (%)
Alberto	2016	APB	High	7263	64.2	55.6	40.1
			Low	4352	63.8	55.3	
Desert Gold	2018	CCIA	High	7771	65.0	50.1	43.5
			Low	4390	62.6	47.1	
Desert King	2005	CCIA	High	7239	64.9	54.0	43.8
			Low	4067	63.9	48.7	
Desert King HP	2011	CCIA	High	6643	61.8	45.1	36.6
			Low	4211	61.7	40.7	
Dorato	2023	APB	High	8050	66.4	52.6	40.4
			Low	4799	65.8	53.8	
Falcon	na	Dunn Grain	High	7882	64.1	44.0	42.4
			Low	4536	64.0	44.9	
Kronos	1993	APB	High	6489	64.6	62.2	36.9
			Low	4094	64.4	62.6	
Matt	1999	APB	High	6245	64.9	53.9	45.3
			Low	3415	65.2	56.4	
Mexicali 75	1977	ACIA	High	7111	64.7	56.0	44.7
			Low	3930	63.8	56.4	
Miwok	2013	Western Milling	High	7184	64.5	58.5	42.8
			Low	4110	63.9	53.4	
Ocotillo	1991	APB	High	6625	64.6	53.2	56.0
			Low	2918	64.9	52.1	
Pegasus	na	Dunn Grain	High	6728	64.9	48.3	36.4
			Low	4281	63.1	44.9	
Phoenix	na	Dunn Grain	High	7238	64.3	43.4	42.4
			Low	4168	65.0	46.2	
Saragolla	2004	University of Arizona	High	7663	65.8	51.5	51.2
			Low	3737	63.5	49.1	
Shasta	na	2nd Nature Research	High	6610	65.4	66.3	48.5
			Low	3403	65.1	66.1	
Sky	1999	APB	High	6338	63.4	49.9	32.9
			Low	4254	64.5	50.9	
Tiburon	2013	APB	High	7413	64.1	60.9	43.8
			Low	4166	63.4	60.1	
Yavaros 79	1982	ACIA	High	6930	66.7	58.1	46.6
			Low	3704	65.7	57.3	

APB=Arizona Plant Breeders, CCIA=California Crop Improvement Association, ACIA=Arizona Crop Improvement Association

Table 4. Grain quality performance of the durum wheat varieties (in alphabetical order) used in the field trial conducted at MAC, 2024. Values (best linear unbiased estimators, BLUEs) of each variety under each input were determined using a linear mixed model that considered the variety and input as fixed effects and blocks as random effects.

Variety name	Input	Grain vitrousness (%)	Flour protein (%, at 14% moisture)	Flour gluten index
Alberto	High	97	10.5	95
	Low	71	13.2	65
Desert Gold	High	95	9.0	93
	Low	57	11.9	41
Desert King	High	98	9.3	87
	Low	62	12.1	22
Desert King HP	High	98	10.6	69
	Low	92	13.6	41
Dorato	High	93	9.1	93
	Low	58	11.9	81
Falcon	High	75	9.3	77
	Low	27	12.0	16
Kronos	High	95	10.3	91
	Low	61	13.6	42
Matt	High	97	10.3	95
	Low	88	12.7	77
Mexicali 75	High	86	9.3	35
	Low	40	12.1	28
Miwok	High	95	9.6	56
	Low	65	12.9	8
Ocotillo	High	99	9.9	77
	Low	81	13.7	30
Pegasus	High	93	8.9	85
	Low	17	11.9	47
Phoenix	High	87	10.2	90
	Low	47	12.7	61
Saragolla	High	76	8.4	86
	Low	11	11.7	36
Shasta	High	92	9.6	93
	Low	64	12.3	40
Sky	High	97	10.6	94
	Low	87	13.1	85
Tiburon	High	96	10.3	94
	Low	67	12.7	60
Yavaros 79	High	91	9.2	19
	Low	55	12.1	9

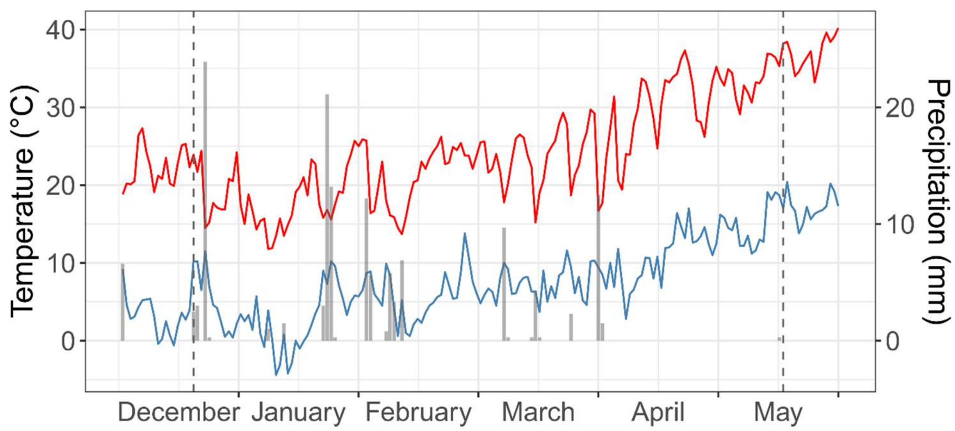

Figure 1. Daily maximum (red) and minimum (blue) temperatures (°C), and precipitation (gray bars, mm) during the 2024 field season in Maricopa, AZ (data collected from the AZMet metereological station located at the UA farm). The first vertical dashed line (left) indicates the date of planting date while the second one (right) indicates the date of harvest.

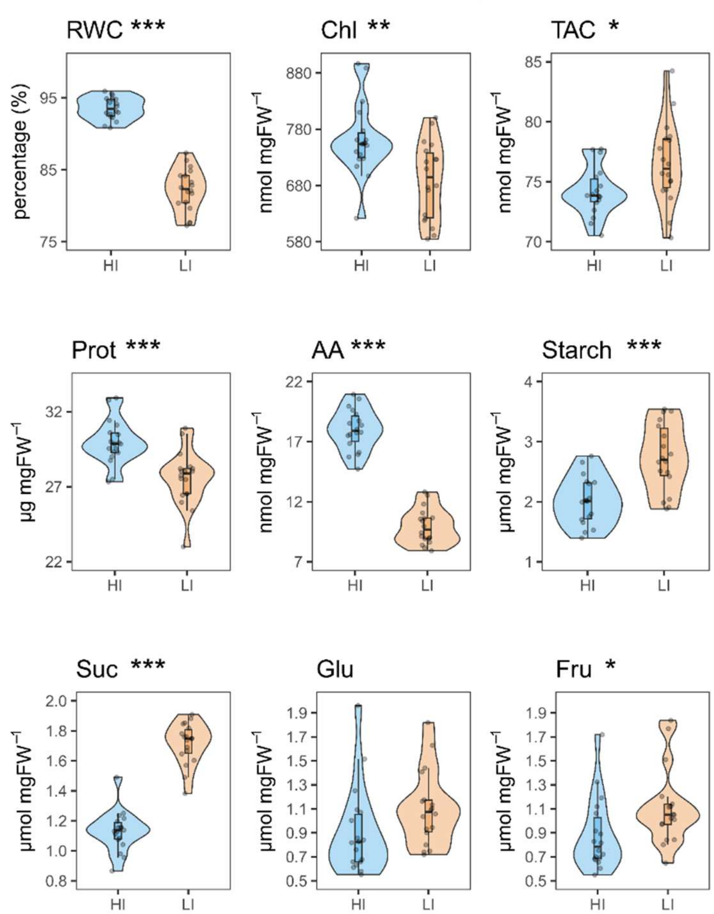

Figure 2. Violin plots and boxplots displaying the variation of total relative water content RWC), total chlorophyll (Chl), total non-enzymatic antioxidant capacity (TAC), total proteins (Prot), total free amino acids (AA), starch, sucrose (Suc), glucose (Glu), and fructose (Fru) of the 18 durum wheat varities under high and low input (HI and LI) treatments. For each variable, single values of the varieties (best linear unbiased estimators, BLUEs) were calculated using a linear mixed model that considered the variety and input as fixed effects and blocks as random effects. Statistical significance (paired t-test's *p*-value) of the effect of the input on each variable is indicated by asterisks ('*'<0.05; '**'<0.01; '***'<0.001); ' '> 0.05).

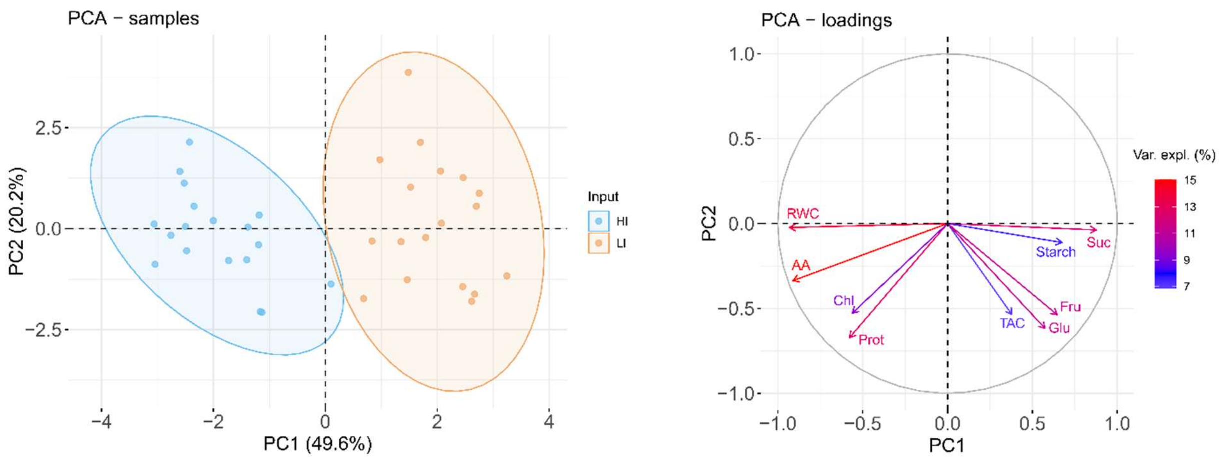

Figure 3. (Left) Principal component analysis (PCA) scores of HI (blue) and LI (orange) flag leaf samples based on RWC and the other biochemical variables. The percentage of sample variation explained by the first two principal components (PC1 and PC2) is reported in brackets. (Right) PCA loadings of the nine variables colored based on their single contribution (percentage) to the total explained variance (see legend in the figure for color code).