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RELATIONSHIPS AMONG WATER USE EFFICIENCY AND THE PHYSIO-AGRONOMIC TRAITS IN DURUM WHEAT (*TRITICUM DURUM* DESF.) CULTIVARS ASSESSED UNDER RAINFED CONDITIONS OF THE EASTERN HIGH PLATEAUS OF ALGERIA.

SUMMARY

Genetic advances in grain yield under rainfed conditions haves been low, slowed by genotype x environment interaction arising from unpredictable rainfall in drought prone areas. A good understanding of factors regulating yield provides the opportunity to identify and select for physiological and agronomic traits that increase both water use efficiency and grain yield under rainfed conditions. The results of this investigation exhibited large variation for physiological and agronomic traits among varieties and cropping seasons. Modern varieties had high harvest index, grain yield, and leaf chlorophyll content, low leaf relative water content, and were shorter than varieties derived from land races. Total dry matter and specific leaf area differences, among groups of varieties, were not significant. Water use efficiency for total dry matter showed no significant correlations with the measured physiological and agronomic traits, while water use efficiency for grain yield was significantly correlated with harvest index, plant height and to a lesser extent with leaf chlorophyll content. Path analysis, based on phenotypic correlations, showed the consistent direct and indirect effects of harvest index and to a lesser extent those of plant height. Selecting for plant height and harvest index could improve both water use efficiency and grain yield under drought prone environments.

Key words: *Triticum durum*, water use efficiency, harvest index, grain yield, path analysis, rainfed.

INTRODUCTION

Durum wheat cultivation, in Algeria, is practiced in a fallow-wheat rotation, relying on stored water during the fallow period, in addition to the cropping season's rainfall**.** Annual precipitations, inherently low in amount, varied quantitatively and qualitatively, mainly on the high plateaus area, where nearly 70% are receipted during the cold winter months. Under such growing conditions, the occurrence of intermittent drought stress limits grain yield and

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online renders water scarcity as the most penalizing production factor (Chennafi *et al.*, 2006). The high plateaus area belongs to a vast geographical region where agriculture has been forecast to be at greater risk due to an increase in the frequency and severity of drought episodes (Sahnoune *et al.*, 2013). Selection of drought tolerant cultivars is sought to minimize the effects of water scarcity and to sustain crop production. The release of improved cultivars requiring lower amounts of water per unit yield and characterized by high yield potential is essential for more sustainable agricultural practices, particularly in rainfed, drought prone areas. Water conserving breeding strategy could combine high yield, high WUE and good drought resistance traits in one variety (Zhang *et al.*, 2004). Water use efficiency (WUE) is seen as an important determinant of yield under stress and as a component of crop drought resistance (Ehdaie, 1995 ; Kirda *et al.*, 1999). This trait remains among the most appropriate strategies to cope with drought stress under rainfed conditions. Several studies have shown that selection based on this trait improved grain yield potential (Rebetzke *et al.*, 2002, Franks *et al.*, 2015). Zhang *et al. (*2005) reported that grain yield improved by 50%, resulting in significant WUE increases. Studies are needed to focus on plant traits that are beneficial to both grain yield and WUE improvement.

Besides crop husbandry, numerous plant characteristics are reported to affect WUE and grain yield (GY). In fact GY and WUE, due to their close association with harvest index (HI), could be improved by manipulating this trait (Ehdaie and Waines, 1993; Zhang *et al.*, 2008). Siddique *et al.* (1990) reported that WUE of modern cultivars was higher than old cultivars among Australian tested wheat varieties, because of significant changes in plant stature and crop cycle duration, leading to improved HI and stress escaping. Slafer and Araus (1998) reported that the improved crop performance may be achieved by improvements in water use (WU), WUE and HI. Several plant traits such as chlorophyll content, osmotic adjustment, relative water content, translocation of stem stored carbohydrate, stay green, early seedling vigor, earliness, canopy temperature, carbon isotopic discrimination, coleoptile length, stem and leaf waxiness, leaf and root architecture as well as the amount of soil moisture available to the crop and its partitioning between evaporation and transpiration are reported to related to WUE and GY(Quin *et al.*, 2013; Richard *et al.*, 2015; Farjam *et al.*, 2015; Nakhforoosh *et al.*, 2016; Christy *et al.*, 2018; Rashid *et al.*, 2018; Abdolahi *et al*,2018). The present investigation aimed to analyze the association between some physio-agronomic traits and WUE in eight durum wheat (*Triticum durum* Desf.) varieties, belonging to two different eras, evaluated under semi-arid conditions during three cropping seasons.

MATERIAL AND METHODS

Plant material and experimental design

The experiment was carried out at the Field Crop Institute-Agricultural Experimental Station of Setif (ITGC-AES, 36°12' N and 05°24' E, 1080 masl, Algeria), under rainfed conditions during three growing seasons (2013/14-

2015/16). Eight durum wheat varieties were evaluated (Table 1). Waha and Gaviota durum are selections from Cimmyt–Icarda joint durum wheat breeding program. Simeto is an Italian cultivar while Megress is an ITGC-AES Setif selection. These varieties proved to be well adapted to the Setif region and are classified as early-heading genotypes (Haddad *et al.*, 2016). Mohamed Ben Bachir (MBB), Hedba$_3$, Guemgoum Rkhem, and Oued Zenati$_{368}$ are old varieties selected from land races. MBB is selected from a land race native to the Setif region. Hedba$_3$, alias Pelissier, is a drought tolerant cultivar. Guemgoum Rkhem is native from Tiaret region (Western Algeria), while Oued Zenati$_{368}$ is a selection from a population native to the Guelma region (Eastern Algeria). Varieties derived from landraces are taller and late maturing compared to recently released ones (Nouar *et al.* 2012).

Table 1.Name of varieties evaluated during the 2013/14 - 2015/16 cropping seasons at the ARS-ITGC, Setif, Algeria.

Variety name	Abv	Cross name	Origin (released year)
Waha	WAH	Plc/Ruff//Gta/3/Rolette	Cimmyt-Icarda (1985)
Gaviota durum	GTA	Crane/4/Polonicum PI$_{185309}$//*T.glutinenano*/2* Tc60/3/Gll	Cimmyt-Icarda (1985)
Simeto	SMT	Capeiti$_8$/Valvona	Italy
Megress	MGS	Ofanto/Waha//MBB	ITGC- AES, Setif (2015)
Med Ben Bachir	MBB	Local variety	INRA Algeria (1950)
Hedba$_3$	H$_3$	Local variety	INRA Algeria (1950)
Guemgoum Rkhem	GMG	Local variety	INRA Algeria (1950)
Oued Zenati$_{368}$	OZ$_{368}$	Local variety	INRA Algeria (1950)

The experiment was arranged according to a randomized complete block design, with four replications. Soil site is a silt-clay soil with calcium carbonate and organic matter contents of 30.4 % and 1.4%, respectively. Sowing dates were 09/12/2013,15/2014,29/11/2015for 2013/14, 2014/15 and 2015/16 cropping seasons, respectively. Recommended cultural practices for the area were followed to raise a good crop. Monoammonium phosphate (52% P_2O_5 + 12% N) with 80 kg ha^{-1} was applied just before sowing and 80 kg ha^{-1} of urea (46%) were broadcasted at the tillering stage. Weeds were controlled chemically by application of 150 g ha^{-1} of Zoom [*Dicamba 66% Triasulfuron 4%]* and 1.2 L ha^{-1} of Traxos [*22.5 g/l de Pinoxaden, 22.5 g/l Clodinafop-propargyl, 6.5g/l de Cloquintocet-méxyl]* herbicides.

Measurements

At the heading stage, leaf relative water content (LRWC), leaf chlorophyll content (LCHC) and specific leaf area (SLA) were measured. LRWC was determined by the method of Barrs and Weartherly (1962) described by Pask *et al.*, (2012). Four leaves were sampled per plot and immediately weighed to obtain the fresh weight. Leaf samples were then placed in test tubes containing distilled water, and let to stand for four hours, under dim light at laboratory ambient temperature. Leaf samples were then reweighed to obtain the leaf turgid weight. Leaf samples were then oven dried at 80°C for 48 h for leaf dry weight determination. The LRWC was calculated according to the following formulae reported by Pask *et al.,* (2012):

$$\mathbf{LRWC} = \left[\frac{\mathbf{FW - DW}}{\mathbf{TW - DW}}\right]\mathbf{x}100$$

where FW is the sample fresh weight, TW is the sample turgid weight, and DW is the sample dry weight. SPAD chlorophyll meter (Minolta SPAD-502 meter, Tokyo, Japan) was used to estimate leaf chlorophyll content. Three readings were taken per leaf from a sample of five fully expanded flag leaves per plot. Readings were averaged to get the plot mean SPAD value. The same leaf samples were used to estimate the specific leaf area, which was measured with an image scanner software (Mesurim pro, version 3.4). Leaf dry weight (LDW) was determined after oven-drying at 80 °C for 48 hours. SLA, derived as leaf area (LA) per unit leaf dry weight ($cm^2 . g^{-1}$), was calculated using the following formulae reported by Rashid *et al.,* (2018):

$$\mathbf{SLA} = \frac{\mathbf{LA(cm^2)}}{\mathbf{LDW(g)}}$$

At crop maturity, 2-row segments, 2 m long, were sampled per plot to estimate plant height, measured from ground level to the tip of the terminal spikelet, awns excluded; total dry matter, grain yield, and harvest index, derived as the ratio of grain yield over total dry matter yield. The amount of water evaporated and that transpired by each variety during the cropping cycle (water used =WU) was determined as the sum of the soil moisture available at seeding minus soil moisture available at harvest, plus the accumulated rainfall, from seeding to harvest. Soil available moisture (ASM, mm), at sowing and at harvest was deduced by the following formulae: ASM (mm) = [(H%-WP) x h x ρb]/100, where H% = 100(wet soil weight-dry soil weight)/dry soil weight, WP =wilting point =12%, average of the soil of the experimental site, h = soil profile depth in mm(600 mm), and ρb = bulk density = 1.23 (Chennafi et al. 2011;Belagrouz et al.,2016). Water use efficiency for total dry matter ($WUE_{TDM,}$ kg ha^{-1} mm^{-1}) and grain yield ($WUE_{GY,}$ kg ha^{-1} mm^{-1}) were derived according to Cheikh M’hamed *et al.,* (2015) as follow:

$$\mathbf{WUE_{TDM}} = \frac{\mathbf{TDM}}{\mathbf{WU}}$$

$$\mathbf{WUE_{GY}} = \frac{\mathbf{GY}}{\mathbf{WU}}$$

Where TDM= total dry matter (kg ha^{-1}) and GY=grain yield (kg ha^{-1}).

Data analysis

Collected data were subjected to a combined analysis of variance using balanced anova subroutine implemented in Cropstat software package (Cropstat, 2007). Years, replications within years, and genotype by year interaction effects were considered as random and genotype effect was considered as fixed. Year main effect was tested against the replication hierarchized within years, while the genotype main effect was tested against the interaction which was tested against the residual. Mean comparisons were performed using the Fisher's protected least significant difference test at 5% probability level. Relationships among the measured traits were computed using Pearson’s simple correlation test implemented in Past software (Hammer *et al.*, 2001). Path coefficient analysis was performed to divide the correlation coefficient between WUE and the physio-agronomic traits (r$_{iy}$) into direct (p$_{iy}$) and indirect effects (r*ij* p*jy*) according to the following equation reported by Garcıa del Moral *et al.*, (2003):

$$\mathbf{r_{iy} = P_{iy} + r_{ij}.P_{jy}}$$

RESULTS AND DISCUSSION

1.Physiological characteristics

The combined analysis of variance indicated significant year main effect for leaf chlorophyll content and leaf relative water content, but not for specific leaf area. Genotype main effect was significant only for leaf chlorophyll content, while the genotype x year interaction was significant for the three measured physiological traits (Table 2). The significant interaction indicated that ranking order of the varieties changed between years suggesting that differences existed for the same trait between varieties within year and varied significantly also for the same variety among years.

Table 2. Combined analysis of variance mean squares of the measured traits.

Traits	Year (Y)	Rep/year	Variety (V)	V x Y	Residual
			Physiological traits		
LCHC	3280.00^{**}	24.0	150.25^{**}	25.87^{*}	10.80
LRWC	2346.00^{**}	56.7	78.80^{ns}	85.10^{**}	29.80
SLA	10.90^{ns}	5.7	24.60^{ns}	24.30^{**}	2.40
			Agronomic traits		
PHT	4632.89^{**}	17.10	1980.10^{**}	346.30^{**}	17.40
TDM	25930.32^{**}	68.50	364.10^{ns}	232.10^{**}	24.10
GY	3173.52^{**}	3.40	247.26^{**}	27.21^{**}	5.60
HI	1225.98^{**}	14.70	947.82^{**}	30.09^{**}	8.20
			Water use efficiency		
WUE_{TDM}	3397.67^{**}	8.10	36.30^{ns}	22.70^{**}	2.80
WUE_{GY}	436.32^{**}	0.40	28.40^{**}	3.60^{**}	0.61

*, ** = Significant effect at the 5 and 1% probability level, respectively; LCHC= Leaf chlorophyll content, LRWC= Leaf relative water content, SLA = Specific leaf area, PHT = Plant height, TDM= Total dry matter, GY= Grain yield, HI = Harvest index, WUE_{TDM}= Water use efficiency for total dry matter, WUEGY= Water use efficiency for grain yield.

Leaf chlorophyll content values, averaged over varieties, varied from 25.6 to 45.8 spad units indicating that 2013/14 cropping season was less favorable to the expression of high chlorophyll content compared to the 2014/15 cropping season. Averaged over cropping seasons, chlorophyll index values ranged from 32.7 spad units, measured in GMG, to 42.3 Spad units, measured in MGS. This indicated that MGS possesses higher potential for chlorophyll content expression than GMG. Per cropping season, GMG, in 2013/14, (20.3 spad units), MBB, in 2014/15 (43.0 spad units), and H3, in 2015/16, (31.6 spad units), expressed the lowest leaf chlorophyll content. SMT, in 2013/14, (30.3 spad units), and MGS, in 2014/15 and 215/16, (49.8 and 47.1 spad units), exhibited the highest chlorophyll content mean values (Table 3).

Table 3. Mean values of the three measured physiological traits, averaged over years (variety main effect), averaged over varieties (year main effect), variety mean value per cropping season and the least significant difference at 5% probability level.

	LCHC				LRWC				SLA			
	Cropping seasons			Variety effect	Cropping seasons			Variety effect	Cropping seasons			Variety effect
Varieties	2014	2015	2016		2014	2015	2016		2014	2015	2016	
GMG	20.3	45.5	32.4	32.7	74.6	90.1	78.8	81.1	10.8	12.5	8.9	10.7
OZ3	25.4	45.8	31.9	34.4	77.7	93.4	88.5	86.5	9.5	15.4	8.6	11.2
H3	23.3	45.2	31.6	33.3	76.3	88.7	91.3	85.4	9	5.3	10.2	8.2
MBB	24.5	43.0	32.1	33.2	78.6	85.4	86.3	83.4	9.8	10.7	6.9	9.1
SMT	30.3	47.3	43.1	40.2	74.3	83.8	88.2	82.1	9.9	5.4	8	7.8
WAH	26.3	45.5	39.8	37.2	69.3	90.4	90.1	83.3	9.6	7.8	7.6	8.3
GTA	25.1	44.7	35.7	35.1	68.7	97.2	90.8	85.6	9.2	3.5	8.6	7.1
MGS	29.9	49.8	47.1	42.3	69.3	89.6	77.7	78.9	9.2	11.1	8.9	9.7
Lsd5%		*4.6*		*4.5*		*7.7*		*8.1*		*2.2*		*4.3*
Year effect	25.6	45.8	36.7		73.6	89.8	86.5		9.6	9	8.5	
Lsd5%		*2.5*				*4.3*				*1.4*		

LCHC= Leaf chlorophyll content, LRWC= Leaf relative water content, SLA = Specific leaf area. GMG =Guemgoum Rkhem, OZ$_{368}$= Oued Zenati 368, H$_3$= Hedba3, MBB= Mohammed ben Bachir, SMT= Simeto, WAH= Waha, GTA= Gaviota, MGS= Megress, LSD5%= Least significant difference at the 5% probability level.

Leaf relative water content mean values, averaged over varieties, varied from 73.6 to 89.8% indicating that 2013/14 cropping season was less favorable to the expression of high leaf relative water content compared to the 2014/15 cropping season. Averaged over cropping seasons, leaf relative water content mean values ranged from 78.9%, in MGS, to 86.5%, in OZ$_{368}$. The range among varieties main effect was not statistically significant when compared to the value of 8.1% taken by the least significant difference at 5% probability level. Per cropping season, GTA, in 2013/14, (68.7%), SMT, in 2014/15 (83.8%), and MGS, in 2015/16, (77.7%), expressed the lowest leaf relative water content. MBB, in 2013/14, (78.6%), GTA, in 2014/15, (97.2%), and H$_3$, in 215/16, (91.3%), showed the highest leaf relative water content mean values.

Differences among extreme mean values were statistically significant as indicated by the significant genotype x cropping season interaction (Tables 2 and 3). Differences among cropping seasons (average over varieties) and among varieties (average over cropping seasons) main effects were not statistically significant for specific leaf area, whose mean values ranged from 8.5 to 9.6 cm² g^{-1}, among cropping seasons and from 7.1 to 11.2 cm² g^{-1} among varieties main effect. Per cropping season, GMG, in 2013/14, (10.8 cm² g^{-1}), SMT, in 2014/15, (83.8%), and MGS, in 2015/16, (77.7%), expressed the lowest leaf relative water content. Meanwhile MBB, in 2013/14, (78.6%), GTA, in 2014/15, (97.2%), and H3, 215/16, (91.3%), showed the highest leaf relative water content mean values. Differences among extreme varieties mean values were statistically significant as indicated by the significant genotype x cropping season interaction (Tables 2 and 3). These results indicated that the expression of the physiological traits was strongly affected by the environment and to a lesser extent by the genotype.

2.Agronomic performances

The combined analysis of variance indicated significant year main effect for the four measured agronomic traits. Plant height, grain yield and harvest index showed significant genotype main effect. The genotype x year interaction was significant for the four measured agronomic traits (Table 2). The 2015/16 cropping season was the most favorable environment for the expression of the potential of plant height, total dry matter and grain yield. The less favorable environment for the expression of these traits were the 2014/15 for plant height and the 2013/14 for both grain yield and total dry matter. Plant height was reduced from the favorable to less favorable environments by 23.4 cm which represents 29.3% of plant height mean value recorded under favorable environment (Table 4). Total dry matter and grain yield were reduced by 56.6 and 17.5 q ha^{-1} , respectively, which represents 59.8 and 57.4 % of the mean values recorded under favorable environment for total dry matter and grain yield (Table 4). The best mean value of harvest index (34.3 %) was expressed under the 2013/14 cropping season, which was less favorable to the expression of grain yield and total dry matter. The lowest harvest index mean value (22.9%) was recorded in 2014/15 cropping season. These results suggested that the measured respectively (Table 4).

Even though the small set of varieties assessed, the results showed the presence of variability for all the measured traits. Globally, newly released varieties were shorter, high grain yielding and allocating more dry matter to the grain than old varieties. Difference in terms of total dry matter produced was not significant. This corroborated results of Waddington et al., (1987) whom mentioned that increases in HI have accounted, in many instances, for the grain yield improvement in wheat since new high-yielding wheat varieties have higher HI than older ones. Samarrai et al. (1987) reported that HI is influenced by environment, as the results of the present study suggested.

Table 4. Mean values of the four measured agronomic traits, averaged over years (variety main effect), averaged over varieties (year main effect), variety mean value per cropping season (year) and the least significant difference at 5% probability level.

	PHT				TDM			
	Cropping seasons			Variety	Cropping seasons			Variety
Varieties	2014	2015	2016	main effect	2014	2015	2016	main effect
GMG	70.1	60.3	97.9	76.1	35.3	47.1	90.1	57.5
OZ3	72.8	59.0	96.0	75.9	42.8	57.0	106.9	68.9
H3	75.5	73.5	106.4	85.1	39.9	70.2	102.0	70.7
MBB	62.5	58.5	101.1	74.0	33.4	60.0	97.1	63.5
SMT	54.6	54.5	57.9	55.7	36.6	45.9	88.7	57.1
WAH	59.3	54.3	58.3	57.3	40.1	59.4	89.9	63.1
GTA	54.8	48.3	57.0	53.3	34.5	80.4	98.9	71.3
MGS	53.9	41.5	62.2	52.5	43.9	68.1	85.5	65.8
Lsd5%		*5.9*		*16.3*		*6.9*		*13.3*
Year main effect	62.9	56.2	79.6		38.3	61.0	94.9	
Lsd5%		*2.3*				*4.7*		
	GY				HI			
	Cropping seasons			Variety	Cropping seasons			Variety
Varieties	2014	2015	2016	main effect	2014	2015	2016	main effect
GMG	9.1	12.8	23.0	15.0	27.6	16.0	23.3	22.3
OZ3	9.4	10.3	25.2	15.0	22.2	18.1	23.6	21.3
H3	8.2	10.0	24.5	14.2	20.7	14.2	24.0	19.7
MBB	9.0	11.3	24.4	14.9	27.1	19.0	25.1	23.7
SMT	16.5	13.8	36.2	22.2	45.1	30.2	40.9	38.7
WAH	17.0	18.0	37.4	24.1	42.6	30.3	41.5	38.1
GTA	15.4	14.2	39.0	22.9	44.1	30.1	43.3	39.2
MGS	19.7	17.0	34.2	23.6	44.9	25.2	40.1	36.7
Lsd5%		*3.3*		*4.6*		*4.1*		*4.8*
Year main effect	13.0	13.4	30.5		34.3	22.9	32.7	
Lsd5%		*1.0*				*2.2*		

PHT = Plant height,(cm) TDM= Total dry matter,(q ha$^{-1)}$ GY= Grain yield, ,(q ha$^{-1)}$, HI = Harvest index, (%) WUE$_{TDM}$= Water use efficiency for total dry matter, (kg ha^{-1} mm^{-1}) WUEGY= Water use efficiency for grain yield (kg ha^{-1} mm^{-1}). GMG =Guemgoum Rkhem, OZ$_{368}$= Oued Zenati 368, H$_{3}$= Hedba3, MBB= Mohammed ben Bachir, SMT= Simeto, WAH= Waha, GTA= Gaviota, MGS= Megress, LSD5%= Least significant difference at the 5% probability level.

3.Water use efficiency

Total rainfall, accumulated from sowing to harvest, reached 251.9, 299.4 and 237.7 mm in 2013/2014, 2014/2015 and 2015/16, respectively. Compared to the long term average of 321.2 mm reported by Mekhlouf *et al.*, (2006), these figures appeared to be very low, mainly during the 2013/14 and 2015/16 cropping seasons, suggesting a strong drought stress effect during the course of the experiment. At sowing, soil relative humidity, in the 600 mm profile, reached 19.0, 18.3 and 18.6%, in 2013/14, 2014/15 and 2015/16 cropping seasons, respectively. These figures are the equivalents of 51.6, 46.7 and 48.9 mm soil moisture available to the plant. This soil moisture resulted from early autumn rain showers and from moisture stored during the fallow season. Soil relative humidity, measured at harvest, was below the wilting point and thus the available moisture left in the soil was assumed to be nil. Water available for use (evapotranspiration) by the crop during the growing cycle reached 303.6, 346.1 and 286.7 mm, in 2013/14, 2014/15 and 2015/16 cropping seasons, respectively.

Table 5. Mean values of water use efficiency for total dry matter and for grain yield, averaged over years (variety main effect), averaged over varieties (year main effect), variety mean value per cropping season (year) and the least significant difference at 5% probability level.

	WUE_{TDM}				WUE_{GY}			
	Cropping seasons			Variety	Cropping seasons			Variety
Varieties	2014	2015	2016	main effect	2014	2015	2016	main effect
GMG	11.6	13.6	31.4	18.9	3.0	3.7	8.0	4.9
OZ_{368}	11.4	23.2	34.5	23.0	5.1	4.1	13.6	7.6
H_3	13.1	20.3	35.6	23.0	2.7	2.9	8.5	4.7
MBB	11.0	17.3	33.9	20.7	3.0	3.3	8.5	4.9
SMT	14.4	19.7	29.8	21.3	6.5	4.9	11.9	7.8
WAH	14.1	16.5	37.3	22.6	3.1	3.0	8.8	5.0
GTA	12.0	13.3	30.9	18.8	5.4	4.0	12.6	7.4
MGS	13.2	17.2	31.4	20.6	5.6	5.2	13.0	7.9
Lsd5%		*2.4*		*4.2*		*1.1*		*2.2*
Year main effect	12.6	17.6	33.1		4.3	3.9	10.6	
Lsd5%		*1.6*				*0.4*		

WUE_{TDM}= Water use efficiency for total dry matter, (kg ha^{-1} mm^{-1}) WUEGY= Water use efficiency for grain yield (kg ha^{-1} mm^{-1}). GMG =Guemgoum Rkhem, OZ_{368}= Oued Zenati 368, H_3= Hedba3, MBB= Mohammed ben Bachir, SMT= Simeto, WAH= Waha, GTA= Gaviota, MGS= Megress, LSD5%= Least significant difference at the 5% probability level.

Water use efficiency data analysis indicated significant cropping season main and genotype x cropping season interaction, for both total dry matter and grain yield. Variety main effect was significant for grain yield only (Table 2). Among cropping seasons, WUE_{TDM} and WUE_{GY} varied from 12.6 (2013/14) to 33.1 kg ha^{-1} mm^{-1} (201516), and from 3.9 (2014/15) to 10.6 kg ha^{-1} mm^{-1} (2015/16), respectively. These figures were in line with those reported by Sadras *and* Angus *al.,* (2006) whom reported that average wheat grain yield per unit water use was 9.9 kg grain ha^{-1} mm^{-1} for southeastern Australia, 9.8 kg grain ha^{-1} mm^{-1} for the China Loess Plateau, 8.9 kg grain ha^{-1} mm^{-1} for the northern Great Plains of North America, 7.6 kg grain ha^{-1} mm^{-1} for the Mediterranean Basin, and 5.3 kg grain ha^{-1} mm^{-1} for the southern-central Great Plains. Averaged over cropping seasons, GTA showed lower WUE_{TDM} (18.8 kg ha^{-1} mm^{-1}) and both, H_3 (23.0 kg ha^{-1} mm^{-1}) and OZ_{368} (23.0 kg ha^{-1} mm^{-1}), had high WUE_{TDM} mean values. Low WUE$_{GY}$ (4.7 kg ha^{-1} mm^{-1}) was noted for H$_3$ and high WUE$_{GY}$ mean value (7.9 kg ha^{-1} mm^{-1}) was exhibited by MGS (Table 5). MBB, in 2013/14 (11.0 kg ha^{-1} mm^{-1}), GTA, in 2014/15 (13.3 kg ha^{-1} mm^{-1}) and SMT, in 2015/16 (29.8 kg ha^{-1} mm^{-1}) exhibited low WUE$_{TDM}$. High WUE$_{TDM}$ mean values were expressed by SMT, in 2013/14 (14.4 kg ha^{-1} mm^{-1}), OZ$_{368}$, in 2014/15 (23.2 kg ha^{-1} mm^{-1}) and WAH, in 2015/16 (37.3 kg ha^{-1} mm^{-1}). Lower WUE$_{GY}$ were noted in 2013/14 and 2014/15 (2.7 and 2.9 kg ha^{-1} mm^{-1}) for H$_3$, and for GMG (8.0 kg ha^{-1} mm^{-1}) in 2015/16; while high WUE$_{GY}$ mean values were exhibited by SMT, MGS and OZ$_{368}$, in 2013/14, 2014/15 and 2015/16, respectively (Table 5). Ancient varieties tented to have lower WUE$_{GY}$ (5.5 kg ha^{-1} mm^{-1}) than newly realized ones (7.0 kg ha^{-1} mm^{-1}), while no clear differences appeared for WUE$_{TDM}$ (21.4 kg ha^{-1} mm^{-1}vs 20.8 kg ha^{-1} mm^{-1}, respectively). These supported results reported by Zhang *et al.*, (2016) whom carried out studies to understand the genetic gains in yield and WUE and their associated physiologic and agronomic traits for winter wheat and found that WUE increased substantially from 1.0 to 1.2 kg m^{-3} for cultivars from the early 1970s to 1.4–1.5 kg m^{-3} for recently released cultivars. Genotypic differences in WUE$_{GY}$ were also reported by van den Boogaard *et al.* (1997), and Zhang *et al.* (2010).

4.Relationships between WUE and the physio-agronomic traits

The correlation coefficients relating WUE$_{TDM}$ to the measured physio-agronomic traits were statistically no significant, except the correlation coefficient between LCHC and WUE$_{TDM}$, measured in 2015/16, which reached significance and had a negative sign (Table 6).

Table 6. Simple correlation coefficients between water use efficiency for total dry matter and grain yield and physio-agronomic traits.

		LCHC	*LRWC*	*SLA*	*PHT*	*HI*	*WUE$_{TDM}$*
WUE$_{TDM}$	2013/14	0.398	-0.171	-0.507	0.141	-0.008	
	2014/15	-0.087	0.602	-0.429	-0.184	0.134	
	2015/16	-0.772	0.598	0.247	0.565	-0.540	
WUE$_{GY}$	2013/14	0.792	-0.836	-0.277	-0.876	0.950	0.295
	2014/15	0.512	0.078	-0.199	-0.746	0.767	0.081
	2015/16	0.720	0.230	-0.240	-0.977	0.990	-0.435

PHT = Plant height,(cm), HI = Harvest index, (%) WUE$_{TDM}$= Water use efficiency for total dry matter, (kg ha^{-1} mm^{-1}) WUEGY= Water use efficiency for grain yield (kg ha^{-1} mm^{-1}), LCHC= Leaf chlorophyll content, LRWC= Leaf relative water content, SLA = Specific leaf area, r$_{5\%}$= 0.666.

These results suggested that, among the measured physio-agronomic traits, no one could be able to predict WUE$_{TDM}$, and to be used as selection criterion for screening purposes. Correlation coefficients of SLA and TDM with WUE$_{GY}$ were non-significant, suggesting that these two traits were of little value for WUE$_{GY}$ prediction. Results about SLA didn’t supported findings of van den Boogaard *et al.* (1997) whom studied wheat plant growth and water-use efficiency and found that WUE was higher for plants with higher leaf area per unit plant weight. Richards *et al.* (2002) suggested using specific leaf area as an indirect selection criterion for yield potential in wheat. Atta (2013) found that specific leaf area was negatively correlated with WUE and grain yield and suggested that selection against this trait may be effective in raising grain yield. The relationship between WUE_{GY} and LRWC was unreliable, being dependent on the environment for its expression. However PHT and HI, and to a lesser extent LCHC were reproducible and significantly correlated with WUE_{GY}. These traits appeared to be useful for WUE_{GY} improvement (Table 6). In this context, Zhang *et al.*, (2016) found no significant correlations between WUE_{GY} and LCHC, or LRWC, but significant correlations were found between WUE_{GY} and HI. Through multiple regression analysis Atta (2013) identified several key traits that contribute to improve WUE among which leaf traits, plant height, total dry matter at maturity, harvest index and grain yield which corroborated partially the results of this study.

Taking LCHC, LRWC, PHT and HI as causing traits and WUE_{GY} as caused trait, path analysis indicated that direct and indirect effects were inconsistent and varied from one environment to another (Table 7).

Table 7. Direct and indirect effects of the physio-agronomic traits on WUE_{GY}.

	LCHC	LRWC	PHT	HI	riy
	2013/14 cropping season				
LCHC	**0.450**	0.170	0.008	0.164	0.792
LRWC	-0.161	**-0.475**	-0.008	-0.196	-0.840
PHT	-0.321	-0.325	**-0.011**	-0.224	-0.881
HI	0.313	0.394	0.010	**0.236**	0.953
	2014/15 cropping season				
LCHC	**0.200**	0.002	0.196	0.152	0.512
LRWC	-0.018	**-0.023**	0.064	0.054	0.078
PHT	-0.143	0.005	**-0.275**	-0.365	-0.746
HI	0.059	-0.002	0.195	**0.514**	0.767
	2015/16 cropping season				
LCHC	**-0.080**	-0.036	0.315	0.520	0.720
LRWC	0.027	**0.108**	0.019	0.075	0.230
PHT	0.065	-0.005	**-0.389**	-0.648	-0.977
HI	-0.063	0.012	0.383	**0.658**	0.990

LCHC= Leaf chlorophyll content, LRWC= Leaf relative water content, PHT = Plant height,(cm), HI = Harvest index, (%) , WUE_{GY}= Water use efficiency for grain yield (kg ha^{-1} mm^{-1}).

Hence LCHC exhibited a large positive direct effect (0.450) in 2016/14, which lessened in the second cropping season (0.200) then vanished (-0.080) in the third one. This trait acted indirectly via HI during the three cropping seasons (0.164, 0.152, 0.520), via LRWC, in one season (0.170) and via PHT during two seasons (0.196, 0.315). The positive sign of the direct and indirect effects of LCHC suggested that higher LCHC was desirable to improve WUE_{GY}, either directly (but depending on the environment) or indirectly via HI and to lesser extend via PHT. Recently released cultivars expressed consistently high LCHC and HI compared to old ones which explain their observed high WUE_{GY} (Table 3). Similarly LRWC exhibited a large direct effect (-0.475) associated to sizeable indirect effects via LCHC (-0.161) and HI (-0.196) in one season, and both direct and indirect effects vanished during the two other seasons (Table 7). High LRWC was expressed by local varieties which had lower HI and LCHC, but the effect of this trait were inconsistent depending on the environment. PHT expressed a direct effect variable which was lower than the consistent indirect effects via HI. Taller varieties tended to have low HI and WUE_{GY}. HI expressed a consistent positive direct effect; the indirect effects, either via PHT or via LCHC and LRWC, were inconsistent (Table 7).

CONCLUSIONS

Experiment results revealed that modern cultivars are more efficient users of rain water than all others in semi-arid conditions, It is also revealed that those varieties, which use more water, produce hi harvest index value and give more grain yields. Our studies demonstrated that LCHC, LRWC, PHT and HI are more important traits linked to the WUEg in semi-arid regions. Thus, path analysis, based on phenotypic correlations between WUE_{GY} and HI, PHT, LRWC, LCHC, showed the consistent direct and indirect effects of HI and to a lesser extent those of PHT. Selecting for PHT and HI could improve both WUE_{GY} and grain yield under variable environments. The high WUE_{GY} genotypes identified in the current study can be used to develop more efficient cultivars that increase grain yield per unit of water used, in drought prone areas. However, selection for high HI, to improve GY and WUE_{GY}, will reduce plant height and biomass production under severe drought conditions. Conversely grain yield, at excessive crop height, can be reduced because of poor HI and increased lodging. It is suggested to select for tall, high-yielding plants within dwarf segregating populations.

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