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Responses of some Moroccan watermelon (*Citrullus lanatus*) landraces to water stress compared with commercial hybrids

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Abstract

The effect of water stress on 9 watermelon genotypes among which five Moroccan landraces and four commercial varieties. Two irrigation levels were imposed to determine variability on drought tolerance of cultivars. T1 treatment (Well irrigated) received full irrigation which plants received sufficient water to maintain soil water content close to pot capacity, while T2 (limited irrigated) treatment received 50 % of T1. The drought tolerance was estimated by the ratio of the value of a trait under the T1 irrigation level and the value of this trait under the T2 irrigation level. Generally, all traits were affected by water stress and the percentage of reduction was highly variable for all characters. The analysis of variance revealed that genotypic differences were highly significant for all parameters. Genotypes-trials interactions were also highly significant for all characters except for Brix. Moderate to high values of broad-sense heritability were observed for all characters except for rind thickness. The values of heritability in limited watered where lower to those obtained in well-watered conditions and the Brix had the highest heritability in T1 and T2. Under water stress, the average heritability vary between 0.32 and 0.65 obtained respectively for RT and Brix. In well-watered conditions, it vary between 0.26 (RT) and 0.81 (Brix). The results also show that only local cultivars have maintained their stable potential while modern varieties were affected by water stress. The results from this study can therefore serve as an initial step to plan the conservation of local watermelon genotypes in Morocco.

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Introduction

Citrullus lanatus (Thunb.) Matsum. &Nakai, commonly known as " watermelon " is a herbaceous plant belonging to the *Cucurbitaceae* family(Mujaju *et al.*, 2010)which includes 118 genera and 825 species (Bates & Robinson, 1990), and which is widely grown in many African countries. The genus includes four diploid species (2n = 22) that are cultivated in Africa, Asia and the Mediterranean countries (Levi *et al.*, 2001). All *Citrullus* species are native to Africa while the origin of *Citrullus lanatus* is the Kalahari Desert. It has been cultivated for a long time in Africa and the Middle East (Ulutürk, 2009). According to (FAOSTAT, 2012), China is the largest producer of watermelon followed by Turkey and Iran. Nowadays, watermelon is widespread in all tropical, subtropical and warm temperate regions of the world. Melons are mostly found in the northern and eastern parts of the Kalahari Desert. As for the watermelon, it is grown mainly in the United States and South Africa(Van der Vossen*et al.*, 2004).

In Morocco, watermelon is grown in most of the central and southern regions of the country with a concentration in the Marrakech-Tansift-Al Haouz region, Souss-Massa and the Draa-Tafilalt region. These regions are constantly threatened by aridity due to interannual and intra-annual irregularities and by strong evaporation linked to high temperatures throughout the year. In these regions, farmers rely on local watermelon cultivars, which they say are important sources of resistance genes and specific ecological adaptations.

The present study consists in characterizing five local cultivars and 4 modern varieties of watermelon (*Citrullus lanatus*) with regard to water stress in two different tests (a first test carried out under favorable water supply conditions and a second test conducted in limiting water conditions) by measuring certain agro-morphological characters.

Material and methods

Experimental site

The experiment is carried out at the experimental domain of Melk Zhar of INRA, (+ 30 ° 2 '39.55 "N, -9 ° 33' 9.72" W) located 53 km south of the city of Agadir in southern Morocco on 2 trials, one conducted in optimal irrigation conditions (2013) and the other in limited water conditions (2014).

Field experimental setup

The experimental design used for the two trials is a randomized complete block design with three repetitions oriented north-south. Each elementary plot comprises 10 plants spaced 0.8 m inter-plant and 3.5 m interlineate. Both trials had the same crop management, the same maintenance plots (regular manual weeding), the same phytosanitary treatments (a single treatment based on Methomyl: Lannate 250 cc / hl) and the same intake of organic manure at 30T / Ha or 85.7 kg / plot. The irrigation dose provided during this test was reduced to 50% of the dose delivered during the first test (283.1mm) (Table 1).

Characters studied

The characters studied are the fruit weight (FW), its length (FL), its width (FWth), the rind thickness (RT) and the Brix (BX). All these parameters wererecorded on all the harvested fruits. Plant vigor was also assessed through two traits: the number of branches of the main stem (NB) and the length of the main stem (SL). These data were collected on 10 plants / repetition (30 plants / genotype).

Statistical analysis

For each measured parameter, the percentage of reduction was calculated to evaluate the response of each cultivar and variety to limiting water conditions. The formula used is as follows:

$$\text{Percent Reduction} = \left(1 - \frac{Y}{X}\right) \times 100$$

With X is the average of the character measured in non-limiting irrigation conditions and Y is the average of the character measured under limiting irrigation conditions.

The study of the variability of the characters measured according to the two factors was made using the model GLM (General linear model):

The GLM used is the following:

$$Yijkm = m + Ai + Bj + (AB)ij + Eijk$$

The symbols of this model are: Yijkm: the measured value, m: the general average, Ai: the effect of the year, Bj: the effect of the genotype, (AB) ij the effect of the interaction and Eijk : the residual error.

For multiple comparisons of averages, the Newman-Keuls comparison test was used.

For each variable analyzed, the estimate of individual and broadly defined heritability was also calculated. These estimates are determined by the ratio of genotypic variance to phenotypic variance:

Heritability in the broad sense has been estimated by:

$$\hat{H}^2 i = \frac{\hat{\sigma}^2_G}{\hat{\sigma}^2_G + \hat{\sigma}^2_E}$$

Average inheritance was estimated by:

$$H^2_m = \frac{\hat{\sigma}^2_G}{(\hat{\sigma}^2_E / n) + \hat{\sigma}^2_G}$$

Genetic gain was estimated by:

$$\Delta G_i = iH^2_i \hat{\sigma}_P \text{ et } \Delta G_m = iH^2_m \hat{\sigma}_P$$

i: selection differential, it is 1.40 at a selection intensity of 20% Statistical analyzes were performed using the SAS version 9.2 software (SAS Institute 2008).

Results and discussion

Phenotypic variation

Examination of Table2 shows the existence of large differences between the minima and the maxima for both tests (Limiting and non-limiting irrigation). In optimal irrigation conditions, the phenotypic coefficients of variation vary between 17% (length fruit) and 43% (fruit weight). The largest coefficient of variation was observed for fruit weight, while the lowest coefficient of variation was noted for fruit length. Significantly high values (CV> 20%) are noted for five of the seven characters analyzed.

The values obtained under conditions of water stress are generally higher than those recorded under non-limiting irrigation conditions. Under limiting water conditions, phenotypic coefficients of variation range from 17% (Brix) to 54% (fruit weight). And contrary to the other parameters, it is observed that the water stress has led to a decrease in the average value of the fruit content in soluble sugars (Brix).

Table 1. Water intake of the two tests.

	Rainfall (mm)	Irrigation (mm)	Total (mm)
T1 (INL)	82	566.5	678.5
T2 (IL)	31.6	283.1	314.7

INL: Non-limiting Irrigation, IL: Limiting Irrigation.

As shown in Table 3, analysis of the variance of the measured variables reveals that test effects (limiting or non-limiting irrigation) are very highly significant for almost all traits. This highlights the great variability of the measured parameters. Only Brix shows an insignificant effect and therefore a lower variability than the other variables. As for the genotype effect, it is very highly significant for fruit weight and length and highly significant for fruit width, rind thickness and Brix. In contrast, the block effect was not significant for all measured characters. As for the interaction between the trial and the genotypes, it shows a very highly significant effect for the fruit weight, length and width; a highly significant effect on the rind thickness and a significant effect on Brix. These results permit the evaluation of the variability of the 9 watermelon genotypes with respect to the tolerance to water stress and which has been developed thanks to tests carried out under favorable and unfavorable conditions. According to Rajaram, Braun, and van Ginkel (1996); El Madidi, Diani, and Aameur (2005) and Ceccarelli (1989), the best approach for the selection of water-stress tolerant genotypes is to examine the performance of several genotypes under favorable conditions and under stress. Thus, simultaneous evaluation of genotypes under favorable conditions and conditions of water stress appears to be the most convenient procedure for the identification and selection of dry tolerance genotypes.

Table 2. Descriptive statistics of traits measured in both trials (limiting irrigation and non-limiting irrigation).

	Trial	Medium	Minimum	Maximum	Standard deviation	PCV(%)
FW (Kg)	1	5.69	1.07	15.72	2.44	43.24 %
	2	4.05	0.99	10.91	2.18	54 %
FL (cm)	1	27.37	12	46	5.55	20.10 %
	2	24.36	12.5	38.90	5.31	28 %
FWth (cm)	1	19.81	12	32	3.34	17.61 %
	2	17.87	10.5	25.3	3.30	18 %
RT (mm)	1	16.41	6.43	36.01	4.23	26.49 %
	2	12.95	6	27.5	3.33	32 %
BX (°Brix)	1	8.42	2.4	12.8	1.74	21 %
	2	8.34	4.4	11.7	1.45	17 %

1: non-limiting irrigation; 2: limiting irrigation.

Percentage of reduction and ranking order

Examination of Table 4 reveals that all traits were affected by water stress. The percentage of reduction varies from one character to another. Indeed, we note 29% reduction for the weight of the fruit and 21% for the thickness of the bark. The length and width of the fruit were slightly affected by the stress with respectively 11% and 10% reduction. While the Brix has been very little affected by stress with a percentage reduction equal to 1%.

Table 3. Summary of variance analysis of characteristics measured in both trials.

Origin of variation	Degree of freedom	FW	FL	FWth	RT	BX
Trials	1	51.61 ***	45.35 ***	41.49 ***	23.82 ***	1.69 ns
Genotypes	8	6.19 ***	7.67 ***	3.57 **	4.18 **	2.84 **
Blocks	2	NS	NS	NS	NS	NS
Interaction Gen-Exp	8	10.99 ***	7.27 ***	11.83 ***	3.12 **	2.07 *
Residual	507					
Total	522					

F: Fisher-Snedecor variable value.

*, ** and ***: significant effect at the 0.05, 0.01 and 0.001 threshold respectively, NS: Not significant effect.

In order to assess the diversity of the performance of cultivars and varieties in relation to tolerance to limiting irrigation conditions, the cultivars were ranked according to their reduction percentages for each parameter studied (Table 5). The examination in Table 5 shows that the classification of genotypes varies according to the parameter studied. The RM1 cultivar ranks first in terms of fruit weight, length and width, and second place for rind thikness and Brix. The average rank varies between 1.4 and 7.2 recorded respectively for RM1 and Farao. The Cerrato, Venizia and Farao varieties recorded the highest average ranks, with 6.6, 6.8 and 7.2, respectively. While the local cultivars RM1, ZG1 and ZG2 recorded the lowest mean rankings with respectively 1.4, 1.8 and 3.6.

The hierarchical classification partitions all the genotypes and groups them according to their resemblance to the studied parameters. In fact, the hierarchical tree makes it possible to distinguish three groups of genotypes. The first group includes the genotypes ZG1, RM1 and ZG2 which are genotypes characterized by the lowest reduction percentages, the average ranks of the genotypes of this group vary between 1.4 and 3.6 respectively recorded for RM1 and ZG2. The second group consists of both RM2 and Daytona genotypes. The third group includes the Venizia, Cerrato and Farao genotypes, all with relatively high percentages of reduction. The average ranks of the genotypes in this group vary between 6.6 and 7.2 observed respectively for Cerrato and Farao (Fig. 1). Therefore, all genotypes appear to behave differently to changes in the water regime. Indeed, only local cultivars have maintained their stable potential while modern varieties have been affected by limiting irrigation conditions.

Table 4. Mean and percent reduction for each measured parameter.

Character	Trial 1 (INL) X	Trial 2 (IL) Y	% of reduction (1- (Y / X)) x 100
FW	5.69 ± 2.44	4.05 ± 2.22	29%
FL	27.37 ± 5.55	24.37 ± 5.31	11%
FWth	19.80 ± 3.34	17.87 ± 3.30	10%
RT	16.40 ± 4.23	12.95 ± 4.92	21%
BX	8.42 ± 1.74	8.35 ± 1.45	1%

Several previous studies have highlighted the better performance of some local cultivars compared to varieties selected under conditions of water deficit. Our results consolidate the idea adopted by several authors (Ehdaie *et al.*, 1988; Denčić *et al.*, 2000; Zhang *et al.*, 2011; Nantoume *et al.*, 2012) and that insists selection of varieties tolerant to water stress, it is imperative to resort to local cultivars which are a source of resistant genetic material and more adapted to drought conditions.

Table 5. Reduction percentages and classification of different genotypes.

	FW		FL		FWth		RT		BX		Average Rank
	PR	R	PR	R	PR	R	PR	R	PR	R	
RM1	-0,13	1	-0.09	1	-0.04	1	0.06	2	-0.05	2	1.4
RM2	0.5	5	0.19	5	0.16	5	0.06	3	0	4	4.4
ZG1	0.09	3	0.06	2	-0.04	2	-0.09	1	-0.06	1	1.8
ZG2	0.04	2	0.06	3	-0.01	3	0.19	5	0.02	5	3.6
CER	0.66	8	0.31	8	0.28	7	0.19	4	0.04	6	6.6
DAY	0.46	4	0.19	4	0.12	4	0.23	6	-0.02	3	4.2
FAR	0.64	7	0.28	7	0.33	8	0.28	7	0.08	7	7.2
VEN	0.6	6	0.23	6	0.2	6	0.31	8	0.19	8	6.8

Broad-sense heritability and relative genotypic gain

As shown in Table 6, estimates of heritability vary according to the character measured. The values of heritability and genotypic gain observed in the limiting water supply conditions are generally relatively lower than those recorded under the conditions of non-limiting water supply. In the conditions of water stress, the coefficients of average heritability vary between 0.32 and 0.65 obtained respectively for the rind thickness and the Brix.

In the absence of water stress, the coefficients vary between 0.26 and 0.81 obtained respectively for the rind thickness and the Brix. The broad sense heritability estimates for fruit weight, fruit length and fruit width ranged from 0.41 to 0.45 in T1 and from 0.26 and 0.39 in T2, indicates large environmental effect. Gusmini and Wehner (2007) reported that broad-sense and narrow-sense heritability estimates for fruit weight were low to intermediate (0.59 and 0.41, respectively) and a high number of effective factors (mean, 5.4) was found to influence this fruit character in watermelon. For total soluble solids content (Brix), high heritability is observed in this study. Similar results was also reported in watermelon by Lou (2009) and Kumar and Wehner (2013) suggesting that genotypic components may play an important role in the improvement of this trait in watermelon and genetic advance could be effectively used in selection on the basis of phenotypic performance.

Table 6. Estimates of Heritability (Individual and Mean) of Characteristics Measured in Different Genotypes.

	H_i^2 INL	H_i^2 IL	H_m^2 INL	H_m^2 IL
FW (Kg)	0.41	0.36	0.67	0.49
FL (cm)	0.45	0.29	0.71	0.52
FWth (cm)	0.43	0.31	0.70	0.47
RT (mm)	0.13	0.22	0.26	0.32
°Brix	0.62	0.48	0.81	0.65

INL: non-limiting irrigation, IL: limiting irrigation.

Table 7. Estimates of Genetic Gain (Individual and Medium) of Characteristics Measured in Different Genotypes.

	Trial	ΔG_i	$R\Delta G_i$	ΔG_m	$R\Delta G_m$
FW(Kg)	1	1.40	24.68%	2.29	40.33%
	2	1.21	19.45 %	1.87	36.45%
FL (cm)	1	3.50	12.60%	5.52	19.88%
	2	2.98	12.01%	5.21	18.38%
FWth(cm)	1	2.01	10.23%	3.27	16.66%
	2	1.88	9.36%	2.89	16.23%
RT (mm)	1	0.77	4.73%	1.78	10.92%
	2	0.85	6.10%	2.64	12.61%
°Brix	1	1.51	18.23%	1.97	23.81%
	2	1.12	16.34%	1.56	20.08%

1: non-limiting irrigation, 2: limiting irrigation.

The results presented in Table 7 show that in the non-limiting irrigation conditions and for all the variables studied, the individual genetic gain (ΔGi) varies between 3.5% and 0.77% obtained respectively for the fruit length and the rind thickness. Similarly, for the mean genetic gain (ΔGm), the highest value was recorded for fruit length (5.52) and the lowest value is observed for rind thickness (1.78). In the conditions of water stress, the individual genetic gain (ΔGi) varies between 2.98% and 0.85% obtained respectively for the fruit length and the rind thickness.

For the mean genetic gain (ΔGm), the highest value was recorded for the fruit length (5.21) and the lowest value was observed for the Brix (1.56). Knowledge of the gain by selection and the consequent predicted genetic gain is essential to determine appropriate selection criteria including those related to grain production components (Acquaah, 2007). Edmeades*et al.* (1999) and Kumar*et al.* (2007) suggest that direct selection under drought stress can produce yield gains without reducing yield potential and selection for yield under stress is the most effective approach to identifying drought-tolerant genotypes combining high yield potential with high levels of drought tolerance.

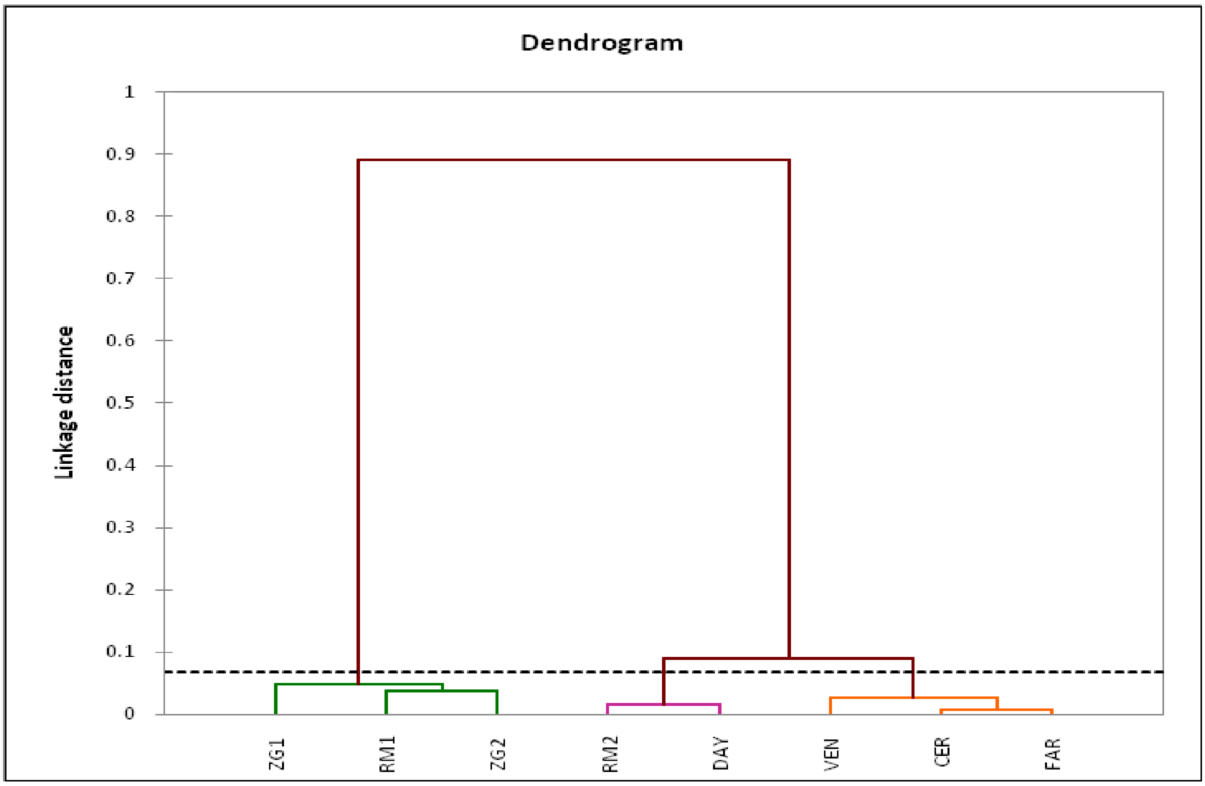

Fig. 1. Dendrogram based on genotype rankings based on their reduction percentages.

Conclusion

Our study revealed the existence of a genotypic variability within the studied cultivars; this variability is expressed as well under conditions of favorable water supply as under limited irrigation. Our results also show that only local cultivars have maintained their stable potential while modern varieties have been affected by limiting irrigation conditions. This experiment underlines the interest that a material traditionally cultivated in a region can have as regards its average adaptation value to this region. The observed differences are a prime argument for exploiting this genetic resource in breeding and improving for resistance to water scarcity and could serve as a basis of reflection for future prospecting and collection work, genetic characterization, agronomic evaluation and improvement of the production of these varieties through varietal selection and / or appropriation of cultural techniques.

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