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The productivity of bread wheat under different irrigation conditions

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Abstract

Wheat production in Mexico depends on more than 90% of the irrigated areas, which are classified as having a high water shortage, so varieties that are efficient in the use of water must be planted. In such a way that the objective of the investigation was to evaluate the behavior of the yield and its components of genotypes in function of the decrease of irrigation sheets (LR). Eight varieties of bread wheat and four LR were used. Genotypes were established in a split-plot design with large plots arranged as a randomized full-block design, with two replications. LR reductions of 1 to 0.8, 0.6, and 0.4 m decreased grain yield by 14.4, 37.6, and 76.8%, respectively. In limiting humidity (0.4 m) the number of spikes and biological yield decreased 63.7 and 73.3%. Grain yield was correlated with the number of grains and spikes per square meter. When the LR decreased from 1 to 0.8 m, Rebeca F2000 and Temporalera M87 presented grain yields greater than 6.5 t ha^{-1} associated with high biological yields. While Temporalera M87, in the 0.4 m sheet, was the one with the highest biological yield, number of grains and grain yield with 2.4 t ha^{-1}. Therefore, genotypes and yield components were identified to help in the selection process with higher yield potential in limiting humidity conditions.

Keywords: *Triticum aestivum* L., irrigation sheets, limited humidity, yield, yield components.

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Introduction

Wheat production in Mexico is carried out in more than 90% under irrigation conditions (SIAP, 2018). One of the limitations in the main wheat production areas such as southern Sonora and Bajío is their low water availability, which is why both regions are classified within the administrative hydrological regions with a high degree of stress (CONAGUA, 2015). and that future scenarios of greater scarcity should be considered (Herrera-Pantoja and Hiscock, 2015).

In Guanajuato, more than 90% of its irrigated area is planted annually, placing it in the first three places of the planted area and the sixth place in national production (SIAP, 2018). Additionally, according to Bolaños-González *et al*. (2001) in a study carried out in Guanajuato of twelve analyzed crops, wheat was in third place with the highest expenditure on its irrigation sheet with 0.97 m per agricultural cycle, being higher than those of chickpea, tomato, tomato, onion, broccoli, asparagus, corn, green beans, and beans.

The foregoing indicates the dependence of national wheat production on irrigation water and the scarcity of this resource in the main production areas (Soils-Moya *et al*., 2019). Thus, the efficient use of water should be promoted by evaluating the grain yield based on the number of irrigations applied in the crop cycle so that under these conditions yields can be maintained (Xu *et al*., 2018; Solis-Moya *et al*., 2019) as well as industrial quality (Martínez *et al*., 2017).

According to Ledesma-Ramírez *et al*. (2012) there are recommended bread wheat varieties for the Bajio that presented good yield potential under normal and limited irrigation conditions, which is partly due to the fact that in segregating stages of the genetic improvement process they were selected based on their low yield limited irrigation. For this reason, an important step is the identification of the components of said variability and evaluating the physiological and agronomic response of the plants to limiting humidity conditions to identify genotypes that show tolerance.

Likewise, various authors have reported the effect of water deficit on genotypes at different stages of cultivation applying different number of irrigations (Shirazi *et al*., 2014), with irrigation supply and under drought (Li *et al*., 2011), the study of the physiological characteristics and efficiency in the use of water (Khakwani *et al*., 2012), until the study of the molecular and physiological bases related to resistance to drought in wheat (Sallam *et al*., 2019).

In such a way that the selection should be based on the evaluation of materials before different degrees of water stress (Li *et al*., 2011), for example, the evaluation of segregating material and varieties in the field, based on the yield components that most they are affected by the decrease in water availability (Bagrei and Bybordi, 2015).

This will allow identifying genotypes with greater tolerance to drought, as well as variables associated with yield that contribute to lessen the unfavorable effect of lack of water. Therefore, the objective of the present investigation was to evaluate the yield behavior and its components of bread wheat genotypes based on the reduction of irrigation sheets in different phenological stages of cultivation in the Bajio irrigation region in Guanajuato, Mexico.

Materials and methods

Genetic material and field evaluation

The plant material used were the commercial varieties of bread wheat: Zacatecas VT-74, Pavón F76, Gálvez M87, Temporalera M87, Batán F96, Romoga F96, Náhuatl F2000 and Rebeca F2000. The sowing was carried out in the INIFAP Experimental Field of Bajío (CEBAJ) in Celaya, Guanajuato. Located at 20° 32’ north latitude and 100° 48’ west longitude with an altitude of 1 752 meters above sea level, as well as an average annual rainfall and temperature of 578 mm and 19.8 °C, respectively.

The soils where the tests were established are classified as vertisols with clay texture, pH 7.8 and 2.3% organic matter, the nitrogen contained in one kilogram of soil is close to 5.62 mg, phosphorus of 12.3 mg and potassium of 1016 mg (Ledesma-Ramírez *et al*., 2012). The climate is classified as C (W0) (W) b (i’) g, which corresponds to a sub-humid temperate climate with rains in summer (García, 2004).

Genotypes were established in a divided plot design with large plots arranged as a randomized complete block design, with two replications, the experimental unit was four rows of 3 m in length with a separation of 30 cm, the planting density was 120 kg ha^{-1}. The sowing was carried out in the first week of December, applying four sheets of irrigation, at 0-35 (0.4 m, dry in box), 0-35-70 (0.6 m, dry in bloom), 0-35-70 -105 (0.8 m, grain filling drought) and 0-35-70-105-125 (1 m, no drought).

The number zero indicates the irrigation of sowing and the following numbers the days to which the relief irrigations were applied. The fertilization dose 240-60-00 was applied, half of the N and all the P_2O_5 with the sowing and the rest of the N with the first aid irrigation. Fertilizer sources were urea with 46% N [CO $(NH_2)_2$] and triple calcium superphosphate with 46% P_2O_5 [Ca $(H_2PO_4)_2$].

Narrow-leaved weeds were controlled with an application of Topik® 240 EC (Clodinafop-propargil + Cloquintocet-mexyl) 30 days after planting irrigation and broad-leaved weeds with Esteron® 47 EC (Acid 2-4- dichlorophenoxyacetic) at 34 days after birth. An application of Cypermethrin® 2.5% (C22H19Cl2NO3) was made to control aphids in the grain formation and filling stage. To control the incidence of foliar diseases in the infusion stage, Folicur® was applied.

The variables measured in the field were: grain filling period (PLLG), number of spikes per square meter (EPMC), number of grains per square meter (GPMC), weight of a thousand grains (PMG), biological yield (RB) and harvest index (IC). In each test, once the commercial maturity of the grain (less than 13% humidity) had been reached, the plots were harvested using a Wintersteiger® mini-thresher for small grain cereals, separating the grain from each plot to cleaning and weighing to estimate the grain yield (REG) in kg ha^{-1}.

Statistical analysis

An analysis of variance was performed using the GLM procedure of the SAS (SAS Institute, 2002) and the means were compared using the Tukey test to identify the differences between irrigation sheets and varieties. Additionally, Pearson's correlations were made between the yield and its components for each of the irrigation sheets.

Results and discussion

Significant differences were found in almost all the variables evaluated for the different irrigation sheets except for the weight of one thousand grains. The same behavior of the variables was observed for genotypes, only there were no differences for harvest index. This indicates that in general the availability of irrigation water and the variability of the genotypes used affected productivity and yield components. The above agrees with Tari (2016) who indicated that the effect of the water deficit, on the yield and quality of the grain, is associated with the growth stage of the crop.

It also agrees with what was found by Ul-Allah *et al*. (2018) who found that grain yield is affected by irrigation, genotype, and nitrogen application. For the irrigation sheet interaction by genotype, differences were found for the period of filling of grain, grains per square meter and weight of a thousand grains (Table 1).

Table 1. Average squares of agronomic variables of bread wheat under irrigation conditions, Roque, Guanajuato.

FV	gl	PLLG	EPMC	GPMC	PMG	RB	IC	REG
Irrigation sheet (LR)	3	480**	313121.9**	634478813**	17.0 ns	4332926.7**	0.02**	88730903.7**
Error (a)	4	6.6	2961	863927	11.9	68815.7	6x10^{-3}	241405.3
Genotypes (G)	7	11.9*	17371.9**	22070648**	107.4**	124532.5**	3x10^{-3} ns	793328.6*
LR∗G	21	11.4**	5694.3 ns	6065670*	18.1**	35614.5 ns	1x10^{-3}ns	458385 ns
Error (b)	28	3.8	4283	3126694	6.7	34313	1x10^{-3}	280161.5
Mean		39.9	369.2	12902.7	36.8	1144.3	0.42	4723.8
CV		4.9	17.7	13.7	7	16.2	10	11.2

*, **= significant with $p \leq 0.05$ and $p \leq 0.01$; Gen= genotype; FV= source of variation; gl= degrees of freedom; CV= coefficient of variation; PLLG= grain filling period; EPMC= spike per square meter; GPMC= grains per square meter; PMG= thousand grain weight; RB= biological yield; IC= harvest index; REG= grain yield.

But no differences were found for spikes per square meter, biological yield, harvest index and grain yield, indicating that these variables increased in parallel in all genotypes depending on the irrigation sheet. The latter indicates that the yield is affected to a greater extent by the irrigation sheets and not by the genotype, which coincides with Gizaw *et al*. (2016) who indicated that the availability of moisture in the soil and the environmental temperature explained 86% of the variation in yield in different years and locations.

Table 2 shows the averages for irrigation sheets of the analyzed variables. The 1 m irrigation sheet was associated with the highest values of grain filling period, harvest index, number of grains and grain yield. One way to select advanced lines with greater tolerance to lack of water is by applying smaller irrigation sheets in such a way that in this study it was observed that the reduction from 1 m to 0.8 m was associated with the decrease in the filling period of grain, harvest index and number of grains which were reduced by 4.5, 14.9 and 11.8%, respectively, which consequently decreased grain yield by 14.4%.

Table 2. Comparison of yield means and their components of bread wheat in different irrigation sheets.

LR	PLLG	(%)d	EPMC	(%)d	PMG	RB	(%)d	IC	(%)d
1	44.9 a*		461 a		38.2 a	1509 a		0.47 a	
0.8	42.9 b	4.4	478.9 a		36.7 a	1502.6 a		0.4 b	14.9
0.6	39.6 c	11.8	363.5 b	21.4	36.6 a	1163.5 b	22.9	0.39 b	17
0.4	32.4 d	27.8	173.7 c	63.7	35.7 a	402.3 c	73.3	0.41 b	12.8
DSH	1.9		63.2		2.5	178.8		0.04	

*= averages per column with the same letter are not statistically different (Tukey, p= 0.05). LR= irrigation sheet (m); PLLG= grain filling period (days); EPMC= spike per square meter; PMG= thousand grain weight (g); RB= biological yield (g m^{-2}) and I = harvest index; (%)d= percentage decrease with respect to the LR of 1 m. DSH= Tukey's honest significant difference (p= 0.05).

Said decrease in yield is similar to that indicated by Paquini-Rodríguez *et al*. (2016) who reported percentages of 12.4 and 17.9 for the first and second planting dates, respectively, when going from normal to restricted irrigation in Celaya, Guanajuato. But it is less than that reported by Valenzuela-Antelo *et al*. (2018) of 33.6% in the same locality. However, both authors obtained their results in different years and used different genotypes.

The 0.6 and 0.4 m sheets showed the lowest values for the grain filling period, spikes per square meter, biological yield, harvest index and grains per square meter, as well as the lowest yields. The above agrees with that indicated by Ayed *et al*. (2017); Valdes *et al*. (2017) and Thapa *et al*. (2019) who stated that the yield and some components decrease with the application of less irrigation water. However, Thapa *et al*. (2019) mentioned that lower water regimes did not affect the harvest index, which partially agrees with what was found in this study given that the harvest index was similar for irrigation sheets 0.8, 0.6 and 0.4 m. While the weight of a thousand grains was similar for all irrigation conditions.

The greatest losses in grain yield of 37.6 and 76.8% were observed when passing the irrigation sheet from 1 m to 0.6 and 0.4 m, respectively, Figure 1. The above was due to the fact that irrigation was suspended in the phenological stages of gleaning and tillering, respectively. In such a way that in the case of irrigation that was applied up to the tillering stage (0.4 m) it caused the highest percentages of decrease in the grain filling period (18.2%), spikes per square meter (63.7%) and biological yield (73.3%), which corresponded to the highest loss of grain yield, which agrees with that reported by Tari (2016), who indicated that significant losses in grain yield occurred due to water deficiency in the stages of stem elongation. and flowering.

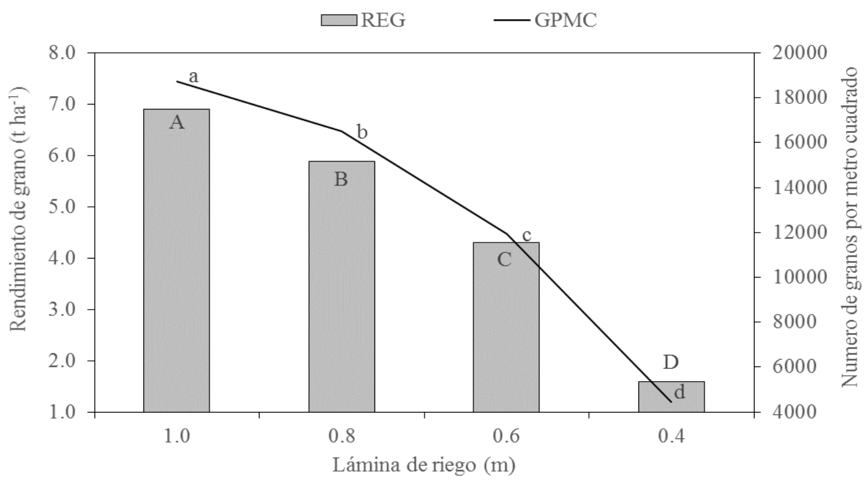

Figure 1. Behavior of grain yield (REG) and grains per square meter (GPM) of bread wheat in the different irrigation sheets evaluated. Bars and lines with the same letter are not statistically different (Tukey, p= 0.05).

Table 3 shows the averages of the variables analyzed by genotype. Numerically Rebeca F2000 presented the highest grain yield, which is partly explained by its longer grain filling period and superior biological yield. While Temporalera M87, which ranked second in grain yield, presented the highest value for the weight of a thousand grains of all genotypes, which was greater than 40 g, which is similar to that found by Gutiérrez-García *et al*. (2006) who reported approximate values of 42 g for this variety.

Table 3. Comparison of yield means and their components, by bread wheat genotype under irrigation conditions.

	PLLG	EPMC	PMG	RB	IC	GPMC	REG
Rebeca F2000	41.1 a*	368.6 bac	38.9 b	1284.3 a	0.39 a	13124.9 bac	5092 a
Temporalera M87	41.4 a	369 bac	43.6 a	1156.4 ba	0.44 a	11326.3 bc	4993.1 a
Náhuatl F2000	37.7 b	393.7 bac	31.5 d	1260.7 a	0.4 a	15718.5 a	4952.8 a
Pavón F76	39.6 ba	409.9 ba	35.5 cbd	1198.2 ba	0.42 a	14202.3 ba	4875 a
Romoga F96	39.4 ba	437.9 a	33.8 cd	1229.9 a	0.39 a	13859.8 ba	4772.6 a
Batán F96	39.1 ba	316.4 bc	36.6 cb	1052.1 ba	0.43 a	12258.5 bc	4468.4 a
Gálvez M87	40.4 ba	295.8 c	36 cb	1047.1 ba	0.42 a	12109.3 bc	4404.5 a
Zacatecas VT74	40.9 ba	363 bac	38.6 b	926.4 b	0.45 a	10622.5 c	4232.6 a
DSH	3.2	107	4.2	302.8	0.06	2891.3	865.5

*= averages per column with the same letter are not statistically different (Tukey, p= 0.05); LR= irrigation sheet (m); PLLG= grain filling period (days); EPMC= spikes per square meter; PMG= thousand grain weight (g); RB= biological yield (g m^{-2}) and IC= harvest index; GPMC= grains per square meter; REG= grain yield (t ha^{-1}). DSH= Tukey's honest significant difference (p= 0.05).

On the other hand, Náhuatl F2000 showed the highest value for the number of grains, but it was associated with the shortest grain filling period as well as the lowest weight of one thousand grains, so it presented a lower yield compared to Rebeca F2000 and Temporalera M87. For a thousand grain weight in Náhuatl F2000, Gutiérrez-García *et al*. (2006) presented similar results with values less than 34 g. In the case of Zacatecas, VT74, which had the lowest yield, was associated with the lowest values of biological yield and grains per square meter.

Table 4 shows the Pearson correlations between the grain yield and its components for the different irrigation sheets analyzed. It was observed that the grain yield presented high positive correlations with the biological yield in the four irrigation conditions, which agrees with Beche *et al*. (2014) who found values of 0.88 of correlation. Likewise, productivity was positively correlated with number of grains and spikes per square meter in the different irrigation sheets.

Table 4. Pearson correlations of the yield components in different irrigation sheets.

	LR	IC	RB	EPMC	PMG	GPMC	REG
PLLG	1	0.23^{*}	0.28^{**}	-0.01	0.29^{**}	0.11	0.36^{**}
PLLG	0.8	0.21	0.08	-0.13	0.39^{**}	-0.11	0.27^{**}
PLLG	0.6	-0.02	0.34^{**}	0.033	0.3^{**}	0.22^{*}	0.45^{**}
PLLG	0.4	-0.04	0.18	-0.01	0.12	0.07	0.16
IC	1		-0.14	0.04	0.23^{**}	0.14	0.34^{**}
IC	0.8		-0.56^{*}	-0.2	0.38^{**}	-0.09	0.3^{**}
IC	0.6		-0.68^{*}	-0.15	-0.01	0.06	0.03
IC	0.4		-0.43^{*}	-0.35^{*}	0.33^{**}	-0.16	$-1.8x10^{-2}$
RB	1			0.62^{**}	0.14	0.68^{**}	0.87^{**}
RB	0.8			0.57^{**}	0.03	0.51^{**}	0.6^{**}
RB	0.6			0.5^{**}	0.09	0.51^{**}	0.68^{**}
RB	0.4			0.8^{**}	-0.11	0.86^{**}	0.9^{**}
EPMC	1				-0.26^{*}	0.75^{**}	0.63^{*}
EPMC	0.8				-0.19	0.56^{**}	0.43^{**}
EPMC	0.6				-0.37^{*}	0.69^{**}	0.56^{**}
EPMC	0.4				-0.24^{*}	0.77^{**}	0.75^{**}
PMG	1					-0.48^{*}	0.24^{*}
PMG	0.8					-0.59^{*}	0.4^{**}
PMG	0.6					-0.49^{*}	$9.2\ x10^{-2}$
PMG	0.4					-0.42^{*}	0.01
GPMC	1						0.71^{**}
GPMC	0.8						0.49^{**}
GPMC	0.6						0.81^{**}
GPMC	0.4						0.88^{**}

*, **= significant with $p\leq 0.05$ and $p\leq 0$, respectively. LR= irrigation sheet; PLLG= grain filling period (days); EPMC= spikes per square meter; PMG= thousand grain weight (g); RB= biological yield (g m^{-2}); IC= harvest index; GPMC= grains per square meter; REG= grain yield (t ha^{-1}).

The above, agrees with Sukumaran *et al*. (2015) that found correlations of 0.56 between yield and number of grains, while Beche *et al*. (2014) reported correlations of 0.93 for these two variables. On the other hand, the highest correlations were observed for grain yield with biological yield, number of grains per square meter and spikes per square meter in the 0.4 m irrigation sheet.

Which agrees with what was reported by del Pozo *et al*. (2016) who reported correlations of 0.75 and 0.6 between number of grains and spikes, respectively, with grain yield under drought conditions. It also coincides with that reported by López-Castañeda (2011); Domínguez *et al*. (2016) who indicated an equivalent behavior in barley in irrigation and drought environments. The foregoing shows that these yield components should be used as selection variables in humidity-limiting conditions to generate genotypes with higher yield potential.

On the other hand, the yield components and the genotypes evaluated behaved as follows depending on the irrigation sheet. The Pavón F76 variety in the irrigation sheet 1 m presented the highest grain yield with values higher than 8.5 t ha^{-1} (Figure 3d), which is explained by its higher number of grains and spikes per square meter than it was 24 000 and 590, respectively (Figure 2b and 3a), as well as for its biological yield greater than 1 650 g m^{-2} (Figure 3c).

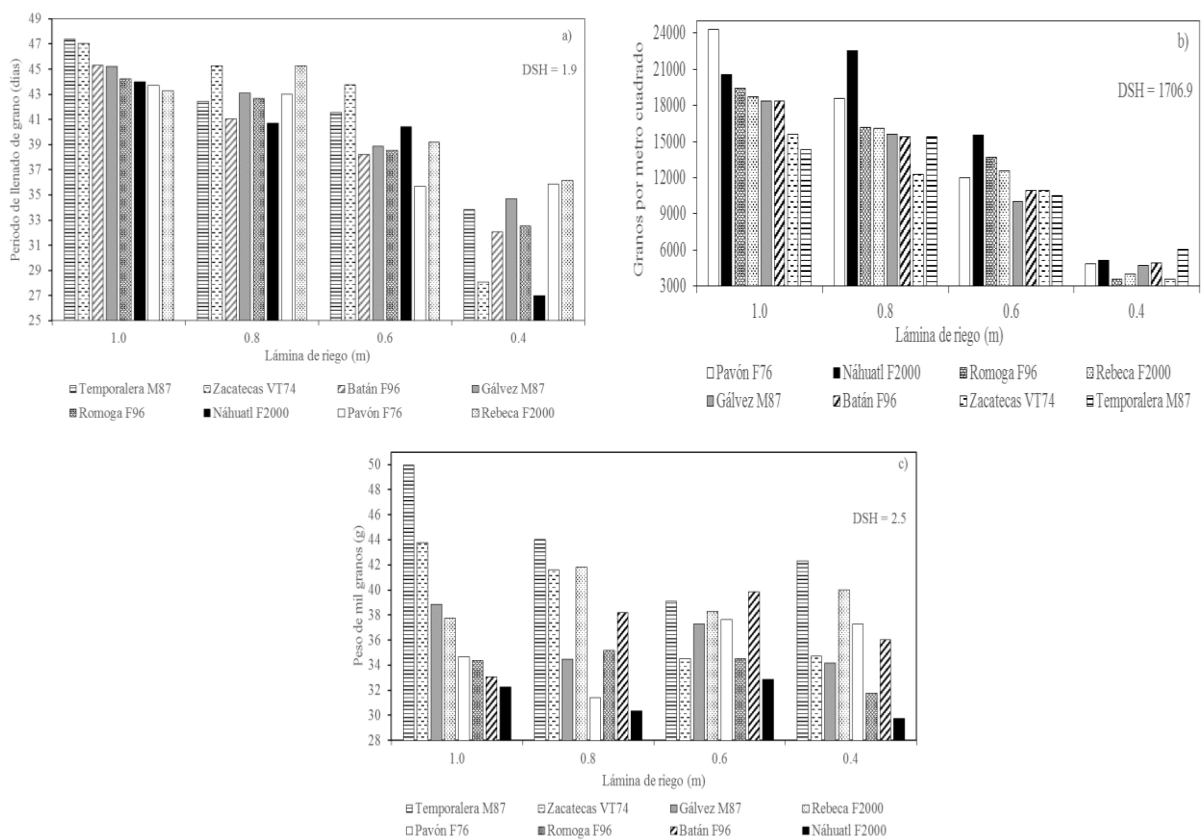

Figure 2. Behavior of the grain filling period (a); grains per square meter (b); and weight of a thousand grains (c) of the genotypes analyzed for each irrigation sheet.

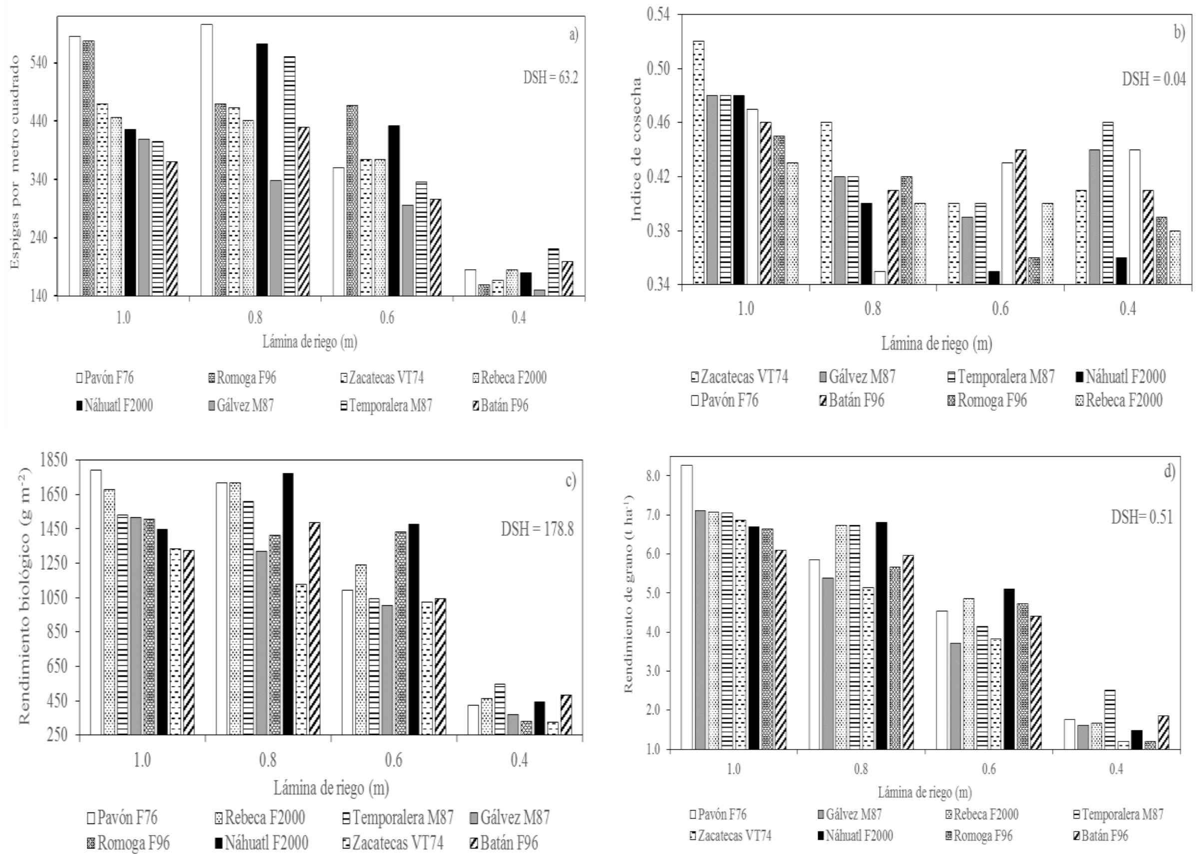

Figure 3. Spike behavior per square meter (a); harvest index (b); biological yield (c); and grain yield; (d) of the genotypes analyzed for each irrigation sheet.

However, when the irrigation sheet decreased from 1 to 0.8 m, the genotypes with the highest productivity were Rebeca F2000, Temporalera M87 and Náhuatl F2000 with yields greater than 6.5 t ha^{-1}. These three genotypes were associated with the highest biological yields with values of 1 550 g m^{-2}. Likewise, in the case of Náhuatl F2000 and Temporalera M87 they presented values greater than 540 spikes per m^2. And in the case of Temporalera M87 and Rebeca F2000 they presented weight values of one thousand grains greater than 41 g. It is important to mention that Nahuatl F2000 stood out for its high grain yields under the conditions of 0.8 and 0.6 m of irrigation sheet, this behavior is explained by its high values of number of grains per square meter of 21 000 and 15 000, respectively, likewise showed high values of biological yield.

However, it presented the lowest values of weight of one thousand grains (less than 34 g), with respect to all genotypes. The above partially agrees with Bustos *et al*. (2013) who reported in double haploid lines that the components that most favored grain yield were mainly the biological yield and the number of grains, but not the harvest index and grain weight.

In the condition of greater humidity limitation; that is, in the 0.4 m irrigation sheet, the variety with the highest grain yield was Temporalera M87 with a value greater than 2.4 t ha^{-1}, which is explained by its higher values, compared to the rest of the genotypes, for biological yield of 450 g m^{-2}, harvest index of 0.46, values of 220 and 6 029 spikes and grains per m^2, respectively. Additionally, it presented the weight of a thousand grains greater with 42 g.

Said behavior of this variety coincides with that found by Rodríguez *et al*. (2002) who indicated that Temporalera M87 presented excellent behavior in regular storm conditions with rainfall of 400 to 600 mm. It is important to note that the Temporalera M87 variety for each of the irrigation sheets presented the highest value for the weight of a thousand grains (Figure 2c).

So this variety under the irrigation sheet of 0.8 m had the highest weight of one thousand grains, close to 50 g, but also had the lowest number of grains, which agrees with the negative correlations found between these two variables in this investigation (Table 4) and corroborates what is indicated by Acreche and Slafer (2006); Sukumaran *et al*. (2015); Gizaw *et al*. (2016). Náhuatl F2000 presented the inverse behavior, which was associated in all the irrigation sheets with the highest number of grains, but with the lowest weight of one thousand grains (Figures 2b and 2c).

Conclusions

Grain yield and its components were affected to a greater extent when irrigation was suspended in the tillering and gleaning stage. The variables biological yield, number of grains and spikes are variables that were correlated with grain yield under normal and restrictive humidity conditions.

Therefore, they must be applied within breeding programs to help improve efficiency in the process of selecting genotypes with greater potential for grain yield. Under limiting humidity conditions, the Temporalera M87 and Náhuatl F2000 varieties combined higher grain yield with high variables of biological yield, number of grains and spikes.

Therefore, they must be used as parents within breeding programs to derive progenies that combine these characteristics. In the case of Temporalera M87, it can be used as a parent to derive progenies with higher grain weight and in the case of Náhuatl F2000 to increase the number of grains.

Cited literature

Acreche, M. M. and Slafer, G. A. 2006. Grain weight response to increases in number of grains in wheat in a Mediterranean area. Field Crops Res. 98(1):52-59.

Ayed, S.; Rezgui, M.; Othmani, A.; Rezgui, M.; Trad, H.; Silva, J. A. y Kharrat, M. 2017. Respuesta al estrés hídrico de trigos duros (*Triticum turgidum* ssp. durum) y harineros (*Triticum aestivum* L.) de Túnez. Agrociencia. 51(1):13-26.

Bagrei, B. and Bybordi, A. 2015. Yield and yield components in bread wheat (*Triticum aestivum* L.) under non-stress and drought stress conditions. Int J Biosci. 6(3):338-348.

Beche, E.; Benin, G.; Silva, C. L.; Munaro, L. B. and Marchese, J. A. 2014. Genetic gain in yield and changes associated with physiological traits in Brazilian wheat during the 20th century. Euro. J. Agron. 61(1):49-59.

Bolaños-González, M.; Palacios-Vélez, E.; Scott, C. y Exebio-García, A. 2001. Estimación del volumen de agua usado en una zona de riego mediante una imagen de satélite e información complementaria. Agrociencia. 35(6):589-597.

Bustos, D. V.; Hasan, A. K.; Reynolds, M. P. and Calderini, D. F. 2013. Combining high grain number and weight through a DH-population to improve grain yield potential of wheat in high-yielding environments. Field Crops Res. 145(4):106-115.

CONAGUA. 2015. Comisión Nacional del Agua. Statistics on Water in Mexico 2015. Edition. http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/EAM2015_ing.pdf.

Del-Pozo, A.; Yáñez, A.; Matus, I. A.; Tapia, G.; Castillo, D.; Sanchez-Jardón, L. and Araus, J. L. 2016. Physiological traits associated with wheat yield potential and performance under water-stress in a Mediterranean environment. Frontiers in plant Sci. 7(7):1-13.

Domínguez, L. E. M.; Castañeda, C. L.; Riquelme, I. B. y Contreras, J. A. M. 2016. Desarrollo radical y rendimiento en diferentes variedades de trigo, cebada y triticale bajo condiciones limitantes de humedad del suelo. Rev. Terra Latinoam. 34(4):393-407.

García, M. E. 2004. Modificaciones al sistema de clasificación climática de Köppen para adaptarlo a las condiciones de la República Mexicana. Quinta edición. Universidad Nacional Autónoma de México (UNAM). México, DF. 90 p.

Gutiérrez-García, A. S.; Carballo-Carballo, A.; Mejía-Contreras, J. A.; Vargas-Hernández, M.; Trethowan, R. y Villaseñor-Mir, H. E. 2006. Caracterización de trigos harineros mediante parámetros de calidad física y fisiológica de la semilla. Agric. Téc. Méx. 32(1):45-55.

Gizaw, S. A.; Garland-Campbell, K. and Carter, A. H. 2016. Evaluation of agronomic traits and spectral reflectance in Pacific Northwest winter wheat under rain-fed and irrigated conditions. Field Crops Res. 196(9):168-179.

Herrera-Pantoja, M. and Hiscock, K. M. 2015. Projected impacts of climate change on water availability indicators in a semi-arid region of central Mexico. Environ. Sci. Policy. 54(12):81-89.

Khakwani, A. A.; Dennett, M. D.; Munir, M. and Abid, M. 2012. Growth and yield response of wheat varieties to water stress at booting and anthesis stages of development. Pak. J. Bot. 44(3):879-886.

Ledesma, R. L.; Solís, M. E.; Suaste, F. M. P.; Rodríguez, C. J. F. y Cruz, G. M. L. D. 2012. Análisis GGE BIPLOT del rendimiento de trigo (*Triticum* spp.) con riego normal y restringido en el Bajío, México. 2012. Agrociencia. 46(2):119-131.

Li, P.; Chen, J. and Wu, P. 2011. Agronomic characteristics and grain yield of 30 spring wheat genotypes under drought stress and nonstress conditions. Agron. J. 103(6):1619-1628.

López-Castañeda, C. 2011. Variación en rendimiento de grano, biomasa y número de granos en cebada bajo tres condiciones de humedad del suelo. Trop. Subtrop. Agroecosys. 14(3):907-918.

Martínez, C. E.; Espitia, R. E.; Villaseñor, M. H. E.; Hortelano, S. R.; Muñiz, R. E. y Zamudio, C. A. 2017. Calidad industrial del trigo harinero en función del número de riegos. Revi. Mex. Cien. Agrí. 8(7):497-1508.

Paquini-Rodríguez, S. L.; Benítez-Riquelme, I.; Villaseñor-Mir, H. E.; Muñoz-Orozco, A. and Vaquera-Huerta, H. 2016. Incremento en el rendimiento y sus componentes bajo riego normal y restringido de variedades mexicanas de trigo. Rev. Fito. Mex. 39(4):367-378.

Rodríguez, P. J. E.; Sahagún, C. J.; Villaseñor, M. H. E.; Molina, G. J. D. y Martínez, G. A. 2002. Estabilidad de siete variedades comerciales de trigo (*Triticum aestivum* L.) de temporal. Rev. Fitotec. Mex. 25(2):143-151.

Sallam, A.; Alqudah, A. M.; Dawood, M. F. A.; Baenziger, P. S. and Börner, A. 2019. Drought stress tolerance in wheat and barley. Adv. Physiol. Breed. Gen. Res. Int. J. Mol. Sci. 20(13):31-37.

SAS Institute. 2002. SAS/STAT User's Guide, Software versión 9.0. Cary, N. C., USA. 4424 p.

Shirazi, S. M.; Zardari, N. H.; Yusop, Z.; Ismail, Z. and Othman, F. 2014. Performance of wheat crop under different irrigation regimes and nitrogen levels. A field experiment. J Environ. Protec. Eco. 15(3):973-982.

SIAP. 2018. Servicio de información y Estadística Agroalimentaria y Pesquera. www.siap.gob.mx.

Solís-Moya, E.; Huerta-Espino, J.; Villaseñor-Mir, H. E.; Mariscal-Amaro, L. A.; Ledesma-Ramírez, L. y Pérez-Herrera, P. 2019. Elia m2016, nueva variedad de trigo harinero para riego restringido en el Bajío, México. Rev. Fito. Mex. 42(1):79-81.

Sukumaran, S.; Dreisigacker, S.; Lopes, M.; Chavez, P. and Reynolds, M. P. 2015. Genome-wide association study for grain yield and related traits in an elite spring wheat population grown in temperate irrigated environments. Theor. Appl. Genet. 128(2):353-363.

Tari, A. F. 2016. The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions. Agr. Water Manage. 167(3):1-10.

Thapa, S.; Xue, Q.; Jessup, K. E.; Rudd, J. C.; Liu, S.; Marek, T. H.; Devkota, R. N.; Baker, J. A. and Baker, S. 2019. Yield determination in winter wheat under different water regimes. Field Crops Res. 233(3):80-87.

Ul-Allah, S.; Iqbal, M.; Maqsood, S.; Naeem, M.; Ijaz, M.; Ashfaq, W. and Hussain, M. 2018. Improving the performance of bread wheat genotypes by managing irrigation and nitrogen under semi-arid conditions. Archives Agron. Soil Sci. 64(12):1678-1689.

Valdés, V. C.; Estrada, C. G.; Martínez, R. C. G. y Domínguez, L. A. 2017. Rendimiento de grano en trigo modificado por cambios en la fuente durante el llenado de grano. Rev. Mex. Cien. Agr. 8(1):79-90.

Valenzuela-Antelo, J. L.; Benítez-Riquelme, I.; Villaseñor-Mir, H. E.; Huerta-Espino, J.; Lobato-Ortiz, R.; Bueno-Aguilar, G. y Vargas-Hernández, M. 2018. Comparación del rendimiento de trigos harineros y cristalinos a través de diferentes ambientes de riego. Rev. Fitotec. Mex. 41(2):159-166.

Xu, X.; Zhang, M.; Li, J.; Liu, Z.; Zhao, Z.; Zhang, Y.; Zhou, S. and Wang, Z. 2018. Improving water use efficiency and grain yield of winter wheat by optimizing irrigations in the North China Plain. Field Crops Res. 221(5):219-227.