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Water productivity at two sowing dates of simple white grain maize hybrids

Produtividade hídrica em dois datas de plantio de híbridos simples de milho de grano branco

Productividad hídrica en dos fechas de siembra de híbridos simples de maíz de grano blanco

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Abstract
In Mexico, maize stands out for its economic, food and cultural importance. Since ancient times, attempts have been made to increase maize grain yields with different alternatives, including hybridization. Currently, maize hybridization offers great advantages since from the first simple hybrids it is possible to evaluate important variables such as water productivity. The present work was carried out under field conditions in southern Sonora, in two sowing seasons: December 2022- May 2023 (SD 1) and April-August 2023 (SD 2). The research aimed to evaluate the effect of two sowing dates (SD) on phenology, water requirements, water productivity and grain yield. Three single white grain hybrids (L5 X L7; L1 X L2; L2 X L7) obtained from a dialelic design were evaluated. Phenophase occurrence time, irrigation time and interval, total water volume, evapotranspiration, grain yield and water productivity were the evaluated variables. The results showed that in SD 2 significantly reduced the time of occurrence of phenophases in

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all hybrids due to the effect of temperature. Irrigation time was significantly shorter in SD 2 compared to SD 1. Similarly, the irrigation interval decreased in SD 2 compared to SD 1 with a significant increase in the irrigation lamina. It was necessary to apply two more irrigations to achieve grain filling. Water productivity showed highly significant differences between hybrids and between sowing dates. The simple hybrid L5 X L7 showed better agronomic performance on both sowing dates, demonstrating tolerance to the increase in temperature on SD 2.
Keywords: Diallelic; Phenophases; Irrigation Intervals; Evapotranspiration.

Resumo
No México, o milho destaca-se pela sua importância económica, alimentar e cultural. Desde a antiguidade, têm sido feitas tentativas para aumentar a produtividade de grãos de milho com diferentes alternativas, incluindo a hibridização. Atualmente, a hibridização do milho oferece grandes vantagens, pois a partir dos primeiros híbridos simples é possível avaliar variáveis importantes como a produtividade hídrica. O presente trabalho foi realizado em condições de campo no sul de Sonora, em duas épocas de semeadura: dezembro de 2022-maio de 2023 (SD 1) e abril-agosto de 2023 (SD 2). A pesquisa teve como objetivo avaliar o efeito de duas épocas de semeadura (SD) sobre a fenologia, as necessidades hídricas, a produtividade hídrica e a produtividade de grãos. Foram avaliados três híbridos simples de grão branco (L5 X L7; L1 X L2; L2 X L7) obtidos a partir de delineamento dialélico. Tempo de ocorrência da fenofase, época e intervalo de irrigação, volume total de água, evapotranspiração, produtividade de grãos e produtividade de água foram as variáveis avaliadas. Os resultados mostraram que no SD 2 reduziu significativamente o tempo de ocorrência das fenofases em todos os híbridos devido ao efeito da temperatura. O tempo de irrigação foi significativamente menor no SD 2 comparado ao SD 1. Da mesma forma, o intervalo de irrigação diminuiu no SD 2 comparado ao SD 1 com um aumento significativo na lâmina de irrigação. Foi necessária a aplicação de mais duas irrigações para conseguir o enchimento dos grãos. A produtividade da água apresentou diferenças altamente significativas entre os híbridos e entre as épocas de semeadura. O híbrido simples L5 X L7 apresentou melhor desempenho agronômico nas duas épocas de semeadura, demonstrando tolerância ao aumento da temperatura no SD 2.
Palavras-chave: Dialélica; Fenofases; Intervalos de Irrigação; Evapotranspiração.

Resumen
En México el maíz destaca por su importancia económica, alimentaria y cultural. Desde la antigüedad se ha intentado incrementar el rendimiento del grano de maíz con diferentes alternativas, entre ellas la hibridación. Actualmente la hibridación de maíz ofrece grandes ventajas ya que a partir de los primeros híbridos simples se pueden evaluar variables importantes como la productividad del agua. El presente trabajo se realizó en condiciones de campo en el sur de Sonora, en dos épocas de siembra: diciembre de 2022-mayo de 2023 (FS 1) y abril-agosto de 2023 (FS 2). La investigación tuvo como objetivo evaluar el efecto de dos fechas de siembra (FS) en la fenología, los requerimientos hídricos, la productividad del agua y el rendimiento de grano. Se evaluaron tres híbridos de grano blanco único (L5 X L7; L1 X L2; L2 X L7) obtenidos a partir de un diseño dialélico. Las variables evaluadas fueron el tiempo de ocurrencia de la fenofase, el tiempo e intervalo de riego, el volumen total de agua, la evapotranspiración, el rendimiento de grano y la productividad del agua. Los resultados mostraron que en el FS 2 se redujo significativamente el tiempo de ocurrencia de las fenofases en todos los híbridos por efecto de la temperatura. El tiempo de riego fue significativamente más corto en FS 2 en comparación con FS 1. El intervalo de riego disminuyó en SD 2 en comparación con SD 1 con un aumento significativo en la lámina de irrigación. Fue necesario aplicar dos riegos más para lograr el llenado de grano. La productividad del agua mostró diferencias muy significativas entre híbridos y entre FS. El híbrido simple L5 X L7 presentó mejor rendimiento en ambas FS, demostrando tolerancia al aumento de temperatura en FS 2.
Palabras clave: Dialélico; Fenofases; Intervalos de Riego; Evapotranspiración.

1. Introduction

In Mexico, maize breeding has made great advances in recent years (Woodmansee, 2022). These advances correspond to the need to produce more food, decrease the volumes of imported maize (Hernández-López, 2022) and thus contribute to national food sovereignty (Padilla-Fidencio et al., 2022). On the other hand, work has been done to increase water use efficiency (Blankenagel et al., 2022), since this crop demands large volumes to generate high yields (Wang et al., 2023). Furthermore, there is not always correlation between high yield and high water use efficiency (Kresović et al., 2016). The water-yield relationship is influenced by the environment (Shuai & Basso, 2022), because of this, growers seek alternatives to reduce water volumes such as varying the sowing date (Djaman et al., 2022).

In the state of Sonora, Mexico in 2022, 5,100 hectares of maize were harvested, with an average yield of 10 t ha-1. In this region, this grain is grown year-round, mainly in the winter-spring and spring-summer seasons (Portillo-Vázquez et al., 2023). There is variability in yield, although the volumes of water invested in each cycle are generally not quantified, without determining the water use efficiency of the established genotypes (Villaseñor et al., 2023). Taking these elements into account, a research was developed with the objective of evaluating the effect of sowing date variation on the water use efficiency of three simple white grain maize hybrids grown under experimental field conditions in the Yaqui Valley, Sonora, Mexico.

2. Methodology

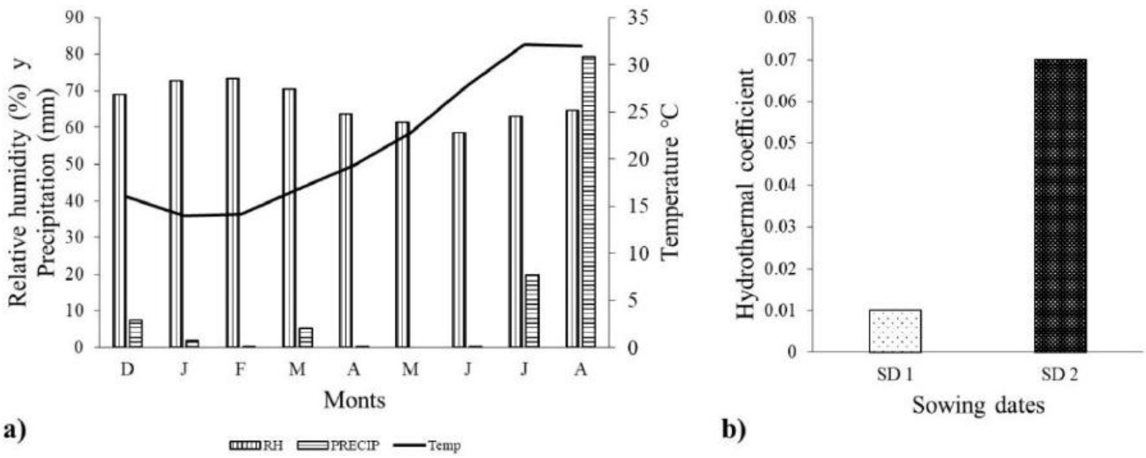
2.1 Location of the experimental area

The research was conducted at the experimental site of the Tecnológico Nacional de México-I.T. Valle del Yaqui, located in Block 611 of the Yaqui Valley (27.41452, -110.13159). Two sowing dates were carried out: SD 1 (01/Dec/2022), winter-spring cycle (Dec/2022-May/2023) and SD 2 (01/Apr/2023), spring-summer cycle (Apr-Aug/2023).

2.2 Climatic variables

To obtain data on climatic variables, the REMAS platform (Network of Meteorological Stations of Sonora) of the existing agrometeorological station in the municipality of San Ignacio Río Muerto, Sonora, located 4.6 km from the experimental site, was accessed. During the period from Dec/2022-Aug/2023 there was variability in temperature, fluctuating between 15 and 33°C (Figure 1a).

Figure 1 - a) Climatic variables, temperature, relative humidity and precipitation during Dec/2022 and Jun/2023, b) Hydrothermal coefficient at sowing dates Dec 2022 - May 2023 (SD 1: Dec/2023-May/2023) (SD 2: Apr-Aug/2023).



Source: Siafeson (2023).

The months with the highest temperatures were July and August 2023 with similar values. Relative humidity was more stable, with values between 60-73%. Precipitation was very low, with three months where it did not reach two millimeters (April, May and June). The highest rainfall was recorded in August during the entire period to be evaluated. Based on the variable's temperature (above +10°C) and accumulated precipitation, the hydrothermal coefficient was determined (Evarte-Bundere & Evarts-Bunders, 2012). It was observed that both sowing dates were associated with a dry climate (Figure 1b), with SD 1 being the driest, compared to SD 2, due to the fact that the latter date recorded a greater volume of precipitation in August 2023.

2.3 Plant material

Three single hybrids obtained from a dialelic design crosses of homozygous lines (S8) were used. The parents were supplied by the International Maize and Wheat Improvement Center (CIMMYT). These single white grain maize hybrids (L5XL7; L1XL2; L2XL7) were established in the Yaqui Valley, following a randomized complete block experimental design, on a master plot of more than 45 years of cultivation, which classifies as a clay loam soil (Almazán et al., 2023). Experimental plots were formed with an area of 1786.4 m^2. In furrows of 5 m length, plant spacing 0.16 m and spacing between furrows 0.80 m.

2.4 Crop management

Fertilization was carried out in four applications: a background application (urea and a mixture of DAP 400 kg ha^{-1}) and three other applications prior to the auxiliary irrigations at a rate of 150 kg ha^{-1} NPK each.

During the conduct of the experiment, the significant presence of thrips (*Rankliniella occidentalis*) and fall armyworm (*Spodoptera frugiperda*) was found. Both pests were controlled with the insecticides Rimon® Supra and Decís® (deltamethrin), respectively, at a dose of 1.0 L ha^{-1}.

2.5 Harvest

The single hybrids were harvested according to the established sowing dates: SD 1 on May 30, 2023 and SD 2 was harvested on August 30, 2023.

2.6 Variables evaluated

Time of occurrence of the phenophases. The phenophases studied were: VE: emergence; V4: emission of the fourth leaf; V6: appearance of the sixth leaf development; V8: appearance of the eighth leaf; V12: appearance of the twelfth leaf; VT (M): emission of male flowering, VT (F) emission of female flowering, R2: grain filling, R6: grain maturation, and CF: harvest. These phenophases were analyzed following the decimal scale of comparison for maize cultivation proposed by Valdez-Torres et al. (2012), taking as phenophase occurrence when 50+1% of the plants in the useful plot met the related characteristics. The time of occurrence was determined by the difference between the starting date of a phenophase and the starting date of the following phenophase.

Crop evapotranspiration. The formula proposed by Allen et al. (2006) was used to calculate crop evapotranspiration (ETc):

$$ETc = ET0 \times Kc$$

Where ET0 is the reference evapotranspiration and Kc is the crop coefficient.

The crop coefficient for maize was taken based on studies conducted by Piccinni et al. (2009).

Time and intervals of irrigation and total volume of water applied. After birth irrigation, a tensiometer (IRROMETER) was installed to monitor moisture variations. This device was installed at a depth of 30 cm in the center of the experimental plot. Once the readings of the installed tensiometer were read, where it was verified that the soil was at 70 cbar, irrigation was started. The irrigation interval (IR) was determined by the difference between the current irrigation date and the date of the previous irrigation.

Grain yield. Grain yield was evaluated prior to harvest at 191 days after emergence (dde), by sampling at representative sites in the two central furrows of each experimental plot of each genotype in an area of 8 m^2 per site (5 m x 0.8 m x 2 furrows). Grain yield it was calculated based on the formula described by Inamullah et al. (2011).

Water productivity. Water productivity (WP) was calculated by dividing the grain yield (kg ha^{-1}) of each hybrid evaluated by the total volume of water applied (V) (m^3 ha^{-1}).

2.7 Statistical analysis

After verifying compliance with the theoretical assumptions of normality and homogeneity of variances, we proceeded to determine the existence of possible significant differences by means of the theoretical t-Student probability distribution (8) for 5% and 1% significance levels.

In the analysis of grain yield, a double classification ANOVA was performed, taking sowing dates (A) and hybrids (B) as sources of variation. The statistical indicators coefficient of variation (CV), coefficient of determination, unadjusted (R^2) were determined for the two sources of variation involved in the mathematical model used. The analyses were performed in the STATISTICA statistical package, version 14.0 for Windows.

3. Results and Discussion

3.1 Phenophase occurrence time

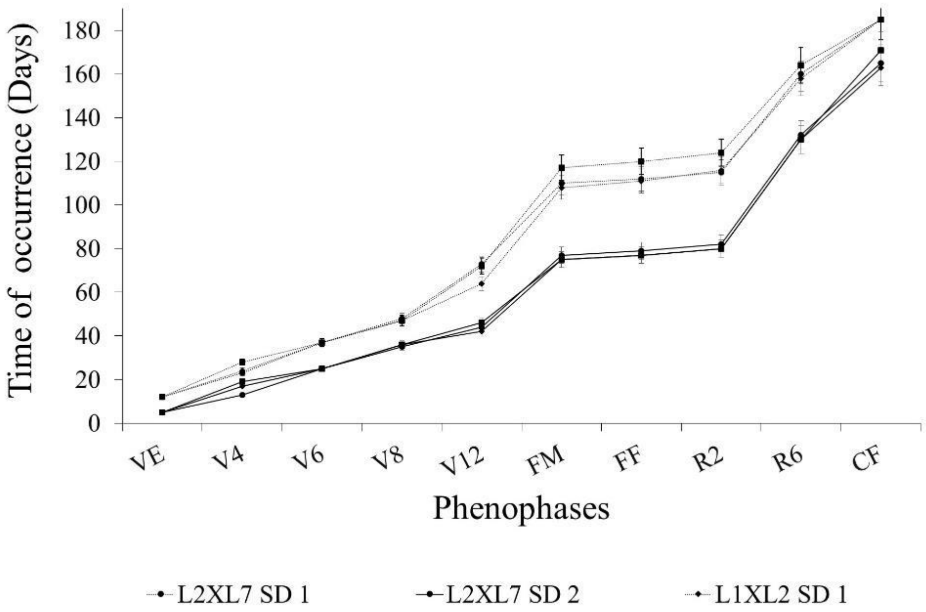
A reduction in the time of occurrence of the phenophases was observed in SD 2, with respect to SD 1. The greatest variations were found during male and female flowering and grain filling phenophases, with an average reduction in the three hybrids of 9 days. This average remained constant in the three phenophases mentioned above. In the physiological maturity phenophase, this time was reduced to 8 days in SD 2, with respect to SD 1. Harvest, on average, presented a difference of 8 days between the sowing dates (SD 1: 185 days and SD 2: 193 days). The occurrence of the grain maturation and harvest phenophase in SD 1 is in agreement with studies developed by Ibarra et al. (10), where they found that the varieties used in their experiment reached physiological maturity and harvest at 191 days under optimum conditions. The single hybrid L2XL7 showed the least variation between sowing dates, suggesting greater tolerance to the increase in temperature recorded in SD 2, compared to SD 1.

In a study developed by Schoper et al. (1986), they showed that the reduction of phenology from flowering onwards leads to a decrease in the amount of viable pollen. A similar study was developed by Li et al. (2022) who showed that pollen viability was regulated by the enzyme sucrose synthase, which is sensitive to heat and drought. These responses may explain the reduction in phenology observed in the white maize hybrids evaluated.

The decrease in the time of occurrence of the final crop phenophases is associated with some biochemical and, even, molecular alterations that impact grain yield. For example, the rate of protein and carbohydrate mobilization can be affected as shown by Tiwari & Yadav (2019). In addition, the effect of temperature can affect the hormone imbalance in maize. In a study developed to evaluate the zeatin and salicylic acid content in the ears of two experimental maize varieties, it was reduced by more than 15% with respect to the control due to the effect of temperature associated with the crop cycle; whereas, the content of abscisic and gibberellic acids increased, affecting the normal plant metabolism and grain yield (Sun et al., 2023).

In a phenology study developed by Wang et al. (2019) shows evidence of the effect of temperature on flowering dynamics and the contribution of pollen and pistil viability to grain yield in response to high temperatures. In this study, the number of grains per ear was the most affected variable in maize due to sowing dates variation (Figure 2). The same analysis was used for the variable's evapotranspiration, irrigation time, and irrigation interval and water productivity being significant reduction. On the other hand, Wang et al. (2019) determined that 38°C is the maximum lethal temperature for flowering and seed formation in maize with contrasting sensitivities, emphasizing that this stressor can significantly affect grain yield.

Figure 2 - Time of occurrence of phenophases: VE: emergence; V4: emission of the fourth leaf; V6: appearance of the sixth leaf development; V8: appearance of the eighth leaf; V12: appearance of the twelfth leaf; VT (M): emission of male flowering, VT (F) emission of female flowering, R2: grain filling, R6: grain ripening, and CF: harvest. Rectangular bars represent standard deviations from the mean.



Source: Authors (2024).

3.2 Evapotranspiration, irrigation timing, intervals and water productivity

There were significant differences (p≤0.01) in evapotranspiration values in all crop phenophases between SD 1 and SD 2, with the exception of the time of harvest, where minimum evapotranspiration was obtained, due to plant senescence. These values were similar to the evapotranspiration obtained during crop emergence in SD 1 (Figure 3a).

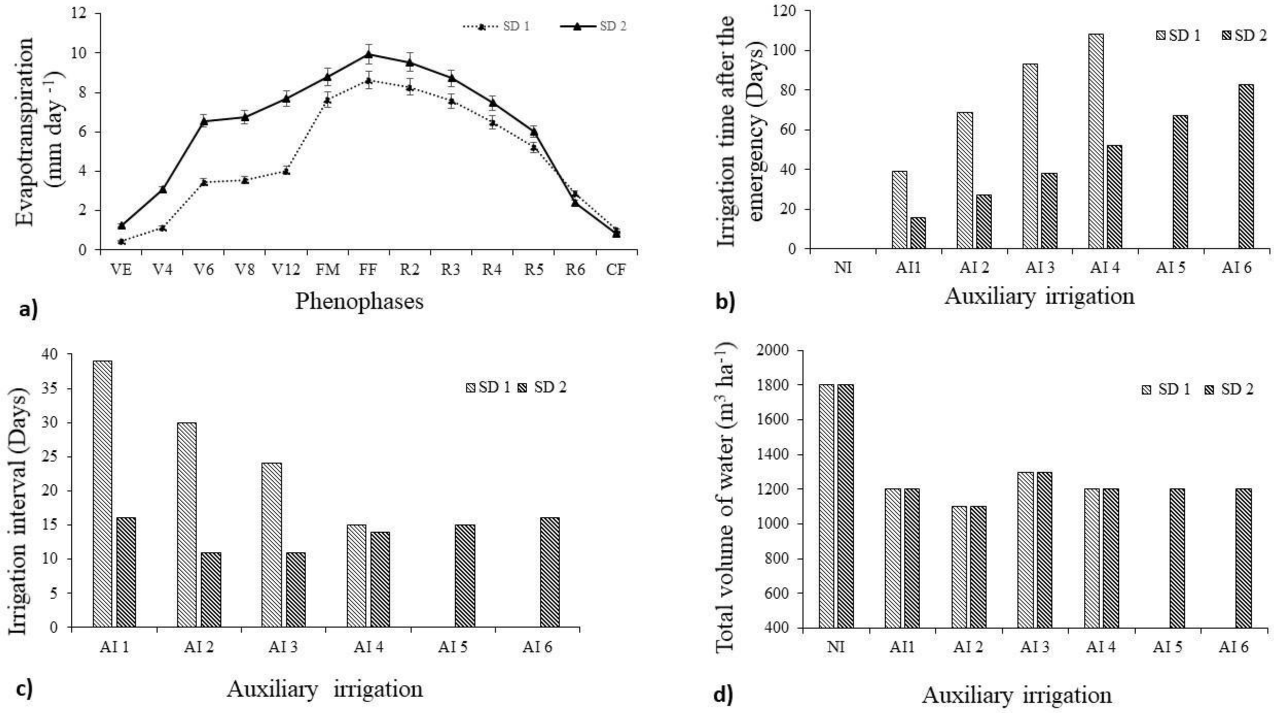
On the first sowing date, only four auxiliary irrigations were applied, while on the second it was necessary to apply six irrigations (Figure 3b). These results are in agreement with Cota et al. (1993) and Ortega (1997), who applied four irrigations in the autumn-winter growing season, while in summer it was necessary to apply six irrigations due to high temperatures.

The irrigation intervals (Figure 3c) in SD 1 decreased as the crop developed. This result could have been a function of the crop's own development according to the phenology of the plants and perhaps due to the effect of the seasonal temperature that dried the soil faster and increased the water requirements of the plants. In these phenophases there was a maximum crop coefficient between 1.06-1.20, which increased the water demand both by transpiration and evaporation. There was only similarity of irrigation intervals in RA4 between the two sowing dates, and the volume of water applied did not show significant differences in this auxiliary irrigation (p=0.54231). However, the irrigation intervals for the second sowing date were shorter and more regular, ranging from 11 to 15 days after each irrigation (Figure 3c).

The greatest differences among irrigation intervals were found in the first three auxiliary irrigations. In these three relief irrigations the IR of SD 1 was twice the number of days than in SD 2. In SD 2 it was necessary to apply two more auxiliary irrigations for the crop to complete its phenology under adequate conditions of water availability.

The variations in water volumes (Figure 3d) are due to the water requirements of the crop in the phenophases. The irrigation with the highest lamina was the birth irrigation (RN), followed by auxiliary irrigation 3 (AR3), which was carried out in the flowering phenophase. In SD 2 it was necessary to apply two more irrigations in relation to SD 1 with an irrigation lamina of 0.12 m.

Figure 3 - Crop evapotranspiration at phenophases (a), irrigation application time (days after emergence) (b) irrigation intervals (c) and total irrigation volume (d) at two sowing dates (SD) of white grain maize hybrids at Tecnológico Valle del Yaqui, Sonora, Mexico.



Source: Authors (2024).

3.3 Grain yield of white grain maize hybrids

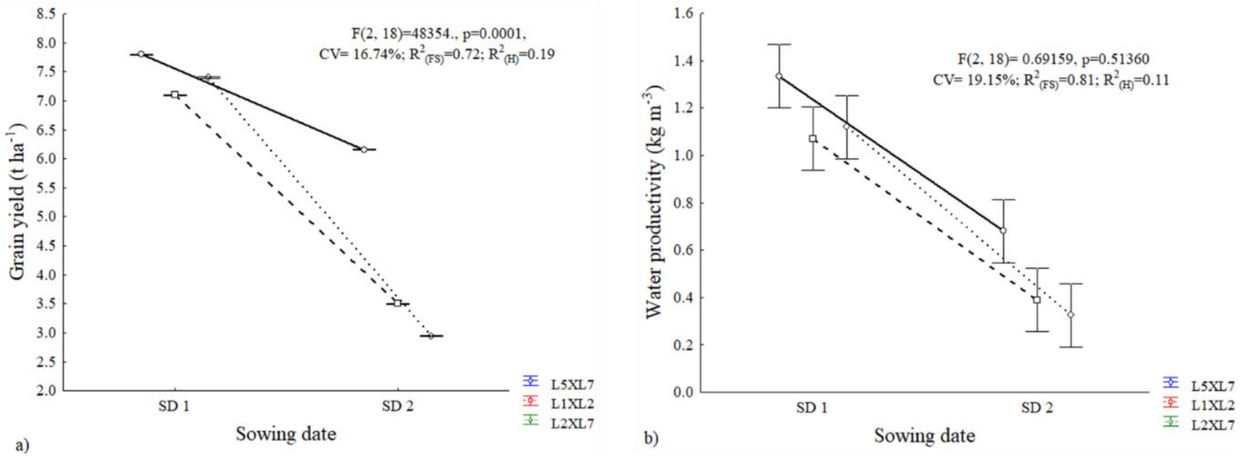
There was a highly significant interaction between the established sowing dates and the hybrids evaluated. The greatest contribution to the total variability found among the hybrids in the two sowing dates was attributed to the source of variation sowing date (R^2 =0.72) (Figure 4a). This shows that sowing time does influence the agronomic performance of the hybrids evaluated. On the other hand, the source of variation "hybrids" only contributed 19%, demonstrating that there is also variability in the individual response of these white grain hybrids.

In SD 1, the single hybrid L5XL7 presented the highest grain yield, followed by L2XL7 and finally the hybrid L1XL2, with significant differences among them. In SD 2, a decrease in yield was observed in the hybrids, with respect to sowing date 1. The hybrid with the greatest decrease in yield was L1XL2, which indicates greater sensitivity to the climatic conditions that occurred in SD 2. On the other hand, hybrid L5XL7 presented the lowest sensitivity to heat stress.

Variation in grain yield generated variability in water productivity. In this study there was no significant interaction between the sources of variation SD and hybrids (Figure 4b). Although there were highly significant differences between SD (F=187.604, p=0.00026) and hybrids (F=13.091, p=0.00031), the greatest contribution to the total variability found in water productivity was attributed to SD, with a contribution of 81% (R^2 =0.81), leaving only 11% attributed to the response variability of the hybrids (R^2 =0.11). In SD 2, where it was necessary to apply six auxiliary irrigations, water use efficiency was reduced to half of what was obtained at sowing date 1 in the three hybrids evaluated. In both interactions, an average of

8% of the total variability was attributed to experimental error.

Figure 4 - Interaction between grain yield and sowing dates (a) and water productivity and sowing dates (b) in three white grain maize hybrids at Tecnológico Valle del Yaqui. (F: Fisher's calculated value, p: probability, CV: coefficient of variation, R^2(SD) and R^2(H): unadjusted coefficients of determination for the sources of variation sowing dates, and hybrids, respectively.



Source: Authors (2024).

The most recent climate change scenarios and predictions for Mexico show significant variability in precipitation patterns (Murray-Tortarolo, 2021). This will affect water reserves in reservoirs used for agriculture (Martínez-Sifuentes et al., 14). Therefore, it is necessary to generate new maize genotypes with high productivity and less water demand. Currently, under irrigated conditions, mainly for central and northern Mexico, maize is one of the staple crop species with the highest water demand and the largest areas of cultivated land (Alonso-Sánchez et al., 2022). In maize breeding programs in Mexico, the evaluation of water productivity (volume of production per cubic meter of water applied) will have an important effect on regional and national food sovereignty.

4. Conclusion

The time of occurrence of the phenophases of the white grain maize hybrids evaluated was reduced by an average of 10 days on sowing date 2. The temperature factor on sowing date 2 led to an increase in evapotranspiration, the number of irrigations applied and a decrease in irrigation intervals. Water productivity was reduced at sowing date 2 by 43% on average among all hybrids, compared to sowing date 1, demonstrating that it is not feasible to establish these hybrids in the April-August period. Of the single hybrids evaluated, L5 X L7 presented the best phenological and agronomic performance at sowing date 2.

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