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WATER PRODUCTIVITY IN RICE GENOTYPES UNDER RAINFED CONDITIONS

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Abstract: The present study evaluated water productivity (WPE) and water conversion efficiency (WCE) in 36 rice genotypes *(Oryza sativa L.*) under rainfed conditions in Tabasco, Mexico, with the objective of identifying promising materials for areas with limited water availability. The experiment was established at the Huimanguillo Experimental Field of INIFAP, using a randomized complete block design with three replications. Key agronomic variables such as plant height, number of grains per panicle and grain yield were recorded, as well as water indicators derived from crop evapotranspiration (ETc). The results showed highly significant differences ($P<0.001$) among genotypes for all variables evaluated. Genotype T30 (Gulf FL-16) presented the highest yield (4127.2 kg ha$^{-1)}$, the highest water productivity (0.54 kg m^{-3}) and the lowest ETc (1.98 m^{3}kg$^{-1)}$, standing out as the most efficient in the use of water resources. Likewise, genotypes T15, T4, T16 and T25 also showed high efficiency and agronomic performance. These findings reflect the existence of genetic variability that can be used for breeding and validation programs for varieties adapted to the humid tropics. It is concluded that, under rainfed conditions and climate change scenarios, the selection of water-efficient genotypes represents a key strategy for the sustainable increase of national rice production.
Keywords: *Oryza sativa*, water efficiency, yield, rainfed, climate change, genotypes.

INTRODUCTION

Rice (*Oryza sativa L.*) is the second largest source of food worldwide and has been cultivated on 163.2 million ha, with an average annual production of 740.9 million tons worldwide (FAOSTAT, 2023). It has been estimated that global rice production needs to increase by 116 million tons by 2035 to meet the growing demand for rice (Yamano *et al.*, 2016). However, the arable land used for rice production has decreased in recent years due to urbanization and industrialization (Long, 2014), which threatens the increase in global rice production. Rice is considered one of the most important crops in the Mexican diet, only behind corn, beans and wheat. Between 2010 and 2020, its per capita consumption in Mexico increased from 9.4 kg to 11 kg, evidencing the growing need for this grain and its importance in the population's diet (CEDRSSA, 2020). National production in 2023 was 36, 877 hectares harvested, with a production of 252, 099 tons and an average yield of 4 ton $ha^{(-1)}$ (SIAP, 2023). Likewise, there were imports of 986,000 tons; exports of 11,000; consumption of 1,139,000 and final stocks of 75,000 tons (SE, 2023). Therefore, Mexico is not self-sufficient in this crop. One of the ways to increase yields is by increasing the cultivable area and improving agronomic management per unit of productive area. The basis of agronomic management is based on the selection of good genetic potential of the plant species that is adapted to the environmental conditions of production (Flores and Delgado, 2023). On the other hand, the increasing pressure on water resources and climate variability require sustainable strategies for agricultural production, especially in high-consumption crops such as rice (López-López *et al.,* 2018). Climate variability, characterized by more intense and unpredictable patterns of precipitation and increasing temperatures, directly affects rice productivity and its response to water stress. In Mexico, an average temperature increase of +0.6 °C has been recorded since 1960, with projected increases of between 1.1 °C and 3.0 °C by 2060, along with greater rainfall variability, which increases evapotranspiration and threatens water availability in critical periods (Estrada *et al.,* 2022). Studies have estimated rice yield decreases of up to 24%-36% between 2031 and 2060 in vulnerable areas of Mexico, if water management and genetic adaptation strategies are not implemented (Zhao *et al.,* 2022). Correlating yield and water efficiency among genotypes with these practices is essential to advance in breeding and selection programs aimed at climate resilience, promoting alternatives that reduce the vulnerability of the rice system to climate change (Heredia *et al.,* 2025). In this context, the identification of genotypes with higher yield and water use efficiency is essential to maintain productivity under rainfed conditions in the face of climate change. This study focused on evaluating 36 rice varieties, including commercial genotypes and experimental lines, under rainfed conditions in the state of Tabasco, Mexico. The objective was to identify materials with high yield and better performance in terms of water productivity and efficient use of water resources, in order to contribute to the development of more resilient and sustainable production systems.

MATERIALS AND METHODS

STUDY SITE

The work was carried out in a Fluvisol eutrophic soil cultivated with rice for 20 years, located in the experimental fields of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) in the municipality of Huimanguillo, Tabasco (Figure 1). The average annual rainfall is 2356 mm; from February to May there is a dry season (276 mm), and the average minimum temperature is higher than 20°C. The crop cycle was rainfed and rainfed. The crop cycle was rainfed and established on June 15, 2024 (Salgado-Velázquez *et al.,* 2025).

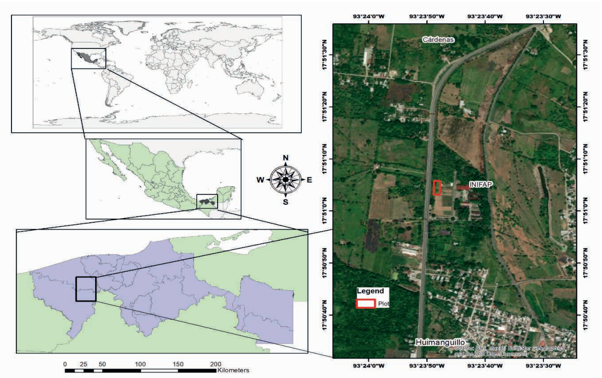

Figure 1. Spatial location of the rice fields under study.

2.2 Genotypes

Experimental varieties and lines generated by INIFAP for rainfed and irrigated conditions in the Mexican tropics from the project "Genetic improvement of rice in Mexico, to incorporate resistance to biotic and abiotic problems caused by the effects of climate change" were used and are presented in Table 1:

EXPERIMENTAL DESIGN

To generate the treatments, a randomized block experimental design with three replications was used, where the treatments consisted of the genotypes (experimental lines and rice varieties). The experimental plot was 6 m long by 6 furrows wide with a separation between furrows of 0.2 m. The useful plot consisted of the 4 central furrows.

AGRONOMIC MANAGEMENT

A pass was made with the mower to eliminate the weeds present in the field. This was followed by a fallow step with the disk plow. Subsequently, two harrow passes were made to leave the soil well loosened. The soil was leveled with a rototiller to allow a homogeneous distribution of the water sheets. The sowing method was by broadcasting, which consisted of spreading and distributing the seed uniformly over the planting furrows. Fertilization was done with the NPK formula 130-40-120, applying all the phosphorus and potassium at the time of sowing and the urea was divided in two moments: the first at 30 days after germination and the second at 35 days (panicular initiation). The insecticides used to control the pests of the brown bug (*Oebalus insularis*), rice borer *(Rupela albinella*) and the vaneo mite *(Steneotarsonemus spinki*) were imidacloprid at 0.25 L of commercial product, methamidophos at 1 L of commercial product and cypermethrin at 0.5 L of commercial product. Six applications of insecticides were made during the cycle. Weed control was carried out two days after the first irrigation, with a pre-emergence application of the commercial product Pendimethalin and clomazone. One month after planting, Propanil, fenoxaprop-p-ethyl, bispyribac-sodium, cyhalofop-butyl, 2,4-D and bentazon were applied to control the most persistent weeds. Manual weeding was performed to control weeds in the alleys and curbs, mainly (Jiménez-Chong et al., 2017).

IRRIGATION

During the tillering stage and flowering, irrigation was continuous, keeping the soil completely flooded with a 5 cm layer until the physiological maturity of the materials.

STUDY VARIABLES

The following variables were recorded during the reproductive phase and physiological maturity of the materials:

Plant height (PA): measured from the base of the plant to the apex of the panicle, taking as reference the main or tallest stem, in 10 plants per plot (Álvarez Hernández *et al.,* 2018).

Number of grains per panicle (NGP). Its determination was performed on the same panicles used for NEP. All grains in each panicle were counted (Álvarez Hernández *et al.,* 2018).

Trat	Genealogies
1	Milagro (Zacatepec)
2	Miloax 98-2
3	INIFLAR RT-1
4	IR 69915-12MI-15UBN-22
5	IR8-2
6	El Silverio-2
7	INIFLAR RT-2
8	Tabasqueña A-17-2
9	Temporalero A-95
10	Pacifico-FL-15-1
11	FL06689-3P-1-4P-M
12	FL02768-2P-6-4P-1P-M-1P
13	Pacific FL15-2
14	FL084430-8P-4-3P-3P-M
15	PCTMADR-707-2-1-1-3SR-2P
16	PCTMADR-682-2L-2-3-3SR-2P
17	PCTMADR-707-2-1-4-2SR-1P
18	PCTMADR-707-2-1-4-2SR-2P
19	PCTMADR-707-2-1-2-4SR-1P
20	FL010030-12P-9-2P-1P-M
21	FL0 10127-7P-1-2P-2P-2P-M
22	FL07162-7P-3-3P-3P-3P-M
23	RC 88
24	IR11141-6-1-4
25	Crash A-05
26	Campeche A-80
27	El Silverio
28	INIFLAR R
29	Pacifico FL-15
30	Gulf FL-16
31	Veracruzana A-21-3
32	Temporalero A-95
33	Miloax 98 (2006)
34	Milver 05 (2008)
35	Miloax 38 (2012)
36	Milagro Filipino (2010)(Veracruz)

*Trat = treatment

Table 1. Genotypes under study.

Grain yield (GY): All panicles in each plot were harvested, shelled, placed in a brown paper bag and labeled. Subsequently, they were weighed on an analytical balance and the moisture in each sample was determined with a Delmhors model G-7 digital grain moisture meter. The following equation 1 was used to calculate GY adjusted to a moisture content of 14% (Barrios-Gómez *et al.,* 2023):

$$GY\left(\frac{kg}{ha}\right)\ al\ 14\%\ humedad = \frac{(100-M)\ x\ Rendiiento\ de\ parcela\ (kg)\ x\ 10000}{(100-14)\ x\ Área\ neta\ de\ parcela,\ m^2} \quad (1)$$

Where *M* is the moisture content of the grain sample. It is multiplied by 10000 for conversion from $m^2$to ha.

METEOROLOGICAL DATA

They were taken from the climatological station of the Huimanguillo Experimental field near the study plot, where air temperature (°C), precipitation and evaporation (mm) data were collected. Extraterrestrial radiation (MJ m2/day) was estimated using the methods established in the FAO manual (Allen *et al.,* 2006; Wehbe *et al.,* 2020). Data were recorded daily and plotted as monthly and cumulative means.

CROP EVAPOTRANSPIRATION (ETC, MM)

Rice crop evapotranspiration (ETc) is related to the evapotranspiration of a grass crop taken as a reference (ET_0) by using crop coefficients (Kc). First, the reference evapotranspiration was obtained using the Penman-Monteith method with equation 2 (Allen *et al.,* 2006).

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + y\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + y(1 + 0.34u_2)} \quad (2)$$

where *Rn* is the net radiation at the crop surface (MJ $m^{-2}day^{-1)}$, *G* is the heat flux at the ground (MJ $m^{-2}day^{-1)}$, *T* the mean daily air temperature (°C), $u_2$the wind speed at 2 m height (m $s^{-1)}$, $e_s$the saturation vapor pressure (kPa), $e_a$the actual vapor pressure (kPa), Δ the slope of the vapor pressure curve (kPa °C($^{-1)}$) and *γ* the psychrometric constant (kPa °$C^{-1)}$. Meteorological data were obtained from the climatological station of the experimental field located 100 m away from the study area. Crop evapotranspiration was calculated as follows with equation 3:

$$ET_c = K_c\,ET_0 \qquad (3)$$

where *Kc* values depend on the phenological stage of the crop. The values used for rice were 1.05 in the vegetative stage, 1.2 in the reproductive stage and 0.9 to 0.6 in the ripening stage (Allen *et al.,* 2006).

WATER PRODUCTIVITY (PA, KG/M$^{3)}$

Water productivity (WP) was estimated as the ratio between grain yield (kg ha^{-1}) and total water consumed during the rice development cycle ($m^3ha^{-1)}$, expressing the result in kilograms of grain per cubic meter of water (kg $m^{(-3))}$. This metric makes it possible to evaluate the efficiency with which each genotype converts the available water resource into harvestable biomass. The following equation 4 was used for its calculation:

$$PA\left(\frac{kg}{m^3}\right) = \frac{Rendimiento\ de\ grano\ \left(\frac{kg}{ha}\right)}{ET_c\ (mm)x\ 10} \quad (4)$$

Where:

PA = Water productivity (kg m^{-3})

Crop yield (kg ha^{-1}), obtained at 14% humidity.

ET_c= Crop evapotranspiration ($m^3ha^{-1)}$, determined from the water balance and the estimation of the reference evapotranspiration (*ETo*) multiplied by the crop coefficient (Kc), adjusted to each phenological stage of rice.

All the water used by the crop was assumed to come from effective precipitation considering only 70% of precipitation and supplemental irrigation, considering excess runoff and deep percolation in medium to heavy textured soils, typical of Tabasco rice growing areas.

WATER CONVERSION EFFICIENCY (WCE, M³/KG)

Water conversion efficiency (WCE) was calculated as the volume of water consumed per unit of grain production, expressed in cubic meters per kilogram of rice produced (m^3kg^{-1}) . This variable quantifies the amount of water required to produce one kilogram of dry grain and is an inverse indicator of water productivity, providing a complementary perspective on the efficient use of water resources. Equation 5 was used for its calculation:

$$ECA\left(\frac{m^3}{kg}\right) = \frac{ET_c\left(\frac{m^3}{ha}\right)}{Rendimiento\ de\ grano\left(\frac{kg}{ha}\right)} \quad (5)$$

Where:

ECA = Water conversion efficiency (m^3kg^{-1}),

ET_c= Crop evapotranspiration (m^3ha^{-1}) ,

Crop yield ($kg\ ha^{-1}$), adjusted to the standard moisture content of 14%.

The joint analysis of ECA and water productivity (PA) allowed a comprehensive evaluation of the water performance of genotypes, facilitating the identification of varieties that optimize water use to maximize production under the specific rainfed conditions in Tabasco.

STATISTICAL ANALYSIS

Analysis of variability was performed on all data according to classical statistics, and measures of central tendency and dispersion were determined. In addition, all the variables under study were subjected to a randomized complete block analysis of variance, where the treatments were the different genotypes (experimental lines and varieties). For those variables where significant differences were found between treatments, the multiple comparison of means test was performed by Tukey's method (P≤0.05) (Álvarez-Hernández *et al.*, 2022). The anova, agricolae and ggplot libraries were used. All analyses were performed with the R studio statistical program (R Core Team, 2023).

RESULTS AND DISCUSSION

CLIMATIC CHARACTERISTICS DURING RICE CROP GROWTH

During the growth of the rice genotypes under study, climatological data were collected from the weather station located at the INIFAP experimental field in Huimanguillo, Tabasco, Mexico near the evaluation plot. Figure 2 shows the climogram of the average monthly maximum, minimum and mean temperature; and the monthly accumulated evaporation and precipitation of the weather station used in this study.

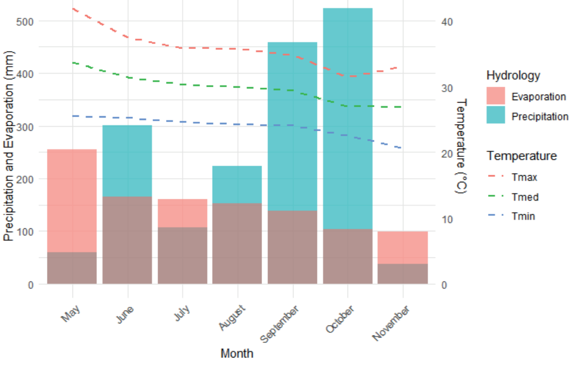

Figure 2. Climogram of temperatures, evaporation and precipitation in the evaluation plot of the rice genotypes under tropical conditions.

During the spring-summer 2024 cycle, from June 15 when planting began until the end of November when harvesting was completed, an average temperature of 29.2°C was recorded, with a maximum of 41.9°C in May and a minimum of 20.1°C in November. Total accumulated rainfall was 1651.3 mm and total evaporation was 819.3 mm. Rice requires temperatures between 18°C and 40°C for germination, with those between 25°C and 30°C being optimal (Lu et *al.,* 2022). In the evaluation plot during sowing in June, temperatures of 25.3 to 37.5°C were recorded, which are within the optimum range, favoring good seedling germination. During tillering, rice develops its secondary stems or tillers. The ideal temperature for good tillering is 31 °C (Xu *et al.,* 2021). Temperatures in July and August recorded ranged from 24.3 to 35.6°C, which may affect this process. However, it is essential to ensure adequate water availability, as rice requires a warm and humid climate for proper development. Rainfall during these months was 331 mm. Flowering is a critical phase where rice is particularly sensitive to weather conditions . High temperatures above 35 °C during flowering most severely affect the lower spikelets of the panicle, decreasing the rate of fertilization and accelerating grain filling, resulting in smaller and lower quality grains. For rice cultivation, it has been determined that during flowering a one degree Celsius increase in temperature between 30 and 40 °C reduces fertility and grain formation by 10 % (Jimenez, 2021). In the study plot, a temperature range from 24.1 to 34.9°C was recorded in September during flowering of the genotypes, which may have negatively affected some rice genotypes. During grain filling, rice needs solar energy throughout its life cycle, but its requirement is higher in the final stages of the crop, especially during grain filling. Ideal temperatures for its growth range between 25 °C and 30 °C; temperatures below 20 °C or above 35 °C can negatively affect plant development and grain formation (López-Hernández *et al.,* 2018). During panicle filling, conditions of high solar radiation, above 450 cal/cm^2/day (approximately 18.8 MJ/m^2/day), together with cool night temperatures (minimum of 20-22 °C), are ideal to maximize this process. Solar radiation received (data not shown) during the months of September, October and November was estimated to be 36.41, 32.83 and 28.94 MJ/m^2/day (approximately 869.74, 784.16 and 691.26 cal/cm^2/day) which are sufficient to satisfy this parameter.

One study indicates that, at present, between 1900 and 5000 liters of water are required to produce 1 kg of rice grain (Jarin *et al.,* 2024). It is considered that a rainfall of about 200-300 mm well distributed per month, during the crop cycle, are necessary for a good yield. The reproductive phase of rice is particularly sensitive to water deficit, with the 10 to 15 days prior to flowering being critical for spikelet fertility. During this period, water deficit can cause up to 59% flower sterility, resulting in significant yield reduction (Yang *et al.,* 2019). Also, it has been noted that water stress during flowering and grain filling stages can significantly reduce grain weight and fertility rate, decreasing rice yield. The study highlights that the most sensitive periods to water deficit are the flowering and grain filling stages (Zhang *et al.,* 2023). In the study area, even though this water requirement is met Figure 2, the distribution is not adequate, which is why irrigation was used to maintain a rainfall of at least 5 mm during the critical stages. The minimum accumulated precipitation occurred in November with 38 mm and the maximum in September and October with 458.5 and 522.3 mm, respectively. With the calculation of crop evapotranspiration (ETc) and effective precipitation (Pe) (data not presented) it was determined that the stages with irrigation needs were the periods from June 26 to July 25 (tillering) and October 21 to November 15 (physiological maturity), with 983.3 and 578.9 m^3/month.

EXPLORATORY DATA ANALYSIS

This study presents a detailed statistical evaluation of in the selected agronomic variables: plant height (PA), number of grains per ear (NGP), grain yield (GY), and water productivity (PA) and water conversion efficiency (ECA) providing crucial information on their variability and distribution. Central tendency and dispersion values are presented in Table 2.

Plant height (PA) ranged from 66.8 cm to 105.5 cm, with a mean of 84.7 cm and a CV of 10.4%, indicating moderate variability in plant stature. This result suggests that growth may be influenced by genetic and environmental factors. In this vein, one study analyzed phenotypic and genetic variability in yield and associated traits in rice. The study identified significant variability in plant height, with a CV of 8.5%, and noted that both genetic and environmental factors contribute to this variability. The authors suggest that selection of genotypes with optimal plant heights can improve yield and crop adaptability in different environments (Khan *et al.,* 2023).

The number of grains per panicle (NGP) presented a wide range (61.4 - 161.4 grains), with a mean of 106.9 grains and a CV of 20%, reflecting the influence of environmental conditions and agronomic practices on grain filling, suggesting that the variability observed in the 36 rice genotypes evaluated may be influenced by the resistance of each genotype to various diseases affecting these parameters. Diseases such as leaf spot and scald can affect grain filling, reducing the NGP. Genotypes resistant to these diseases show a greater ability to maintain high GQL (Shi *et al.,* 2021).

Grain yield (GY) exhibited the greatest variability, with values ranging from 101.5 kg/ha to 6032.3 kg/ha, and a CV of 61.9%, which evidences the influence of multiple factors on final crop productivity. In this regard, Mongiano *et al.* (2020) conducted a comprehensive study on phenotypic variability in Italian rice germplasm. They evaluated 40 cultivars in two seasons, analyzing 14 traits related to phenology, plant architecture and yield. They found wide phenotypic variation in many traits, including yield, with coefficients of variation ranging from 5.9% to 45.4%.

Water productivity (WP) showed values ranging from 0.01 kg/m^{3}to 0.83 kg/m^3, with a mean of 0.31 kg/m^{3}and a coefficient of variation (CV) of 56.2%, indicating high variability in the conversion of water to biomass. Water use efficiency (WUE) ranged from 1.20 m^3/kg to 77.19 m^3/kg, with a mean of 5.66 m^3/kg and a CV of 58%, reflecting a very high variability in the amount of water needed to produce one kilogram of biomass. This amplitude suggests that both genetic and environmental factors have a notable impact on water resource utilization. Similarly, *Hussain et al.* (2022) evaluated the genotypic and phenotypic variability of water use efficiency in low rice cultivars and reported coefficients of variation greater than 25% (both genotypic and phenotypic), highlighting that there is significant potential for breeding genotypes that optimize water use under water stress conditions. According to the authors, the selection of varieties with high water efficiency can be an effective strategy to increase crop sustainability.

ANALYSIS OF VARIANCE

Table 3 presents the results of the analysis of variance for a randomized complete block experimental design with three replications, where the treatments corresponded to the different rice genotypes (experimental varieties and lines, Table 1).

Analysis of variance (ANOVA) of agronomic parameters evaluated in rice genotypes established under rainfed conditions in Tabasco, Mexico, during the 2024 cycle, revealed significant differences in

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Variable	Min. value	Max. value	Rank	1st. Q	3rd. Q	Me	M	DS	CV	SW
AP (cm)	66.8	105.5	38.6	77.2	90.1	84.7	83.8	8.8	10.4	0.98
NGP	61.4	161.4	100	89.3	119.7	106.9	108.2	21.4	20	0.99
GY (kg/ha)	101.5	6032.3	5930.7	910.6	2789.7	2042.7	1987.8	1265.5	61.9	0.96
PA (kg/m³)	0.01	0.83	0.82	0.14	0.41	0.29	0.26	0.18	54	0.65
RCT (m³/kg)	1.2	77.2	75.9	2.4	7.1	7.78	3.79	11.2	58	0.78

M= Median, Me= Mean, SD= standard deviation, CV= coefficient of variation; SW= Shapiro-WilK.

Table 2. Main countries with the highest rice yields and area under cultivation in the world.

Trat	PA (cm)	NGP	GY (kg/ha)	PA (kg/m³)	ECA (m³/kg)
1	84.7 abcd	104.2 ab	1623.6 ab	0.21 ab	13.17 ab
2	82.5 abcd	124.8 ab	2033.9 ab	0.34 ab	11.09 ab
3	82.3 abcd	91.9 ab	1126 ab	0.18 ab	14.3 a
4	98.6 a	93.9 ab	3236 ab	0.43 ab	2.37 c
5	81.7 abcd	110.2 ab	2450.1 ab	0.36 ab	3.12 b
6	81.2 abcd	116.9 ab	780.3 b	0.13 ab	29.44 a
7	84.3 abcd	100.4 ab	2338.8 ab	0.33 ab	3.19 b
8	83 abcd	122 ab	2491.5 ab	0.36 ab	2.93 b
9	85.5 abcd	104.3 ab	2029.6 ab	0.26 ab	14.19 a
10	90.4 abc	83.3 b	2561.4 ab	0.34 ab	8.14 ab
11	87.6 abcd	107.3 ab	2523.8 ab	0.39 ab	2.82 c
12	88.5 abc	83.7 b	2838.4 ab	0.39 ab	2.72 c
13	88.2 abc	103.9 ab	2291.8 ab	0.3 ab	5.48 ab
14	79.2 abcd	93.5 ab	1998.5 ab	0.26 ab	4.31 b
15	93.6 ab	105.6 ab	3415.7 ab	0.46 ab	2.86 c
16	94.7 ab	122.4 ab	3157.4 ab	0.47 ab	2.36 c
17	89.8 abc	105 ab	2655.7 ab	0.37 ab	3.05 b
18	80 abcd	102.3 ab	1856.7 ab	0.25 ab	5.23 b
19	81.8 abcd	112 ab	1757.1 ab	0.25 ab	4.59 b
20	83.2 abcd	131.3 ab	2006.1 ab	0.29 ab	3.63 b
21	82.6 abcd	140.4 a	1982.5 ab	0.29 ab	4.28 b
22	91.7 abc	96 ab	2466.6 ab	0.32 ab	4.39 b
23	98.7 a	108.7 ab	2603.2 ab	0.27 ab	3.94 b
24	79.9 abcd	88.5 ab	1149.3 ab	0.16 ab	7.75 ab
25	86.6 abcd	113.4 ab	3117.6 ab	0.46 ab	2.37 c
26	75.6 bcd	91.1 ab	664 b	0.1 b	11.18 ab
27	81.6 abcd	114.4 ab	1099.3 ab	0.16 ab	12.12 ab
28	79.3 abcd	105.1 ab	1710.2 ab	0.26 ab	7.74 ab
29	84.9 abcd	92.9 ab	1895.7 ab	0.25 ab	10.1 ab
30	97.7 a	130 ab	4127.2 a	0.54 a	1.98 c
31	77.6 bcd	83.4 b	1691.7 ab	0.24 ab	5.34 ab
32	88.7 abc	91.8 ab	2866.3 ab	0.4 ab	2.76 c
33	81.2 abcd	141.3 a	552.7 b	0.08 b	13.74 ab
34	72.4 dc	97.8 ab	917.1 b	0.12 ab	15.76 a
35	80.8 abcd	136.5 ab	840.2 b	0.12 ab	9.76 ab

36	68.4 d	100.4 ab	681.3 b	0.1 b	29.47 a
Mean	84.7	106.9	2042.7		
C.V. (%)	10.4	15.6	45.85	54	
Prob. F.	<0.001	<0.001	<0.001	<0.001	<0.001
DMS	19.73	54.54	3064.6		

NS: not significant; LSD: least significant difference; Prob F: Fisher's F probability at P≤0.05.

Table 3. Analysis of variance of DEBA and Tukey's means of agronomic parameters of rice genotypes established in temporal cycle 2024 under conditions of Tabasco, Mexico.

key variables for crop yield. Plant height (PA), number of grains per spike (NGP), grain yield (GY), water productivity (PA) and efficient water use (ECA) showed highly significant differences (P<0.001), indicating genotypic variability in these traits.

Plant height (PA, cm). Significant variability was observed in PA (P < 0.001), with values ranging from 68.4 cm (T36) to 98.6 and 97.7 cm (T4 and T30, respectively). The difference between genotypes suggests that some materials have taller growth habit, which may be related to a greater capacity for light interception and competition for resources. However, genotypes with shorter height could be more resistant to lodging, a key characteristic for rainfed rice production. Genotypes with greater height (T4, T23, T30 and T16) could be associated with vigorous vegetative growth, which, depending on agronomic management and environmental conditions, can positively or negatively impact yield. A study analyzed the relationship between plant height and yield in different rice ecotypes over a span of 1978-2017. The results showed that, in indica ecotypes, greater plant height was positively associated with grain yield, while in "japonica hybrid" ecotypes, this relationship was negative. This suggests that the impact of plant height on yield may vary by ecotype and environmental conditions (Li *et al.,* 2019).

Number of grains per panicle (NGP). NGP did show significant differences (p < 0.001), with values ranging from 83.3 (T10) to 141.3 (T33). Genotypes with higher NGP may be related to higher efficiency in the production of reproductive structures (Lu *et al.,* 2022). One investigation analyzed 38 rice varieties with different yield types and found that high-yielding varieties had a higher total number of spikelets. The study revealed a significant positive correlation between the number of spikelets per panicle and grain yield, although a negative correlation was also observed with the percentage of filled grains and grain weight. These findings suggest that while higher spikelet number may contribute to yield increase, it is essential to balance this component with other factors to optimize productivity (Liu *et al.*, 2024).

Grain yield (GY, kg/ha). Grain yield showed highly significant differences (P<0.001), with an overall average of 2042.7 kg/ha. Treatment 30 stood out with the highest yield (4127.2 kg/ha), suggesting a favorable combination of agronomic attributes. In contrast, treatments 6, 26, 33, 34, 35 and 36 presented the lowest values (<1000 kg/ha), indicating that yield expression is influenced by both genetic potential and interaction with the environment. Genotypes such as T30, T15, T4 and T16 presented the highest yields with 4127.2, 3415.7, 3236 and 3157.4 kg/ha, respectively; suggesting their potential to be selected in breeding programs. However, some materials with lower yields could be limited by factors such as lower grain filling capacity or lower photosynthetic efficiency. Recent research has deepened the understanding of genotype-by-environment interaction (GEI) and its impact on rice yield. One study evaluated 89 rice varieties in temperate, subtropical and tropical regions over two years, analyzing grain yield and components such as panicle length, number of panicles, number of spikelets per panicle and thousand-grain weight. Results indicated that consideration of GEI in diverse environments facilitates accurate identification of optimal genotypes with high yield and adaptability to specific or diverse environments (Huang *et al.,* 2021). An example of this was treatment 30 which corresponded to the Gulf variety FL-16 which is multienvironmental and possesses high spectrum resistance to the sogata-WHV complex (white leaf virus) and the endemic disease "rice scorch" (*Pyricularia oryzae*), as well as moderate resistance to the new disease "spotted grain", caused by *Helminthosporium oryzae* in association with other pathogens, and to stem borers (*Chilo loftini, Rupela albinella* and *Diatraea saccharialis*) (Hernández-Aragón *et al.,* 2019). On the other hand, treatments 15, 4 and 16, which correspond to experimental lines PCTMADR-707-2-1-1-1-1-3SR-2P, IR 69915-12MI-15UBN-22 and PCTMADR-682-2L-2-3-3-3SR-2P, are shown as promising materials for release (Hernández-Aragón *et al.,* 2023).

Water productivity (PA, kg/m[3]) . Analysis of variance revealed highly significant differences ($P < 0.001$) in water productivity (PA) among the genotypes evaluated. Values ranged from 0.08 kg/m[3] (T33) to 0.54 kg/m[3] (T30), with an overall mean of 0.31 kg/m^3. This wide variation, also reflected in a coefficient of variation (CV) of 54%, indicates a marked influence of the genetic component on the efficiency with which varieties convert water used into grain yield. The value of 0.54 kg/m^3, means that T30, for each cubic meter of water consumed produced 0.54 kilograms of grain. The genotype T30 (Gulf FL-16), which presented the highest PA, also showed the highest grain yield, which reinforces the usefulness of this variable as an indicator of agronomic performance under rainfed conditions. These results coincide with those reported by Hussain *et al.* (2022), who observed a high genotypic variability in water productivity in rice under water stress, highlighting that genotypes with high PA present better utilization of water resources and greater sustainability. In addition, treatments T15, T25, T16 and T4 also presented PA values higher than 0.43 kg/m[3], which positions them as promising materials for environments where access to water is limited.

Water conversion efficiency (WCE, m^3/kg). For RCT, highly significant differences ($P < 0.001$) were also identified, with values ranging from 1.98 m^3/kg (T30) to 29.47 m^3/kg (T36), with the overall mean being 5.66 m^3/kg. The high CV of 58% evidences variability among genotypes, suggesting a high selection potential for this trait. Genotypes with lower RCT, such as T30, T16, T4, T25 and T11, are particularly relevant, as they require less water to produce one unit of yield, making them suitable for water-restricted environments. The value of 1.98 m^3/kg in T30 (Gulf FL-16) implies that 1980 liters of water are needed to produce one kg of rice grains. Studies such as Bouman *et al.* (2007) point out that improving water use efficiency in rice is a crucial objective in the face of climate change and increasing water scarcity. These authors propose that the combination of appropriate agronomic practices and the selection of genetic materials with lower RCA can significantly improve crop sustainability. In this study, materials with higher water efficiency were also those with higher yields, suggesting a direct relationship between water use efficiency and yield potential.

CONCLUSION

This study was able to determine that there are genotypes suitable for rainfed conditions in Tabasco, Mexico. In addition, it was corroborated that Tabasco presents ideal climatic conditions for rice crop growth. The results indicate that there are significant

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differences in plant height (PA), number of grains per ear (NGP), grain yield (GY), water productivity (PA) and water conversion efficiency (ECA), which suggests an important genetic variability among the genotypes evaluated. The highest yielding materials (T15, T4 and T16) show favorable agronomic characteristics and could be considered for release as new varieties. The variables PA and ECA are effective tools to evaluate the efficiency of water use in rice, allowing the selection of genotypes with greater sustainability in the face of climate change scenarios. On the other hand, genotype T30 presented the highest grain yield and silver height, in addition to presenting PA of 0.54 kg $m^3$and ECA of 1.98 m^3kg^{-1}. It is recommended to validate the most outstanding genotypes in other rainfed environments and under different agronomic management to confirm their stability and adaptability.

REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. 2006. Evapotranspiración del cultivo: Guías para la determinación de los requerimientos de agua de los cultivos (Paper 56 de la Serie de Riego y Drenaje). Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). Recuperado de https://www.fao.org/4/x0490s/x0490s.pdf

Álvarez, J. C., Tapia, L. M., Hernández, A., Barrios, E. J., and Pardo, S. 2018. Estabilidad productiva de líneas avanzadas de arroz grano largo delgado en Michoacán México. Revista Mexicana de Ciencias Agrícolas 9(3): 629-637. DOI: https://doi.org/10.29312/remexca.v9i3.606

Álvarez-Hernández, Juan Carlos, Tapia-Vargas, Luis Mario, Hernández-Aragón, Leonardo, Tavitas-Fuentes, Leticia, and Apaez-Barrios, Maricela. 2022. Potencial productivo del arroz 'Lombardía FLAR 13' genotipo de grano largo y delgado de la zona arrocera de Michoacán. Revista mexicana de ciencias agrícolas 13(6): 1117-1127. DOI: https://doi.org/10.29312/remexca.v13i6.3037

Barrios-Gómez, E. J., Canul-Ku, J., Hernández-Arenas, M., Canales-Islas, E. I., & Patishtan-Pérez, J. 2023. Nayarita 22, variedad de arroz tipo milagro filipino para México. Revista fitotecnia mexicana 46(2): 211-213.

Bouman, B. A. M., Humphreys, E., Tuong, T. P., & Barker, R. (2007). Rice and water. Advances in Agronomy, 92, 187–237. https://doi.org/10.1016/S0065-2113(04)92004-4

Centro de Estudios para el Desarrollo Sustentable y la Soberanía Alimentaria (CEDRSSA). 2020. Distribución de granos básicos: Lugar de adquisición o compra. Ciudad de México: Cámara de Diputados.

Estrada, F., Mendoza-Ponce, A., Calderón-Bustamante, O., & Botzen, W. 2022. Impacts and economic costs of climate change on Mexican agriculture. Regional Environmental Change 22(4): 126.

Flores, P. C., and Delgado, F. M. 2021. Evaluación agronómica de seis variedades de arroz (Oryza sativa L.) sembradas en dos épocas bajo riego, en el municipio de San Buenaventura, Bolivia: Pamela Cordero Flores, Fernando Manzaneda Delgado. Revista de Investigación e Innovación Agropecuaria y de Recursos Naturales 8(1): 7-16.

Hernández-Aragón, L., Tavitas-Fuentes, L., and Álvarez-Hernández, J. C. 2023. Origen y características de la diversidad genética del arroz en México. Revista fitotecnia mexicana 46(4): 461-469.

Huang, X., Jang, S., Kim, B., Piao, Z., Redona, E., and Koh, H. J. 2021. Evaluating genotype× environment interactions of yield traits and adaptability in rice cultivars grown under temperate, subtropical and tropical environments. Agriculture 11(6): 558. DOI: https://doi.org/10.3390/agriculture11060558

Hussain, T., Hussain, N., Tahir, M., Raina, A., Ikram, S., Maqbool, S., Fraz Ali, M., & Duangpan, S. 2022. Impacts of drought stress on water use efficiency and grain productivity of rice and utilization of genotypic variability to combat climate change. Agronomy 12(10): 2518. https://doi.org/10.3390/agronomy12102518

Jarin, A. S., Islam, M. M., Rahat, A., Ahmed, S., Ghosh, P., and Murata, Y. 2024. Drought stress tolerance in rice: Physiological and Biochemical Insights. International Journal of Plant Biology 15(3): 692-718. DOI: https://doi.org/10.3390/ijpb15030051

Jiménez, M. B. 2021. Importancia de los factores climáticos en el cultivo de arroz: Importance of climate factors in rice crop. Ciencia y Tecnología Agropecuaria 6(1): 28-34.

Jiménez-Chong, J. A., López-López, R., y Esqueda-Esquivel, V. 2016. Guía para producir arroz en el estado de Tabasco. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Folleto Técnico Numero 82. ISBN: 978-607-37-0454-0. 72 p.

Khan, M. A. R., Mahmud, A., Ghosh, U. K., Hossain, M. S., Siddiqui, M. N., Islam, A. A., ... and Tran, L. S. P. 2023. Exploring the Phenotypic and Genetic Variabilities in Yield and Yield-Related Traits of the Diallel-Crossed F5 Population of Aus Rice. Plants 12(20): 3601. DOI: https://doi.org/10.3390/plants12203601

Li, R., Li, M., Ashraf, U., Liu, S., and Zhang, J. 2019. Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017. Frontiers in plant Science 10: 543. DOI: https://doi.org/10.3389/fpls.2019.00543

Liu, K., Zhang, K., Zhang, Y., Cui, J., Li, Z., Huang, J., and Chen, H. 2024. Optimizing the Total Spikelets Increased Grain Yield in Rice. Agronomy 14(1): 152. DOI: https://doi.org/10.3390/agronomy14010152

Long-ping, Y. U. A. N. 2014. Development of hybrid rice to ensure food security. Rice science 21(1): 1.

López-López, R., Jiménez-Chong, J. A., Hernández-Aragón, L., & Inzunza Ibarra, M. A. 2018. Water productivity of rice genotypes with irrigation and drainage. Irrigation and Drainage 67(4): 508-515.

Lu, Y., Chuan, M., Wang, H., Chen, R., Tao, T., Zhou, Y., and Yang, Z. 2022. Genetic and molecular factors in determining grain number per panicle of rice. Frontiers in Plant Science 13: 964246. DOI: https://doi.org/10.3389/fpls.2022.964246

Mongiano, G., Titone, P., Pagnoncelli, S., Sacco, D., Tamborini, L., Pilu, R., and Bregaglio, S. 2020. Phenotypic variability in Italian rice germplasm. European Journal of Agronomy 120: 126131. DOI: https://doi.org/10.48550/arXiv.2007.15117

Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). 2023. FAOSTAT. Base de datos, consultada el 13 de julio de 2024 en https://www.fao.org/faostat/es/#data/QCL

R Core Team. 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

Salgado-Velázquez, S., Olvera-Rincón, F., Ramos-López, D. R., Hernández-Lara, P. U., Inurreta-Aguirre, H. D., & Palma-Cancino, D. J. 2025. EcoCrop model approach for agroclimatic suitability of rice (Oryza sativa L.) cultivation. Agro Productividad.

Secretaría de Economía (SE). 2021. Sistema de información arancelaria vía internet. SIAVI 5.0. Secretaría de Economía. Ciudad de México. http://www.economia-snci.gob.mx/ (Abril 2021).

Shi, J., Zhou, X. G., Yan, Z., Tabien, R. E., Wilson, L. T., and Wang, L. 2021. Hybrid rice outperforms inbred rice in resistance to sheath blight and narrow brown leaf spot. Plant Disease 105(10): 2981-2989. DOI: https://doi.org/10.1094/PDIS-11-20-2391-RE

Wehbe, M., Jobbágy, E. G., Nosetto, M. D., Marchesini, V. A., and Di Bella, C. M. 2020. Runoff response of a small agricultural basin in the Argentine Pampas under dry and wet conditions. Hydrological Processes, 34(4): 908–924. DOI: https://doi.org/10.1002/hyp.13782

Xu, Y., Chu, C., and Yao, S. 2021. The impact of high-temperature stress on rice: Challenges and solutions. The Crop Journal 9(5): 963-976. DOI: https://doi.org/10.1016/j.cj.2021.02.011

Yamano, T., Arouna, A., Labarta, R. A., Huelgas, Z. M., and Mohanty, S. 2016. Adoption and impacts of international rice research technologies. Global Food Security 8: 1-8.

Yang, X., Wang, B., Chen, L., Li, P., & Cao, C. 2019. The different influences of drought stress at the flowering stage on rice physiological traits, grain yield, and quality. Scientific Reports 9(1): 3742. https://doi.org/10.1038/s41598-019-40161-0

Zhang, Y., Zhao, X., Liu, F., Zhu, L., and Yu, H. 2023. Effect of different water stress on growth index and yield of semi-late rice. Environmental Sciences Proceedings 25(1): 84. DOI: https://doi.org/10.3390/ECWS-7-14318

Zhao, Y., Xiao, D., Bai, H., Liu, D. L., Tang, J., Qi, Y., & Shen, Y. 2022. Climate Change Impact on Yield and Water Use of Rice–Wheat Rotation System in the Huang-Huai-Hai Plain, China. Biology 2022 11: 1265.