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Agronomic Evaluation of Castor Bean Cultivation (*Ricinus communis* L.) Under Soil Moisture-Limiting Conditions

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ABSTRACT

Objective: To assess yield and growth responses of castor bean collections under soil moisture-restricted conditions.

Design/methodology/approach: The study was conducted in the municipality of Salinas de Hidalgo, San Luis Potosí. Twenty castor bean collections were evaluated under rainfed conditions and irrigation at 50% of crop evapotranspiration, with treatments arranged in randomized blocks.

Results: Significant differences (α=0.05) between collections were observed for variables such as stem diameter, plant height, number of clusters per plant, number of fruits per cluster, 100-seed weight, and aerial biomass. Regarding soil moisture levels, variables including stem diameter, plant height, number of branches, number of leaves, number of clusters, number of fruits per cluster, 100-seed weight, seed yield, and aerial biomass showed significant differences (α=0.05).

Limitations on study/implications: The results are based on a single production cycle.

Findings/conclusions: The Calvillo and Encarnación de Díaz collections showed the highest seed yields under rainfed conditions, with 385 and 326.7 g/plant, respectively, while the Luis Moya collection exhibited the highest yield under irrigation, with 680.7 g/plant. Seed yield was influenced solely by soil moisture, independent of collection origin. Collections under the most restrictive soil moisture condition (rainfed) flowered and fruited slightly earlier.

Keywords: Rainfed, biomass, yield.

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INTRODUCTION

Population growth, increasing energy demands, environmental changes, and the depletion of fossil fuels —as well as the growing difficulty in accessing fossil fuel reserves— have highlighted the need for society to seek alternative energy sources. Various countries have channeled efforts and public policies in this direction, exploring alternatives for energy generation for both domestic consumption and export (SAGARPA, 2009).

Mexico, with its great biodiversity and favorable climatic and geographic conditions, is a country rich in natural resources suitable for bioenergy production, which could enable it to achieve energy autonomy and support the development of the biofuel industry (ASA, 2014). One of these products is biodiesel, which has garnered considerable interest due to its beneficial properties (Vyas, 2010; Moreira *et al.*, 2022). Several bioenergy crops can be used for biodiesel production, including castor bean (*Ricinus communis* L.).

Castor bean is highly adaptable to diverse climatic conditions, with drought resistance being one of its most notable characteristics. However, to achieve high seed yields, it requires a minimum annual rainfall of 600 mm. The crop is susceptible to high relative humidity during the flowering and fruiting stages, which can lead to increased disease incidence. Excessive soil moisture also negatively affects its development. The ideal average temperature range for castor bean cultivation is 20 to 30 °C. The plant does not tolerate frost, and production can be impacted at temperatures above 38 °C. It thrives in deep, medium- to high-fertility soils that are loose, permeable, well-aerated, well-drained, with moderate to high nutrient levels, and a pH above 5.5 (Mazzani, 2007; Díaz-López *et al.*, 2020).

The oil extracted from castor bean can be used as a biofuel, which has increased interest in this plant (Cardona *et al.*, 2009). This biofuel may contribute to reducing petroleum-based fuel consumption, thereby decreasing negative environmental impacts (Sepúlveda, 2012). Additionally, cultivating castor bean presents an opportunity for development in degraded areas, enabling viable activities on currently unproductive lands (Mazzani, 2007; Díaz-López *et al.*, 2020). This plant also has applications in the production of medicines, cosmetics, plastics, fuel additives, and biopolymers, among other uses (Cardona *et al.*, 2009; Rocha *et al.*, 2022; Singh *et al.*, 2023).

Given castor bean's adaptability and the need to generate theoretical and practical research accessible to rural communities in the San Luis Potosí-Zacatecas Highlands, the objective of this study was to evaluate the performance of 20 castor bean collections under two soil moisture-limiting conditions. The agronomic evaluation considered morphological variables (plant height, stem diameter, number of branches, and number of leaves) and yield components (seed weight and number of clusters) to identify the best collections for potential use in future castor bean breeding programs.

MATERIALS AND METHODS

Castor Bean Collections and Experiment Site Location

The castor bean collections evaluated in this study originate from four states within Mexico (Table 1). The experiment was conducted in the locality of Diego Martín (22° 43.875' N, 101° 42.6825' W, 2096 m.a.s.l.), approximately 10 kilometers north of the town center of Salinas de Hidalgo, San Luis Potosí.

Treatments and Experimental Design

Two soil moisture conditions were applied. Treatment one (T1) involved irrigation at 50% of crop evapotranspiration (ETc). Treatment two (T2) involved rainfed conditions, with a recorded rainfall of 390.8 mm during the crop cycle.

Table 1. Geographic Distribution of Castor Bean Collections.

Sample No.	Estate	Municipality	Community	Altitude (amsl)
1	San Luis Potosí	Ciudad del Maíz	Francia Chica	1851
2	San Luis Potosí	Moctezuma	Moctezuma	2063
3	San Luis Potosí	Ciudad del Maíz	San Antonio	2003
4	San Luis Potosí	Capulines	Capulines	1830
5	San Luis Potosí	Mexquitic	Milpillas	1728
6	San Luis Potosí	Mexquitic	Las Moras	1773
7	San Luis Potosí	Venado	Venado	2083
8	San Luis Potosí	Mexquitic	Corte Primero	1955
9	San Luis Potosí	Salinas	Salinas	2083
10	San Luis Potosí	Mexquitic	Rancheria Guadalupe	1349
11	Aguascalientes	Tepezala	Tepezala	1851
12	Aguascalientes	San José de Gracia	San José de Gracia	2095
13	Aguascalientes	Aguascalientes	Fraccionamiento Soledad	1819
14	Aguascalientes	Calvillo	Calvillo	1936
15	Jalisco	Encarnación de Díaz	Encarnación de Díaz	1811
16	Jalisco	Villa Hidalgo	Villa Hidalgo	1920
17	Jalisco	Encarnación de Díaz	Tecuan	1971
18	Zacatecas	Orito	Orito	2399
19	Zacatecas	Noria	Noria	2040
20	Zacatecas	Luis Moya	Luis Moya	1971

The 20 collections under rainfed conditions were randomly assigned in blocks within one plot, while those under irrigation were arranged in another plot, with each collection replicated three times. Thus, each treatment comprised 60 experimental units (20 collections and 3 replications = 60 experimental units), with each unit consisting of four plants.

Planting

Planting was conducted in 2 kg plastic pots using a mix of sand, volcanic soil, and coconut fiber, with each substrate constituting 33.3% of the total. Seeds were sown at a depth of 2.5 cm, with daily morning watering for six weeks.

Land Preparation and Transplanting

In a 2,300 m^2 plot, soil cleaning and tillage were carried out to a depth of approximately 50 cm using a chisel plow.

Castor bean seedlings were transplanted 46 days after planting. Prior to transplanting, each seedling received 3 liters of water, with an additional 2 liters applied per plant after transplanting was completed. Plants were spaced 2 m apart in rows 1.5 m apart, resulting in a population density of 3,333 plants per hectare.

Cultural Practices and Irrigation

Throughout the crop development, pest control and weed removal were conducted. Half of the plants received supplemental water in addition to rainfall, delivered through a drip irrigation system. Crop evapotranspiration was estimated using the Penman-Monteith equation, with castor bean crop coefficients (Shuba *et al.*, 2006) and data from a nearby meteorological station. Crop evapotranspiration (ETc) was calculated as:

$$ETc = ETo \bullet Kc$$

where: ETc is crop evapotranspiration; ETo is reference evapotranspiration and Kc is the crop coefficient for castor bean.

Evaluated Variables

a) Phenological Variables: Emergence (days from sowing to full exposure of cotyledons), flowering (days from sowing to the appearance of the first floral cluster), and physiological maturity (days from floral cluster emergence until 50% of the fruits in the clusters changed from green to brown).

b) Growth Variables: Stem diameter (measured at the stem base), plant height (from the stem base to the plant apex), number of branches, and number of leaves. These variables were measured biweekly, with one plant per experimental unit selected.

c) Production Variables: Number of clusters (panicles) per plant, number of fruits per cluster, number of seeds per fruit (capsules), and weight of 100 seeds. Fresh and dry biomass weights were also determined to estimate moisture content and produced biomass.

Harvest, Drying, and Biomass Determination

For dehiscent castor bean plants, clusters were harvested when 50% of the fruits changed color from bright green to dark green or brown. For indehiscent collections, fruits were harvested when they reached a brown color. The clusters and aerial biomass were transported to a glass greenhouse for drying, with clusters placed vertically in paper bags to allow sunlight penetration to the bag's base for uniform drying of plant material. The clusters were then placed in an oven at 30 °C for 72 hours to reach a 10% moisture level, while the remaining aerial biomass was dried at 70 °C for 72 hours.

Dry matter weight was determined using an electronic scale with a 10 kg capacity, and a precision balance was used to measure the weight of 100 seeds.

RESULTS AND DISCUSSION

Tables 2 and 3 present the average values for the variables days to fruit maturity, number of fruits per cluster, weight of 100 seeds, seed yield, and aerial biomass for the 20 castor bean collections under rainfed (Table 2) and irrigated (Table 3) conditions, along with each variable's measure of dispersion (SD=standard deviation). The collections are ordered according to the mean seed yield. The tables show that the collections with the highest yield values differed between rainfed and irrigated conditions; Calvillo had the highest yield under rainfed conditions, while the Luis Moya collection showed the highest yield under irrigation.

Phenological Variables

The variables days to seedling emergence, days to flowering, and days to fruit maturity for the 20 castor bean collections under both soil moisture conditions showed no significant differences ($\alpha=0.05$). However, some general differences in mean values were observed; for instance, the Moctezuma and Venado collections were the earliest to mature under rainfed conditions.

Growth Variables

Only stem diameter and plant height ($\alpha=0.05$) showed significant differences among the 20 collections (Figures 1 and 2). Figure 1 shows that the Luis Moya, Zac. collection recorded the largest stem diameter (4.5 cm) under irrigation, while the Salinas, S.L.P. collection had the largest diameter (3.8 cm) under rainfed conditions. The Tepezalá, Ags. collection displayed the smallest stem diameter (1.8 cm). These differences in stem diameter and plant height appeared early in the crop's development, specifically from the second

Table 2. Recorded Variables for 20 Castor Bean Collections Under Rainfed Conditions.

Community	Days to fruit maturity		Fruits per cluster		Weight of 100 seeds (g)		Seed yield (g/plant)		Biomass above ground (g/plant)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Calvillo, Ags.	190	2.65	29	9.8	29.7	2.04	385	437.6	366.6	390
Encarnación de Díaz, Jal.	196	12.7	62	34.7	29.2	2.14	326.7	259.7	455	296
Corte Primero, SLP.	200.5	7.78	64.3	48.3	16.38	2.1	189	195.6	233.3	242
Salinas, SLP.	206	0	36.6	3.7	27.5	0	161.8	90.7	873.3	770
Fracc. Soledad, Ags.	198.6	11.8	27	3.6	21.2	2.77	142.7	20.4	250	106
Villa Hidalgo, Jal.	197.6	7.37	25.6	12.6	25.7	2.35	132.4	107.6	136.6	94
Francia Chica, SLP.	205	0	79	54.0	16.59	1.61	123.4	97.1	368.3	154
Orito, Zac.	205	0	97.6	31.5	11.23	0.5	122.1	98.8	153.3	88
Luis Moya, Zac.	200	7.07	45.6	18.1	18.56	0.45	121.5	110.8	310	242
Moctezuma, SLP.	189.3	14.6	42.3	20.6	14.3	1.08	115.7	118	171.6	145
Tecuán, Jal.	194.5	13.4	84.5	28.9	11.24	1.42	114.4	70.7	175	86
Venado, SLP.	187.3	16.6	26.6	3.5	20.5	2.41	110.7	66.3	226.6	85
San José de Gracia, Ags.	200.3	7.37	70.3	22.5	14.8	1.51	94.8	34.5	170	48
Noria, Zac.	204.5	0.71	63	31.5	11.24	0.77	86	96	236.6	287
Milpillas, SLP.	196	12.7	72.6	15.0	11.22	0.18	73.7	85.7	100	108
Ranchería Guadalupe, SLP.	201	7.81	70.6	6.03	10.23	1.16	59	20.8	95	37
Capulines, SLP.	205.5	0.71	44.6	33.3	8.71	0.65	52.4	55.8	140	102
Tepezalá, Ags.	192	9.9	70.6	62.9	10.1	0.87	51.6	40.3	91.6	50
San Antonio, SLP.	205.6	0.58	41.3	22.9	16.89	0.3	32.2	19.8	166.6	83
Las Moras, SLP.	205.3	0.58	33	20	16.86	1.5	29.8	21	100	52

Table 3. Recorded Variables for 20 Castor Bean Collections Under Irrigated Conditions.

Community	Days to fruit maturity		Fruits per cluster		Weight of 100 seeds (g)		Seed yield (g/plant)		Biomass above ground (g/plant)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Luis Moya, Zac.	201	7.8	77.3	26.6	24.5	1.01	680.7	344.5	935	452
Venado, SLP.	200	8.3	63.3	29.5	20.1	2.01	433.4	529.9	673	579
Francia Chica, SLP.	199	9.9	96.3	17.2	22.8	2.7	371.7	290.2	558	307
Ranchería Guadalupe, SLP.	194	9.07	77.3	19.5	11.6	0.36	278.2	242.5	390	305
Villa Hidalgo, Jal.	195	14.1	34.6	3.06	22.49	1.67	275.6	145.1	528	230
Moctezuma, SLP.	193	10.1	50.6	15.2	17.8	0.58	271.5	219.4	555	384
Fracc. Soledad, Ags.	191	12.1	28.6	9.45	24.05	1.31	235	188	713	488
Calvillo, Ags.	197	11.9	23	4.36	30.7	2.52	229.8	152.8	221	100
Orito, Zac.	185	3.21	74.6	18.8	12.7	0.68	226.6	150.8	351	149
Capulines, SLP.	205	0.58	74	8.54	12.4	0.21	223	76.8	576	195
Milpillas, SLP.	191	12	87.3	52.6	10.7	0.42	193.1	110.3	300	229
Corte Primero, SLP.	195	8.8	81	22.3	13.9	1.68	191	264.2	228	231
Las Moras, SLP.	187	8.6	53.3	17.5	18.5	0.16	171.3	91.3	365	45.8
Tepezalá, Ags.	196	7.8	93.6	13.3	10.1	0.78	166.3	88.5	300	146
Encarnación de Díaz., Jal.	192	14.8	38.6	12.2	28.6	0.15	156.1	119.8	350	285
Tecuán, Jal.	206	0	104.5	9.19	13.6	0	150.8	43.3	420	301
Noria, Zac.	198	13	129	61.1	10.5	0.61	150.6	76.3	338	195
San José de Gracia, Ags.	205	0.58	103	20.2	14.3	0.24	146	21.1	203	60.4
Salinas, SLP.	205	0	40	6.56	32.6	0	145.6	42.5	565	353
San Antonio, SLP.	204	2.65	86.3	33.2	17.8	1.23	128.7	39.4	246	44.8

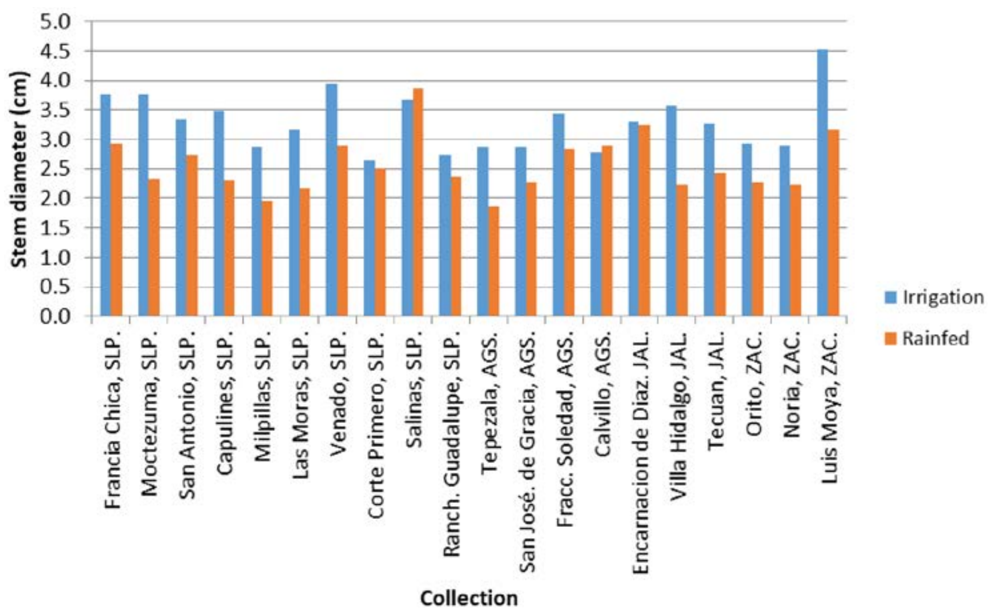

Figure 1. Stem Diameter of 20 Castor Bean Collections Under Two Soil Moisture Conditions.

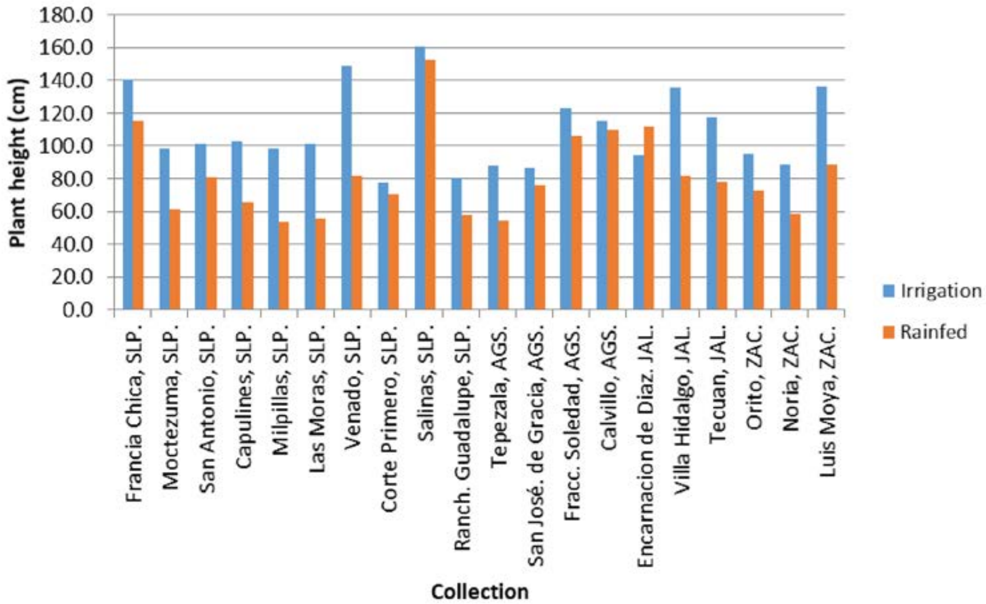

Figure 2. Plant Height of 20 Castor Bean Collections Under Two Soil Moisture Conditions.

sampling onward, and became more pronounced by the final sampling during the crop's developmental stage (sampling No. 11) (Figure 3).

Production Variables

The variables number of clusters per plant, number of fruits per cluster, and weight of 100 seeds showed significant differences ($\alpha=0.05$) both among collections and between soil moisture conditions (Figures 4 and 5). In contrast, yield displayed significant differences only between irrigation and rainfed conditions, not among collections. Additionally, Figure 5 shows that the 100-seed weight values for plants grown under

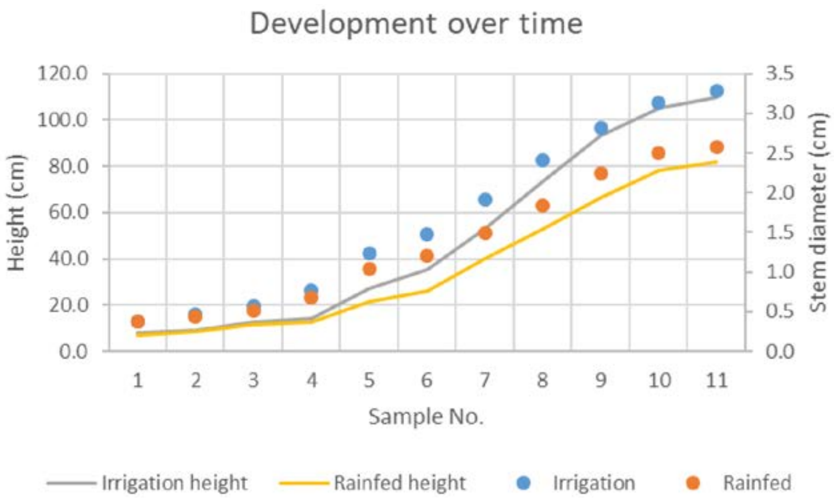

Figure 3. Castor Bean Development (Plant Height and Stem Diameter) Throughout the Crop Cycle Under Two Soil Moisture Conditions.

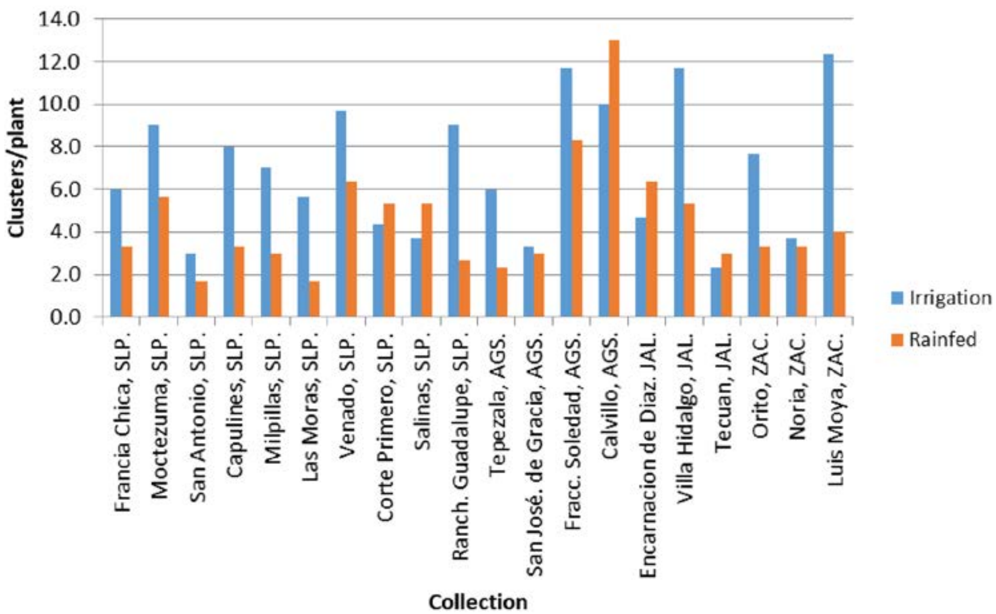

Figure 4. Number of Clusters per Plant for 20 Castor Bean Collections Under Two Soil Moisture Conditions.

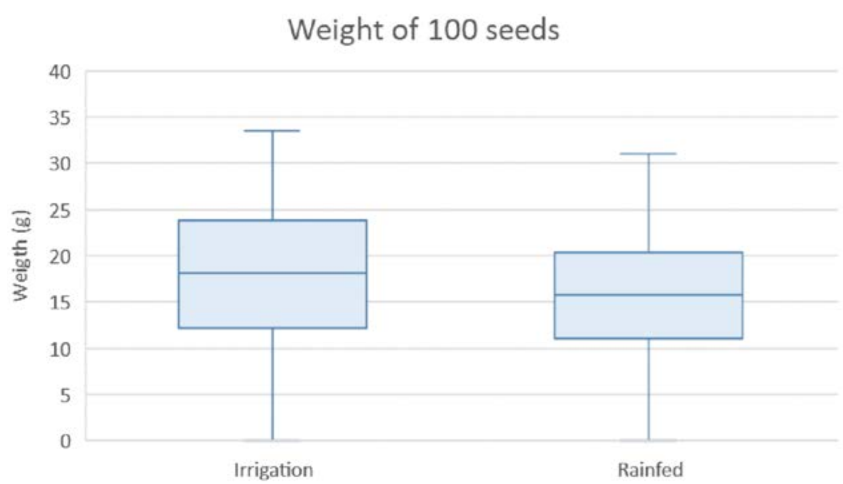

Figure 5. Weight of 100 Seeds for 20 Castor Bean Collections Under Two Soil Moisture Conditions.

rainfed conditions were more closely clustered around the mean and median compared to those grown under irrigation.

Figure 6 shows that collections grown under irrigation conditions had the highest seed yield (1078.0 g/plant for the Luis Moya collection). In contrast, the highest yield under rainfed conditions was not significantly lower, reaching 888.7 g/plant (Calvillo collection). Despite some experimental units showing zero yield, the highest yields under both rainfed and irrigated conditions were much higher than those reported by García-Herrera *et al.* (2019), who recorded 190.4 and 192.7 g/plant for the Calvillo and Venado collections, respectively, for the same site and soil type, but under unrestricted moisture conditions (full

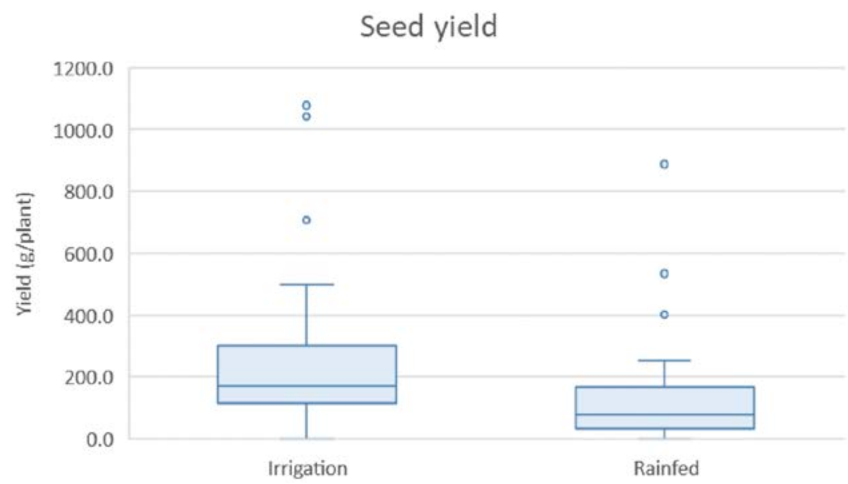

Figure 6. Seed Yield of 20 Castor Bean Collections Under Two Soil Moisture Conditions.

irrigation). Figure 6 also indicates that the yield of collections under irrigation exhibited slightly greater variation compared to those under rainfed conditions.

CONCLUSIONS

No single collection showed the highest values across all evaluated variables. Both the origin of the collection and soil moisture influenced the growth of the evaluated castor bean collections. Seed yield was affected only by soil moisture and not by the origin of the collection. The Calvillo and Encarnación de Díaz collections achieved the highest seed yields, attributed to the number of branches, number of fruits per cluster, and weight of 100 seeds. Collections grown under the most restrictive soil moisture conditions (rainfed) showed slightly earlier flowering and fruit maturation. Aerial biomass is considered an important variable due to its high production; the Salinas collection had the highest aerial biomass production, though it did not produce a high seed yield. Cultivating bioenergy plantations should be considered a productive option for farmers with marginal or idle lands.

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