Scientific Paper

Performance of variability in provenances of *Jatropha curcas* L.

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Abstract

Objective: To characterize different provenances of *Jatropha curcas* L., introduced and collected, through morphoagronomic indicators, in order to select those with the best performance.

Materials and Methods: The study was conducted during one year (2019) in areas of the Pastures and Forages Research Station Indio Hatuey. The work was done with plant material from Paraguay, Ecuador and eastern Cuba. The different *Jatropha curcas* L. provenances were propagated by seeds. The indicators height, number of branches, stem diameter, quantity of racemes and their length, quantity and length of inflorescences, quantity of fruits and their sizes, were measured, among other variables. The data were processed through the principal component (PCA), cluster and correlation analyses.

Results: Of the variability, 96,8 % was explained through four components. The fruit quantity, length and width, quantity of seeds and their sizes, as well as quantity of inflorescences and stem diameter were the indicators with which 55,6 % of the variability was explained in the first two components. Five groups were formed. The second was the one with the best performance in six of the evaluated indicators.

Conclusions: There is variability for the evaluated morphoagronomic traits. The provenance Ecuador 2 was the one with the best performance in six of the evaluated indicators. It was followed by Paraguay 2 in four indicators, for which both were selected and turned out to be promising for their study in future breeding programs.

Keywords: germplasm, indicators, selection

Introduction

Jatropha curcas L. is a perennial, deciduous, succulent stem shrub, belonging to the family *Euphorbiaceae* (Tsuchimoto, 2017). It grows under varied climate conditions, although it develops better in the tropics, where the mean temperatures vary between 20 and 28 ºC (Laviola *et al*., 2017). In the world a large diversity of uses has been described for the different parts of this plant. It has recently gained importance, because its oil, which is extracted from the seeds, has great possibilities to be utilized as raw material in the elaboration of biodiesel (Borah *et al*., 2018). However, in spite of the different potential uses of this crop, the establishment of commercial *J. curcas* plantations in several countries has been limited by problems related to the high yield variability among plants and the attack of potentially pest insects and diseases, among others (Laviola *et al*., 2017). This proves the little knowledge there is about this plant, which is still in a domestication process. Thus, it is required to select individuals with outstanding characteristics to integrate them in breeding programs. Anggraeni *et al*. (2018) state that the agronomic characterization of different agricultural crops allows to know the constitution and functioning of plant components. In order to incorporate *J. curcas* to commercial productive systems, it is necessary to have genetic materials with high yields of fruits, seeds and oil, so that the agroindustrial demand for biodiesel production can be supplied. That is why the identification of genetic variability in the germplasm banks of *Jatropha* and reproductive populations is an important step that provides information about the future of the breeding programs of the species, and helps identify collections with high genetic variability that can be researched for future studies (Kumar and Das, 2018). Due to the above-exposed facts, the objective of the research was to characterize the introduced and collected *J. curcas* provenances through morphoagronomic indicators, in order to select the ones with the best performance.

Materials and Methods

Study area. The study was conducted during one year (2019), in areas of the Pastures and Forages

Received: 12/01/2022
Accepted: 30/05/2022

How to cite a paper: Ibañez-Cossío, Rosa de la Caridad; Wencomo-Cárdenas, Hilda Beatriz; Morales-Querol, Dariel & Cáceres-Amores Julia Cecilia. Performance of variability in provenances of *Jatropha curcas* L. *Pastos y Forrajes*. 45:eI19, 2022

Research Station Indio Hatuey, located at 22º 48' and 7'' North latitude and 79º 32' and 2'' West longitude, at an altitude of 19,9 m.a.s.l. in the Perico municipality, Matanzas province, Cuba (ACC, 1989). The experiment was carried out on a flat-topography soil, with slope from 0,5 to 1,0 %, classified by Hernández-Jiménez *et al.* (2015) as lixiviated Ferralitic Red, of fast desiccation, clayey and deep on limestone.

Climate characteristics. The monthly records that indicate the performance of the most important climate variables were obtained from the meteorological station, located in areas of the institution (fig. 1). It could be observed that the highest mean temperature (27,1 ºC) was recorded in July; while the lowest one occurred in January. The highest rainfall occurred in May (368,1).

Plant material. The work was done with introduced plant material, identified with a key (table 1) and with two provenances of eastern Cuba (Guantánamo). The material was propagated by seed.

Experimental design. The experiment was established according to a complete randomized experimental design. Each plant was considered a replica. After being sown in nursery, at a distance of 3 m between rows x 2 m between plants, they were transplanted to the field. The only management practice was periodic weed control, which was done manually.

Evaluated morphological variables. Data were taken from the plants using the descriptors indicated by Avendaño and Zamarripa (2012) and the *Jatropha* spp Network, (SAGARPA-SNICS, 2014). The number of fruits (NF) per plant was counted and the fruit length (FL), width (FW) and thickness (FT) were measured (Laviola and Macedo, 2009), as well as the quantity of seeds per fruit. The latter were sampled with weekly frequency.

Floral morphological variables. Five inflorescences were sampled per plant of each provenance. The variable inflorescence length was measured, from the initial base of the branch with the inflorescence

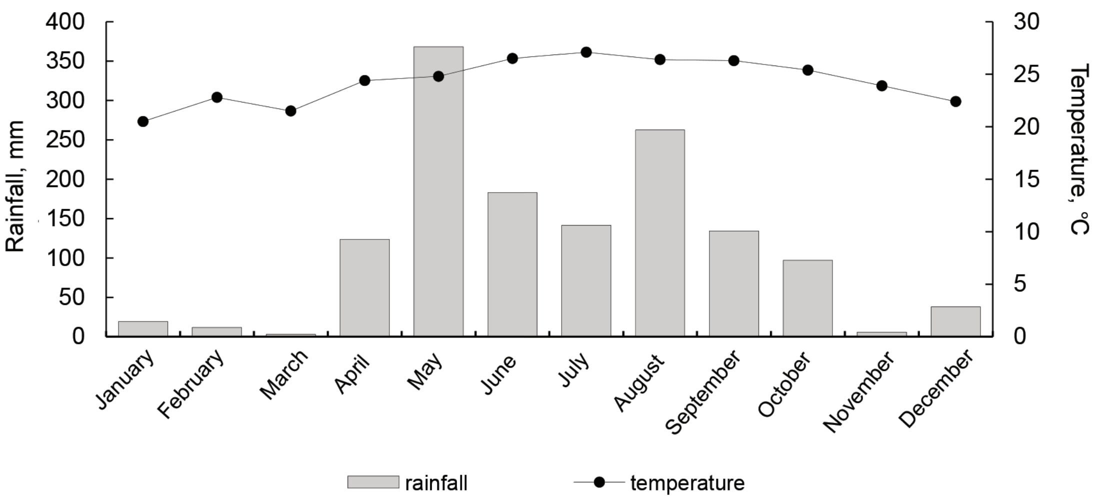

Figure 1. Performance of the climate variables during the experimental period.

Table 1. Utilized plant material.

Rows	Key
I	Paraguay 1
II	Paraguay 2
III	IMIAS-2
III	Ecuador 1
IV	IMIAS-1
IV	Ecuador 2

to the union of the branchlet, for which a graduated ruler was used. The number of branchlets with flowers present in each inflorescence was also recorded.

The variable plant height (PH) was measured, from the basis of the stem to the apex of the central stem, with a metric tape, at 30 and 60 days. The stem diameter or thickness (SD) was determined with a caliper, 10 cm over the mean soil level. The total number of branches was also recorded in each of the sampled plants (Hernández-Verdugo *et al*., 2012; Sosa-Segura *et al*., 2012).

Pests and diseases. The percentage of diseases in each one of the evaluated trees (infestation produced by fungi and/or viruses in the whole plant) and the percentage of damage caused by phytophagous insects were also estimated. For such purpose, a six-value scale, proposed by CNSV (2005) was used. A scale of four degrees was also used: 0 (immune), 1 (resistant), 2 (tolerant) and 3 (susceptible). To each one of these four degrees, the following lesion ranges correspond:

Degree	Range of lesions, %
0	0 to 1 (immune)
1	2 to 10 (resistant)
2	11 to 20 (tolerant)
3	> 20 (susceptible)

Statistical analysis. For the data processing, descriptive statistics was used for the variables number and length of inflorescences and of flower racemes that produce fruits. A principal component analysis (PCA) was also carried out, in which those components that showed eigenvalues greater than 1 and sum or preponderance factor higher than 0,70 (Morrison, 1967) were taken as analysis criterion. Cluster analysis was applied for the grouping and selection of provenances, using the Euclidean distance as a similarity index, based on the PCA results (Torres *et al*., 2008). The stadigraphs mean and standard deviation were determined for the analyzed variables. In addition, correlation analysis was used to find the interrelation among the variables. All the above-mentioned analyses were performed using the statistical program SPSS®, version 22.0 for Microsoft® Windows®.

Results and Discussion

Figure 2 shows the performance of the inflorescence number and length in the *J. curcas* plants. Regarding length, there were no significant differences, but they did exist for the indicator number of inflorescences.

The provenances of higher number of inflorescences were Paraguay 1 and IMIAS-1 (between which there were no significant differences). IMIAS-2 and Ecuador 2 (between which there were no differences) were the ones with the lowest number of inflorescences. Hernández (2012) in her study of floral biology of non-toxic *Jatropha* accessions reported similar results, as well as Divakara (2017) in the evaluation of the variability and divergence of a *J. curcas* germplasm under *ex situ* conditions.

Table 2 shows the results of the principal component analysis. The accumulated variance in the first four components was 96,82 %. The indicators that best explained the variance in the first component

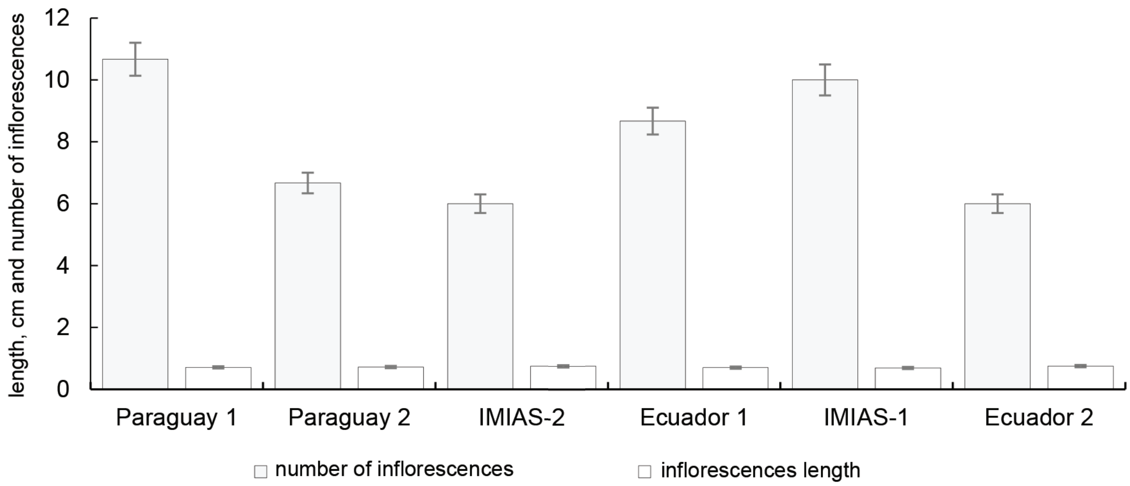

Figure 2. Performance of number and length of inflorescences in *J. curcas*.

Table 2. PCA results and relation among the evaluated indicators.

Indicator	Principal components			
	PC_1	PC_2	PC_3	PC_4
Height, m	0,42	0,02	0,89	-0,15
Number of branches	0,29	0,28	0,86	0,32
Stem diameter, mm	0,96	0,13	0,14	-0,19
Quantity of racemes	-0,27	-0,30	0,39	-0,82
Raceme length, mm	0,06	0,28	-0,03	0,92
Branchlet length, mm	-0,07	-0,25	-0,85	0,45
Quantity of inflorescences	0,91	0,31	-0,22	0,08
Inflorescence length, mm	0,04	-0,06	-0,04	0,97
Quantity of fruits	0,94	-0,09	0,09	0,28
Fruit length, mm	-0,73	-0,59	-0,12	-0,20
Fruit width, mm	-0,40	-0,90	-0,01	0,04
Fruit thickness, mm	-0,03	0,94	0,09	0,10
Quantity of seeds	-0,51	-0,28	0,75	-0,22
Seed length, mm	0,86	0,08	0,48	0,07
Seed width, mm	0,26	0,83	0,14	0,47
Seed thickness, mm	0,86	0,40	0,18	0,21
Eigenvalue	5,48	3,42	3,34	3,26
Variance, %	34,24	21,35	20,86	20,38
Cumulative, %	34,24	55,59	76,44	96,82

(34,24 %) were diameter, quantity of fruit inflorescences and their length (negatively), just like seed length and thickness. The second component extracted a variance of 21,35 %, explained by fruit width (negatively), thickness and seed width. The formation of the third component was influenced by height, number of branches, branchlet length (negatively) and quantity, which explained 20,86 % of the variance. In the fourth component, 20,38 % of the variance was extracted, which was manifested by the quantity of racemes (negatively) and their length, as well as by inflorescence length.

Although the variance value of the first component (34,24) was low, this analysis is valid, because each one of the selected components had eigenvalue higher than 1. According to the criteria expressed by Kaiser (1960), this assumes considering a factor that improves the variance provided at the beginning for each variable alone. In addition, this proves the complexity of the correlations among indicators; that is, there was high variation among the plant traits, which was also related to high morphological diversity, because each one of them may have a different proper determinant in productivity (Peixoto *et al*., 2017).

When considering the importance of the relation of the indicators that made up the first two components, it can be stated that *J. curcas* is a plant of low water requirement which, under conditions of extreme drought, loses its leaves as mechanism to preserve humidity in its tissues. This might be a factor that induces sprouting in some of its species, because it reduces water loss by the plant, which would lead to branch rehydration and production of new leaves (Wencomo-Cárdenas *et al*., 2021). Afterwards, with the emergence of leaves by a translocation process, higher drainage occurs. This increases growth and provides leafiness and the emergence of inflorescences. Later flowering season follows, one of the main phenological stages, related to oil production in this crop, because the number of female flowers and their adequate pollination determine how many fruits and seeds will be developed.

Mulato-Sepúlveda (2018) states that the flowering periods coincide with the phases of higher vegetative growth. This result is extremely transcendental from the point of view of crop science. During the growth/flowering period, plant management is important to favor high growth rate, because the number of inflorescences like the number of female flowers is, in fact, one of the main factors that determine yield. Meanwhile, the determination of the number of inflorescences per plant and the number of female flowers depends on environmental and genetic factors. The flowering and determination of the flower type are influenced by the occurrence of low temperatures and high rainfall, and up to two flowering peaks per year. the above-cited authors also confirm a high number of female flowers in *J. curcas*, and refer that higher branching and adequate pollination are the main factors that benefit seed production and oil yield.

Mulato-Sepúlveda (2018) conducted studies that proved that cross-pollination flowers have a significantly high fruit production. The flowers exposed to single and multiple visits by bees, produce significantly more fruits than the ones that were not visited, which indicates that bees are efficacious pollinators. Likewise, Mulato-Sepúlveda (2018) reports that after flowering plants begin the fructification stage. The number of fruits per plant depends, ultimately, on the number of inflorescences and female flowers, factors that determine their productivity, because the plants with higher number of flowers tend to have higher yield.

Mulato-Sepúlveda (2018) indicates that oil quality and quantity in the *J. curcas* seeds depend

Table 3. Distribution of the individuals, mean and standard deviation, according to the cluster analysis.

Indicator	Group I		Group II		Group III		Group IV		Group V	
	X	SD	X	SD	X	SD	X	SD	X	SD
Height, m	150,83	2,70	138,62	-	125,71	-	120,48	-	136,13	-
Number of branches	7,21	0,11	7,00	-	5,50	-	4,28	-	7,58	-
Stem diameter, mm	45,35	4,80	47,33	-	41,75	-	37,54	-	37,08	-
Quantity of racemes	20,00	0,00	12,00	-	12,00	-	20,00	-	15,00	-
Raceme length, mm	0,70	0,00	0,72	-	0,72	-	0,70	-	0,72	-
Branchlet length, mm	0,70	0,00	0,72	-	0,75	-	0,73	-	0,72	-
Quantity of inflorescences	6,50	2,12	9,00	-	7,00	-	5,00	-	5,00	-
Inflorescence length, mm	0,70	0,00	0,72	-	0,75	-	0,69	-	0,75	-
Quantity of fruits	38,0	19,79	44,00	-	44,00	-	3,00	-	20,00	-
Fruit length, mm	3,54	0,02	3,50	-	3,55	-	3,57	-	3,54	-
Fruit width, mm	4,00	0,02	3,36	-	4,22	-	4,05	-	3,99	-
Fruit thickness, mm	1,09	0,01	1,14	-	1,07	-	1,10	-	1,13	-
Quantity of seeds	52,50	3,53	30,00	-	35,00	-	45,00	-	55,00	-
Seed length, mm	18,48	0,16	18,53	-	18,04	-	17,27	-	17,78	-
Seed width, mm	11,17	0,01	11,86	-	11,15	-	10,99	-	11,55	-
Seed thickness, mm	8,88	0,09	9,30	-	8,80	-	8,35	-	8,63	-

Groups	Quantity	Provenances
I	2	Paraguay 1, Ecuador 1
II	1	Ecuador 2
III	1	Paraguay 2
IV	1	IMIAS-2
V	1	IMIAS-1

on several factors (genetic, physical, physiological, ecological conditions, moisture content, crop fertility and management). According to this author, inherent attributes that determine their germination potential and growth characteristics can be defined. During seed development, the environmental conditions can influence the biosynthesis and accumulation of the mixture of fatty acids present in triacyglycerids (TAG) that form the oil storage within them.

The cluster analysis based on the PCA results allowed the formation of five groups. The provenances belonging to each one of them are shown in table 3, just like the mean and standard deviation of each one of the formed groups. The highest values for the case of stem diameter, quantity of inflorescences and fruits, fruit thickness, seed length, width and thickness, were found in group II, which was made up by provenance Ecuador 2. It was followed by Paraguay 2, which makes up group III, and which has significant values regarding branchlet and inflorescence length, fruit quantity and width.

Group II included the provenance that gathered the largest amount of evaluated indicators with the highest values. It was introduced in the country from a place where the climate conditions are different from those of the evaluation zone. This could indicate that in the populations of this species genotypes can be found whose development occurs rapidly; while others are a little slower. For such reason, independently from the differences that were observed among the indicators, the evident variability in the *J. curcas* population must be pointed out.

Genetic diversity in plant species is a gift for mankind, because it constitutes the basis for selection and later breeding. In this study, the grouping pattern revealed that geographic diversity must not necessarily be related to genetic diversity. This type of diversity could be due to differential adoption, selection criteria, selection pressure and the environment. The above-explained facts indicate that genetic diversity produces higher variety than the geographic one. The trees that were originated in a region were distributed in different groups, suggesting that trees with the same geographic origin could have experienced changes by different traits under selection (Divakara, 2017).

Similar results were reported for this species by Wencomo-Cárdenas *et al*. (2020) in non-toxic accessions from Mexico, who found high and moderate variability respectively, regarding the performance of the evaluated indicators.

Gwafila *et al*. (2019), in studies of morphoagronomic and molecular characterization of a *J. curcas* germplasm in Bostwana, also found significant differences among the accessions, for the qualitative as well as for quantitative indicators. Likewise, Chakrabarty *et al*. (2022) in studies conducted on 45 genotypes in Bangladesh, found significant genetic variation for the 17 evaluated morphoagronomic indicators.

Table 4 shows the results of the correlation analysis among the indicators of the plants and environmental factors due to the importance that is ascribed to the interrelations among the latter and the morphological and productive characteristics of plants.

Strong correlations were found between height and number of branches (0,832), branchlet length (0,865) and seed length (0,795), stem diameter and quantity of inflorescences (0,879), fruit quantity (0,858) and length (-0,769 negatively), seed length (0,886) and thickness (0,847) and temperature (-0,917 negatively), raceme quantity and length (-0,893 negatively) and inflorescence length (-0,773 negatively). There was also correlation between the quantity of seeds (0,717), raceme length and inflorescence length (0,804), quantity of inflorescences and fruit quantity (0,851) and length (-0,871 negatively), as well as among the seed quantity (-0,704 negatively), seed thickness (0,855) and temperature (-0,845 negatively).

Likewise, correlation was recorded between the fruit quantity and length (-0,737 negatively) and seed length (0,846), just like between seed thickness (0,814) and temperature (-0,894 negatively), fruit length and width (0,775), seed length (-0,711 negatively), width (-0,775 negatively) and thickness (-0,877 negatively). There was also correlation between fruit width and thickness (-0,783 negatively), seed width (-0,842 negatively) and seed thickness (-0,723 negatively), as well as between fruit thickness and seed width (0,823), humidity (0,844) and rainfall (0,806), and between seed length, thickness (0,890) and temperature (-0,751 negatively).

Equally, moderate correlations were observed between height and stem diameter (0,554) and seed thickness (0,517); between number of branches and branchlet length (-0,664 negatively), fruit length (-0,554 negatively) and seed length (0,696), as well as between seed width (0,576) and thickness (0,570). Moderate correlations were also recorded

Table 4. Matrix of phenotypical correlations between the evaluated indicators and environmental factors.

Indicator	H	NB	SD	QR	RL	BRL	QI	IL	QF	FL	FW	FT	QS	SL	SW	ST
Height, m	1															
Number of branches	**0,832**	1														
Stem diameter, mm	0,554	0,377	1													
Quantity of racemes	0,334	-0,084	-0,079	1												
Raceme length, mm	-0,098	0,347	-0,106	**-0,893**	1											
Branchlet length, mm	**0,865**	-0,664	-0,295	-0,597	0,335	1										
Quantity of inflores-cences	0,169	0,195	**0,879**	-0,470	0,173	0,099	1									
Inflorescence length, mm	-0,190	-0,287	-0,144	**-0,773**	**0,804**	0,505	0,135	1								
Quantity of fruits	0,415	0,428	**0,858**	-0,403	0,239	0,024	**0,851**	0,352	1							
Fruit length, mm	-0,363	-0,554	**-0,769**	0,462	-0,312	0,178	**-0,871**	-0,243	**-0,737**	1						
Fruit width, mm	-0,220	-0,348	-0,497	0,358	-0,281	0,291	-0,612	0,120	-0,255	**0,775**	1					
Fruit thickness, mm	0,035	0,381	0,100	-0,294	0,273	-0,227	0,291	0,116	-0,025	-0,646	**-0,783**	1				
Quantity of seeds	0,049	0,359	-0,368	**0,717**	-0,388	-0,609	**-0,704**	-0,188	-0,410	0,439	0,480	0,140	1			
Seed length, mm	**0,795**	0,697	**0,886**	-0,137	0,152	-0,466	0,693	0,048	**0,846**	**-0,711**	-0,433	0,058	-0,144	1		
Seed width, mm	0,192	0,576	0,280	-0,651	0,686	-0,141	0,484	0,392	0,303	**-0,775**	**-0,842**	**0,823**	-0,370	0,392	1	
Seed thickness, mm	0,517	0,570	**0,847**	-0,476	0,399	0,229	**0,855**	0,167	**0,814**	**-0,877**	**-0,723**	0,336	-0,502	**0,890**	0,687	1
Temperature	-0,325	-0,115	**-0,917**	0,126	0,138	-0,020	**-0,845**	0,035	**-0,894**	0,578	0,195	0,203	0,458	**-0,751**	-0,009	-0,684
Humidity	-0,111	0,192	0,074	-0,093	-0,042	-0.072	0,257	0,130	0,007	-0,537	-0,444	**0,844**	0,000	-0,099	0,480	0,075
Rainfall	-0,164	0,265	-0,474	-0,181	0,320	-0,111	-0,282	0,268	-0,456	-0,144	-0,333	**0,806**	0,225	-0,386	0,561	-0,182

H: height (m), NB: number of branches, SD: stem diameter (mm), QR: quantity of racemes, RL: raceme length (mm), BRL: branchlet length (mm), QI: quantity of inflorescences, IL: inflorescence length (mm), QF: quantity of fruits, FL: fruit length (mm), FW: fruit width (mm), FT: fruit thickness (mm), QS: quantity of seeds, SL: seed length (mm), SW: seed width (mm), ST: seed thickness (mm) between quantity of racemes (-0,597 negatively) and seed width (-0,651 negatively), raceme length and seed width (0,686), quantity of inflorescences and fruit width (-0,612 negatively) and seed length (0,693). Likewise, there were moderate correlations between fruit length and thickness (-0,646 negatively), temperature (0,578) and relative humidity (-0,537 negatively), seed width and thickness (0,687) and rainfall (0,561) and between seed thickness and temperature (-0,684 negatively).

Correlation establishes the degree of association between plant traits and their attributes, so that these components can form additional criteria for selection in the breeding program. The correlated quantitative traits are of high interest in a breeding program, because the improvement of one trait can cause correlated simultaneous changes in others.

The presence of significant correlations was noted between some of the evaluated indicators with the climate variables (table 4), aspect that indicates according to references by Cárdenas-Travieso *et al*. (2018) how the latter can influence the growth and development and reproduction of *J. curcas* plants. In this regard, it was observed that the quantity of inflorescences per plant was positively correlated with temperature. This might indicate that flowering in *J. curcas* is related to the occurrence of low temperatures. As nights are cooler than days, the decrease of the night temperature can be one of the factors that trigger flowering. Likewise, there is a strong correlation between fruit thickness and humidity, which reached higher values in the period from October to May, considered as rainy. In this season, fruit thickness increases, and according to Membreño-Taleno *et al*. (2022) the growth and reproductive potential of plants are favored.

Associated with temperature, rainfall seems to have a main influence on flowering, because there was a positive correlation between rainfall and quantity of inflorescences per plant. Thus, flowering seems to depend on the increase of both. Taking into consideration that inflorescences are produced in the terminal buds of young branches, the positive correlation can show that rainfall increases after a long period of dry conditions. Plants begin to grow immediately and the sprout of new branches occurs constantly. With that the number of branches of the plants increases as their growth is resumed with rainfall. In addition, it is important to verify how plants perform in terms of height, flowering season, number of inflorescences per plant and quantity of female flowers. According to Mulato-Sepúlveda (2018), these characteristics are essential in the analysis of yield, because the plants that are bigger and show higher growth rate, can produce higher quantity of inflorescences and fruits than smaller plants.

Positive correlation was also found between the quantity of fruits and seed length. The variation in seed size plays an important role in the germination and seedling establishment processes. Valverde and Ávila (2022) state that large seeds tend to increase their viability, germination and emergence rate; likewise, they survive adverse conditions better than small seeds. On the contrary, the latter have the advantage of being able to form a seed bank and evade predation more successfully. Meanwhile, the plants that produce variable seed sizes, in general, show good permanence in their environment.

These results are similar to those found by Araiza-Lizarde *et al*. (2016), who stated that the highest temperatures did not favor the growth of *J. curcas* individuals, unlike rainfall and relative humidity. They are also similar to the ones reported by Cardoso *et al*. (2018) in studies of genetic evaluation and selection of plants of this species.

Conclusions

High variability was observed for the morpho-agronomic traits. In turn, the provenance Ecuador 2 was the one with the best performance in six of the evaluated indicators, followed by Paraguay 2 (four indicators). Thus, both were selected and are promising for their inclusion in future studies related to breeding programs.

Acknowledgements

The authors thank the Projects GEF UNDP "Clean energy technologies for the rural areas in Cuba (Clean Energy-Cuba)" (Bioenergía) and "Technological alternatives for the production of *J. curcas* seed and coproducts, in the development of agroenergetic farms", funded by the Science and Innovation Financial Fund (FONCI, for its initials in Spanish), for facilitating the development of the study.

Conflict of interests

The authors declare that there is no conflict of interests among them.

Authors' contribution

- Rosa de la Caridad Ibañez-Cossío. Carried out the data taking and processing, the manuscript writing and corrections.
- Hilda Beatriz Wencomo-Cárdenas. Participated in the genesis of the idea, in the advisory of the

research, developed the experiment design and setting up, data processing and interpretation.

- Dariel Morales-Querol. Participated in the genesis of the idea, data collection, interpretation, analysis of results, as well as in the manuscript preparation and revision.
- Julia Cecilia Cáceres-Amores. Participated in the sample taking and data collection.

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