Scientific Paper

Morphoagronomic characterization of non-toxic accessions of *Jatropha curcas* L.

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Abstract

Objective: To characterize the morphoagronomic variability of 12 non-toxic *Jatropha curcas* L. accessions, in the experimental field of the College of Postgraduate Studies-Veracruz Campus, in the central region of Veracruz state, Mexico.

Materials and Methods: Six accessions propagated by seeds and six by stakes, established eight years earlier, were taken. The indicators height, number of branches, stem diameter, quantity and length of racemes, quantity and length of inflorescences, quantity of fruits and seeds and their sizes, were measured. The data were processed through principal component analysis, cluster and correlation analysis. Of the variability, 91,65 % was explained through five components.

Results: The quantity, length and width of the fruits, quantity of seeds and their sizes; as well as height, number of branches and racemes and diameter, were the most variable indicators with which 54,17 % of the variability was explained in the first two components. Three groups were formed. Group II was the one with the best performance in 10 of the 15 evaluated indicators. The accessions I-32 and I-65 showed the best performance. The existence of strong and positive correlations between quantity of fruit and seed quantity and length; and moderate between minimum temperature and height, was observed.

Conclusions: High variability was observed with regards to the studied traits; while the degree of affectation by diseases was from moderate to low. The accessions I-32 and I-65 showed the best performance in 10 of the evaluated indicators.

Keywords: agronomic characters, *Jatropha curcas*, oil crops

Introduction

Jatropha curcas L., known as physic nut, is an oil seed plant that originated in tropical America (Tsuchimoto, 2017), which belongs to the family *Euphorbiaceae*, with approximately 188 species, of wide distribution in Central America, the Caribbean, South America, Asia and Africa. According to Laviola *et al*. (2017), it is most likely that it was distributed from the Caribbean by Portuguese sailors to countries of Africa through Cape Verde and Guinea Bissau, as well as nations of Southeast Asia, like Indonesia, Malaysia and Philippines.

At present, *J. curcas* is cultivated for biofuel production (Borah *et al*., 2018) in central and southeast India. Also in Asia, Africa and America studies are conducted about its potentialities for that purpose (Savaliya *et al*., 2015).

J. curcas is considered a multipurpose plant (Zavala, 2016), due to the variety of uses it has. Its plant cover is utilized, in most of India, to protect crops from the damage caused by the animals, because cattle and sheep do not consume it. In this sense, the aqueous extract of the oil from its seeds contains biodegradable toxins, which can be applied as natural insecticide on diverse crops (Laviola *et al*., 2017).

The edible use of *J. curcas* has been documented only in Mexico (Pecina-Quintero *et al*., 2014), in the Quintana Roo and Veracruz states. In the latter, particularly in Totonacapan, it is traditionally used as food (Valdés-Rodríguez *et al*., 2013). In this region, its seeds are used as appetizers, salsas, tamales and in traditional dishes (Martínez-Herrera *et al*., 2012). These materials are considered non-toxic, as they lack phorbol esters. For the case of the territories to the South of the state, its use is very limited, because most plants are toxic (Sukla *et al*., 2015).

In recent years, great attention has been paid to the physiological, agronomic, agroecological and productive characteristics of *J. curcas* (Niestche *et al*., 2015). This characterization considers quantitative and qualitative descriptors (Martín and Montes,

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2015). Some works on several populations of this species have reported low level of genetic variability (Santos *et al*., 2016).

From the above-stated facts, the objective of this study was to characterize the morphoagronomic variability of non-toxic *J. curcas* accessions, propagated by seeds and by stakes and cuttings, established eight years earlier in the experimental field of the College of Postgraduate Studies-Veracruz Campus, in the central region of Veracruz state, Mexico.

Materials and Methods

Study area. The research was conducted in the germplasm bank of non-toxic *J. curcas* L., located in the experimental field of the College of Postgraduate Studies-Veracruz Campus, in the central region of the Veracruz state, Mexico. This facility is located on km 88,5 of the Federal Xalapa-Veracruz highway, Tepetates Colony, Manlio Fabio Altamirano municipality, Veracruz, Paso de Ovejas road. Its geographical location is 19° 11' 8.62'' N and 96° 20' 31.26'' W, at an altitude of 24 m. the climate is of the type Aw (w) (i) g, which corresponds to subhumid rainfall climate in summer. Mean annual rainfall and temperature are 1 239,5 mm and 25 ºC, respectively, with less than 5 % rainfall in winter and temperature fluctuation from 5 to 7 ºC (García, 1988).

Climate characteristics. The temperature data (maximum, medium and minimum), and rainfall were obtained from the Meteorological Station of the College of Postgraduate Studies-Veracruz Campus, from January to September, 2019.

Figure 1 shows the performance of temperatures (maximum, medium and minimum); besides rainfall during the evaluation period (January to September). The maximum temperature was 35,6 ºC, and the minimum, 20,3 ºC.

Vegetative material. Work was done on a plantation of 49 accessions (23 sown by seeds and 26 by stakes), eight years old, planted according to complete randomized design, collected in the Veracruz state. From them, six plants propagated by seeds and six by stakes, were selected, with three repetitions. For the selection the results from research works conducted by García (2015), in which morphological and productive characteristics of these accessions were evaluated, and the studies conducted by Zavala (2016), who did a morphogenetic characterization in their centers of origin, were taken into consideration. Table 1 shows the evaluated accessions.

Experimental design. The experiment was established according to complete randomized block design. Each plant to be sampled was considered a replica. The plants were sown in June, 2011, at a distance of 3 m between rows x 2 m between plants. The only management practice was the periodical control of weeds.

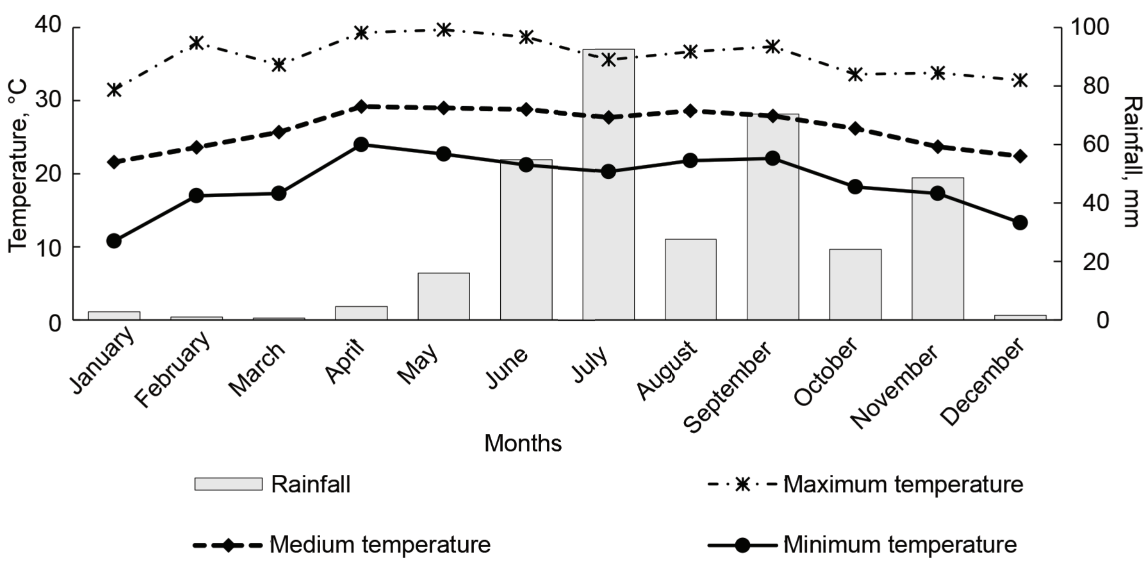

Figure 1. Performance of temperature (maximum, medium and minimum) and rainfall

Table 1. Location of the accessionsof of the Veracruz state, Mexico.

Accessions	Locality	Municipality	Latitude N	Latitude W	Height, m.a.s.l.	Propagation
I-13	Paplanta	Paplanta	20° 27' 28.9''	97° 19' 16.2''	173	stakes
I-18	Insurgentes socialistas	Paplanta	20° 11' 25.5''	97° 15' 53.4''	119	seeds
I-26B	Cementeres	Nautla	20° 10' 38.9''	96° 53' 37.0''	9	seeds
I-32	Tuzamapán	Coatepec	19° 24' 00.7''	96° 52' 05.9''	892	stakes seeds
I-34	Alvarado	Papaloapán	18° 47' 26.1''	95° 45' 31.7''	22	stakes seeds
I-64	Tepetates	Sotavento	19° 11' 39.7''	96° 20' 38.0''	16	seeds
I-65	Tepetates	Sotavento	18° 11' 41.1''	96° 20' 37.2''	16	stakes
I-78	Paso del correo	Totonaca	20° 21' 24.0''	97° 14' 30.0''	39	stakes
I-80	Buenos Aires	Nautla	19° 56' 09.0''	95° 50' 00.0''	321	stakes seeds

Source: Zavala (2016)

Evaluated morphological variables. Data were taken of the plants propagated by seeds and by stakes, using the descriptors indicated by Campuzano (2009), Laviola *et al.* (2009) and by the Network of *Jatropha* spp. (SAGARPA and SNICS, 2014). The variable plant height (PH) was measured from the stem base to the apex, with a ruler graduated in cm. The stem diameter or thickness (SD) was determined with a caliper (mm), at 10 cm over the mean soil level. The total number of branches was obtained by counting the ones of each of the sampled plants. The above-mentioned measurements were carried out in July and September, after the rains.

The number of seeds and their length (mm), quantity of inflorescences and their length (mm) and number of racemes (NRac) and of fruits (NF) per plant, were also quantified. The last ones were weekly sampled. The fruit length (FL), width (FW), and thickness (FT) according to the methodology described by Laviola and Macedo (2009). In addition, the number of seeds per fruit was counted. The seeds were manually extracted from the fruits and once they were dried a sample was randomly taken (50). With a caliper the length, width and thickness (mm) was measured.

Pests and diseases. The percentage of diseases in each one of the evaluated trees (infestation produced by fungi, viruses or both, in the whole plant) and the percentage of damage caused by potentially pest insects, were estimated. A four-degree scale was used:

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

Statistical analysis. The data were processed through a principal component analysis (PCA) (Morrison, 1967). The principal components that showed proper values higher than 1, and sum or preponderance factor higher than 0,70, were taken as analysis criterion (Morrison, 1967). Cluster analysis was applied for the grouping and selection of the accessions, using as similarity index the Euclidian distance, from the results obtained in the PCA (Torres *et al*., 2006). The statigraphs mean and standard deviation were determined for the analyzed variables. In addition, linear correlation analysis was used to know the interrelation among the variables. All the analyses were made through the statistical program SPSS® version 22,0 for Microsoft® Windows®.

Results and Discussion

Table 2 shows the results of the principal component analysis. An accumulated variance of 91,65 % was detected in the first five components. The variables that best explained variance in the first component (34,20 %) were fruit quantity, length and width, besides the quantity of seeds and their dimensions. The second component extracted a variance of 19,96 %, explained by height, number of branches and diameter (the last two ones negatively).

The formation of the third component was influenced by branchlet length, inflorescence quantity and length, which explained 18,91 % of the variance. For the fourth component, 10,68 % of the variance was extracted, supported by raceme length (negatively); while the fifth component was explained by the number of branchlets, and extracted 7,87 % of the variance.

Table 2. Results of the PCA and relation among indicators.

Indicator	Principal components				
	CP_1	CP_2	CP_3	CP_4	CP_5
Height, m	-0,089	**0,708**	-0,189	0,628	-0,027
Number of branches	-0,134	**-0,938**	0,077	-0,111	0,175
Stem diameter, mm	-0,152	**-0,821**	0,121	0,401	-0,138
Number of branchlets	0,059	-0,107	-0,193	0,090	**0,926**
Length of branchlets, mm	0,089	-0,036	**0,902**	-0,193	-0,145
Quantity of inflorescences	0,419	-0,221	**0,739**	-0,236	0,017
Length of inflorescences, mm	-0,012	-0,081	**0,932**	-0,027	-0,126
Number of racemes	0,058	**0,905**	-0,031	0,139	0,009
Raceme length, m	0,291	-0,030	0,302	**-0,762**	-0,169
Quantity of fruits	**0,959**	0,114	0,077	-0,122	0,041
Fruit length, mm	**0,961**	-0,074	0,111	-0,179	0,031
Fruit width, mm	**0,952**	-0,083	0,120	-0,188	0,047
Fruit thickness, mm	0,622	0,497	-0,178	0,128	0,533
Quantity of seeds	**0,933**	0,152	0,015	-0,010	-0,078
Seed length, mm	**0,798**	0,327	0,358	0,246	0,230
Seed width, mm	**0,784**	0,213	-0,499	0,156	0,109
Seed thickness, mm	0,480	0,054	-0,599	0,604	0,080
Proper value	5,81	3,39	3,21	1,81	1,33
Variance, %	34,20	19,96	18,91	10,68	7,87
Cumulative %	34,20	54,17	73,08	83,77	91,65

The variance value of the first component (34,20) was low, which proves the complexity of the correlations among variables; that is, there is high variation among the traits of plants, which is also related to a large morphological diversity, because each one of them might have their own determinant, different in productivity. Nevertheless, this analysis is valid, because each of the selected components had a proper value, higher than 1. According to the criteria expressed by Kaiser (1960), this implies considering a factor that improves the variance provided at the beginning for each variable. Similar results, regarding the variance value, were reported by Yengle-Ruíz (2012) in studies conducted to obtain synthetic indexes of environmental quality, as well as Olivares (2014) in the social-environmental diagnosis of a case study, and López-Roldán and Fachelli (2015), in works of methodology of quantitative social research.

The variables fruit and seed thickness were not included in any of the five components, because the value of the sum or preponderance factor (0,622 and 0,604, respectively) was lower than 0,70. Thus, they could be obviated, when other evaluations are conducted under similar circumstances to the ones in this research.

For the variability corresponding to each indicator to be better related to each axis, in correspondence with this type of analysis, the proper value should be one or higher than one (Philippeau, 1986). This could be proven in this work, in which the variability was well distributed, because such indicator was higher in all cases.

In this regard, the report by Machado (2011) should be considered, who refers that generally fruit and other woody plants have a high degree of variability. This is due to the fact that they are purely heterozygous and allogamous (of crossed pollination), situation that leads to the genetic segregation in the offspring, as occurs in *J. curcas*.

The above-explained facts could indicate that, independently from the edaphoclimatic conditions, populations and, particularly, the *J. curcas* accessions (non-toxic), could express marked variations among individuals for some indicators and could be grouped depending on those variables, which can represent c a positive element in the evaluation and characterization work. This could have been influenced by the interspecific and intraspecific variability of the studied sample, because it was made up by several accessions collected from different environments and planted differently (by seed or by stake). They also vary in a marked way from the morphological point of view, and according to the climate conditions under which the evaluation is conducted. This is the case of the differences that exist with regards to the conditions under which the studies of floral biology, quantification and measurement of floral components and their relation to climate, were developed, carried out by García (2015). This author identified the morphological descriptors related to production in *J. curcas* accessions, collected in different regions of Veracruz state, and propagated by seeds and stakes.

The value reached by the accumulated variance and the proper value of the components, allowed almost all the indicators to be included in the cluster analysis, and thus determine the differentiation or similarity among the accessions. The variables fruit and seed thickness were excepted, because they did not contribute to the expression of variability of the components.

The cluster analysis based on the results of the PCA allowed the formation of three groups. The accessions belonging to each one of them are shown in table 3, just like the mean and standard deviation of each group.

The highest values for the quantity and length of the branchlets and inflorescences, raceme length, fruit number and width as well as seed quantity and sizes, were found in group III. The last one was formed by the accessions I-32 E, I-65 E (plants sown by stakes). It was followed by group II (I-32, I-34, I-18, I-80, I-13E, I-80E and I-78E), regarding the number of branches, stem diameter, quantity of branchlets and fruit length. Regarding the height and quantity of racemes, the highest values corresponded to I, represented by the accessions I-26B, I-64, I-34E.

As can be observed, groups I and II include accessions of plants propagated by seeds and stakes. This could indicate that in the populations of this species genotypes can be found, whose

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

Indicator	Group I		Group II		Group III	
	X	SD	X	SD	X	SD
Height, m	3,3	0,20	2,8	0,18	2,4	0,58
Number of branches	9,3	1,20	12,0	0,48	11,5	1,50
Stem diameter, mm	123,2	6,17	256,7	8,70	187,2	33,25
Quantity of seeds	7,3	1,33	8,0	0,61	8,0	2,00
Branchlet length, mm	0,7	0,00	0,7	0,02	0,7	0,03
Quantity of inflorescences	6,0	1,00	7,3	0,71	9,5	0,50
Inflorescence length, mm	0,7	0,01	0,7	0,01	0,7	0,05
Quantity of branches	18,3	1,66	11,1	02,02	12,0	5,00
Raceme length, mm	0,7	0,03	0,8	0,02	0,8	0,01
Quantit of fruits	36,7	9,26	23,1	6,91	158,0	20,00
Fruit length, mm	2,4	0,08	2,5	0,28	11,4	0,96
Fruit width, mm	1,6	0,20	1,7	0,11	7,3	0,59
Quantity of seeds	62,0	18,90	48,9	23,66	212,0	38,00
Seed length, mm	1,7	0,05	1,7	0,05	2,2	0,45
Seed width, mm	1,1	0,02	1,0	0,02	1,1	0,02

Group	Quantity	Accessions
I	3	I-26B, I-64, I-34E
II	7	I-32, I-34, I-18, I-80, I-13E, I-80E, I-78E
III	2	I-32E, I-65E

E: sown by stakes

development occurs rapidly; while others are a little slower, without considering that they were sown or propagated directly by seed, a method that presupposes a better establishment of the plant. For such reason, independently from the differences that were observed among the indicators, the evident variability existing in the *J. curcas* population should be pointed out.

Similar results were recorded for this species by Saadaoui *et al.* (2015), in Tunisia, when evaluating five qualitative traits (leaf surface area, leaf length and width, petiole length and number of nodes, which showed high morphological variability ($p < 0{,}05$) in the eight studied accessions. Saikia *et al.* (2015) found moderate variation in plant height, stem diameter, number of branches per plant and seed weight.

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

Table 4 shows the results of the correlation among indicators of the evaluated plants and the environmental factors, due to the importance ascribed to the interrelations between the latter and the morphological and productive characteristics of the plants.

There were strong correlations between height and number of branches (-0,778 negatively); and between the latter and the quantity of racemes (-0,857). There were also correlations between branchlet and inflorescence length (0,839), between the quantity of fruits with their length (0,962) and their width (0,966); as well as between seed quantity (0,856) and length (0,805).

Likewise, high correlations were found between fruit length and width (0,966), seed quantity (0,850) and length (0,751). The correlations between fruit width with seed quantity (0,822) and length (0,745), and between fruit thickness and length (0,749) and width (0,726), were high. This performance was repeated between seed quantity with their length (0,784) and width (0,787), and between the last one with their thickness (0,817).

Moderate correlations were observed between height and minimum temperature (0,552); between the latter and number of branches (-0,501), stem diameter (-610), branchlet length (-0,522) and inflorescence length (-0,536). They were also found between fruit thickness (0,672) and seed width (0,584) and thickness (0,612); between mean temperature and number of branchlets (0,625), seed width (0,762) and thickness (0,624); and between rainfall and inflorescence length (-0,553) and width (0,523).

These results are similar to the ones found by Araiza-Lizarde *et al.* (2016), who stated that the higher temperatures did not favor the growth of *J. curcas* individuals, unlike rainfall and relative humidity.

Morphological characteristics of the fruits and seeds. The report by Hidalgo and Grández (2013), regarding the fruit of this species, could be corroborated. It is a drupaceous and ovoid capsule. After pollination a trilocular ellipsoidal fruit is formed. At the beginning it is green and fleshy, but when it matures it changes its color to yellow, until turning coffee brown, dark or black in color.

A large quantity of fruits was harvested only from two of the selected *J. curcas* (non-toxic) accessions, which belong to the plants propagated by stakes or cuttings (I-32 and I-65). They also stood out regarding the indicators seed quantity per fruits, length, width and volume, just like I-32, propagated by seeds.

This performance, regarding fruit production, could be associated to characteristics of physiological, genetic order or of plant response to environmental conditions, which were not the ideal ones (figure 1) for good crop development; although this species is capable of developing under limiting conditions (Pérez-Vázquez *et al.*, 2013). Another factor that could have influenced was the lack of agronomic management (in this eight-year old plantation only manual cutting of weeds was carried out), to which not all plants respond in the same way.

On the other hand, the presence of lepidopterans, thrips, leafhoppers (*Empoasca* sp.) was observed. In addition, infestation caused by fungi, presumably from de genera *Colletotrichum* and *Cercospora*. A symptom of mosaic was also shown, with stiffening of the leaves and in the new inflorescences, possibly caused by a viral agent.

The degree of affectation caused by diseases was from moderate to low (between 15 and 20 %), and their incidence was shown in the accessions propagated by seeds as well as stakes. Nevertheless, the stiffening of leaves was more stressed among those propagated by seeds.

Quiroga-Madrigal *et al.* (2014) referred anthracnose symptoms, caused by *Colletotrichum gloesporoides*

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

Indicator	H	NB	SD	NBR	BRL	QI	IL	NRS	RSL	QF	FL	FW	FT	QS	SL	SW	ST
Height	1																
Number of branches	**-0,778**	1															
Stem diameter	-0,328	0,675	1														
Number of branchlets	0,008	0,176	0,028	1													
Branchlet length	-0,308	0,108	0,001	-0,324	1												
Quantity inflorescences	-0,484	0,223	0,145	-0,137	0,678	1											
Inflorescence length	-0,254	0,106	0,233	-0,222	**0,839**	0,629	1										
Number of branches	0,651	**-0,857**	-0,636	-0,070	-0,160	-0,183	-0,081	1									
Raceme length	-0,539	-0,021	-0,159	-0,133	0,441	0,481	0,440	-0,132	1								
Quantity of fruits	-0,099	-0,198	-0,285	0,015	0,136	0,520	0,004	0,160	0,323	1							
Fruit length	-0,276	-0,003	-0,172	0,023	0,234	0,527	0,078	-0,043	0,394	**0,962**	1						
Fruit width	-0,290	0,012	-0,163	0,028	0,220	0,553	0,082	-0,043	0,391	**0,966**	**0,997**	1					
Fruit thickness	0,391	-0,457	-0,582	0,473	-0,214	0,031	-0,335	0,507	-0,152	0,672	0,553	0,554	1				
Quantity seeds	0,019	-0,304	-0,251	0,024	0,137	0,325	0,050	0,163	0,380	**0,856**	**0,850**	**0,822**	0,570	1			
Seed length	0,241	-0,363	-0,302	0,173	0,307	0,439	0,276	0,349	0,098	**0,805**	**0,751**	**0,745**	**0,747**	**0,784**	1		
Seed width	0,284	-0,379	-0,257	0,296	-0,432	-0,159	-0,453	0,279	0,034	0,688	0,637	0,617	**0,726**	**0 ,787**	0,574	1	
Seed thickness	0,473	-0,220	0,046	0,297	-0,615	-0,422	-0,556	0,185	-0,468	0,314	0,264	0,241	0,531	0,485	0,355	**0,817**	1
Rainfall	-0,018	-0,222	-0,424	-0,144	-0,284	-0,250	-0,553	-0,074	0,315	0,367	0,387	0,373	0,237	0,352	-0,028	0,523	0,215
Maximum temperature	0,033	0,186	0,451	0,309	-0,135	-0,379	-0,007	-0,213	-0,096	-0,084	0,055	0,010	-0,086	0,186	0,045	0,325	0,454
Medium temperature	0,125	-0,130	-0,135	0,625	-0,486	-0,450	-0,472	0,004	0,108	0,227	0,271	0,240	0,457	0,435	0,178	0,762	0,624
Minimum temperature	0,552	-0,501	-0,610	0,341	-0,522	-0,487	-0,536	0,425	-0,284	0,186	0,077	0,065	0,672	0,323	0,318	0,584	0,612

H: height (mm), NB: number of branches, SD: stem diameter (mm), NBR: number of branches, BRL: branchlet length (mm), QI: quantity of inflorescences, IL: inflorescence length (mm), NRS: number of racemes, RSL: raceme 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).

(Penz) and by *Colletotrichum circinans* (Berk) on the petiole, leaves and fruits, as well as of leaf spot by *Cercospora* sp. Sacc, for *J. curcas* plantations, in southern Mexico.

Conclusions

High variability could be observed with regards to the studied traits; while the degree of affectation by diseases was moderate to low. In turn, the accessions I-32 and I-65 were the ones with better performance in 10 of the evaluated indicators.

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Authors' contribution

- Hilda Beatriz Wencomo-Cárdenas. Conducted the experiments, data taking and processing, writing and correction of the manuscript.
- Arturo Pérez-Vázquez. Contributed to the advisor of the research.
- Eliseo García-Pérez. Developed the design and setting up of the experiment and advised the research.
- Ofelia Andrea Valdés-Rodríguez. Participated in the genesis of the idea, data collection, interpretation and analysis of the results, as well as in the manuscript preparation and revision.

Conflict of interests

The authors declare that there are no conflicts of interests among them.

Bibliographic references

Araiza-Lizarde, Nidia; Alcaraz-Meléndez, Lilia; Angulo-Escalante, M. Á.; Reynoso-Granados, T.; Cruz-Hernández, P.; Ortega-Nieblas, Magdalena *et al.* Caracterización y distribución de germoplasma silvestre de *Jatropha curcas* l. (Euphorbiaceae) en el noroeste de México. *Polibotánica*. 42:137-152, 2016. DOI: https://doi.org/10.18387/polibotanica.42.7.

Borah, Nilakshi; Mapelli, S.; Pecchia, Paola; Mudoi, Kalpataru Dutta; Chaliha, Bithika; Gogoi, A. *et al.* Variability of growth and oil characteristics of *Jatropha curcas* L. in North-east India. *Biofuels*.1-11. 2018. https://doi.org/10.1080/17597269.2018.1472979.

Campuzano, L. F. Perspectivas de la investigación de *Jatropha curcas* L. en Colombia Parte I: Componente genético. *Rev. Fac. Nac. Agron., Medellín*. 62 (3):51-63, 2009.

Chakrabarty, S.; Aminul-Islam, A. K. M.; Sultana, Nasrin & Chakraborty, P. Genetic diversity of *Jatropha curcas* L. genotypes: a potential biofuel crop in Bangladesh. *Biofuels*, 2019. DOI: https://doi.org/10.1080/17597269.2019.1655213.

García, Florencia. *Características morfológicas y productivas de accesos de* Jatropha curcas *L., no tóxicos, del Estado de Veracruz, México*. Tesis presentada como requisito parcial para obtener el grado de Maestra en Ciencias. México: Colegio de Postgraduados-Campus Veracruz, 2015.

García, M. *Observaciones de la polinización en* Jessenia bataua *(Arecaceae) en la reserva de producción faunística Cuyabeno, Amazonia del Ecuador*. Tesis en Biología. Quito: Pontificia Universidad Católica del Ecuador, 1988.

Gwafila, C.; Batlang, U. & Ngwako, S. Morphological and molecular characterization of *Jatropha curcas* L. germplasm in Botswana. *Afr. J. Biotechnol*. 18 (28):726-734, 2019. DOI: https://doi.org/10.5897/AJB2019.16845.

Hidalgo-Meléndez, E. & Grández-López, Segunda. *Mecanismo de polinización para el mejoramiento de piñon blanco (*Jatropha curcas *L.)*. La Molina, Perú: Gobierno Regional de San Martín, 2013.

Kaiser, H. F. The application of electronic computers to factor analysis. *Educ. Psychol. Meas*. 20 (1):141-151, 1960. DOI: https://doi.org/10.1177/001316446002000116.

Laviola, B. G.; Bhering, L. L.; Albrecht, J. C.; Marques, S. & Rosado, Tatiana B. Caracterização morfo-agronômica do banco de germoplasma de pinhão manso. En: *Congresso brasileiro de plantas oleaginosas, óleos, gorduras e biodiesel. Anais*. Lavras, Brasil: UFLA, 2009.

Laviola, B. G. & Macedo, J. *Red Jatropha Latinoamérica y Caribe. I Reunión de la Red Jatropha*. Brasilia: LAC, 2009.

Laviola, B. G.; Rodrigues, Erina V.; Teodoro, P. E.; Peixoto, L. de A. & Bhering, L. L. Biometric and biotechnology strategies in Jatropha genetic breeding for biodiesel production. *Renew. Sust. Energ. Rev*. 76:894-904, 2017. DOI: https://doi.org/10.1016/j.rser.2017.03.116.

López-Roldán, P. & Fachelli, Sandra. *Metodología de la investigación social cuantitativa*. Barcelona, España: Universitat Autònoma de Barcelona, 2015.

Machado, R. Caracterización morfológica y productiva de procedencias de *Jatropha curcas* L. *Pastos y Forrajes*. 34 (3):267-279, 2011.

Martin, M. & Montes, J. M. Quantitative genetic parameters of agronomic and quality traits in a global germplasm collection reveal excellent breeding perspectives for *Jatropha curcas* L. *Glob. Change Biol. Bioenergy*. 7:1335-1343, 2015. DOI: https://doi.org/10.1111/gcbb.12227.

Martínez-Herrera, J.; Jimenez-Martínez, C. & Guemes-Vera, A. Norma. Use of *Jatropha curcas* L. (non-toxic variety) as traditional food and generation of new products in México. In: *Jatropha, challenges for a new energy crop*. Vol. 1. Farming, economics and biofuel. New York: Springer Science+Business Media, 2012.

Morrison, D. F. *Multivariate statistical methods*. New York: Mc Graw-Hill Book Company, 1967.

Nietsche, Silvia; Vendrame, W. A.; Crane, J. H.; Pereira, M. C. T.; Costa, Anne & Reis, S. T. Variability in reproductive traits in *Jatropha curcas* L. accessions during early developmental stages under warm subtropical conditions. *Glob. Change Biol. Bioenergy*. 7:122-134, 2015. DOI: https://doi.org/10.1111/gcbb.12113.

Olivares, B. Aplicación del análisis de componentes principales (ACP) en el diagnóstico socioambiental. Caso: Sector Campo Alegre, municipio Simón Rodríguez de Anzoátegui. *Multiciencias*. 14 (4):364-374, 2014.

Pecina-Quintero, V.; Anaya-López, J. L.; Zamarripa-Colmenero, A.; Núñez-Colína, C. A.; Montes-García, N.; Solís-Bonilla, J. L. *et al.* Genetic structure of *Jatropha curcas* L. in Mexico and probable centre of origin. *Biomass Bioenerg.* 60:147-155, 2014. DOI: https://doi.org/10.1016/j.biombioe.2013.11.005.

Pérez-Vázquez, A.; Hernández-Salinas, G.; Ávila-Reséndiz, C.; Valdés-Rodríguez, O. A.; Gallardo-López, F.; García-Pérez, E. *et al.* Effect of the soil water content on Jatropha seedlings in a tropical climate. *Int. Agrophys*. 27 (3):351-357, 2013. DOI: https://doi.org/10.2478/intag-2013-0004.

Philippeau, G. *Comment interpreter les résultats d'une analyse en composantes principales*. Lusignan, France: Services de Etudes Statistiques, ITCF, 1986.

Quiroga-Madrigal, R.; Rosales-Esquinca, Maria; Rincón-Espinosa, Mercedes P.; Salazar-Pinacho, W. M. & Sol-Hernández, Gabriela. Enfermedades del piñón. En: A. Pérez-Vázquez, Ofelia A. Valdés-Rodríguez y E. García-Pérez, eds. *Manual de buenas prácticas para el cultivo de* Jatropha curcas *L.* México: Colegio de Postgraduados, 2014.

Saadaoui, E.; Martín, J. J.; Bouazizi, R.; Romdhane, C. B.; Grira, M.; Abdelkabir, S. *et al.* Phenotypic variability and seed yield of *Jatropha curcas* L. introduced to Tunisia. *Act. Bot. Mex*. 110:119-134, 2015.

SAGARPA & SNICS. *Guía técnica para la descripción varietal de* Jatropha curcas. México: Secretaría de Agricultura y Ganadería, Desarrollo Rural, Pesca y Alimentación-Servicio Nacional de Inspección y Certificación de Semillas, 2014.

Saikia, S. P.; Mapelli, S.; Breviario, D.; Galasso, I.; Giani, S.; Braglia, L. *et al.* Comparative studies for selection of *Jatropha curcas* L. capable of high yield and oil quality in Assam environment. *Curr. Sci*. 109 (3):352-366, 2015.

Santos, D. N.; Ferreira, J. L.; Pasqual, M.; Generoso, A. L.; Setotaw, T. A.; Cançado, G. M. A. *et al.* Population structure of jatropha and its implication for the breeding program. *Genet. Mol. Res*. 15 (1), 2016. DOI: https://doi.org/10.4238/gmr.15017770.

Savaliya, M. L.; Dhorajiya, B. D. & Dholakiya, B. Z. Recent advancement in production of liquid biofuels from renewable resources: a review. *Res. Chem. Intermed*. 41:475-509, 2015. DOI: https://doi.org/10.1007/s11164-013-1231-z.

Shukla, A.; Singh, S. P. & Tiwari, Sakshi. Transformation of toxic potential of *Jatropha curcas* (Ratanjyot) into protein source: a mini-review. *J. Adv. Vet. Anim. Res*. 2 (2):89-94, 2015.

Torres, V.; Figueredo, J.; Lizazo, D. & Álvarez, A. *Modelo estadístico para la medición del impacto de la innovación o transferencia tecnológica en la rama agropecuaria. Informe técnico*. San José de las Lajas, Cuba: Instituto de Ciencia Animal, 2006.

Tsuchimoto, S., Ed. *The Jatropha genome*. Kalyani, India: Springer International Publishing, 2017.

Valdés-Rodríguez, Ofelia A.; Pérez-Vásquez, A. & Sánchez-Sánchez, O. Saberes Totonacas: el piñón manso (*Jatropha curcas* L. no tóxica). *VII Congreso Nacional de Agricultura Sostenible.* Puebla, México: SOMAS, COLPOS, BUAP. p. 44-53, 2013.

Yengle-Ruíz, C. Aplicación del análisis de componentes principales como técnica para obtener índices sintéticos de calidad ambiental. *Scientia*. 4 (2):145-153, 2012.

Zavala, I. *Caracterización morfogenética de accesiones de* Jatropha curcas *L., recolectadas en el Estado de Veracruz, México*. Tesis presentada como requisito parcial para obtener el grado de Doctor en Ciencias. México: Colegio de Postgraduados-Campus Veracruz, 2016.