Scientific Paper

Phenological evaluation of non-toxic *Jatropha curcas* L. accessions in the Veracruz region

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Abstract

Objective: To evaluate the phenological performance of non-toxic *Jatropha curcas* L. accessions, sexually and asexually propagated in the central region of Veracruz State, Mexico.

Materials and Methods: The work was conducted with six accessions propagated by seeds as well as by cuttings with three repetitions, from an eight-year old plantation. The observation period took place from July to December, 2019, with weekly evaluations. The presence of the following phenophases was recorded: emission of inflorescences, flowers, floral anthesis, green and mature fruits, falling and emission of leaves. The research was conducted with the semi-quantitative measurement method, proposed by Fournier, and the activity index suggested by Bencke and Morellato.

Results: The highest flowering occurred from October to November for the plants propagated by seeds as well as by cuttings. The *J. curcas* accessions showed falling of leaves, in the period July-August (60 %) and in October (98 %). The leaves were emitted in all the evaluated months, except in the period July-August and at the end of November-December. The highest number of individuals in this phase was in the months of September and October, with 100 % of the individuals with leaf emission.

Conclusions: Variation was observed in the phenological performance of the accessions, especially regarding the falling of leaves. The studied accessions showed unequal phenological patterns, because most of them flowered and fructified at different moments.

Keywords: *Jatropha*, phenology, physic nut, phenophases, propagation

Introduction

In recent decades, the use of plant species aimed at the production of agrofuels has generated a significant search to identify new plant genetic resources with high potential for such production, without risking the food security of countries. *Jatropha curcas* L. is visualized as an excellent alternative due to its composition of fatty acids, which makes it ideal for the production of a biodiesel with high quality. In additions, its use could decrease the demand for oily seed plants, releasing them for human and animal feeding.

J. curcas, is a perennial species, from the family *Euphorbiaceae* (Tsuchimoto, 2017), which has not been completely characterized, for which the knowledge of its phenotypic and genotypic characteristics is still limited, although certain botanical characteristics have been documented until now (Laviola *et al*., 2018).

Phenology is the study of the periodical and repetitive phases of the life cycle of plants and their temporary variation over the course of the year. This discipline analyzes the events that occur in plants, such as germination, growth, flowering, fructification, abscission and dispersal of seeds. Nietsche *et al*. (2014) state that it is a mainly descriptive and research phenomenological specialty, which requires observation and information compilation methods, associated to accuracy in field work. Belo *et al*. (2019) state that its knowledge allows to form strategies of fruit collection, which favor seed quality and quantity for the production of new seedlings. Aguirre-Mendoza and León (2012) assure that phenology is related to the climate seasons of the year, in which the reproductive events in plants follow each other, determinant for the succession of the population and for ensuring the survival and establishment of young individuals.

Plant phenology has been relatively little studied in tropical and subtropical regions. Hence the need to conduct deeper analyses about it, and its relation to climate conditions.

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Ma *et al*. (2015) refer that through the study of the phenology of species an attempt is made to establish the possible causes of their presence, with regards to environmental or climate factors. In addition, it can contribute to the solution of many forestry problems, because it constitutes a methodology that favors the understanding of the reproduction biology of the species and allows to understand the dynamics of communities.

Eras-Chacho and Pintado-Muy (2018) state that phenology constitutes an aid that can contribute to the knowledge about the flowering and fructification seasons, foliage quantity, emission of leaves and fruits, and their relation to climate factors or environmental stimuli. In this regard, Hidalgo-Meléndez and Grández-López (2013) corroborate the incidence of hours light, relative humidity, temperature and rainfall on the temporary variation of the reproductive phenology of the species. In this sense, rainfall has been one of the climate variables mostly associated to the expression of foliage and to flowering.

The study presented here is of essential importance to be able to understand the performance of the *J. curcas* accessions. Its objective was to evaluate the phenological performance of the non-toxic *J. curcas* accessions, propagated by seeds and by cuttings, established eight years ago in the experimental field of the College of Postgraduate Students-Veracruz Campus, in the central region of the Veracruz State, Mexico.

Materials and Methods

Study area. The research was conducted in the germplasm bank of non-toxic *Jatropha curcas* L., at the experimental field of the College of Postgraduate Students-Veracruz Campus, which is located on km 88,5 of the Xalapa-Veracruz Federal road, Tepetates Farm, Manlio Fabio Altairano municipality, Veracruz, via Paso de Ovejas. Its geographical location corresponds to 19° 11' 38,62'' LN and 96° 20' 31,26'' LW, at an altitude of 24 m.a.s.l. The climate is of type Aw1 (w) (i) g, which is in correspondence with sub-humid climate of rainfall in the summer, with mean annual rainfall of 1 100 mm and mean annual temperature of 25 ºC, with less than 5 % rainfall in the winter, and temperature fluctuation in a range from 5 to 7 ºC (García, 1988).

Climate data. The temperature and rainfall data, corresponding to the period from January to December, 2019, were obtained from the Meteorological Station of the College of Postgraduate Students-Veracruz Campus, and are shown in figure 1.

Plant material. The work was done with six previously selected accessions, propagated by seeds as well as by cuttings, with three repetitions from a plantation of 49 (23 planted by seeds and 26 by cuttings) with eight years of age (table 1), collected in the Veracruz State. For such selection the results from other research works, conducted by García (2015) and Zavala (2016), were considered.

Experimental design. The trial was established from a complete randomized block experimental design. Each plant to be sampled was considered a replica and they were sown at a distance of 3 x 2 m. The only management practice that was applied was weed control periodically.

Phenological evaluations. The observation period took place from July to December, 2019, with weekly evaluations. The phenophases emission of

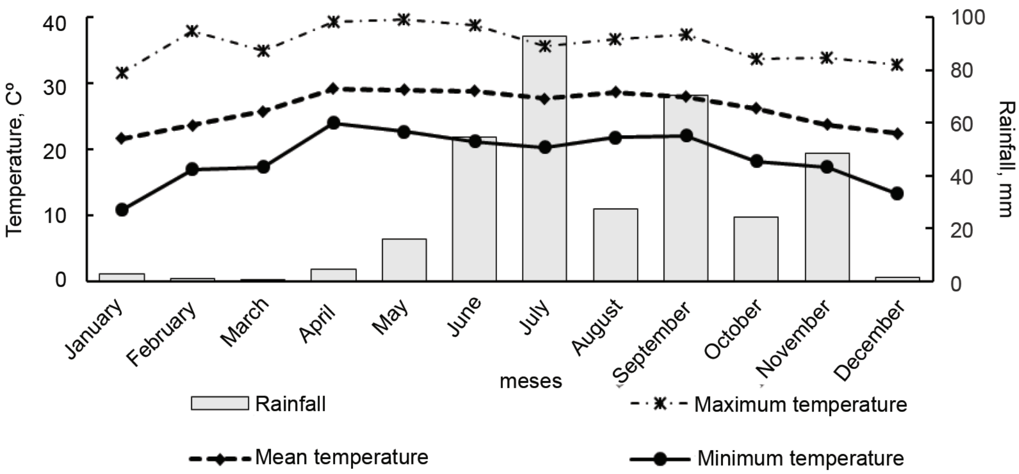

Figure 1. Performance of temperature (maximum, mean and minimum) and rainfall.

Table 1. Locality, collection region and altitude of the accessions of Veracruz State, Mexico.

Accession	Locality	Municipality	N Latitude	W longitude	Altitude, msnm	Propagation
I-13	Paplanta	Paplanta	20° 27' 28.9''	97° 19' 16.2''	173	cuttings
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	cuttings and seeds
I-34	Alvarado	Papaloapán	18° 47' 26.1''	95° 45' 31.7''	22	cuttings and 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	cuttings
I-78	Paso del correo	Totonaca	20° 21' 24.0''	97° 14' 30.0''	39	cuttings
I-80	Buenos Aires	Nautla	19° 56' 09.0''	95° 50' 00.0''	321	cuttings and seeds

Source: Zavala (2016)

inflorescences, flowers, floral anthesis, green and mature fruits, falling of leaves and emission, were recorded. The methodology proposed by Fournier (1974) was followed. Codes were used (table 2) to identify the main phenophases (sprouting, flowering and fructification).

The evaluation criterion was based on the semi-quantitative measurement method, proposed by Fournier (1974), which follows a scale from 0 to 4, and an interval of 25 % between each category, and allowed to estimate the percentage of intensity of the phenophase in each individual. In this method, each one of the phenophases is individually developed, and the scale values are interpreted as follows: 0) absence of the observed phenomenon; 1) presence of the phenomenon with width between 1 and 25 %; 2) presence of the phenomenon with width between 26 and 50 %; 3) presence of the phenomenon with width between 51 and 75 % and 4) presence of the phenomenon with width between 76 and 100 %.

The activity index was also used, through which it is possible to verify the presence or absence of the phenophase in the individual, without detailing intensity. This method has quantitative character at population level, by indicating the percentage shown by a certain phenological event (Bencke and Morellato, 2002).

The data were reflected in dendrophenograms elaborated in Excel and were associated with the temperature and rainfall values recorded during the evaluation period. There were no differences in the performance of phenophases of the seed- and cutting-propagated plants, for which the dendrophenograms were presented in a general way.

Results and Discussion

Leaf loss can be a sprouting-inducing factor of some species, because it reduces water loss by the plant, which would lead to rehydration of the branches without leaves and to the production of new leaves, even in dry periods. The *J. curcas*

Table 2. Symbology of the phenophases.

Phenophase	Code	Identification of the phenophase
Sprouting	1	without or almost without leaves
	2	sprouting
	3	adult leaves
Flowering	1	presence of floral buds
	2	flowering onset
	3	full flowering
Fructification	1	end of flowering
	2	green fruits
	3	mature fruits

Source: Modified from Fournier (1974)

accessions would show the intensity of falling of leaves (fig. 2), according to the evaluation made by Fournier's index, in the July-August period was the lowest amount (60 %) and in October the highest value (98 %). Nevertheless, the highest percentage of individuals with falling of leaves occurred from November to December. This process, according to García-Pérez *et al.* (2013), normally occurs from April to November, when the rainy season starts, and its intensity increases with the decrease of rainfall.

Nietsche *et al.* (2014) reported that *J. curcas* is a plant of low water demand, which tolerates drought, hot or cold weather well and, under extreme drought conditions, it loses leaves to preserve moisture in its tissues. As a result, its growth is stopped, but it can survive at the expense of water and of the organic reserves stored in its stem. Diédhiou *et al.* (2017) stated that *J. curcas* shows deciduous performance, in which the leaves fall, partially or totally, at the end of the dry season or during the rainy season; besides, they indicate that it remains dormant until the beginning of spring or during the rainy season in the dry regions.

Taiz and Zeiger (2013) refer that the loss of leaves minimizes environmental stress, related to prolonged drought or cold periods. In addition, when seasonality is low, in temperature as well as in relative humidity, leaf production and loss can occur in any season.

The emission of leaves (fig. 3) occurred non-continually in all the evaluated months, except in the period from July to August and at the end of November-December. In this phase, the total percentage showed

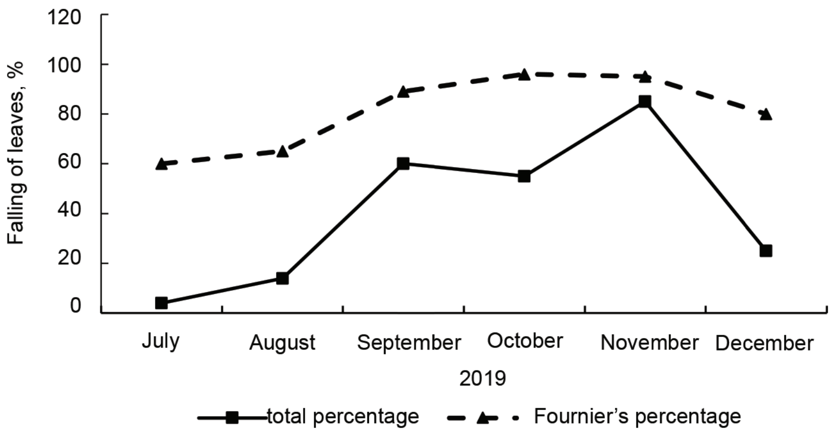

Figure 2. Phenological representation (Fournier's percentage and total percentage) of falling of leaves in *J. curcas.*

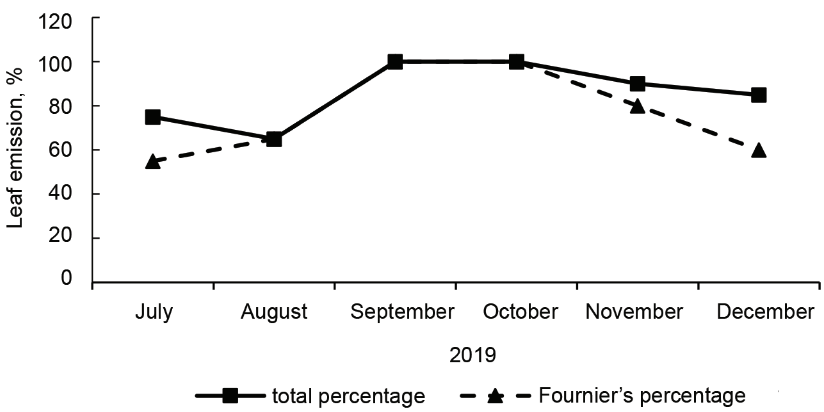

Figure 3. Phenological representation (Fournier's percentage and total percentage) of leaf emission in *J. curcas.*

the highest number of individuals in September and October, with 100 % of the individuals with leaf emission. It decreased again since late November, which is associated to the low humidity in this segment of the month and in December. The presence of small emissions of leaves grants the plant the maintenance of the photosynthetic apparatus, without large energy expenses.

It is worth mentioning that the accessions emitted the new leaves in small quantities, in the terminal region of the branches, or in the new branches; and the new leaves showed purple shades, characterized by the presence of the anthocyanin pigment (Taiz and Zeiger, 2013; Nietsche *et al*., 2015).

A similar performance was observed in other Jatropha species, such as *J. cinerea*, *J. cuneata* and *J. gaumeri*, in which new sprouts emerged when rainfall increased. This can suggest, besides the water availability, the influence of other environmental factors in the phenology of the species, according to references by Santos *et al*. (2010).

In this phase, the presence of inflorescences per plant was evaluated, taking into consideration the individuals with floral buds, open flowers and inflorescences in terminal phase. The flowers were emitted practically throughout the evaluation time, with an intensity that increased gradually, and reached between 100 and 80 % between September and November (fig. 4).

These results coincide with those referred by Pessoa (2011), who states that in *Croton cajucara* Benth. and *Croton sonderianus*, which also belong to the family *Euphorbiaceae*, flowering peaks were observed from October to November, dry season. Nevertheless, such results differ from the ones reported by Diédhiou *et al*. (2017) in a study about flowering and changes in the fructification season of six *J. curcas* accessions. According to these authors, plant flowering is cyclic and occurs throughout the year. They also differ from the report by Anandalakshmi *et al*. (2015), who state that flower emission was observed practically throughout the year. In this research the highest intensity of flower emission was recorded in July and October. According to the total percentage, the highest quantity of individuals with flower sprouts occurred in July, September and October, with approximately 100 % of the plants in this phenophase.

Most of the inflorescences that appear at the end of the falling of leaves were formed, mainly, by masculine flowers, for which in this period the masculine/feminine flowers ratio was higher. This performance could be related to the fact that, in this phase, the plant has little photosynthetic apparatus, and maintaining the feminine flowers causes the loss of photoassimilates, which leads to reserve depletion.

Another hypothesis to be considered for justifying this performance could be that, in this stage, the quantity of rainfall that is needed is lower, which propitiates an adequate pollen production by the masculine inflorescences, because the excess of rainfall could cause the pollen to burst and, consequently, pollination is not viable.

The intensity of the floral anthesis (fig. 5), according to Fournier's index, should have peaks in July and October; however, the percentage of

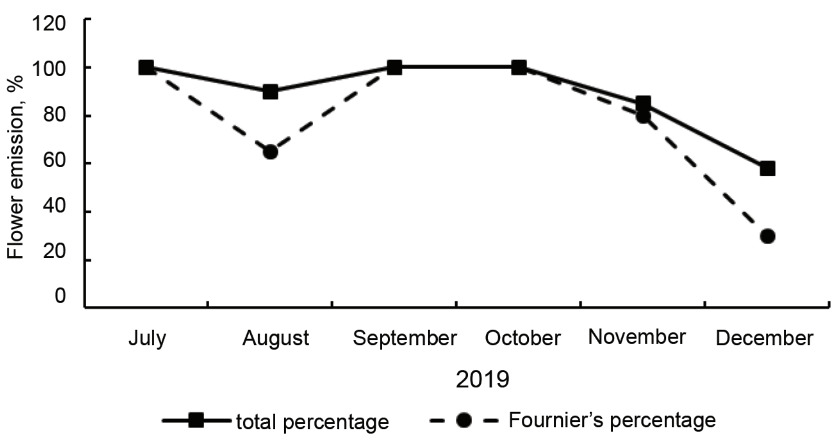

Figure 4. Phenological representation (Fournier's percentage and total percentage) of flower emission in *J. curcas*.

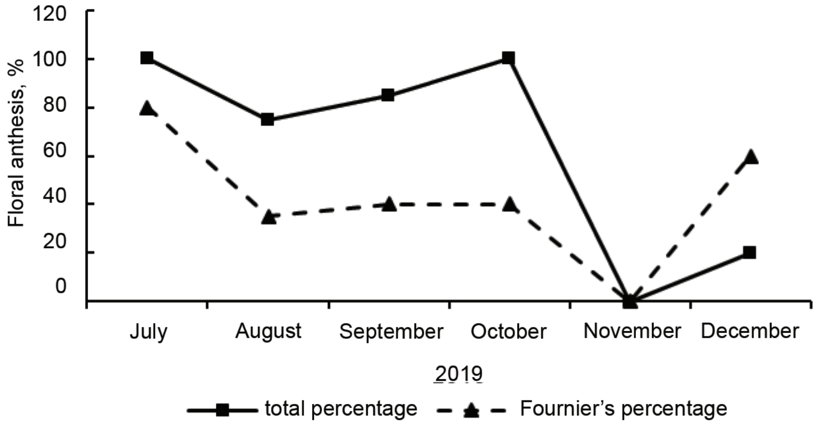

Figure 5. Phenological representation (Fournier's percentage and total percentage) for the floral anthesis in *J. curcas*.

individuals in anthesis reached its maximum point in the months of July and December. According to Nietsche *et al*. (2015), this might be regulated by the interaction of a specific genetic component, with such environmental factors as: temperature, photoperiod, nutrient availability in the soil, besides the hormonal relation (gibberellin, ethylene and auxin).

According to references by Hernández (2012), generally *J. curcas* flowering begins after an inactivity period of the plant. This occurs after winter, when the temperature and rainfall increase. This author refers that the lack of rainfall in previous months allowed the stimulation of flowering. Nietsche *et al*. (2014) state that after its induction, flowering becomes continuous during prolonged periods, according to the water availability in the soil.

J. curcas showed the phase of green fruits in August, October and November (fig. 6). This stage is characterized by the maximum growth in fruit size, although physiologically the plant is immature still and shows green color. Fournier's percentage showed peaks in October and November and the lowest intensity in July.

The highest percentages of individuals with mature fruits were observed in September, late November and December, with approximately 90, 60 and 70 % of individuals in this phenophase, respectively (fig. 7). This proves the poly-cyclical flowering of this plant, which was influenced by the performance of rainfall and temperature.

Similar results to these ones were reported by Nietzsche *et al*. (2014) in studies conducted in southern Florida. These authors indicate that the

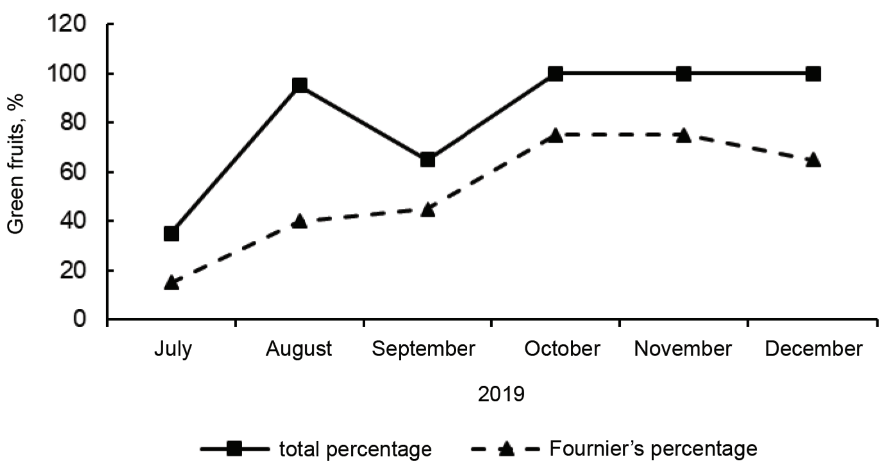

Figure 6. Phenological representation (Fournier's percentage and total percentage) of green fruits in *J. curcas.*

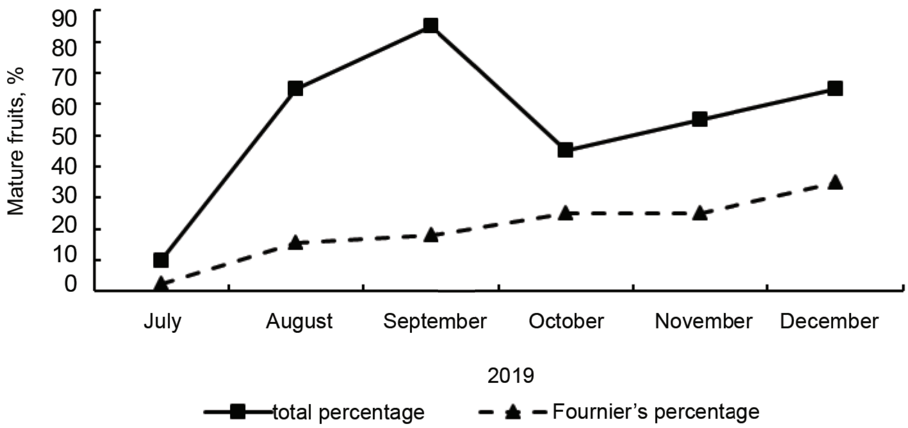

Figure 7. Phenological representation (Fournier's percentage and total percentage) of mture fruits in *J. curcas.*

highest fruit average was obtained in that season (75,5 %), which might indicate a positive effect of climate on this characteristic. They are also similar to those obtained by Anandalakshmi *et al*. (2015) in a 3-year old *J. curca*s plantation, in Tamil Nadu, India.

Nevertheless, they differ from the ones referred by Hernández (2012) in studies conducted in this plantation, who observed that this phenophase appeared continuously, sice July until September, after an intense dry season.

Acccording to Ma *et al*. (2016), the beginning of *J. curcas* fruit production occurs approximately on the tenth month after sowing, but production only reaches the peak around the third or fourth year, and can reach 40 years of age. In Brazil, under the climate conditions of Minas Gerais, *J. curcas* flowering started after the dry season, and the fruits could be harvested from February to April. If the soil receives irrigation or regular rainfall, the plants can produce throughout the year, with monthly harvests. this criterion has been corroborated in studies conducted by García-Pérez *et al*. (2013) and Diédhiou *et al*. (2017).

This performance of the phenophases might be associated not only to the available water quantity, but also to the low temperatures and nutrient availability in the soil. It is valid to mention that the plant flowering and fructification (duration and intensity) not only depend on the two above-mentioned climate factors. Aguirre-Mendoza *et al*. (2015) stated that phenology is influenced by immediate causes, which are the environmental stimuli, and causes that are related to the genetic and physiological mechanisms that determine a phenotype.

These results coincide with those reported by Nietsche *et al*. (2015), who when studying *J. curcas* species observed that they had a continuous flowering pattern and produced flowers throughout the year, with flowering peaks between October and November. But they differ from the ones obtained by Hernández (2012) when analyzing this same population, regarding the emergence of flowers. Yet, they coincide on the fact that the flowering phenophase begins after a period of plant inactivity, which allows to observe higher presence of inflorescences and flowers in October and early November.

Likewise, the results recorded here do not differ much from what has been reported for other subtropical and topical zones, of America as well as of Africa, where relations have been found between the phenological patterns and different climate factors, depending on the alternance and distribution of the rainy and dry seasons and, especially, on the presence, in some tropical zones, of a marked dry season, which can induce falling of the leaves with the subsequent flowering or that it appears at the beginning of rains (Diédhiou *et al*., 2017; Eras-Chacho and Pintado-Muy, 2018).

Fournier (1976) indicates that it is necessary to know the phases and development of plants, as well as to establish the seed collection moments, to understand the natural regeneration processes in plantations. Likewise, he refers that the season in which the reproductive events in plants occur is determinant for the succession of the population, to ensure the survival and establishment of young individuals, and that the studies in this regard allow to understand better the response of species to the physical and biotic environment, as well as its dynamics.

Regarding the above-explained facts, Cabrera *et al*. (2018) state that it is highly significant to have estimators that explain the performance or dynamics of the species, especially, when it is influenced by climate variables, such as temperature and rainfall. In this sense, phenology allows to know the dynamics of the plant biological process, with regards to their biotic and abiotic environment. Ma *et al*. (2016) confirmed the influence of rainfall on the different phenophases of *J. curcas*. These authors also observed a high index of falling of leaves at the end of the rainy season, this being, along with the formation of new leaves, flowering and fructification, the four main phenophases considered by most phenological studies about this species.

Conclusions

Variation was observed in the phenological performance of the *J. curcas* accessions, especially regarding leaf fall. The studied accessions showed unequal phenological patterns, because most of them flowered and fructified at different moments.

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Authors' contribution

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

Conflict of interests

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

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