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Morphological Characterization and Phenological Modeling of *Jatropha platyphylla* (Euphorbiaceae) Muell. Arg. Genotypes

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Abstract

Morphological characterization and phenological modeling were carried out on genotypes of *Jatropha platyphylla* collected from the states of Sinaloa and Durango, Mexico. The morphological characterization evidenced the existence of monoecious plants, finding individuals with male and female flowers in the same inflorescence. Fruit with four seeds was also found. The phenological study was divided into two phases and calculated in thermal requirement (˚D): Vegetative [seedtime (0), germination (24), emergence (98), cotyledons (87), second (302) and fourth (524) true leaves, end of vegetative growth (302)] and reproductive [flowering (303), fructification (342), maturation (126), defoliation and senescence (450)]. The thermal constant (2558) was similar in all eight genotypes. The phenological stages and the accumulated degree days were adjusted with a third-degree polynomial (Stage = $-0.0041x^3 + 0.7446x^2 - 8.6808x + 6.2448$) ($R^2$ = 0.99%) stage. The development of phenological models facilitates the prediction of the flowering date for the selection of varieties with high oil and protein content.

Keywords

Degree-Days, Monoecious, Phenological Modeling, Plant Breeding, Varietal Selection

1. Introduction

The genus Jatropha comprises approximately 170 to 175 known species, of which 45 are found in Mexico [1] with 77.7% of endemism for ecosystems of low deciduous forest and xerophilous scrublands [2]. *Jatropha platyphylla*, a wild plant of the northwestern region of Mexico, is little known and with restricted geographical distribution to the deciduous lowland forest near the Pacific coast between Sinaloa and Michoacán [3]. It is a tree or shrub from 2 to 5 m tall with an almost smooth stem; broad leaves, almost orbicular, 25 to 35 cm [4] with broadly rounded lobes [5]. The fruit has three seeds of 12 mm long [6]. The flowers are white to pink; the plants bloom in May, June and July [7]. The plant is known as Bonete because of the shape of the fruit [5], as well as Sangregado for staining the garments that rub against its branches in blood color [8].

The fruit of *J. platyphylla* is used by the inhabitants of Tacuichamona Communities, Culiacán, Sinaloa, Mexico in traditional food preparation [9]. The fruit is consumed by animals, such as deer (*Odocoileus virginianus*) and wild boar (*Sus scrota*). The seed is food for birds, such as chachalaca (*Ortalis vetula*) and magpie (*Cyanocorax mystacalis*), among others [10]. The seed kernel has high oil content (60%); the oil extraction residue cake contains 75% crude protein [9]. Sosa-Segura *et al.* [11] performed a physical and chemical characterization of three non-toxic oilseeds from the *Jatropha* genus; *J. cinerea* and *J. curcas* oils have fatty acid profile similar to those of sesame and canola oils, whereas that of *J. platyphylla* resembles those of soybean oil. Ambriz-Pérez *et al.* [12] studied extracts from *J. platyphylla* pulp, kernel, and leaves to know their effect on some pro-inflammatory mediators. Altogether, these results suggest that extracts have potential in treating inflammatory diseases, and their activity is mediated by flavonoids and lipophilic compounds. Soto-Landeros *et al.* [13] compared pollen morphology of four *Jatropha* species (*J. curcas*, *J. cinerea*, *J. platyphylla*, and *J. vernicosa*). The pollen grains among *J. cinerea*, *J. platyphylla*, *and J. vernicosa* showed great similarity in shape and size. The most distinctive differences were found in toxic and non-toxic *J. curcas*.

In Mexico and worldwide, the number of studies on *Jatropha* has increased because of the use of its seed oil to produce biodiesel. However, knowledge of taxonomy, distribution, and ethnobotany of these and related species is incomplete [14]. *J. platyphylla* is in domestication period and has not been fully characterized. Morphological studies of seeds represent important tools for the development of efficient agricultural practices [15] and knowledge of the phenology of a species, whether to develop as a new crop or cultivation already established, they have practical applications in planning and coordinating work to be carried out in the crop; thus resource optimization and an increase in productivity may be achieved [16]. Due to the potential of *J. platyphylla* and with the purpose of contributing to the development of a new crop, the objectives of this research aimed at studying the phenology of the plant, morphology of the root, stem, leaves, flowers, and fruit, a phenological development model based on ambient temperature is proposed.

2. Materials and Methods

2.1. Plant Material and Germination

This research was conducted in April 2017 and involved eight wild populations of *J. platyphylla* growing under the tropical conditions of the states of Sinaloa and Durango in Northwestern Mexico (**Table 1**). Ripe fruit was collected to obtain the seeds; 100 seeds of each accession were washed with Axion® detergent (Colgate-Palmolive, NY, U.S.A.) for 10 min and subsequently treated with 30% commercial sodium hypochlorite (Cloralex®, Nuevo León, MX) for 15 min and rinsed five times with distilled water; then, a pre-germination treatment was performed in distilled water at 60˚C for one hour, and the part of the micropile was scarified. The treated seeds were placed on moistened paper for germination and incubated in a growth chamber at 25˚C ± 2˚C in dark conditions. Once germination occurred, they were seeded in 250-mL polypropylene cups, drilled on the base and with Sogemix® substrate (Quebec, CAN). Once the plants developed, they were placed in the greenhouse under controlled light and room temperature of 28˚C ± 7˚C conditions; the seedling percentage obtained was assessed. In the pre-field stage developed in the greenhouse, complete plants were extracted from the pot; germination, emergence, appearance of true leaves and stem elongation were recorded. The plants were transplanted in open field at a distance of 2 m between plants and 3 m between rows; 60 g of triple 17 fertilizers and 1 kg of compost were applied to each plant as base fertilizer. Plants with homogeneous characteristics were selected, and stem length, number of leaves, and morphological evaluations of the different organs were recorded. For determination of stomatal index: Slides as prepared for stomatal index by using the formula,

$$\text{Stomatal index (\%)} = (S/S + E) \times 100 \quad (1)$$

Table 1. Information on the sites where *Jatropha platyphylla* genotypes were collected and the average annual record of weather data.

ID	Collection area	Latitude (˚N)	Longitude (˚W)	Tmax (˚C)	Tmin (˚C)	Relative Humidity (%)	Precipitation (mm)
CP	Cofradia, Sinaloa	24˚51'44"	107˚11'00"	33.4	16.0	78.8	881
DM	Dimas, Sinaloa	23˚45'01"	106˚46'35"	29.5	17.1	79.1	481
LC	Chilla, Sinaloa	24˚23'27"	107˚06'17"	31.2	18.2	74.5	790
LH	Higuerita, Sinaloa	24˚45'37"	107˚08'39"	35.2	22.0	80.1	881
PP	Mocorito, Sinaloa	25˚04'05"	107˚43'15"	33.6	16.7	65.0	684
PR	Rosario, Sinaloa	23˚11'18"	106˚09'09"	35.5	19.1	85.9	828
QP	Quelite, Sinaloa	23˚31'51"	106˚30'10"	32.2	18.4	81.3	640
TP	Tamazula, Durango	24˚59'12"	106˚59'17"	32.2	16.7	86.0	1031

where, S and E are the number of stomata and epidermal cells respectively in microscopic view field. Like stomatal density, stomatal index (%) can be calculated for both the surfaces of leaves [17]. Three-month plants were used and planted in an experimental plot located in the community La Campana, Culiacán, Sinaloa (24˚59'28"N and 107˚34'25"W) at 97 m a.s.l.

2.2. Collected Meteorological, Morphological, and Phenological Data

Daily weather variables were recorded in an automated station (Adcon Telemetry®, Vienna, AT) located in the study area. The calculation of degree-days (˚D) was performed using Equation (2).

$$^{\circ}D = (\text{Maximum temperature} + \text{Minimum temperature})/2 - 18.6 \qquad (2)$$

where 18.6˚C was the base temperature [2]. Weekly observations were made for one year, and the different phenophases were identified.

2.3. Development of Scale and Phenological Model

A third-degree polynomial was adjusted in a variable with phenological stages based on cumulative day-degrees. The phenological stages for *Jatropha platyphylla* were defined by a decimal scale, following the methodology proposed by the Federal Biological Research Centre for Agriculture and Forestry [18].

3. Results and Discussion

3.1. Morphological Description of *Jatropha platyphylla*

Seed germination began on the third day after sowing and continued upon the fifth day at an average temperature of 21˚C. 80% germination was observed in the 8 genotypes. The shelled seed opened and the radicle showed a constant and vertical growth that constitutes the taproot and four lateral roots with abundant ramifications (**Figure 1(a)**).

The structural characteristics of roots may therefore provide soil resistance to water and wind erosion in some sites [19] [20]. *J. platyphylla* presented epigeal germination, where cotyledons emerged above the ground, as for most species of this genus [21]. The cotyledons are wrapped by the thick endosperm and reddish-white coloration. The verticality of the hypocotyl and the emergence of the second leaf true made evident the beginning of vegetative development, where you can see the deployment of the leaves cotyledonary, foliage development and fall of cotyledons.

The stem bark is whitish gray and was observed straight without ramifications during the first year (**Figure 1(b)**). The leaves are distributed alternately (spiral) along the stem and have 5 ribs principal. Each leaf is 33 to 42 cm long and 35 to 44 cm wide. The leaf is peltated because the petiole is inserted almost to the center of the leaf, the petiole is 20 to 38 cm long and has a basal diameter of 7 to 8 mm (**Figure 1(c)**). Dehgan [4], describes the leaves of *J. platyphylla* as thickened,

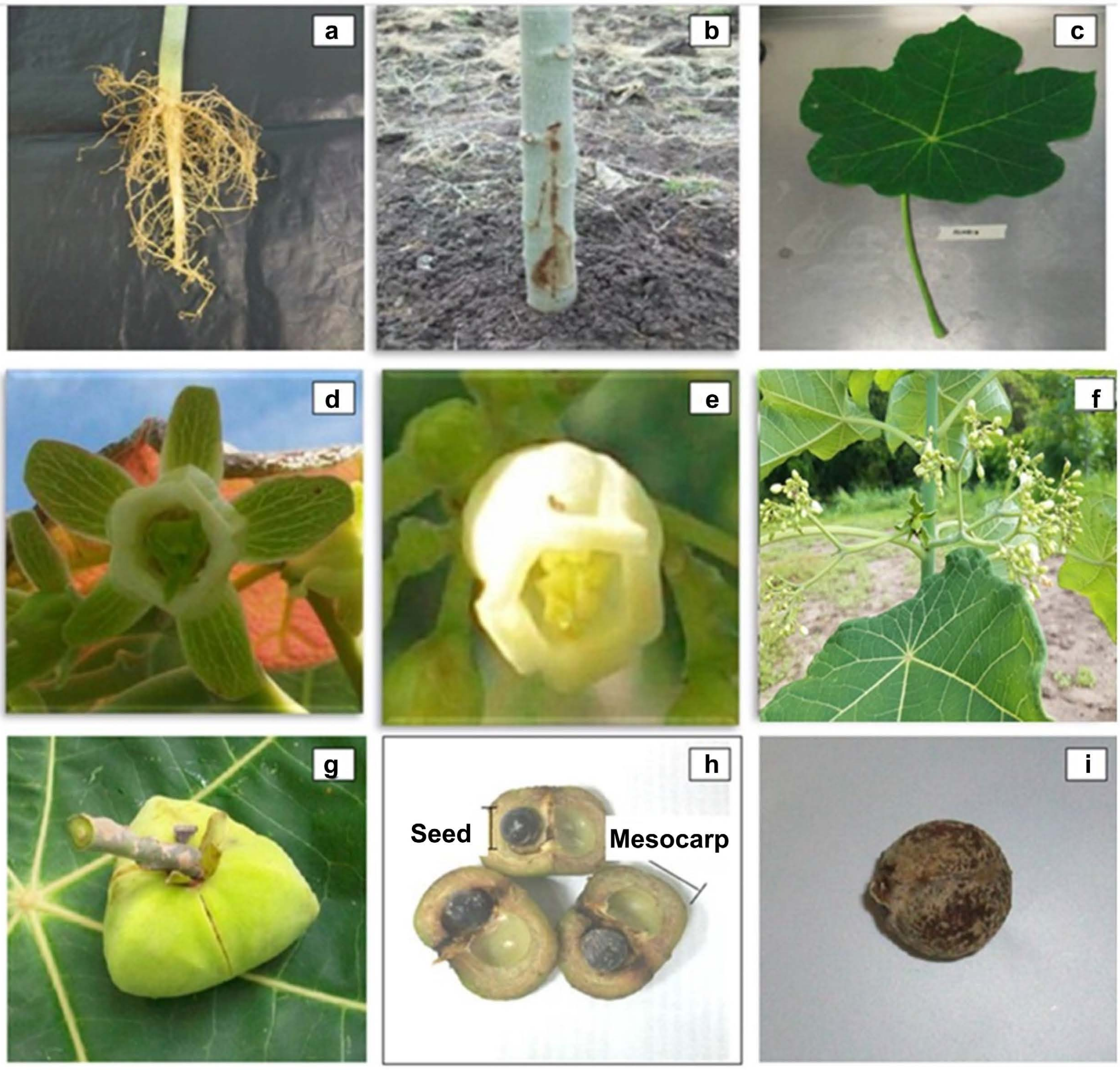
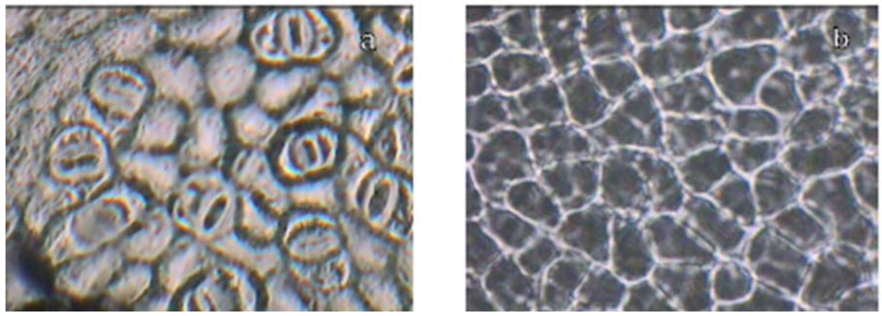


Figure 1. *Jatropha platyphylla* of La Campana, Sinaloa, Mexico; (a) Root, (b) Stem, (c) Leaf, (d) Female flower, (e) Male flower, (f) Monoecious flowering, (g) Mature fruit, (h) Dissected fruit, (i) Seed.

25 to 35 cm, peltated, it should be noted that the description does not mention the size of the petioles, it only describes them as long petioles.

The morphological and anatomical variation of the leaves of the genus *Jatropha* facilitate taxonomic classification. The leaf of the species of the genus varies even those with 35 to 40 cm long [22]. The leaf blades are armored with 5 lobes. They presented stomata only in abaxial epidermis (hypostomatic) and stomata are of paracytic type. (**Figure 2**), unlike *Jatropha curcas* that presents stomata on both surfaces [23]. The stomatic index was found in a range from 23.08 to 35.14 in contrast *J. curcas* attain average of 7.076 in adaxial and 30.959 in abaxial surface [24]. Stomata are a promising trait as they reveal information on habitat preferences and there with ecological characteristics of species such as light conditions, as water use [25].



(a) (b)

Figure 2. View of the abaxial epidermis (a) and adaxial (b) of the leaf lamina of *Jatropha platyphylla* obtained from an experimental lot of La Campana, Sinaloa.

The pistillate and staminate flowers of *J. platyphylla* are white, The pedicel of the pistillate flower ranged in a range of 10.43 to 16.69 mm long (**Figure 1(d)**) and 4.28 to 5.49 mm for the staminate flower (**Figure 1(e)**), both presented 5 petals 5.14 mm wide on average and 8.29 mm long; sepals 12 to 15 mm long by 5 - 6 mm wide. Dehgan and Schutzman [26] describe the sex of the *J. platyphylla* plant as dioecious, however; monoecious individuals were identified that presented male and female flowers in the same inflorescence only in PP (Mocorito, Sinaloa) genotypes (**Figure 1(f)**).

Fruits are trilocular and tricarpelar drupe fleshy capsules that are initially green in colour, but turn yellow and then yellowish-brown and dehiscent as it matures (**Figure 1(g)**). In the genotypes, TP (Tamazula, Durango) and LH (La Higuerita, Sinaloa), the development of fruits with four carpels and four seeds was observed (**Figure 1(h)**). Its dimensions are 4.5 cm wide and 4.5 cm high, with a weight of 31 to 45 grams. The weight of the mature fruit of *J. platyphylla* corresponds to 15% of seeds and 75% of mesocarp and epicarp. Each fruit presented a seed in each locule, round brown in shape, with thick endocarp, weighing 1.01 to 2.06 grams, with an average weight of 1.79 ± 0.22, diameter of 13.03 to 16.02 mm (14.63 ± 0.60). These results agree with Makkar *et al.* [9], who describe the almost circular seed with a diameter of 15.54 ± 1.01 mm. The average weight of 1.80 ± 0.15 for the whole seed, 0.92 ± 0.01 for the shell and 0.85 ± 0.13 for the kernel. Shells represent more than 50% of the total weight of the seed. On the other hand, Standley [6] reports 12 mm seeds (**Figure 1(i)**). The difference in diameter may be due to the climatic and edaphological conditions in which the plants were, or to the genotypes under study [27] [28].

3.2. Phenology of *Jatropha platyphylla*

The development of *Jatropha platyphylla* was observed in two stages: Vegetative; which included 7 phenological events (sowing, germination, emergency, cotyledonary stage, 2nd leaf, 4th leaf and term of vegetative growth), and Reproductive (flowering, fruiting, physiological maturity, defoliation and senescence) (**Figure 3**). **Table 2** shows the relationship between the physiological time (˚D) and the chronological time obtained, and the phenological responses recorded during

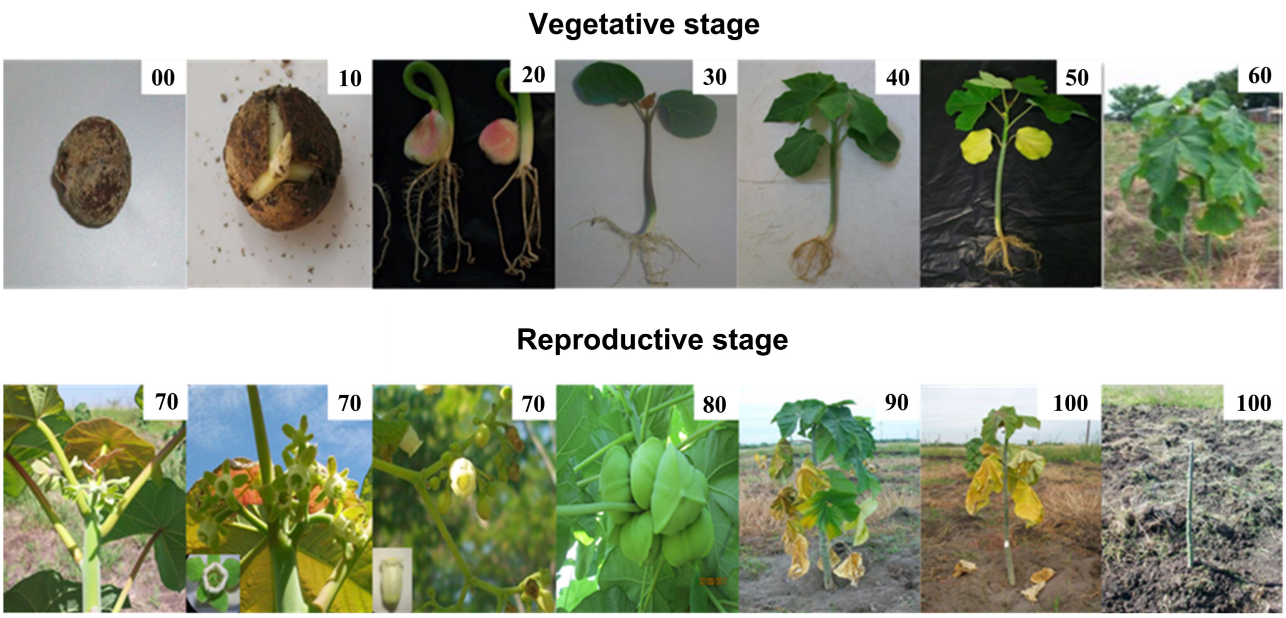


Figure 3. Coding and phenological stages of *Jatropha platyphylla* (monoecious and dioecious) (BBCH, 2001) [18].

Table 2. Thermal requirement [accumulated degree-days (˚D)] and chronological time for the phenological stage of *Jatropha platyphylla*.

BBCH Scale	Phenological stage	Degree days (˚D)		Average date	
		Per stage	Accumulated	Per stage	Accumulated
00	Sowing	0	0	0	0
10	Germination	24	24	3	3
20	Seedling emergence	98	122	14	17
30	Cotyledon stage	87	209	8	25
40	2nd true leaf	302	511	27	52
50	4th true leaf	524	1035	42	94
60	Vegetative cycle	302	1337	25	119
70	Flowering	303	1640	30	149
80	Fruiting	342	1982	41	190
90	Maturing	126	2108	63	253
100	Senescence	450	2558	70	323

the study season. The development of the plant was evident after certain phenomena, such as the appearance of the air system, manifested by the emergence of the curved hypocotyl that occurred between the fifth and fourteenth day after planting with a requirement of 98˚D. The plant was required to accumulate a total of 2558 (˚D) and 323 calendar days, to complete its biological cycle; where, 1337˚D were for the vegetative cycle and 115 calendar days, while 1221˚D and 208 calendar days were required for the reproductive cycle. It was determined that a cumulative thermal requirement of 1035˚D is necessary for the appearance of the first four true leaves. Likewise, 303˚D were required for flowering. The thermal requirements for the formation of the first fruit cluster were 1982˚D accumulated. Moraes *et al.* [29] evaluated *Jatropha curcas* irrigated and non irrigated systems, they found for fruit development was required 3271˚D and 2245˚D, respectively. In more favorable environmental conditions, the plants require more degree days for flowering, whereas a higher percentage of energy is expended on growth and dry matter accumulation. Potentially, there is a physiological binomial growth development, which is sometimes balanced. However, increased investment in one event deters the progress of another and vice versa. The same data distribution is not recognized for the counting of days, because this variable is less appropriate for the estimation of plant development [30].

The growth of the plant expressed in height showed to be continuous. *J. platyphylla* grew rapidly, in 3 months it acquired a height of 30 cm on average, similar to that reported for 12, wherein 3 months it can reach between 30 and 40 cm high [31]. The plants reached an average height of 74 cm until the beginning of fruiting, where a stalk in the growth of the stem was observed, which remained constant until reaching a maximum growth of 80 cm during the cycle April 2017 to March 2018. *Jatropha* plants take 5 to 7 weeks to reach the appropriate transplant height in the field [31]. The phenology of fruit species such as *J. platyphylla* depends largely on the environmental conditions of a particular year, which is why some interannual variability can be expected in the occurrence of phenological events [32]. Reproductive development started after 4 months of sowing, in the month of September during the rainy season. However, in tropical and humid regions it occurs almost all year [31]. The continuous flowering of the place to the production of fruits for 4 months per year, so it must be harvested 3 times during this period [33]. In November, the leaf fall began and in January, completely bare plants were observed, the plant being in a state of winter rest or dormancy.

The data analysis indicates that the highest development rate occurred at an average temperature of 29˚C, where the growth increase was 18 cm. Optimal climate conditions reported for *J. platyphylla* include temperatures of 29˚C - 34.0˚C and annual precipitation of 800 - 1500 mm [22]. In January 2018, the average temperature was 18˚C and low plant growth (0.6 cm) was obtained. This growth habit has been described in *J. curcas* at range of 18˚C [33] - 18.6˚C [34]. The value of lower basal temperatures for the development of *Jatropha* was estimated at 7.2˚C in total cycle stage [28]. The results show that *J. platyphylla* responds better to climates with high average temperatures (greater than 19˚C) than to cold temperatures, where its growth decreases (**Figure 4**).

3.3. *Jatropha platyphylla* Phenology Model

The estimated model for *J. platyphylla* in cumulative degree-days (˚DA) was Equation (3).

$$\text{Stage} = -0.0041x^3 + 0.7446x^2 - 8.6808x + 6.2448 \quad (3)$$

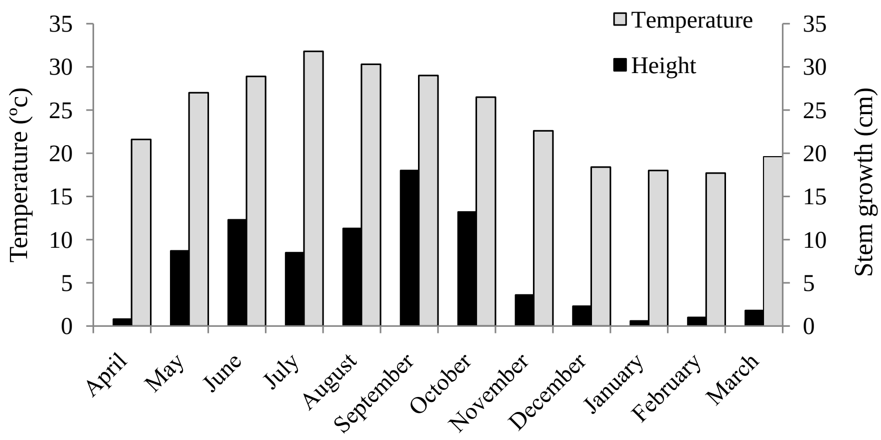


Figure 4. Influence of temperature on the growth of the *Jatropha platyphylla* plant (2017-2018) obtained from the experimental lot of La Campana, Culiacán, Mexico.

High correlation was observed in model (R^2 = 0.9927). Cesaraccio *et al.* [35] mentioned if a model is accurate, the regression slope should be near unity and the intercept near zero. Using the fitted model it was possible to determine phenological stage record from the date of sowing the maximum and minimum temperatures, and calculate the degrees days accumulated (˚DA) (**Figure 5**). The calculated models allow to predict of the phenological stages of the plant, for this it is necessary to record from the date of sowing the maximum and minimum temperatures, and calculate the degrees days accumulated (˚DA). Phenological models are tools aimed at knowing and predicting the development of plants such as flowering and development of seeds [30], and an instrument for observing forest phenology at climate change [36]. The application of these models includes the estimation of the harvest times of some crops; they also allow the implementation of agronomic practices oriented to increase or decrease the development of the crop, with the management of the temperature through ventilation in a production greenhouse of plants. In the same way, it can allow the planning of other management practices with great influence on growth such as fertilization, planting time, irrigation, pest management and diseases [37]. Crop and pest models can be used concurrently to forecast watering points for the crop based on the state of phenological development and thermal requirement [38] [39]. Degree-day calculations are essentially statistical features needed for calculation. In the context of nonlinear development summation, their precise values are less critical, and they are used mostly as convenient cut points for calculation. The actual existence of such thresholds is questionable, because they are very difficult to measure owing to excessive mortality when organisms are kept at those temperatures for long periods [40]. The non-linear relationship between phenology and temperature can explain the different responses to warm climates in woody and herbaceous species [41]. Observational studies at the local scale, together with local meteorological observations, can generate suggestions for possible environmental drivers of phenology [42].

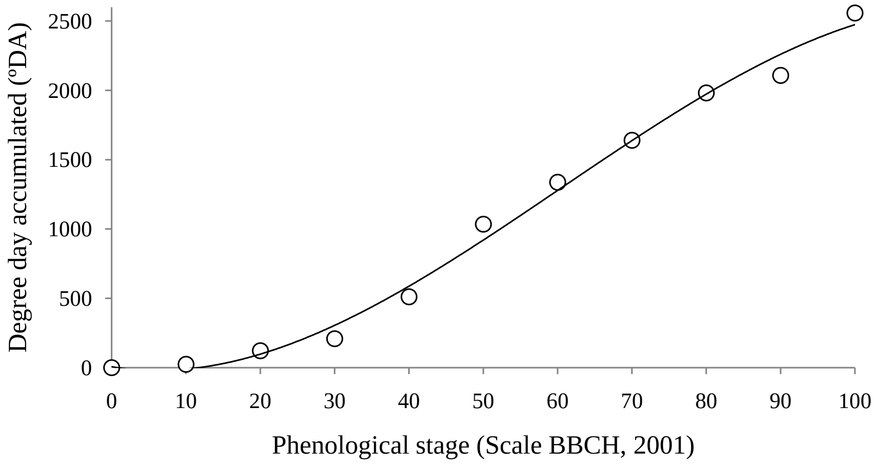


Figure 5. Estimated model for the phenological stages of *Jatropha platyphylla*.

4. Conclusion

Increasing temperatures have a significant effect on crop phenology. The results suggested that the model is a simple and accurate method to approximate the daily temperature curve from maximum and minimum daily temperatures and calculate growing degree-day values. The estimated model for *J. platyphylla* in cumulative degree-days (˚DA) provided excellent estimates of the number of days between phenological stages. The good predictive capability of the algorithms tested suggested that they were adequate for estimating effects on *J. platyphylla* phenology. Phenology is also one of the most important phenotypes considered in varietal selection in plant breeding.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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