Chapter 2
Genetic Resources and Advances in the Development of New Varieties of *Jatropha curcas* L. in México

José Luis Solís Bonilla, Biaani Beeu Martínez Valencia, Guillermo López-Guillén, and Alfredo Zamarripa Colmenero

Abstract The objective of this chapter is to present the studies carried out in Mexico on *Jatropha curcas* L. for the generation of new varieties to satisfy the demand of the industries. The importance of genetic diversity to develop new improved varieties is discussed. Varietal trials were established in four tropical environments of Mexico based on genotypes selected according to their promising agronomical and industrial attributes. The main selection criteria addressed were grain yield, oil content, growth habit, and the presence of female flowers. *J. curcas* presents a large variation in yield over the years with several types of behavior. The best genotypes of the clonal trials were two clones with 100% female flowers and one clone with a predominance of male flowers, but also with the presence of female flowers. The oil content, fatty acid composition, and physicochemical characteristics of 13 selected elite genotypes were evaluated based on their yield, resulting in an oil content between 48.3% and 56.8%. The oil of *J. curcas* is considered unsaturated with the major components, in the genotypes evaluated, being oleic acid (21.5–39.7%) and linoleic acid (29.2–46.7%). Two female varieties with 100% female flowers were registered with the names "Gran Victoria" and "Doña Aurelia," while a variety with the highest proportion of male flowers was used as a pollinator for the two female varieties and registered as "Don Rafael."

Keywords Mexican jatropha · breeding · biodiesel

J. L. Solís Bonilla · B. B. Martínez Valencia (✉) · G. López-Guillén · A. Zamarripa Colmenero
Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Campo Experimental Rosario Izapa, Tuxtla Chico, Chiapas, Mexico
e-mail: martinez.biaani@inifap.gob.mx

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2.1 Introduction

The growing need to reduce greenhouse gas (GHG) emissions has promoted the interest in renewable energy sources, in general, and in the production of liquid bioenergy from oilseeds, in particular; biodiesel is considered as a renewable source of non-toxic fuel that can be produced from a wide range of nonedible oleaginous raw materials.

Jatropha curcas L. has become a crop of industrial interest since the oil produced by this crop can easily be transformed into liquid biofuel that meets American and European quality standards by transesterification (Azam et al. 2005; Tiwari et al. 2007). In addition, the oil of *J. curcas* can also be used for alternative products, such as soap, candles, varnish, lubricant, hydraulic oil, and biocides (insecticide, molluscicide, fungicide, and nematicide) (Adebowale and Adedire 2006; Shanker and Dhyani 2006).

With the purpose of domesticating *J. curcas*, several Asian countries, Indonesia and India in particular, have investigated its genetic diversity; their findings indicate that it was low among the material collected in different geographical regions of India (Pandey et al. 2012). In Latin America, there has been a great interest in working with *J. curcas* to produce biodiesel as well, and plantations of *J. curcas* were undertaken on a large scale. Unfortunately, in Mexico and other countries of America, such as Nicaragua and Brazil, crop productivity was very low, and profitability was zero or even negative, which promoted programs of selective breeding for improved varieties (Zamarripa and Solís 2013a; Zamarripa and Pecina 2017).

Plant breeding uses principles from a variety of sciences to improve the genetic potential of plants; it is an efficient and sustainable economic strategy to meet agronomical challenges, such as low production and biotic or abiotic limitations. The process involves the combination of elite parental plants to obtain the next generation with improved characteristics. Breeders improve plants by selecting individuals with the greatest potential to transmit their valuable features to their progenies. Plants are improved for food, feed, fiber, fuel, and a variety of other features useful to human activities.

Considerable genetic variations can be expected in the growth, chemical composition, and characteristics of seeds according to their provenance, variety, or progeny, particularly in cross-species, such as *Jatropha*, *Acacia*, and *Prosopis*, which are widely used in agroforestry systems across landscapes throughout the world (Kaushik et al. 2007). Variation would be useful as a source of future genetic selection provided that the types desired for agroforestry systems are clearly defined (Cannel 1982; Burley et al. 1984; Von Carlowitz 1986).

According to Zamarripa and Pecina (2017), genetic improvement can be successful if it starts with a selection process that contains high genetic variability that enables to identify genotypes and genes that regulate the agronomical and industrial traits of interest. In this context, this chapter will discuss advances in the development of new varieties of *J. curcas* obtained from the great diversity of genetic resources existing in the southern part of Mexico.

2.2 Genetic Resources

According to the International Plant Genetic Resources Institute (IPGRI), the Plant Genetic Resources (PGRs) are living beings that carry valuable traits and have been used in the development of improved crops since the beginning of agriculture. The importance of PGRs has increased in contemporary times, to face current and future challenges such as the adaptation of crops for changing climatic conditions and to tolerate biotic and abiotic stresses.

Germplasm banks have assumed a paramount importance for the safe ex situ conservation of genetic resources. Germplasm banks have the main responsibility of collecting, regenerating, conserving, characterizing, evaluating, documenting, and distributing their stored germplasm and warrant its secure conservation by maintaining duplicates of unique and important genetic resources (Tyagi and Agrawal 2015).

The value of a germplasm bank of *J. curcas* lies in the use of its genetic resources for the domestication of the species and the obtention of new varieties. The characterization of a plant is defined as the description of the variation that exists in a collection of germplasm in terms of morphological, biochemical, agronomical, and molecular characteristics and allows its relative according to the accessions established in germplasm banks as well as the genetic diversity of the whole (Hidalgo 2003), which is the first step that determines to a large extent the success of future commercial crops.

In 2008, Mexico voted the Law of Promotion and Development of Bioenergetics, which incepted the diversification of energy resources through the promotion of the agro-industry of oilseeds to produce biodiesel (Zamarripa and Solís 2013b). The Federal Government of Mexico, since that date, has fostered the research and development of bioenergetics, which is why the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP) in the Rosario Izapa Experimental Station has germplasm banks of species such as jatropha (*Jatropha curcas* L.), castor bean (*Ricinus communis* L.), moringa (*Moringa oleifera* Lam.), coyol (*Acrocomia mexicana* Karw. ex Mart.), jícaro (*Crescentia* sp.), tevetia (*Thevetia peruviana* Pers.), napahuite (*Trichilia hirta* L.), totoposte (*Licania arborea* Seem.), corozo (*Scheelea lundellii* Bartlett), and forage species.

INIFAP through its research program on bioenergy realizes the conservation of national germplasm of *J. curcas*. In the Rosario Izapa Experimental Station, there are about four hectares of plantations that make up the National Germplasm Bank of *J. curcas* with 422 accessions from Chiapas, Oaxaca, Yucatan, Tamaulipas, Veracruz, Puebla, Guerrero, Morelos, San Luis Potosí, Michoacán, and Jalisco. There is also an exclusive germplasm bank with non-toxic *Jatropha* with a total of 25 accessions that were collected in the state of Puebla, Oaxaca, and Veracruz. The collections were made in the years 2007–2009 under different conditions of soil, climate, and altitudes that varied from 0 to 1950 m above sea level. The national collection is in the municipality of Tuxtla Chico, Chiapas, an area of humid tropical forest (Zamarripa 2011; Zamarripa and Solis 2013a).

2.3 Selection Criteria

The genetic improvement of plants has occurred empirically since the beginning of agriculture with the domestication of plant species of anthropocentric interest. As a result of this selection process that holds for some thousands of years, farmers have selected plants with outstanding shape, color, and taste, among other characteristics. Following the emergence of modern genetics with the publication of the Principles of Inheritance of Gregor Mendel in the nineteenth century, genetic improvement began to lay its scientific basis into what we know today.

The improvement of plants is the continuous search for a genetic gain. Breeders use preexisting genetic material that constitutes its raw material. According to Demarly (1977), selective breeding is the search to produce a genetic structure adapted to the criteria and needs of humans, from an imperfect preexisting construction. Progresses in selective breeding occur only if the available plant materials have significant genetic variability. The variation observed in plants depends on the interaction between genetic factors and the environment. The genetic constitution determines a variation that is intrinsic to each individual and depends on its origin. The variation due to the medium is independent of the origin of the individual and is not heritable.

The genetic improvement of plants is an economic, efficient, and sustainable strategy in the solution of agronomical, as well as biotic and abiotic, constraints, which enables to increase yields and product quality to warrant a better competitiveness. For the genetic improvement process to be successful, large genetic variability is necessary for the identification of genotypes and genes that regulate the agronomical and industrial traits of desirable interest.

In 2007, INIFAP began the collection, conservation, and characterization of genetic resources of *J. curcas* in various states of the Republic of Mexico. From a collection of 422 accessions of diverse geographic origins (Zamarripa 2011), the characterization of morphological (Avendaño and Zamarripa 2012) and biochemical (Zamarripa et al. 2012b) traits as well as the genetic variability within the germplasm through molecular biology confirmed the existence of a large genetic base (Pecina et al. 2011). Pecina et al. (2011) showed that the diversity index of *Jatropha* germplasm in Chiapas was as high as 60%. Another study where a representative set of 175 *Jatropha* accessions from nine states of central and southeastern Mexico was used for the analysis of diversity by means of amplified fragment length polymorphism (AFLP) suggested that Chiapas could be the center of origin of *J. curcas* and that domestication was carried out in the states that border the Gulf of Mexico (Pecina et al. 2014). Thus, breeding materials for selection programs have been collected according to the agronomical features of different genotypes.

2.4 Agronomical Assessment and Selection for Crop Varieties

The agronomical characterization of varieties can be defined as the description of the behavior of a genotype or a population in a given environment. For the agronomic evaluation, we worked with a population of 288 individuals during the fourth year of production and recorded the number of inflorescences, number of male and female flowers, number of fruits, weight of fruit, and yield of fruit and seed (Table 2.1).

The number of fruits varied from 0 to 1018 fruits per plant, with a variation in weight of 4.9–30 g per fruit. The yield varied depending on the accession between 10 g and 4.9 kg of fruit per plant. Zamarripa and Pecina (2017) mentioned that the number of inflorescences in the plant and the number of female flowers are good predictors of yield because they were found to be positively correlated with the yield (0.83 and 0.78, respectively). In addition, the total number of fruits, the number of fruits harvested, the average weight of fruits, the total number of seeds, and the average weight of seeds showed high positive correlations with seed yield. For the variability of toxicity, we found plants without phorbol esters whose material is native to Puebla and plants with a high phorbol ester content of up to 3.56 mg/g.

The number of inflorescences varied from 1 to 230 per plant. The maximum value of male flowers was 17,883 flowers per plant. The maximum value of female flowers was 1064 flowers per plant. The ratio of male to female flowers was 12:1; however, trees with complete female flowers were detected. *J. curcas* is a species which is able to produce fruits by self-pollination and cross-pollination. According to Qing et al. (2007), *J. curcas* is self-compatible, but its cross-pollination achieves 86.6% when performed artificially and 76.4% occurring naturally, which allows a large degree of genetic variation and a broad set of possibilities to select plants with desired traits.

Obtaining varieties with high energy efficiency and good agro-industrial yield will grant security and profitability to Mexican and international producers to face competition in the market of agroenergetic supplies.

Given the great heterogeneity of environments present in Mexico, it was essential to perform experiments in a wide range of environmental conditions to examine both the adaptation and the adaptability of *J. curcas* varieties. The varietal assessment allowed selecting five best genotypes for evaluation in different environments.

Table 2.1 Variation of flower, fruit, and seed characteristics per plant in *J. curcas* accessions from the germplasm bank of INIFAP (Zamarripa and Solis 2013a)

Characteristics	Range
No of inflorescences	1–230
No of male flowers	6–17,883
No of female flowers	1–1064
No of fruits	0–1018
Average seed weight (g)	0.6–1.3
Seed length (cm)	1.1–2.1
Seed thickness (cm)	0.7–1.7
Seed weight per plant (kg)	0.01–4.9
Toxicity (phorbol esters) (mg/g)	Absent–3.56

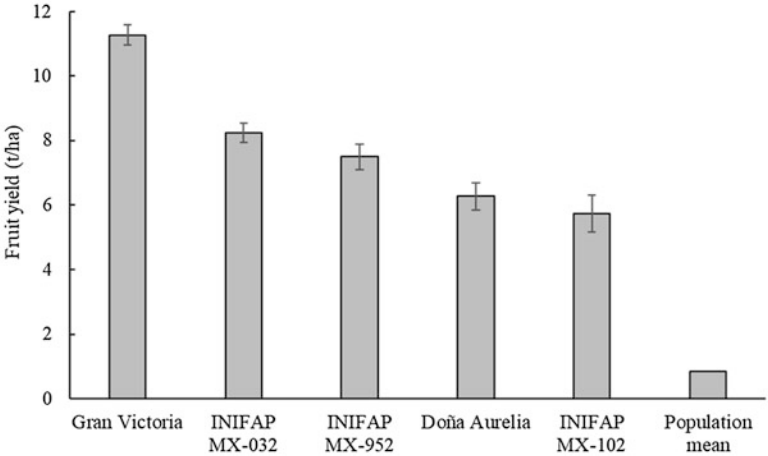

Fig. 2.1 Fruit yield of selected elite genotypes in the germplasm bank of *J. curcas*, compared to the average of 288 genotypes

Figure 2.1 shows the fruit yield of elite selected genotypes of *J. curcas* compared to the population average of 288 varieties that reaches an average yield of 0.839 t/ha of fruits. In contrast, the best five accessions reached between 5.7 and 11.2 t/ha which means that one can obtain genotypes that have 7–13 times higher yield just by individual selection.

Figure 2.2 shows the grain yield of selected elite genotypes of *J. curcas*; the best five accessions reached yields of 1.07–1.98 t/ha, which means that individual selection enables to obtain genotypes that present up to 12 times higher yield.

Considering that *J. curcas* is a perennial crop, the yields of the first three harvests are insufficient to determine the best genotype of the group under study, which makes necessary to assess the yield of at least five harvests (Zamarripa 2011). Consequently, the suitable productive cycle at which a representative selection based on seed yield can be performed was assessed over a period of time, and the seed yield of the genotypes under investigation was recorded during 6 years, as shown in Fig. 2.3. These genotypes were cultivated with the same agronomic management and under the same environmental conditions. It has been observed that yield of these genotypes continuously increased until the fourth year and decreased in the fifth year, as shown in Fig. 2.3. For example, INIFAP-MX 03 produced a yield of 1979 kg/ha in the fourth year; thereafter, the yield fell to 1334 kg/ha in the fifth year and continued to decrease to 826 kg/ha per plant in the sixth year. In general, the yield of these genotypes remained low in the following years. *J. curcas* thus exhibits a great variation in performance over the years and shows varied behavior in terms of yield. However, genotypes with early and sustained production were found, and these genotypes were good candidates for multilocation trials.

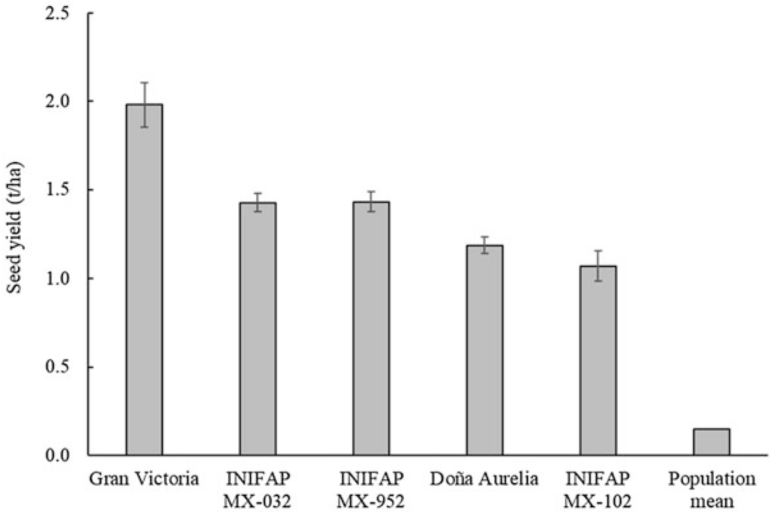

Fig. 2.2 Yield of selected elite genotypes in the germplasm bank of *J. curcas*, compared with the average of 288 genotypes

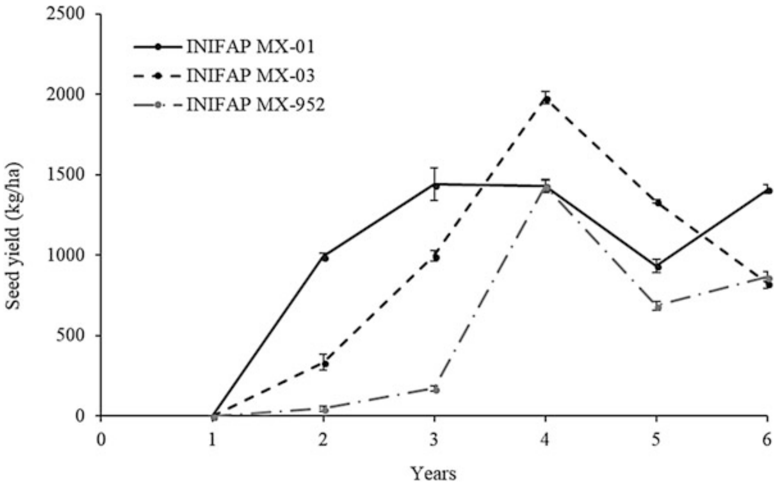

Fig. 2.3 Performance of dry seed yield (kg/ha) during six production cycles in three genotypes of *J. curcas*, in the humid tropics of Mexico

2.5 Physicochemical Characterization of Seeds and Oil of *J. curcas*

Zamarripa et al. (2012a) reported a large variation in oil content, protein content, and fatty acid composition in the germplasm collection of INIFAP. The quality of the biodiesel depends on the fatty acid composition of the vegetable oil from which it is derived, that is to say, the degree of unsaturation and branching of oil influence fuel parameters such as cetane number, point of fusion, and oxidative stability, among others (Knothe 2005; Steen et al. 2010). Samples of 13 elite genotypes selected for their yield characteristics were assessed for their physicochemical properties and fatty acid composition.

In Table 2.2, the results of the physical characterization of the seeds are presented; these were classified in internal (kernel) and external (shell). For the variable of seed weight and humidity, significant differences were detected ($P \leq 0.05$), among the elite genotypes evaluated. The seed weight varied from 0.69 to 1.05 g; the genotypes INIFAP-MX 351, INIFAP-MX 721, and INIFAP-MX 254 showed the highest weight of 0.88, 0.90, and 1.05 g, respectively. The average of the 13 individuals evaluated was 0.82 g. The seed moisture ranged from 3.91% to 5.35%. The water content in the seed is a very important factor during the extraction of the oil regardless of the method chosen. Bernardini (1981) mentions that each seed must have an optimum humidity of less than 9%; a humidity above this value represents a decrease in the effectiveness of transformation, generating emulsions between water and oil, which occurs in the surface of the particles, which prevents the solvent from penetrating the kernel fibers and solubilizing the oil.

In Table 2.3, the oil content, fatty acid composition, and some physicochemical characteristics of *J. curcas* oil are given. The oil content varied from 48.3% to 56.8%. The results of the seed oil content are similar to those obtained by Achten et al. (2008) reporting an oil content of 54.6% and Foidl et al. (1996) reporting 57.4%. It should be noted that ten genotypes had values greater than 50% oil. Two of them stand out for having oil contents between 55% and 60% and were selected as parents in genetic improvement programs. The quality of biodiesel also depends on

Table 2.2 Average weights of *J. curcas* seeds and shells

Genotype	Seed weight (g)	Kernel weight (g)	Shell weight (g)	Humidity (%)
INIFAP-MX 821	0.77bc	0.47b	0.30bcdef	4.66c
INIFAP-MX 254	1.05a	0.67a	0.38a	5.36a
INIFAP-MX 331	0.88ab	0.55ab	0.34abcd	5.26a
"Don Rafael"	0.82bc	0.54ab	0.29cdef	4.94b
INIFAP-MX 721	0.90ab	0.55ab	0.35ab	4.87b
"Gran Victoria"	0.75bc	0.49b	0.26ef	4.50c
INIFAP-MX 952	0.69bc	0.45b	0.24f	3.93d
INIFAP-MX 32	0.80bc	0.51b	0.29cdef	3.80d
INIFAP-MX 102	0.71bc	0.45b	0.25ef	4.49c
INIFAP-MX 341	0.86bc	0.54ab	0.32bcd	4.86b
INIFAP-MX 244	0.86bc	0.51b	0.34abc	4.58c
"Doña Aurelia"	0.81bc	0.51b	0.30bcde	3.84d
INIFAP-MX 362	0.74bc	0.46b	0.28def	3.92d
Average	0.82	0.52	0.30	4.54
CV%	14.10	15.18	14.92	11.47

Averages with the same letters are not statistically different (Tukey = 0.05)

Table 2.3 Chemical characteristics of oil from 13 genotypes of *J. curcas*

Genotype	Oil content (%)	Fatty acids (%)			Iodine (mg iodine/g)	Density at 15 °C (g/cm^3)	Viscosity at 40 °C (mm ^{2}/s)
		Saturated	Monounsaturated	Polyunsaturated			
INIFAP-MX 821	54.6ab	34.60ab	29.72def	35.67cdef	106.183cd	0.920e	35.04d
INIFAP-MX 254	51.0cd	33.27abc	32.86cd	33.87def	96.762g	0.920de	34.01f
INIFAP-MX 331	50.8cd	31.5abcd	39.12ab	29.34f	106.013cd	0.921bc	33.60h
“Don Rafael”	51.1cd	35.9a	29.10def	34.95cdef	105.409d	0.920bc	33.92g
INIFAP-MX 721	48.3cd	23.45fg	41.39a	35.15cdef	106.013cd	0.921bc	33.22i
“Gran Victoria”	53.4bc	20.9g	34.95bc	43.94ab	109.169bc	0.921bc	32.79j
INIFAP-MX 952	55.1ab	24.23efg	35.54bc	40.23abcd	106.323cd	0.920cde	33.94g
INIFAP-MX 32	56.8a	27.77cdef	31.63cde	40.58abc	101.616ef	0.920e	33.22i
INIFAP-MX 102	49.7d	29.69bcde	26.68ef	43.62ab	111.198b	0.922ab	35.56b
INIFAP-MX 341	49.5d	26.38defg	26.90ef	46.72a	115.319a	0.922ab	37.39a
INIFAP-MX 244	50.5cd	35.23ab	32.62cd	32.15ef	94.642g	0.922ab	35.24c
“Doña Aurelia”	53.4bc	35.36ab	24.89f	39.75bcd	98.571fg	0.921ab	34.89e
INIFAP-MX 362	54.8ab	36.43a	25.34f	38.22bcde	103.995de	0.901f	19.12k
CV%	5.12	17.59	16.32	13.41	4.25	0.638	13.018

Averages with the same letters are not statistically different (Tukey = 0.05) the physicochemical properties of the oil. The excess of free fatty acids determines the necessity of an additional prestep of esterification in order to avoid saponification during the transesterification process.

Significant differences were found ($P \leq 0.05$) for fatty acids (saturated, monounsaturated, and polyunsaturated), iodine, density, and viscosity. For saturated fatty acids (palmitic, stearic, arachidic), the proportion interval ranged from 20.9% to 36.4%, while monounsaturated (mainly oleic) varied between 24.9% and 39.1%, and polyunsaturated (linoleic, linolenic, and icosenoic) varied from 29.3% to 46.7%. The unsaturated fatty acids (monounsaturated and polyunsaturated) ranged from 64.7% to 78.9% of the total fatty acid content in the oil of *J. curcas*. Saturated fatty acid content increases the point of cloud or fog (solidification of the oil) and the cetane number (quality of combustion) and improves the oxidation stability of biodiesel. The genotypes with the highest monounsaturated fatty acid content were INIFAP-MX 721 and INIFAP-MX 331 with 41.4% and 39.1%, respectively. Ideal oils should have low content of saturated fatty acids and high content of monounsaturated fatty acids, especially oleic acid.

The iodine index varied between 94.64 and 115.64 mg iodine/g. According to the European standard EN-14214, the maximum permissible value of iodine index of biodiesel is 120 g I_2/100 g. Very low values of this index indicate a higher risk of solidification at cold temperatures. ASTM 6751 establishes permissible ranges of 1.9–6 mm^2/s for fuel viscosity. The oil viscosity of elite genotypes was lower than the value of 42.88 mm^2/s indicated by Akbar et al. (2009) and ranged from 19.12 to 37.39 mm^2/s. It is worth mentioning that the viscosity of *J. curcas* oil decreases by more than 85% when it is transformed into biodiesel and falls within the range of 2.59–5.08 mm^2/s, which is in agreement with international standards.

The oil density of the evaluated elite materials ranged from 0.901 to 0.922 g/cm^3. The European standard states that oils destined for the production of biodiesel should not have densities lower than 0.860 g/cm^3. When transformed into biodiesel, the oil density decreases by 4% and was found in the evaluated genotypes to be in the range of 0.866–0.885 g/cm^3. This parameter determines the maximum proportion of biodiesel that can be used in mixture with fossil diesel (B5, B10, B15, etc.). It may be the case that the mixtures do not comply with the official standard; this may occur with mixtures containing a high amount of biodiesel, or in those in which the density of the mixture of diesel and biodiesel is close to the upper limit allowed, which is 0.900 g/cm^3.

As discussed above, fatty acid profile and quality of oil and biodiesel differ largely between elite genotypes (data not shown), so that genetic improvement through intraspecific hybridization and/or individual selection is a high priority for the future success of *J. curcas* as a main supplier of oil for biofuel production in Mexico. It is clear that the supply of quality oil is key to the biodiesel industry. Therefore, the quality of the biofuels generated is directly dependent on the type of raw material used.

The research and selective breeding programs are key elements in the development of a sustainable and efficient biofuel industry. The species *J. curcas* presents physicochemical characteristics suitable to meet the supply of a sustainable source of raw material to produce biodiesel.

2.6 Variety Selection

According to the productivity of genotype selected individually on the basis of their agronomical performances over several years and in various environments, three clonal varieties were retained for their outstanding seed yield, oil content, growth habit, and/or female flower-only features. "Doña Aurelia "and "Gran Victoria" are female only, while "Don Rafael" serves as a good pollinator since it presents a larger proportion of male flowers. To initiate the commercial sowing and to take care of the high demand of plants and oil to feed the national energy industry, INIFAP registered officially in September 2014 the three clonal varieties just outlined in the "National Catalog of Plant Varieties" (CNVV) of the Inspection and Certification of Seeds of National Service (SNICS) belonging to the Secretariat of Agriculture, Livestock, Rural Development, Fisheries, and Food. The elaboration of the varietal description of the new varieties was based on the "Technical guide for the description of the variety of *Jatropha*" published by SNICS (2014). The breeding methodology used to obtain the varieties was the clonal selection (Zamarripa and Pecina 2017). The clonal varieties are a set of plants that are derived from the same parent plant by vegetative propagation. These collections allow us the first evaluation of a clone for interesting features such as yield, vigor, growth habits, disease resistance, and oil quality. Elite plants are multiplied as rooted cuttings and evaluated in cloning trials along with standard varieties. The best selected clones in a country of origin are not necessarily suitable for other countries due to the environmental interaction. Given the ease of asexual propagation of *J. curcas*, this method is interesting to be considered in genetic improvement programs (Zamarripa and Pecina 2017). Next, we present the characteristics of the elite three varieties of *J. curcas* registered by INIFAP.

2.6.1 Variety "Doña Aurelia"

The tree has an intermediate shape, open canopy, and drip area of 4.0 m^2. The stem is green with a diameter of 4.3 cm, branched from the base with 3 axes and 61 branches on average, which have apical leaves. The leaves are small in web form with five lobes. The shoots are green with tan tones (Fig. 2.4).

This variety is female only with 100% female flowers and has a yield of 211 bunches, with 909 female flowers. It presents yields of 820 seeds with an

Fig. 2.4 Tree characteristics of the variety "Doña Aurelia." (**a**) Branching from the base and structure, (**b**) canopy coverage, and (**c**) height

average weight of 0.83 g. The seeds have a length of 1.99 cm, 1.09 cm in width, and 0.89 cm in thickness (Zamarripa and Pecina 2017). This variety identified for the conditions of Chiapas, Mexico, presents yields at the fourth year of 1,182 kg/ha of seed with oil content of 53.4%.

2.6.2 Variety "Gran Victoria"

This variety is of intermediate size with open cup and drip area of 4.01 m^2. The stem is green with a diameter of 5.5 cm, branched from the base with 4 axes and 95 branches on average, which have apical leaves. The leaves are large heart-shaped with three lobes. The shoots are tanned (Fig. 2.5).

The variety presents 100% female flowers with large sepals, with 94 clusters on average, which produce 408 pistillate flowers (Fig. 2.5). The seed is black, elliptical in shape. This variety presents a production of 799 seeds with an average weight of 0.77 g. The seeds have a length of 1.74 cm, 1.15 cm in width, and 0.93 cm in thickness (Zamarripa and Pecina 2017). For the region of Chiapas, Mexico, this variety presents yields of 1, 979 kg/ha of seeds at the fourth year with oil content of 53.4%.

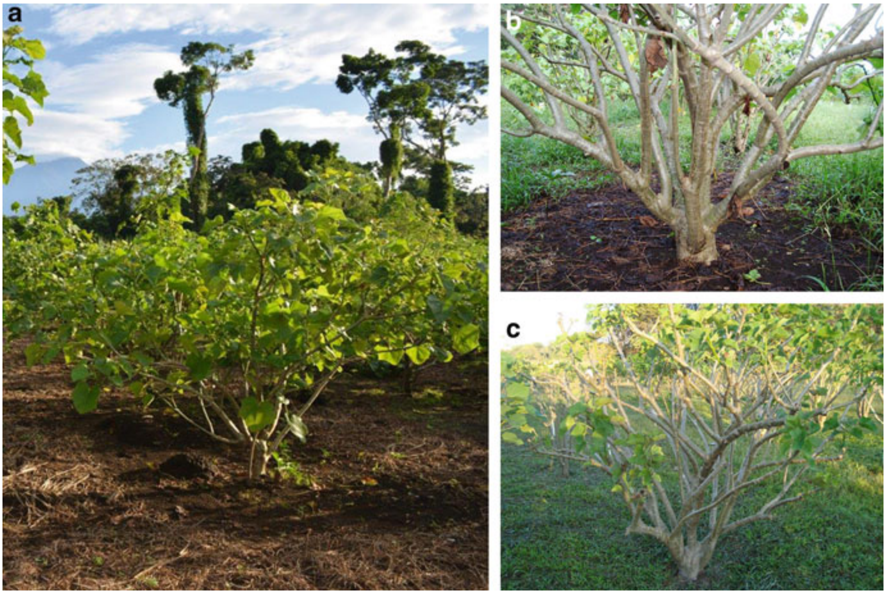

Fig. 2.5 Tree characteristics of the variety "Gran Victoria." (**a**) Canopy coverage and height, (**b**) branching from the base, and (**c**) structure

2.6.3 Variety "Don Rafael"

The trees of this variety are of intermediate size, erect, and with intermediate branching; they have an average of 20 male flowers for each female flower, which is why it is considered as a pollinating variety. The oil content in the grain is 49.8%. The seed yield at the fourth year of planting is 900 kg/ha (Fig. 2.6).

2.7 Conclusions and Future Perspective

To preserve the varietal identity, these three important varieties must be propagated asexually by stem cuttings and established in clonal gardens. The cuttings should be a minimum of 40 cm long and 3 cm thick for greater field strength. The clonal varieties "Don Rafael," "Gran Victoria," and "Doña Aurelia" are found in clonal gardens of 0.5 ha in four experimental stations of the INIFAP: in the Rosario Izapa Experimental Station, in the municipality of Tuxtla Chico, Chiapas; C.E. Valley of Apatzingán, in Michoacán; C.E. Las Huastecas, in the municipality of Altamira, Tamaulipas; and C.E. Mocochá, in the municipality of Uxmal, Yucatán. The use of these three clonal varieties of *J. curcas* will allow to meet

Fig. 2.6 Tree characteristics of the variety "Don Rafael": canopy coverage, height, and structure

the short- and medium-term demand of both the plants and oil for the energy industry. Farmers in Mexico may have other alternatives for profitable and competitive production in terms of production of biofuels and generation of employment through crop production and biofuel processing industry.

The use of clonal varieties of the INIFAP will enable to increase the production of raw material to warrant a sustainable production of biofuels. In Mexico, according to the maps of productive potential generated by the INIFAP, more than 1 million hectares under dryland conditions have been identified with high potential for *J. curcas* cultivation with an altitude of 0–900 m, temperature range of 18 and 28 °C, and rainfall between 900 and 1500 mm per year, excluding the areas currently occupied by natural forests and jungles, in which these varieties could be cultivated not only to increase the current yields but also to address the ecological concerns and issues regarding climate change. The development of *J. curcas* as a crop through the use of the three varieties of INIFAP for the production of biofuels will have a favorable impact on the environment since they yield biodegradable compounds, with positive energy balances of 1:5.1 ratio, which reduce the emission of polluting gases by more than 70% with respect to the fossil diesel reference that equals 83.8 kg CO_2eq GJ. Further, it reduces the greenhouse effect which directly contributes to the reduction of the problems caused by climate change and its impact on human health as well as on the ecological environment (Zamarripa et al. 2012a; Zamarripa and Solis 2013a).

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