FLORAL BIOLOGY AND BREEDING SYSTEM OF *JATROPHA CURCAS* IN NORTH-WESTERN INDIA

K Kaur, GPS Dhillon* & RIS Gill

Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana-14001, India

Received November 2009

KAUR K, DHILLON GPS & GILL RIS. 2011. Floral biology and breeding system of *Jatropha curcas* in north-western India. The study in relation to floral biology conducted at Ludhiana (central plain region of Punjab, India) exhibited that *Jatropha curcas* flowered for two seasons viz. April till June and July till November. Male and female flowers opened 7 to 10 days after bud formation. Fruiting was visible 26.5 to 30.2 days after bud formation. Fruit setting ranged from 37.0 to 61.6% and the anthesis of male and female flowers occurred between 0600 to 0700 hours and 0700 to 0800 hours respectively. Anther dehiscence was observed after 0800 hours. Flowers were unisexual and male and female flowers were produced in the same inflorescence but female flowers were bigger. The male to female ratio was 13.4:1. Mean number of pollen per anther was 122.3 and ranged from 61.9 to 195.1. Mean pollen viability was 71.6%. Results of the breeding system showed fruit setting of 93.2, 72.2, 36.2 and 79.2% in cross pollination, self pollination, apomixis and open pollination respectively.

Keywords: Flowering span, anthesis, pollen dehiscence, pollen viability, breeding system

KAUR K, DHILLON GPS & GILL RIS. 2011. Biologi bunga dan sistem pembiakan *Jatropha curcas* di barat laut India. Kajian tentang biologi bunga yang dijalankan di Ludhiana (daerah dataran tengah Punjap, India) menunjukkan bahawa *Jatropha curcas* berbunga pada dua musim iaitu April hingga Jun and Julai hingga November. Bunga jantan dan betina kembang 7 hari hingga 10 hari selepas kudup terbentuk. Pembuahan kelihatan 26.5 hari hingga 30.2 hari selepas pembentukan kudup. Kejadian buah berjulat antara 37.0% hingga 61.6% dan antesis bunga jantan dan betina berlaku masing-masing antara pukul 6.00 pagi hingga 7.00 pagi dan 7.00 pagi hingga 8.00 pagi. Pembengangan cepu debunga berlaku selepas pukul 8.00 pagi. Bunga bersifat uniseks dan bunga jantan dan betina dihasilkan pada jambak yang sama. Bagaimanapun bunga betina lebih besar daripada bunga jantan. Nisbah bunga jantan kepada bunga betina ialah 13.4:1. Min jumlah debunga bagi setiap cepu debunga ialah 122.3 dengan julat antara 61.9 hingga 195.1. Min kebolehhidupan debunga ialah 71.6%. Keputusan sistem pembiakan menunjukkan kejadian buah sebanyak 93.2%, 72.2%, 36.2% dan 79.2% masing-masing dalam pendebungaan silang, pendebungaan sendiri, apomiksis dan pendebungaan bebas.

INTRODUCTION

In the current scenario of world energy crisis, and with fossil fuels being limited and unsafe to the environment, biofuels are becoming potential renewable sources of fuels. *Jatropha curcas* is one of the species that yield biodiesel. It is a multipurpose non-edible oil-yielding perennial shrub which belongs to the family Euphorbiaceae. Jatropha is believed to be a native of Mexico and Central America and has 470 species (Heller 1996). It is known by nearly 200 different vernacular names that show its wide distribution over the globe. *Jatropha curcas* is adapted to a wide range of climate and soil. It can be grown successfully as an agroforestry crop on wastelands or barren and marginal lands (Heller 1996). It is also known for its medicinal property and is effective against various diseases. It is a potential oil crop that contains 30–35% oil content by seed weight and 50–60% by kernel weight. Oil obtained after transesterification can be used as biofuel in diesel engines (Paramathma et al. 2004). Considering its economic importance, the work on genetic improvement has been taken up by the Punjab Agricultural University, Ludhiana. Information regarding time and span of flowering, phenological behaviour, anthesis pattern and fruit maturity stages are prerequisite for planning and developing breeding strategies. Investigations regarding some aspects of floral biology of *J. curcas* have been conducted in other

**Author for correspondence. E-mail: dhillongps1@rediffmail.com*

parts of India and abroad (Sukarin et al. 1987, Raju & Ezradanam 2002, Bhattacharya et al. 2005, Dhillon et al. 2006). However, no detailed study has been conducted on all aspects of floral biology. Therefore, the present investigation was aimed at understanding the floral biology of *J. curcas* under subtropical conditions of north-western India.

MATERIAL AND METHODS

Study site and plant material

The present study was undertaken from 2006 till 2008 at the Punjab Agricultural University, Ludhiana main campus (30° 56' N, 75° 61' E, 244 m above mean sea level). The region has a subtropical climate and receives a total rainfall of about 700 ± 60.2 mm. The soils are deep, well-drained, sandy loam in texture with low humus content. The pH of soil is neutral. The study was conducted on 10 trees selected randomly from boundary plantation aged four years old.

Floral biology

Weekly observations regarding bud initiation, flower initiation, anthesis of male and female flowers, fruit initiation and development and fruit set were recorded from 50 tagged inflorescences (five inflorescences per tree) from January till December 2006. Twenty inflorescences on different trees were tagged to study time of anthesis. All already opened flowers were plucked in the evening and observations were started the next morning at hourly intervals for four days, i.e. 26–29 August 2006. At each observation, opened male and female flowers were counted and plucked to avoid recounting. Another set of 20 tagged inflorescences were examined visually using a hand lens at hourly intervals starting from 0600 h for anther dehiscence and stigma receptivity. The presence of pollen powder on anther surface was considered to be anther dehiscence. Stigma was said to be receptive when it was glossy, shiny and with profuse secretion of stigmatic fluid. The dull and dry stigmatic surface was considered as non-receptive.

Palynological studies

The number of male and female flowers, anther per male flower and carpels per female flower were counted from the 50 inflorescences. The number of pollens per anther was counted by crushing the anther on a glass slide and counting the number of pollens under compound microscope at 10× magnification. Pollen viability of fresh samples collected from 10 plants was determined using TTC (2, 3 triphenly tetrazolium chloride). Viable pollen stained purplish pink and non-viable remained green or yellow. Insect visits per inflorescence per minute were observed for three times (0900, 1100 and 1300 hours) in a day in the month of August in 2006 and 2007. The flower visitors were caught and identified with help from the Department of Entomology, Punjab Agricultural University.

Breeding system

Five plants, fully covered with flowers, were identified for controlled pollination work. Twenty inflorescences were randomly selected for each breeding system in August 2008. Four tests were conducted, namely, self pollination (flowers pollinated with auto-pollen collected from the same plant), cross pollination (emasculated and bagged flowers pollinated with allo-pollen collected from different plants), apomixis (flowers emasculated prior to anthesis and bagged) and open pollination (flowers not bagged and pollination open to insects). Data were analysed following the model suggested by Panse and Sukhatme (1989).

RESULTS

Flowering and fruit development

Two flowering spans were observed during the whole year. In the first span, flower bud commenced in the third week of April and continued till the fourth week of June (Table 1). About 60 to 70% inflorescences became black, dry and withered out in May. The second flowering span initiated from second week of July and lasted till mid-November. During the first season, fruit formation started 26.5 ± 1.2 days after bud formation and 7–9 days after anthesis, whereas during the second flowering season fruit initiation occurred at 30.2 ± 2.0 days after bud formation. In the same inflorescence, male flowers opened one to two days earlier than female flowers. Fruit set in the first span was significantly lower (37.0%) compared with that of

Table 1 Time and occurrence of different phenological stages of *Jatropha curcas*

Phenological stage	First flowering span	Second flowering span
Flowering span	April third week till June fourth week	July second week till November second week
Fruit initiation	May third week	July fourth week
Opening of male flower	7.80 ± 0.31 days after bud formation	7.78 ± 0.69 days after bud formation
Opening of female flower	9.7 ± 0.75 days after bud formation	10.9 ± 0.34 days after bud formation
Fruit formation	26.5 ± 1.22 days after bud formation, 7–9 days after anthesis	30.20 ± 2.00 days after bud formation, 7–9 days after anthesis
Fruit set (%)	37.0*	61.6*
No. of fruits/inflorescence	5.2* ± 1.15, range 2–14	10.6* ± 0.96, range 6–16
No. of seeds per fruit	1.97* ± 0.16	2.7* ± 0.19
Unit seed weight (g)	0.22* ± 0.01	0.51* ± 0.05
Kernel weight (g)	0.10* ± 0.02	0.29* ± 0.01
Oil content (%)	25.4*	31.1*

*Significant t value ($p < 0.05$) between two flowering seasons

the second season (61.6%). The seed weight and kernel weight were also significantly higher in the second flowering than the first. The average oil content (25.4%) of fruits developed from the first flowering span was significantly lower than that (31.1%) of fruits collected during the second flowering span.

Time of anthesis, pollen dehiscence and stigma receptivity

Male flowers started to open after 0600 hours Maximum male flower opening (86.9%) was noticed at 0700 hours (Table 2). Female flowers anthesis occurred later than male flowers. Maximum number of female flower opened between 0700 and 0800 hours with a value of 76.3%. Within an hour of opening, anthers were fully covered with yellow pollen powder. Anther dehiscence was observed between 0800 and 0900 hours. The stigma became receptive around 0900 hours. Receptivity was confirmed by bifurcated stigma lobes at receptive stage.

Morphological characterisation

Plants produced racemose inflorescences with unisexual flowers. Normally inflorescence produced a central female flower surrounded by a group of male flowers. Male flower bud had a round head with small pedicle and female flower bud had conical head, long sepals and thick long pedicle. Flowers were green and odourless. Male flowers were small and had 10 stamens, arranged in two tiers of five each. The lower tier was free, while the upper was united. Female flowers were relatively larger than the male. The styles and stigma were three each, and the latter bifurcated. Single inflorescence had 117.4 ± 7.98 male flowers, with a range of 86.5 to 151.4 (Table 3). The mean number of female flowers per inflorescence was 13.5 ± 1.53 (range 6 to 16.6). The male to female ratio ranged from 10.4:1 to 16.4:1 with a mean ratio 13.4:1. Mean number of pollen per anther was 122.3 ± 11.5. Mean pollen diameter was 85.5 µm (range from 80.2 to 89.5 µm). Pollen viability ranged from 58.2 to 79.4% (mean 71.6 ± 10.4%).

Insect visitors included honey bees (*Apis dorsata*, *A. florea)*, butterflies, houseflies, robber flies, dragon flies, beetles, ants and bugs. It was found that insect activity was high between 1100 to 1300 hours. Nectar secretions of female flower were 3.2×10^{-4} and 1.50×10^{-3} mg per female flower at 0900 and 1100 hours respectively.

Breeding system

In the study to determine fruit set under different breeding systems, it was observed that fruiting

Table 2 Floral anthesis, anther dehiscence and stigma receptivity of *J. curcas*

	Time (hours)						
	0600	0700	0800	0900	1100	1300	1600
Mean anthesis of male flowers (%)	0	86.9 (78.0–91.6)	11.8 (8.4–22.0)	1.25 (0–5.0)	0	0	0
Mean anthesis of female flowers (%)	0	0	76.3 (61.1–87.5)	23.4 (12.5–38.8)	0	0	0
Anther dehiscence	+	+	+/-	+/-	-	-	-
Stigma receptivity	×	×	×	R	R	R	D

Values in parentheses are the range, × = non-receptive stigma; D = dull, yellowish and with black tip of stigma; +/- = presence/absence of pollen; R = receptive stigma, green shiny

Table 3 Morphology of flowers and pollens of *J. curcas*

Parameter	Range	Mean
Male flower		
Length (cm)	1.10–1.40	1.20 ± 0.01
Breadth (cm)	0.60– 0.90	0.76 ± 0.01
Female flower		
Length (cm)	1.10– 1.90	1.60 ± 0.06
Breadth (cm)	0.71–1.1	1.01 ± 0.02
Male flowers/inflorescence	86.5–151.4	117.4 ± 7.98
Female flowers/inflorescence	6–16.6	13.5 ± 1.5
Male/female flower ratio	10.4:1–16.4:1	13.4:1
Pollens/anther	61.9–195.1	122.3 ± 11. 5
Pollen size (µm)	80.2–89.5	85.5
Pollen viability (%)	58.2–79.4	71.6 ± 10.4

was significantly highest for cross pollination (93.2%) followed by open pollination (79.2%) and self pollination (72.2%) (Table 4). The lowest value was in the case of apomixis (36.3%). The number of seeds per fruit varied from 1.3 to 2.6 with significant differences between breeding systems. Open pollination gave the highest number of seeds per fruit (2.6) and was at par with cross pollination but significantly superior compared with apomixis or self pollination.

DISCUSSION

The observations on floral biology of *J. curcas* revealed that plants flowered twice a year under subtropical conditions of north-western India (Table 1). Sukarin et al. (1987) also observed two peaks of flowering seasons, namely, May and November in *J. curcas*. Similarly, two flowering spans were reported for *J. gossypiifolia* (Ashley 1995, Bebawi et al. 2005). The observations regarding mean fruit set (50%) in this investigation (37.0 and 61.6%) are similar to the value reported by Raju and Ezradanam (2002), i.e. 50%. The lower fruit set, seed and kernel weights and oil content in the first season may be due to the high temperature in May–June, and this may have affected kernel development.

The hourly observations on tagged branches showed that anthesis of male flowers occurred between 0600 and 0700 hours and female flowers opened an hour later (Table 2). Earlier studies by other workers have shown that anthesis occurred between 0530 and 0630 hours in Vishakhapatnam, India (Raju & Ezradanam 2002) and between 0730 and 0830 hours under semi-arid conditions of Hisar, India (Dhillon et al. 2006).

The morphology of infloresences and male and female flowers in the present study (Table 3) is in conformity with results of earlier studies

Table 4 Fruit set in different breeding systems in controlled pollinations

Breeding system	Fruit set (%)	Number of seeds/fruit
Cross pollination	93.2	2.4
Self pollination	72.2	1.3
Apomixis	36.3	1.6
Open pollination	79.2	2.6
CD 5%	11.4	0.5

(e.g. Heller 1996, Raju & Ezradanam 2002, Bhattacharya *et al.* 2005, Chang-Wei et al. 2007). Male and female flower ratio (11:1) observed by Reddi and Reddi (1983) in *J. gossypiifolia* is close to the value obtained in the current study (13.4:1). However, higher values have been reported, i.e. 29:1 and 20:1 by Raju and Ezradanam (2002) and Dhillon et al. (2006) respectively. This ratio varies between populations and climatic as well as nutritional conditions (Chang-Wei et al. 2007). The mean number of pollen per anther (122.3) observed in this study is lower than that (162) reported by Bhattacharya et al. (2005). This may be due to the variation in collection time of pollen and variation from tree to tree. Mean pollen diameter (85.5 µm) in this study is similar to the value (81–89 µm) reported by Raju and Ezradanam (2002) but lower than that (94.5 µm) reported by Bhattacharya et al. (2005). Almost similar pollen viability (98%) was reported for *J. curcas* (Dhillon et al. 2006) and *J. integrrima* (Noor et al. 2004).

Other studies have reported almost similar insect visitors on *J. curcas* (Bhattacharya et al. 2005, Dhillon et al. 2006). The insect activity was high between 1100 and 1300 h in the present study which may be due to the increased nectar secretion at 1100 h (Bhattacharya et al. 2005).

The high fruit setting (93.2%) in the case of cross pollination in this study (Table 4) is similar to earlier reports for *J. curcas* (Raju & Ezradanam 2002, Chang-Wei et al. 2007) and *J. gossypiifolia* (Reddi & Reddi 1983). The high (89.7–90.2 %) fruit set in open pollination reported by Dhillon et al. (2006) and Chang et al. (2007) generally conforms to the findings of the present study. However, relatively low fruit set (50–53 %) in open-pollinated *J. curcas* flowers was reported by Raju and Ezradanam (2002) and Bhattacharya et al. (2005). The differences may be attributed to varying populations, ages, climatic and soil conditions (Chang-Wei et al. 2007). High fruiting (72.2%) in self pollination observed in this study is almost similar to the values (77–83.3%) reported by Dhillon et al. (2006), Raju and Ezradanam (2002) and Chang-Wei et al. (2007). In addition, the low fruiting (36.3%) in apomixis is almost similar to findings (32.0 %) by Bhattacharya et al. (2005) for the same species, whereas Chang-Wei *et al.* (2007) reported it to be very low (12%). The significantly lower number of seeds per fruit in self pollination and apomixis in this study may be due to ovule abortion at the time of fruit development (Raju & Ezradanum 2002). There is a further need to quantify and record observations on seed weight, seed size and oil content in various breeding systems.

The information on floral biology, pollination and breeding systems is a prerequisite for knowing the life history of jatropha and for initiation of future breeding work. The studies have found that second flowering span (July till November) is ideal for high fruit set, number of seeds per fruit and oil content. Jatropha is monoecious and favours outcrossing but self-compatible. Information on timing of floral anthesis, pollen dehiscence, pollen viability and floral characteristics will be helpful for initiation of controlled crossing programmes.

ACKNOWLEDGEMENTS

The financial assistance from National Oilseeds and Vegetable Oils Development (NOVOD) Board, Ministry of Agriculture, Government of India is greatly acknowledged. We also thank the Head, Department of Forestry and Natural Resources, PAU Ludhiana for providing necessary facilities.

REFERENCES

Ashley M. 1995. The biology and management of *Jatropha gossypiifolia*. *Northern Territory Department of Primary Industry and Fisheries Technical Bulletin* 234: 21–26.

Bebawi FF, Mayer RJ & Campbell SD. 2005. Phenology of bellyache bush (*Jatropha gossypiifolia* L.) in northern Queensland. *Plant Protection Quarterly* 20: 46–51.

Bhattacharya A, Datta K & Datta SK. 2005. Floral biology floral resource constraints and pollination limitations in *Jatropha curcas* L. *Pakistan Journal of Biological Sciences* 8: 456–460.

Chang-Wei L, Kun L, You C & Yong-Yu S. 2007. Floral display and breeding system of *Jatropha curcas* L. *Forest Studies China* 9: 114–119.

Dhillon RS, Hooda MS, Handa AK, Ahlawat KS, Kumar Y, Subhash & Singh N. 2006. Clonal propagation and reproductive biology of *Jatropha curcas* L. *Indian Journal of Agroforestry* 8: 18–27.

Heller J. 1996. *Physic Nut—Jatropha curcas*. *Promoting Conservation and Use of Underutilized and Neglected Crops*. International Plant Genetic Resources Institute, Rome.

Noor M J, Ahmed M, Asghar R, Kanwal A & Pervaiz S. 2004. Palynological studies of cultivated plant species at university of Arid agriculture, Rawal Pindi, Pakistan. *Asian Journal of Plant Sciences* 3: 476–479.

Panse VG & Sukhatme PV. 1989. *Statistical Methods for Agricultural Workers*. Third edition. Indian Council of Agricultural Research, New Delhi.

Paramathma M, Parthiban KT & Neelakantan KS. 2004. *Jatropha curcas*. Bharat Press, Mettupalayam.

Raju AJS & Ezradanam V. 2002. Pollination ecology and fruiting behaviour in a monoecious species, *Jatropha curcas* L. (Euphorbiaceae). *Current Science* 83: 1395–1398.

Reddi EUB & Reddi CS. 1983. Pollination ecology of *Jatropha gossypiifolia* (Euphorbiaceae). *Proceedings of the Indian Academy of Sciences—Plant Sciences* 92: 215–231.

Sukarin W, Yamada Y & Sakaguchi S. 1987. Characteristics of physic nut, *Jatropha curcas* L. as a new biomass crop in the tropics. *Japan Agricultural Research Quarterly* 20: 302–303.