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EFFECTS OF ALTITUDE AND WATER ON FLOWERING AND FRUITING OF *JATROPHA CURCAS* L.

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Abstract

Field survey was conducted at three different altitudes in the dry-hot valley of Chin-sha River China. The variances of flowering and fruiting and the quantity of fruit at three different altitudes areas (Low 800m, Middle 1,200m and High 1,700m) were observed and recorded. Data of 100-seeds weight came from 9 experimental groups which classified by three fruiting periods (early, middle and late) at three different altitudes. To ensure single variable, water effect was studied in the cline banks where situated in the 1,200m and controlled by artificial irrigation. The results showed that flowering and fruiting time under different altitude had significant difference, the lower altitude, the earlier flowering. Fruit number in the middle elevation was remarkably higher than the other two altitude areas. Fruit quantity in early and middle fruiting period accounted for 85 percent at 1,200m, which was significantly higher than the late fruiting period. 100-seeds weight between low and middle elevation, early and middle fruiting period had no significant difference respectively, but they were, respectively, higher than the high altitude and late fruiting period. The maximum of the 100-seeds weight was 65.17g while the lightest was only 49.51g. Water promoted flowering earlier, fruiting delayed but open flower and whole fruiting stage extended. Average fruit numbers in the early and middle stages with regularly irrigation were 220.8 per tree and 195.6 per tree respectively, which were 2.26 times as the same period of plant without irrigation. Therefore, in hilly areas, *J. curcas* optimal elevation is 800 -1,200m and have high demand for water during flowering and fruiting period.

Key words: *Jatropha curcas*, phenology, altitude, water, 100-seeds weight.

Introduction

Jatropha Curcas originated from Central America and now thrives in many parts of subtropics and tropics of Asia and Africa which belongs to the family Euphorbiaceae (Heller, 1996). With the study of seed oil, it has been proved that *J. Curcas* is a prospective alternative fuel for diesel engine because of high oil production (oil content up to 40% by weight) (Kouame, 2011), as well as making candles, soaps (Sunil *et al*., 2011) and environmental application (Abhilash *et al*., 2013). At present, it has been widely studied on the aspects of molecular, extracted oil, growth habit and toxicity *et al*., because *J. curcas* is a low demand to environment but wide range uses tree species (Abdelgadir *et al*., 2008; Rakshit *et al*., 2008; Divakara *et al*., 2010; Herak *et al*., 2010; Yue *et al*., 2013). But low productivity is the primary reason that is restraining its development (Liu *et al*., 2012).

Flowering and fruiting are two important stages in the higher plant reproduction because their time difference can affect pollen flow, mating pattern, ultimate success rate of pollination and seed setting rate (Fuchs *et al*., 2003; Naeem *et al*., 2004; Selbo & Snow, 2005). Although it is now widely accepted that phylogenetic and biological interactions can form plant phonological patterns, environmental factors are thought to function as external causes for organisms to time their reproduction (Andreas, 2004; Omesh *et al*., 2012). Plants in different areas experience different variations and phenology because environment factors such as temperature, lighting, water content and so on distributed unbalance. For instance, the success rate of pollination and fruiting rate can be affected by the variance of flowering phenology which caused by different altitude gradients (Zhang & Jin, 2008). The best fit altitude for different plant species is different (Hou *et al*., 2005). Water content shows a significant rectilinear correlation with the quantity of flower, fruiting rate and flowering period (Garnayak *et al*., 2008). Fruiting rate can be decreased because of the consumption of nutrient in the late flowering period (Yang *et al*., 2003). Therefore, the study of plant flowering and breeding in different environment conditions can provide information about plant group function rhythm, diversity and breeding, which is not only beneficial to species conservation and management of genetic resources, also to provide evidence for reasonable cultivation management measures, so as to achieve the aim of increase plant yield (Liu *et al*., 2006).

The main aim of this study was to discovering flowering and fruiting phenophase, fruit quantity and quality in selected *J. curcas* by setting different moisture and elevation gradients. Since, such kind of studies has not been carried out appropriately from the subtropical dry-hot regions of the southwestern China, even other planting areas in the worldwide. Hence, the data illustrated here may be utilize for further resource development of *J. curcas* under different environment and better to address the problem of production shortage.

Materials and Methods

Study sites: The study was carried out at the bank of Chin-sha River (26°05′-27°21′N and 101°08′- 102°15′E) which is situated in the Southwest of Sichuan province, China. *J. curcas* distribution range is 400 -1800m, 84.47% of them distributed in 800-1,400m (Lin *et al*., 2004). All plants lived in this areas are the same cultivar. In the 1,200 m, there is a field cline banks where plants can be irrigated regularly. The terrain of the whole experiment site is rough and belongs to typical South Asian tropical and dry climate, sunshine duration reached to 2220.3-2435.8 h per year, total solar radiation about 126950-133578 cal/cm2 per year and average temperature is 21.9°C. The extreme lowest historical temperature was -3.1°C and the highest temperature reached 44°C the frost-free period more than 300 days per year. Average yearly precipitation in all this areas about 689 mm, July and August are the main rainy months, the others months' precipitation less than 10% of total rainfall. Since 1956, the record of maximum rainfall in the study site was 1088.8 mm (1983), the minimum rainfall was 302.1 mm (1963).

Sample plant and picking time definition: The standards for all sample plants were the same: 5-year-old, health, medium height (2.5-3m), crown diameter (3.5-4m). The three periods were respectively its early flower, open flower and ending flower stage. Also, fruit picking time were divided into three times in response to flowering periods.

Flowering and fruiting in different altitudes: Wild testing grounds were classified into three levels: low elevation (800m), middle elevation (1,200m) and high elevation (1,700m). Tagged 5 sample plants at each elevation and then took regular observations to record their flowering and fruiting phenology. Picked fruits at three maturation periods (early, middle, late) in three different elevations and measured 100-seeds weight. During the measuring procession, selected 100 seeds randomly and repeated three times.

The effect of moisture on flowering and fruiting: Ten sample plants were selected at cline banks (1,200m). Five trees were watered 10 L each week in the ring hole which around the base of the tree from March to the end of June while the other 5 trees without any artificial water. The flowering and fruiting phenology and the quantity of the fruit were recorded periodically.

Result

Flowering phenology: *J. curcas* anthesis at three different altitudes areas showed apparently diversity (Table 1). At the lowest altitude, embryonic stage started in the middle of March, early flower commenced between the beginning and the middle of April, which lasted 1-2 weeks. Open flower period lasted one month from the late April to the late of May. The ending flower period ended in the middle of June. The whole period lasted 3 months. As for 1,200m plot, embryonic stage was near 10 days later, which started in the late of March. Early flower spanned from the end of April to the beginning of May. Flowering ended in the late of June. The middle of May to the early of June was the open flower period. At the highest plot, embryonic stage delayed to the first of April. Early flower opened from the early of May to the end of this month, open flower period started from the late of May and lasted to the end of June. Flowering ended in the late of July. Although their open flower stages were different, each of them experienced approximately one month.

Fruiting phenology: Fruiting time and quantity at three different altitude areas are shown in Table 2. At the lowest altitude, the early fruiting period was 12th of June to the 19th of June. The average fruit-set was 89.2 per tree, which accounted for 47.6% of the sum. Middle fruiting stage started from the 1st of July, mean quantity of fruit was 71.2 per tree, about 38.1% in the total. Late fruiting happened in the early of August, only 26.8 fruited. At the middle altitude, fruiting commenced 7-10 days later than that in the 800m at each time of maturation. The early and the middle stages were the main production stages, reached 177.6 per tree (51.4%) and 145.6 per tree (41.9%) respectively. Only 23.6 fruited at the late fruiting period. At the altitude of 1,700m, the three times of fruit maturity were about one month later than that in the lowest area, 89.6 per tree (7.10-7.13) and 82.2 per tree (8.2-8.5) fruited. In the late fruiting stage, mean quantity of fruit was only 13.4 per tree, about 7.3% in the whole fruit capacity. Compared with three elevation's fruits, the number of fruits in the early and middle fruiting time at 1,200m areas was significantly higher than the others. In the same elevation, the differences of fruit quantities between the early and middle flowering stages were non-significant, but both of them were superior to the late period of fruiting quantities.

Table 1. Flowering phenology from the embryonic stage to ending flower of *J. curcas* in three different altitudes.

Altitude (m)	Sample plant	Embryonic stage	Unfold of leaf	Bud Initiation	Early flower	Open flower	Ending flower
800	1	3.12	3.20	3.29	4.7	4.25-5.20	6.15
	2	3.15	3.23	4.1	4.10	4.29-5.25	6.17
	3	3.13	3.21	3.31	4.8	4.27-5.23	6.18
	4	3.14	3.20	3.30	4.6	4.30-5.25	6.17
	5	3.6	3.25	4.2	4.10	5.2-5.28	6.16
1,200	1	3.23	4.1	4.10	4.19	5.10-6.9	6.28
	2	3.26	4.3	4.12	4.19	5.13-6.9	6.29
	3	3.23	4.2	4.12	4.20	5.12-6.11	6.29
	4	3.25	4.3	4.13	4.21	5.10-6.9	6.29
	5	3.26	4.3	4.12	4.23	5.12-6.12	7.1
1,700	1	4.5	4.13	4.23	5.4	5.29-6.28	7.29
	2	4.7	4.15	4.23	5.4	5.27-6.29	7.29
	3	4.9	4.16	4.24	5.3	5.30-6.25	7.28
	4	4.7	4.16	4.23	5.3	5.26-6.28	7.28
	5	4.7	4.15	4.23	5.2	5.29-6.26	7.30

Table 2. Fruiting phenology of *J. curcas* in three different altitudes.

Altitude (m)	Maturation time and quantifies								
	Early			Middle			Late		
	Fruiting span	Quantity (mean)	Ratio (%)	Fruiting span	Quantity (mean)	Ratio (%)	Fruiting span	Quantity (mean)	Ratio (%)
800	6.12-6.19	89.2	47.6	7.1-7.8	71.2	38.1	8.5-8.9	26.8	14.1
1,200	6.20-6.28	177.6	51.4	7.10-7.15	145.6	41.9	8.12-8.15	23.6	6.8
1,700	7.10-7.13	89.6	48.4	8.2-8.5	82.2	44.3	9.2-9.7	13.4	7.3

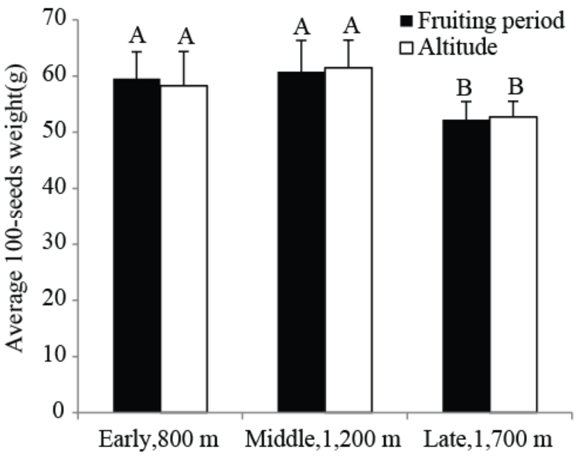

Fig. 1. 100-seeds weight at different altitudes and different maturity time based single factor variance analysis and multiple comparisons.

Weight of 100-seed: Through single factor variance analysis, the results were showed in the Table 3 and Fig. 1. Average 100-seeds weight of 4 groups exceeded 60 g, which were the early and middle fruiting periods at 800m and 1,200m respectively. The maximum of 100-seeds weight was up to 65.17g (1,200m, the second time of fruiting), while the minimum of the 100-seeds weight was 49.51g (1,700m, the third time of fruiting). 100-seeds weight of the first (65.17g) and the second time fruiting (63.12g) in the middle elevation were higher than the other groups. 100-seeds weight of the third time fruiting at the 800 m and 1,200m were 51.27g and 49.51g respectively, which were significantly lower than the other groups. By comparing two environmental factors, average 100-seeds weight in 800m (58.27g) and 1,200m (61.47g) were no significant difference, but both of them showed significant difference when compared with the 1700m (52.73g) fruits. The same trend also existed in fruiting time. The first (59.53g) and the second time of fruiting (60.74g) 100-seeds weight had no significant difference but experienced significant difference with that of the third time of fruiting (52.20g).

The result of irrigation and non-irrigation: Water effects on *J. curcas* flowering and fruiting were showed in the Table 4. Sample plants with regular irrigation unfolded leaves in the late of March, bud initiation began at middle of April or the early of May, open flower commenced from the early of May to the middle of June, flowering ended in the late of June or the early of July, delayed 7-10 days into fruiting stage than plants without irrigation. Trees without irrigation unfolded leaves after ten days, until the early of April. The late of April to the middle of May was the bud initiation period, and one month after the early of May was the open flower stage, flowering ended at the middle of July and almost 20 days later than that of plants with irrigation. Moisture also affected fruiting quantities, which were differed from flowering periods. Irrigation cannot make fruiting earlier, but lead to the fruiting 10 days later than that without water. Instead there was a big difference in the quantity of fruits. At the early and middle fruiting stages, the mean quantities of irrigation trees were 221 per tree and 196 per tree respectively, while the contrast number were 95 and 85 per tree only, less than half of the former. Effects of moisture on the quantity during the late fruiting time were not obvious by contrasting with the early and middle fruiting time.

Discussion

In the dry-hot valley areas, low elevation with high temperature, less precipitation and more evaporation, which caused soil water content decreased. Plants adopt measures to decline leaf saturated content to meet the low water utilization and compensation of stomatal conductance decreased. With the increase of elevation, environment water hot condition improved, making the biomass and saturated water content added, which are beneficial to plant growth and development (Li *et al*., 2005; Duan *et al*., 2013). However, temperature drops while elevation rises, so high elevation areas are not suitable for *J. curcas* to live because it's native to Tropical American and prefer to light and hot environment condition (Carels, 2009). High elevation's temperature limitation and low elevation's moisture limitation complement each other which made their fruiting quantities were no significant difference. But low altitude seed quality, especially 100-seeds weight, was better than that of high altitudes'. Altitude contains a lot of environmental factors such as temperature, humidity, illumination. To be more accurate understanding of the mechanism of *J. curcas* flowering and fruiting still needs further research.

Table 4. Flowering and fruiting phenology of *Jatropha curcas* grouped by irrigation and non-irrigation treatment.

Treatment (Altitude:1200m)		Embryonic stage	Unfold of leaf	Bud initiation	Early flower	Open flower	Ending flower	Early			Middle			Late		
								Fruiting span	Quantity (mean)	Ratio (%)	Fruiting span	Quantity (mean)	Ratio (%)	Fruiting span	Quantity (mean)	Ratio (%)
Irrigation	1	3.13	4.1	4.6	4.12-4.31	5.8-6.16	7.2	6.25	244	49.8	7.2	213	43.4	8.13	34	6.8
	2	3.16	3.30	4.7	4.13-5.1	5.5-6.11	7.3	6.27	238	57.1	7.1	162	37.2	8.13	24	5.7
	3	3.17	3.29	4.7	4.16-4.30	5.7-6.14	6.30	6.27	219	47.7	7.4	213	46.4	8.15	27	5.9
	4	3.20	4.2	4.8	4.15-5.2	5.7-6.17	6.29	6.23	180	47.4	7.1	178	47.1	8.12	21	5.5
	5	3.20	4.1	4.6	4.13-4.29	5.5-6.12	7.4	6.28	223	49.8	7.5	212	47.3	8.13	13	2.9
Non-Irrigation	1	3.29	4.10	4.18	4.28-5.10	5.20-6.18	7.19	6.15	121	49.2	6.27	110	44.7	8.5	15	6.1
	2	3.31	4.9	4.19	4.29-5.9	5.20-6.19	7.19	6.20	86	54.6	7.1	59	37.2	8.8	13	8.2
	3	4.2	4.10	4.18	5.1-5.13	5.21-6.15	7.18	6.17	112	49.6	7.2	95	42	8.8	19	8.4
	4	3.30	4.8	4.17	4.31-5.14	5.22-6.18	7.16	6.23	87	42.6	6.30	105	51.5	8.9	12	5.9
	5	4.1	4.11	4.20	5.2-5.18	5.21-6.16	7.20	6.18	68	47.9	7.2	55	39.1	8.6	19	13

Fruit proportion of the late fruiting stage was only 10%. According to the optimal resource allocation hypothesis, once the fitness of fruit production closes to saturation, continue to supply nutrition on female function means wasting resources (Pannell, 2002). Therefore, getting rid of the ending flowers and fruits was an efficient way to meet the nutrition demands for the early and the middle period fruits development. Similarly, setting percentage recorded by Indian researchers (Bhattacharya *et al*., 2005) was 66.7%, when they adopted pruning treatment, seed-set rate would be improved. According to Kaur's (2011) report, *J. curcas* lived in northwest India flowered twice every year, flowering time of each time and twice flowering time interval were long. Noor *et al*. (2011) get further study on this plant in Malaysia regions, flowering to fruit mature experienced roughly three months and may have 2 to 4 fruiting cycles. This may be because different cultivated areas shaped environmental variances. In present study sites, fruiting periods were less than that in India and Malaysia, so taking introduction into consideration, hybridizing with fine varieties can promote the quality of native plants quality in China.

J. curcas reproductive growth time is just in dry seasons. Because of high water content in half fleshy stems, *J. curcas* has a strong adaptability to drought matrix when facing environment drought stress (Yao *et al*., 2009). For plants, drought, however, is not conducive to the absorption and transformation of nutrients, and then hinder plant's normal growth. Consequently, poor vegetative growth results in low productivity. Traditionally, *J. curcas* was thought to be drought tolerance tree species and low demand to environment. But according to author's observation, almost all natural distributed *J. curcas* grow in gully regions which are close to the water resource. This phenomenon conform to the result that water had a significant effect on *J. curcas* phenology. In addition, if soil nitrogen content is not enough, overhydration will against *J. curcas* photosynthesis, flowering and breeding, because water-nitrogen coupling effect decreased (Jiao *et al*., 2011). Researchers have proved that plants would flower earlier to finish growth cycle when they lived in adversity situation, such as lack of water, high salinity and high luminous. They defined this phenomenon as 'Flowering Induced by Adversity' (Wada & Takeno, 2010). In this study, although open flower and fruiting time extended about 15 days, regular irrigation made blossom ahead of time. Therefore, more physiological change mechanisms of *J. curcas* need to be studied in the future.

Conclusion

This is the first time to study the altitude and water effects on *J. curcas* flowering and fruiting phenology. The data observed showed information about tree phenophases and variance of fruiting quantity. Elevation exceeded 1,200 m is not the optimal growth area for *J. curcas*. Water supply at the beginning of flowering and dry season is an efficient way to advance yield and fruit quality. Hence, these data is useful in mastery of *J. curcas* growth time in different elevation and water condition. Measures, for instance, hand-pollinate, cross-fertilize, blossom and fruit thinning can be regulated for improving fruit quantity in advance. Additionally, suitable range for expanding *J. curcas* can be chosen for world range of plantation based on these basic data information.

Table 3. Multiple comparison of 100-seed weight in three fruiting periods and three different altitudes.

Sample number	Period altitude(m)	Mean number (g)	Significance level of 5%	Very significance level of 1%
5	middle,1,200	65.17	a	A
2	early, 1,200	63.42	ab	AB
4	middle,800	62.58	bc	B
1	early, 800	60.96	c	B
8	late, 1,200	55.81	d	C
6	middle,1,700	54.46	d	CD
3	early, 1,700	54.22	d	CD
7	late, 800	51.27	e	E
9	late, 1,700	49.51	ef	EF

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