EL COQUILLO (*Jatropha curcas* L.) PARA LA PRODUCCIÓN DE BIODIESEL EN LA REGIÓN DEL ARCO SECO, PANAMÁ[1]

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RESUMEN

Un estudio de ocho cultivares de *Jatropha curcas* L. se llevó a cabo en la región del Arco Seco de Panamá. El propósito de esta investigación fue evaluar y comparar el rendimiento de los germoplasmas comerciales de esta especie de árbol, para seleccionar las mejores variedades para la producción de biodiesel, adaptables a suelos marginales de Panamá y a condiciones secas. Se utilizó un diseño de Bloques Completos al Azar, ocho tratamientos y cuatro repeticiones. Las variables dependientes fueron diámetro de copa, número de ramas, altura del árbol, fenología y rendimiento de semilla. Los datos fueron analizados mediante un ANOVA y un análisis post hoc de Fisher (DMS), para cada variable. Se empleó un análisis de componentes principales (ACP) para generar una representación gráfica de la variabilidad de todos los datos. Tres cultivares obtuvieron los mejores resultados y con un buen crecimiento, aunque surgen más preguntas para poder justificar el cultivo de jatrofa a gran escala.

PALABRAS CLAVES: Variedades, biodiversidad, energías renovables, sostenibilidad, rendimiento.

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THE PHYSIC NUT TREE (*Jatropha curcas* L.) FOR BIODIESEL PRODUCTION IN THE ARCO SECO REGION OF PANAMA

ABSTRACT

A study of eight cultivars of *Jatropha curcas* L. was conducted in the Arco Seco (Dry Arc) region of Panama. The purpose of this investigation was to evaluate and compare the performance of commercial germplasms of this tree species, to select the best varieties adaptable to Panama marginal soils and dry conditions for biodiesel production. A Randomized Complete Block Design (RCBD) was employed with eight treatments and four replications. Canopy diameter, number of branches, tree height, phenology and seed yield were the dependent variables under study. The data were analyzed through ANOVA and a post hoc tests (Fisher's LSD), for every variable. A principal component analysis (PCA) was employed to generate a graphical representation of the variability of all data. Three cultivars yielded the best results and were recommended for growth, although more questions remained unanswered to substantiate the cultivation of jatropha on a large scale in Panama.

KEY WORDS: Varieties, biodiversity, renewable energy, sustainability, performance.

INTRODUCTION

For the last couple of decades the Physic nut tree (*Jatropha curcas* L.) has been heralded as a valuable species, possessing advantageous attributes to achieve agricultural sustainability and improve quality of life in many tropical regions of the world (Openshaw 2000, Van Eijck and Romijin 2008, Abhilash *et al*. 2011). The yields and valuable characteristics of the oil that can be extracted from its seed to produce biodiesel make the Physic nut tree, commonly referred to as jatropha, a promising renewable-energy species (Foidl *et al*. 1996, Augustus 2002, Akbar *et al*. 2009). Native to Central America, jatropha belongs to the Euphorbiaceae family and it has been used for a long time among tropical agropastoralists as a live fence (Openshaw 2000). It grows rapidly to a height between three and five meters and it can be propagated asexually and through direct sowing of its seeds. Its bark is grey, smooth and its leaves are broad and green (Figure 1).

The inflorescence is a cyathium very attractive to pollinators, particularly bees. Its fruits, which are on average

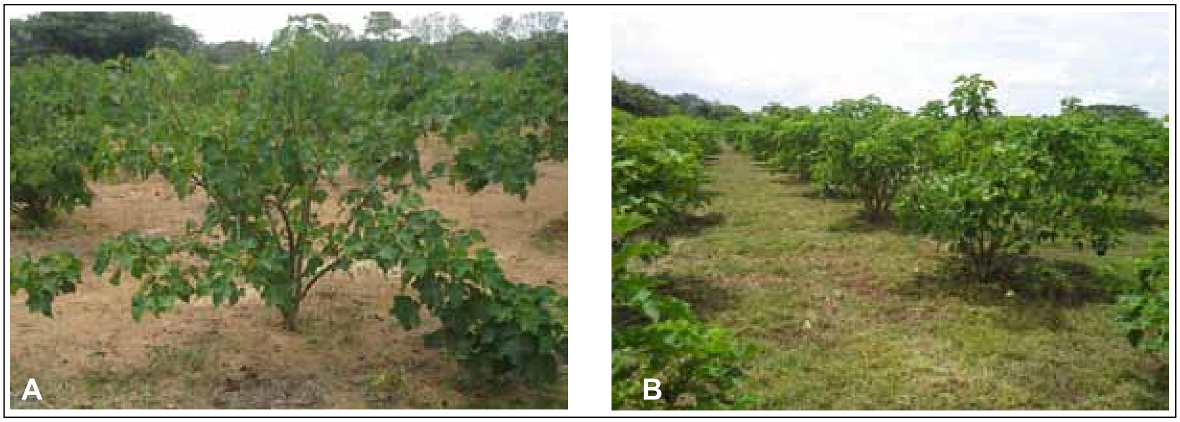


Figure 1. (A) Physic nut tree (one year old), at the Agricultural Experiment Station El Ejido from IDIAP, Los Santos, Panama; (B) Physic nut tree plantation (one year old), at the National Institute of Agriculture, Divisa, Panama.

37,7% shell and 62,5% seed in weight, can be produced throughout the year, depending primarily on soil moisture and temperature (Singh *et al*. 2008).

The Physic nut tree appears to be adaptable for successful growth in a wide variety of soils and climatic conditions and for these reasons its employment could be beneficial also to the reclamation of degraded soils (Openshaw 2000). When propagated sexually, its tap root penetrates deeply through the soil profile and uptakes nutrients and moisture that otherwise would remain unavailable. While growing undisturbed and in less than two years from its establishment in the field, jatropha improves soil structure and other soil physical characteristics (Francis *et al.* 2005). Asexual propagation through cuttings does not produce similar benefits on the soil however, because the young trees develop a shallow system of fibrous roots, rather than a deep tap root, thus having a much more attenuated effect for improving soil physical attributes (Henning 1996).

Like many species in the Euphorbiaceae family, the Physic nut tree produces toxic substances including curcin and phorbol esters that may protect it from a variety of pests and disease, although Jongschaap and his collaborators (Jonschaap *et al*. 2007) conceded that in humid, tropical conditions this species can be affected by some pathogenic fungi, viruses and insect pests. Insect pests are most diverse within the native range of jatropha in Central and South America (Lama *et al*. 2015). However, its high adaptability to water stress, soil conditions, and its outstanding, natural resistance to disease when compared to a majority of agronomic crops, have made jatropha a feasible, multi-purpose tree crop in several tropical and sub-tropical countries (Abhilash *et al*. 2011). Irrigation during the establishment of a Physic nut tree plantation may be necessary to enhance a vigorous vegetative development, as it was suggested by Vimal *et al*. (2012), in their review study about growing jatropha in India.

In addition to the interest in the Physic nut tree for its potential as a renewable energy fuel, jatropha products and by-products can be employed in a wide variety of human activities. For example, jatropha's oil can be used for illumination purposes and its wood can be burned in cooking stoves. Once the seeds are shelled, the harvestable glycerin can be used to make soap and the pressed seed cakes that remain as a residual byproduct after extraction of the oil are employable as organic fertilizers (Tomomatsu and Swallow 2007). In addition to this, the seed cakes can be used as fuel or converted into charcoal (Kumar *et al*. 2008). The toxicity of the plant's exudates can be employed as natural pesticides. Jatropha has also been used for a long time in traditional medicine. For example, the milky sap of *Jatropha curcas* L. is used in Mesoamerica for the treatment of different forms of dermatitis, and also for mucosal infections (Kaushik *et al*. 2007). Historically, the leaves of the plant have been used to treat malaria and its sap has often been used by some cultures as an anti-hemorrhagic medicine.

The potential of the tree species *Jatropha curcas* L. for possible employment as a biodiesel crop has been known for decades (Banerji *et al*. 1985). Indeed, jatropha has become an attractive renewable-fuel crop because of the chemical and physical characteristics of its oil, extractable through a trans-esterification of its seed, which contains between 33-35% oil (Foidl *et al*. 1996). Chemical analyses showed that this oil possessed low acidity and good stability to oxidation when it was compared to soybean oil, lower viscosity than castor oil and cheaper processing costs than producing ethanol from corn (Becker and Makkar 2008). As jatropha yields a non-edible oil it is not expected to exert competition with oil crops that are employed in human or animal nutrition, as demand for these edible oils as foods makes these crops too expensive to be used as feedstocks for biofuels (Pramanik 2003). Likewise, jatropha's ability to grow well on marginal soil reduces its competition for land to grow food crops (Contran *et al*. 2013).

Seed yield remains perhaps the greatest uncertainty when discussing the potential uses of jatropha as a biofuel.

There can be significant yield variations in jatropha agriculture, based on growing conditions (Henning 1996, Achten *et al*. 2010). Also, seed yield can vary considerably within a single plantation because of a broad genetic diversity within the species, which justifies the needs for domesticating the tree and for genetic improvement (Shah *et al*. 2005). Processing of the seed into a biodiesel involves pressing the seed to extract the oil, leaving a seedcake as byproduct. Methods of extraction vary and in many small-scale production centers, such as those found in Africa, oil is extracted through the manual ram-press, or if power is available, through the electric screw-press (Van Eijck and Romijn 2008). In India instead, scientists developed oil extraction through enzyme and ultrasound techniques (Forson *et al*. 2004).

Also, the chemical method of oil extraction process employs solvents with n-hexane and some preliminary studies about this methodology have indicated that oil yields are better than with other extraction methods. Although research emphasis has been given to oil extraction techniques and technologies for biodiesel production, more attention has been devoted recently, to study the growth of jatropha in new agronomic environments, despite some skepticism that a high density of Physic nut trees in a typical plantation setting could be satisfactorily productive, especially in a very arid climate. The main reason that jatropha has not reached its full potential as a biodiesel crop yet is due to a lack of high yielding varieties with high oil content (Shah *et al*. 2004, Tamalampudi *et al*. 2008, Divakara *et al.* 2010).

The lack of domestication, the broad genetic variability and the fact that jatropha has not been cultivated yet on a large scale in Panama inspired the authors to pursue an investigation that could answer questions about the feasibility of growing this tree, to verify its potential as a feedstock crop. Therefore, the purpose of our study was to evaluate and compare the performance of available, commercial germplasms of the tree species *Jatropha curcas* L. in order to select the best varieties adaptable to Panama marginal soils and dry conditions. This work presents the authors' experience of growing jatropha in the Arco Seco region of Panama, which is characterized by marginal soils and prolonged periods of drought.

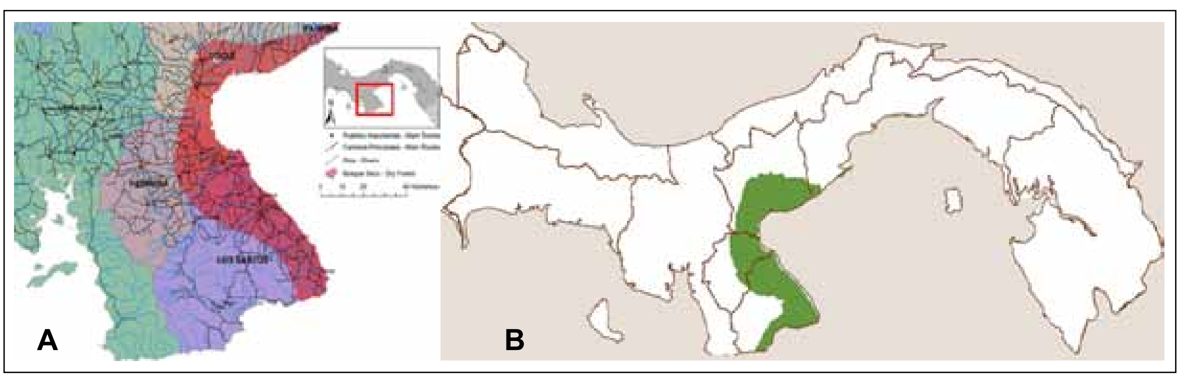
MATERIALS AND METHODS

Site description and soil conditions

The Azuero peninsula of Panama has a long history of human settlement and impacts from archeological evidence, which suggested that this territory was already inhabited by early farming communities during Neolithic times who, most likely, initiated the process of land conversion from forest to agroecosystems (Heckadon and Espinosa 1985). Most of this region belongs to the driest region (Dry Arc) of the Panama isthmus that is characterized by an average annual rainfall of 1053,7 mm, an average annual maximum temperature of 35,4º C, and an average annual minimum temperature of 19,2º C. The dry season occurs between January and May and causes always severe water stresses in this area (Figure 2).

These climatic conditions appear to be suitable to the cultivation needs of jatropha and to the agronomic and hydrologic attributes favorable to a successful growth of this species. Therefore, landowners of the Arco Seco region could pursue the cultivation of jatropha, opening new agronomic and economic venues for local agriculture, should jatropha succeed in its establishment as a renewable energy crop in this region. Consequently, this effort may contribute to attenuate an increasing energy need in Panama with a more renewable fuel, from a multi-purpose plant, that could offer also many other beneficial agricultural and environmental services to rural and urban areas in the Azuero region.

Our study was carried out between March 2013 and March 2014, at the experimental field El Limón, which is located in Divisa, at the National Institute of Agriculture, Panama Republic. The site stands at 17 m altitude above sea level and at 8°09’44,63” N latitude and 80°43’32,35” W longitude. The climate is classified as tropical wet according to Köpen-Geiger climate classification (Peel *et al*. 2007). The historical annual climatic variables are: 33,1° C average annual maximum temperature, 21,8° C average annual minimum temperature and 27,5° C average annual temperature. Relative humidity can range from 96,1% to 57,6% with 77,2%. Average annual rainfall has been 143,8 mm, and evaporation 130,6 mm. The soil



Source: Barrance *et al*. 2003.

Figure 2. (A) Arco Seco - Dry Arc (red area). (B) Potential cultivation areas of Physic nut tree in Panama.

type is clay loam, slightly acidic (pH = 6,3), containing medium amounts of soil organic matter (2,64%).

Soil analyses from the Agricultural Research Institute of Panama Soil Laboratory were done in early 2013 to verify soil characteristics and eventually, correct these, prior to planting (Table 1).

PROCEDURE

A nursery was established from seed at the beginning of May 2013 at the National Institute of Agriculture, Divisa, Panama. Dimensions of the seedbeds were 10 m length and 1 m wide, paths/ drains were 0,3 m deep and 0,5 m wide (Figure 3).

TABLE 1. SOIL ANALYSIS RESULTS FROM EL LIMÓN FIELD, APRIL 2013.

Variables	Sampling depth 0-30 cm	Sampling depth 30-60 cm
Soil color	Dark brown yellow	Dark brown yellow
Sand-Loam-Clay (%)	64-24-12	80-18-2
pH	6,3	6,8
Phosphorus	16	13
Potassium	55,2	35,4
Calcium (cmol/kg)	8,0	11,5
Magnesium	2,5	4,5
Aluminum	0,1	0,2
OM (%)	2,64	2,05
Manganese (Mg/L)	39,2	29,7
Iron	119,8	78,1
Zinc	8,5	4,9
Copper	4,6	3,2

Figure 3. Nursery at the National Institute of Agriculture, Divisa, Panama. (A) Sowing jatropha seeds. (B) Seedbeds 21 days after sowing. (C) Seedbeds 30 days after sowing.

A fertilizer application with: 64 g N/m^2, 32 g P_2O_5/m^2, 32 g K_2O/m^2 was incorporated to the seedbeds. The sowing density in the seedbeds was kept at 64 seedlings/m^2, sowed at the angle of square of 12,5 cm x 12,5 cm. Sowing depth was 2-3 cm deep and seeds were sown horizontally aligned in the holes in order to facilitate germination. Irrigation was available immediately after sowing, and water was applied at 7 L/m^2 of seedbed. At eight weeks after sowing the seedlings were transplanted. A stem diameter (measured with calipers 5 cm above soil level) that was thicker than 1 cm, and bark color that had changed from green to grey were the criteria employed for this operation, as suggested by (Quinvita 2013). Also, seedlings were topped by removing the apical meristem (about 5 cm), 1-2 days before transplanting, in order to favor root growth rather than stem elongation.

Land clearing and tillage was done in the experimental field before transplanting. The 3 - 4 - 5 method for squaring corners was employed to layout the field and to mark the soil for planting. Each planting pit measured 30 x 30 x 30 cm and these were done with a mechanical hole-digger attached to the tractor. No irrigation was used in the trial and plants were not pruned any more.

Research Design and Statistical Analysis

A Randomized Complete Block Design (RCBD) was employed in this trial with eight treatments and four replications (Figure 4).

The treatments consisted in growing six commercial cultivars and two commercial hybrids of *Jatropha curcas* L. from Quinvita India Private Limited Co (Table 2).

The trees were grown from seed and transplanted from the nursery after 8 weeks, keeping them at a distance of 4 m x 4 m, thus achieving a density of 625 trees/ha. The tree seedlings (N=288) were planted on June 22, 2013 and one border row of jatropha surrounded the whole trial site. A fertilizer application was done at transplanting and this consisted in: 84 g N, 24 g P_2O_5, and 48 g K_2O for every tree seedling, as suggested by (Quinvita 2013). The same fertilizer application was repeated at the middle of the rainy season during October 2013, by incorporating the fertilizer to a depth of 20-30 cm in a circle, around each tree. All the tree plots were weeded manually and chemically using glyphosate in the same dosage (3 L/ha). The plantation was scouted every week for pests and diseases. Preventing possible infestations by the broad mite (*Polyphagotarsonemus latus*) in November were insured with a treatment of Spiromesifen (240 g/L) at this time.

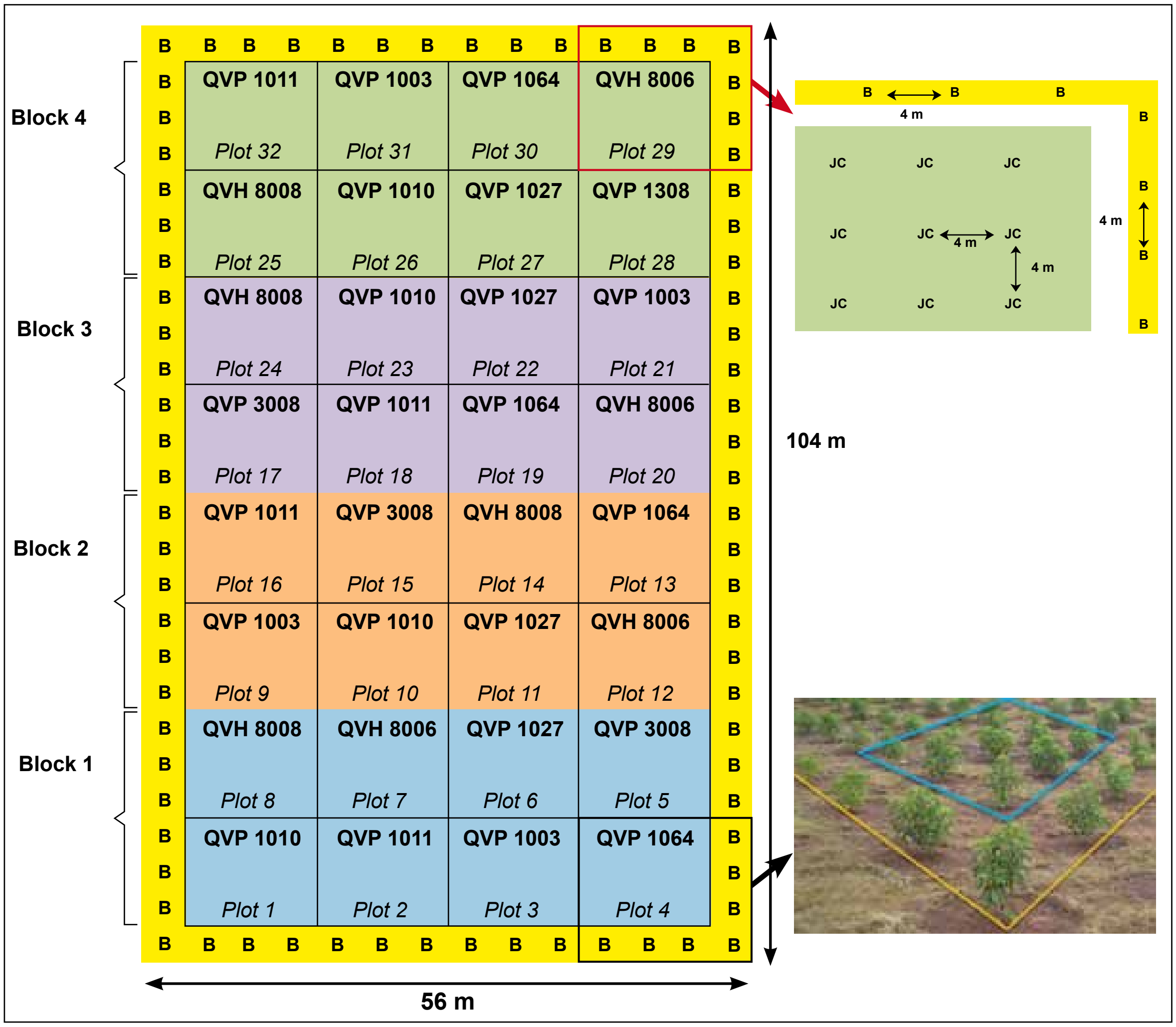


Figure 4. Randomized complete block design diagram.

TABLE 2. QUINVITA COMMERCIAL VARIETIES OF JATROPHA EMPLOYED IN THIS STUDY.

Code	Type	Year of selection*
QVP 1010	Cultivar	2008
QVP 1011	Cultivar	2008
QVP 1003	Cultivar	2010
QVP 1064	Cultivar	2010
QVP 3008	Cultivar	2008
QVP 1027	Cultivar	na*
QVH 8006	Hybrid	na*
QVH 8008	Hybrid	na*

* na: not available.

The seed harvest began in November 2013 and continued until March 2014. The fruits turning yellow, or brown were the indicator deemed valid for the maturity of the seed. Harvesting took place twice a week during those five months. The monthly harvest of each individual treatment per block was kept separate from the others and sheltered for weighing once moisture level of grains had been reduced to 7-8%. Moisture measurements were determined by using a Wile 55 moisture meter.

The data were collected on five dependent variables and these included:

1. Canopy diameter (cm), measured at 10 months after sowing (MAS).
2. Number of branches, measured at 10 MAS.
3. Height of the tree (cm), measured at 10 MAS.
4. Phenology (days needed for the first flower to bloom after planting the young trees in the field).
5. Seed yield per plot (g), after drying to a 7-8% moisture level (November 2013 - March 2014).

An analysis of variance (ANOVA) was considered for each variable and a post hoc test (Fisher's LSD) served to identify statistically significant differences from the eight cultivars, for every variable under study. A principal component analysis (PCA) was run for finding an optimal graphical representation of the variability of all the data collected in this study (Balzarini *et al*. 2008, Di Rienzo *et al.* 2008).

RESULTS AND DISCUSSION

Canopy Diameter

Statistically significant differences (P<0,0001) were measured among varieties considering canopy diameter as variable. The mean scores were significantly higher for cultivars 1010, 1011, 1027 and the hybrid 8008, ten months since sowing the seed. However, cultivar 1027 and hybrid 8008 did not have a significantly wider canopy than cultivar 3008 (Table 3).

Branch numbers

A statistically significant difference (P<0,0001) was measured among varieties when the number of branches was considered. The mean of branch numbers 10 months after sowing (Table 4) was largest for cultivar 1011. This branch number was trailed by cultivar 1010. However, cultivar 1010 was not statistically different from cultivars 3008, 1003 and the hybrid 8006, which were also not different from the hybrid 8008.

TABLE 3. MEAN VALUES OF CANOPY DIAMETER (cm) AT 10 MAS.

Treatment	Mean		Source	DF	F	p-value
	10 MAS					
1064	137,2	a	Model	10	13,33	<0,0001
8006	141,8	a	Block	3	26,63	<0,0001
1003	149,3	ab	Treatment	7	7,62	<0,0001
3008	163,8	bc	Error	277		
1027	181,0	cd	Total	287		
8008	184,9	cd				
1011	187,9	d				
1010	188,4	d				

Means with same letter are not significantly different (P>0,05).

TABLE 4. MEAN FOR BRANCH NUMBER AT 10 MAS.

	Mean		Source	DF	F	p-value
Treatment	10 MAS					
1027	11,3	a	Model	10	25,32	<0,0001
1064	11,4	a	Block	3	56,03	<0,0001
8008	16,6	b	Treatment	7	12,15	<0,0001
8006	18,2	bc		27		
1003	19,6	bc	Error	7		
3008	19,9	bc		28		
1010	20,9	cd	Total	7		
1011	24,1	d				

Means with same letter are not significantly different (P>0,05).

Tree height

The height of trees resulted significantly different (P<0,0001) among varieties. The trees height 10 months after sowing (Table 5) was highest for cultivar 1027 from all other varieties. Cultivars 1010, 1011 and hybrid 8008 were found to be higher than cultivars 1003, 1064, 3008, and hybrid 8006.

Phenology

The number of days prior to flowering after transplanting the trees on-site was significantly different (P<0,0001) among jatropha varieties. The cultivar 1064 took the longest time before reaching the flowering stage, whereas cultivars 1011, 1010 and hybrid 8008 flowered in the shortest amount of time (Table 6).

TABLE 5. MEAN SCORES FOR TREES HEIGHT (cm) AT 10 MAS.

Treatment	Mean		Source	DF	F	p-value
	10 MAS					
1003	145,6	a	Model	10	23,01	<0,0001
8006	149,5	a	Block	3	30,05	<0,0001
1064	150,1	a	Treatment	7	20	<0,0001
3008	153,9	a	Error	277		
1010	175,9	b	Total	287		
1011	176,8	b				
8008	188,1	b				
1027	201,2	c				

Means with same letter are not significantly different (P>0,05).

TABLE 6. MEAN NUMBER OF DAYS FOR FLOWERING AFTER PLANTING.

Treatment	Mean	n	S.E.	
1011	97,6	36	6,36	a
8008	100,3	36	6,36	a
1010	102,9	36	6,36	a
3008	111,7	34	6,55	ab
1003	113,5	34	6,55	ab
8006	121,5	33	6,65	b
1027	126,5	36	6,36	b
1064	150,5	33	6,65	c

Means with same letter are not significantly different (P>0,05).

Seed Yields

For the variable yield, significant differences (P<0,05) were measured among jatropha varieties. The mean seed yield was significantly higher for cultivars 1011, 1010 and the hybrid 8008 (Figure 5).

Principal Components Analysis (PCA)

The principal components analysis (PCA) employed data from: canopy diameter, number of branches, tree height, seed yields and phenology (Table 7). It explained 64,3% of the variability in the PC1 and 28,9% in the PC2; the sum of these two components explained 93% of the variability. The first principal component is strongly correlated with canopy, seed yield and number of days until flowering. These variables tend to vary together in opposing directions indicating that as canopy and yield increase, the number of days until flowering decreases. Also, canopy, seed yield, branches and height tend to increase together along the first principal component. The second principal component instead was strongly correlated with the number of branches and tree height. Plant height and the number of branches tended to vary in opposite directions. Therefore, as height increased, the number of branches per tree tended to decrease.

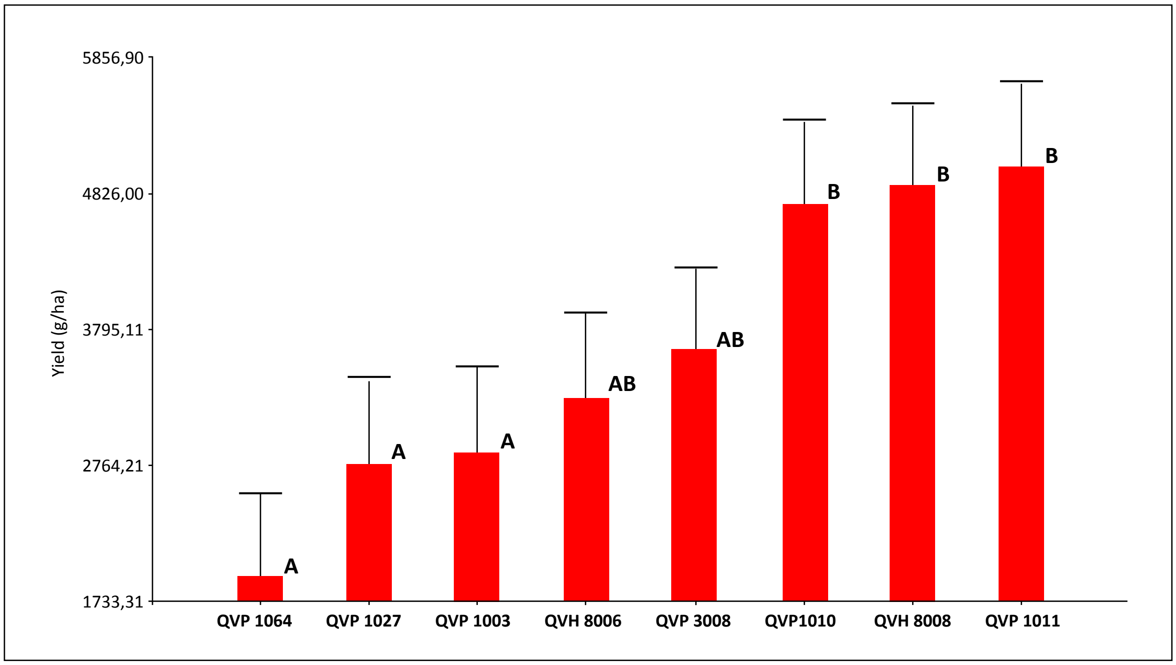


Figure 5. Mean for seed yield in grams per hectare.

TABLE 7. CORRELATIONS BETWEEN THE PRINCIPAL COMPONENTS AND THE ORIGINAL VARIABLES.

Variables	PC 1	PC 2
Canopy	0,97	-0,21
Branches	0,53	0,84
Height	0,71	-0,66
Yield	0,89	-0,19
Flower.days	-0,84	-0,47

Cophenetic correlation= 0,996

The varieties with the greatest seed yield, hybrid 8008 and cultivars 1010 and 1011 were all found in the same cluster on the plane. High canopy diameter, yield and branch number defined varieties 1010 and 1011, while hybrid 8008 was best defined by canopy and yield. Cultivar 1027 was best defined by increased height of the trees, while cultivar 1064 was best associated with more days of flowering. Hybrid 8006 and cultivars 1003 and 3008 were associated with a higher number of branches and increasing number of days until flowering. Within these two axes 93% of the total variability in the observations was explained (Figure 6).

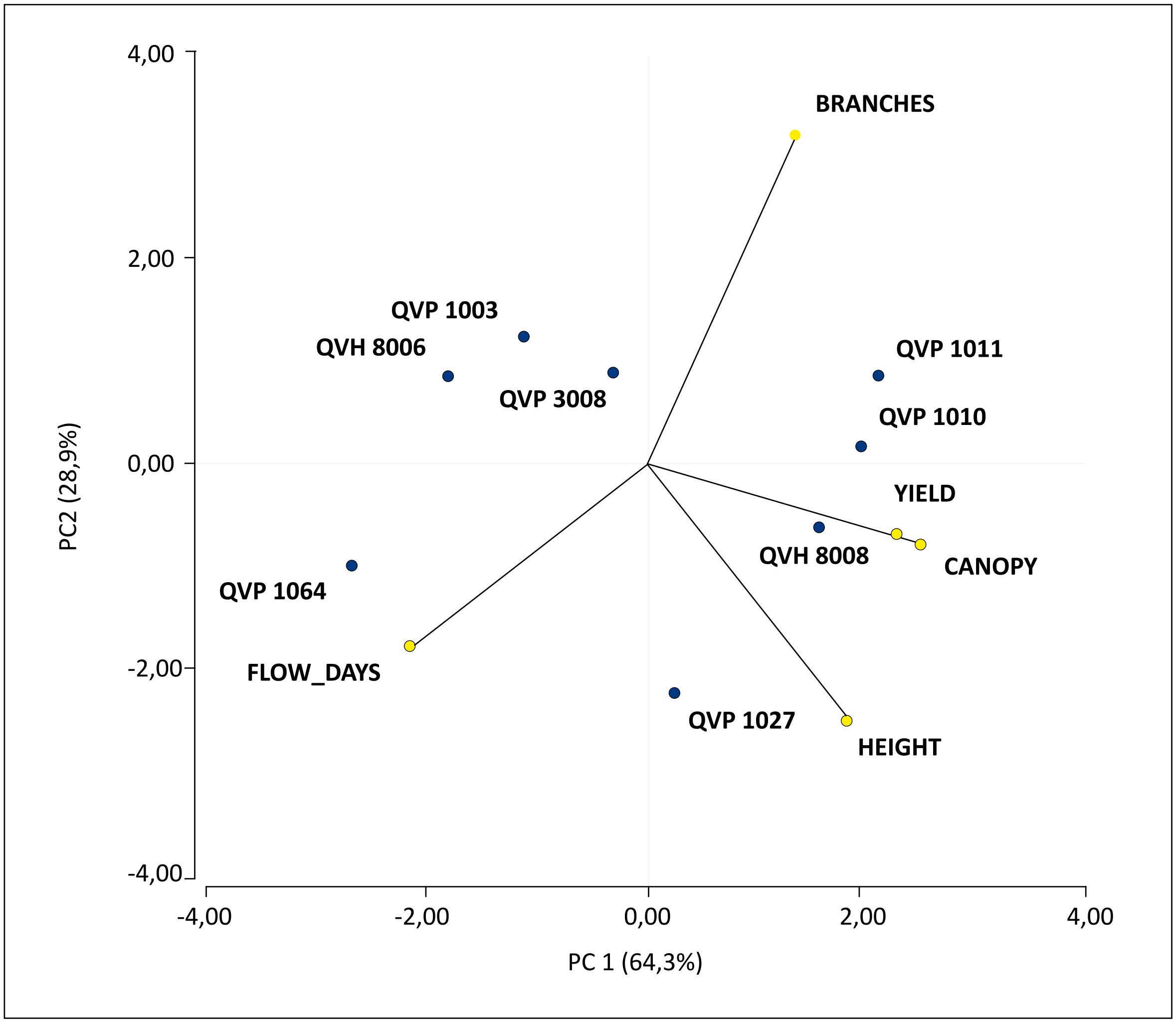


Figure 6. Biplot representation of the principal components analysis (PCA).

Several differences among the cultivars considered in this preliminary study were highlighted by the results, revealing strong implications for seed yield and success of jatropha cultivation in the field. Many of the cultivars that tended to group together on the principal component axis remained grouped together consistently, when analyzing the cultivars' individual properties.

The most notable cluster resulting from this analysis included cultivars 1010, 1011 and hybrid 8008. These three varieties of jatropha were the only one that consistently ranked high in canopy diameter, branch number, and required fewer days to flowering time than any other cultivar. They also yielded the greatest seed biomass. High branch numbers and low canopy height are highly desirable attributes for jatropha cultivated in a typical agricultural setting. This trait combination makes seeds more accessible to the harvester and also enhances the number of inflorescences, which consequently may determine high seed production potential. For these reasons, the canopy and branches are often managed through pruning (Contran *et al*. 2013). The metrics used in this study are common agronomic traits used to assess jatropha as proposed by Yi *et al*. (2010). Overall, in this preliminary investigation the most desirable varieties of jatropha cultivars resulted to be: 1010, 1011, and hybrid 8008.

It is common knowledge that among the oil crop species being considered for biofuel production *Jatropha curcas* L. cannot compete for oil yield, especially when compared to palm, or coconut oil crops grown in Africa, or southeast Asia, which can be four times more productive than the Physic nut tree. However, Okabe and Somabhi (1989) reported that seed yields of jatropha trees can increase to about 300 $kg.ha^{-1}$ with an application of a complete chemical fertilizer 15-15-15 (NPK) at a rate of 250 $kg.ha^{-1}$ in the sandy loam soils (Warin soil series, Oxic Paleustults) of Thailand. In addition to this, jatropha oil can be effectively used raw as a substitute for biodiesel fuel without requiring extra steps in the refinery processes, which instead are necessary for coconut and palm oils (Sadakorn 1984). Therefore, a simple extraction through hydraulic pressure and filtration of raw jatropha oil can become a feasible, renewable energy source for diesel engines among a majority of small scale farmers in the developing world (Ratree 2004). *Jatropha curcas* L. is a native species to Central America and although it is now found in most tropical regions of the world, its cultivation in Panama is free of potential risks of introducing alien plant species, whose population growth and seed dispersion mechanisms may cause serious problems to the ecology of a region in which they become established, due to a lack of natural enemies.

CONCLUSIONS

- Agronomically the potential employment of *Jatropha curcas* L. could be promising for developing an agriculture focused on biodiesel production in Panama.

- Present challenges limiting the adoption of this species for cultivation in Panama are concerned with the domestication of the Physic nut tree, the efficiency of oil extraction techniques and production costs. The economic feasibility of growing jatropha among small-scale farmers in Panama remains a challenge that this investigation was not able to consider at this time.

- Through this preliminary study the investigators recognized that even though jatropha has potential to become most adaptable and feasible for adoption in Panamanian agriculture, the consequences of developing large-scale cultivations of this species, could be deleterious to the services provided by biodiversity.

- Varieties 1010, 1011 and hybrid 8008 are recommended over the other cultivars that were considered in this study for local plantings in the Arco Seco region of Panama.

- This research showed a preliminary difference in performance in this area between varieties when these are fully developed and at the peak of their seed productivity. Such differences may be unique to this region, and may be due to genotype and/or by environmental interactions.

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