Energy for Sustainable Development xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Energy for Sustainable Development

Review

Factors affecting genetic and seed yield variability of *Jatropha curcas* (L.) across the globe: A review

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ARTICLE INFO

Article history:
Received 1 November 2016
Revised 7 September 2017
Accepted 7 September 2017
Available online xxxx

Keywords:
Monoecious
Genetic diversity
Polymorphism
Productivity
Geographic variation
Seed yield

ABSTRACT

Jatropha curcas L. is considered a promising candidate plant for biofuel production. However, data on its seed yield seem to vary greatly in different parts of the globe. Some studies indicate that low genetic diversity might be an important factor causing seed yield variation. In addition to genetic factors, abiotic factors such as rainfall or agronomic practices (e.g. planting density) may influence seed yield. Our study focused on reviewing current data on genetic diversity and other factors behind seed yield variability of *J. curcas* in different parts of its range, including areas both in its native and non-native range. Genetic and seed yield data were collected from published and unpublished documents available online. Our review shows that genetic diversity is significantly higher within its native range than in areas where the species has been introduced. Genetic diversity had a significant positive correlation with the mean annual seed yield. Seed yield varied greatly across the globe. Global mean (±SE) seed yield was 2218 ± 148 kg ha^{-1} y^{-1}. Age of the plants had positive linear effects, whereas annual rainfall and plant density had quadratic effects on seed yield at global scale. The reported low genetic diversity in the non-native range of *J. curcas* may be explained by a low number of common ancestors and the resulting founder effect. The large variability in seed yields across the globe is probably caused by differences in plant age, varying agronomic practices, site specific climates, soil fertility and genetic factors. Although in a large proportion of *Jatropha* plantations worldwide the threshold level for economically feasible seed yield (2500 kg ha^{-1} y^{-1} or more) may not be achieved, other benefits provided by *Jatropha* (e.g. carbon sequestration, erosion control) may support its cultivation even on arid or semi-arid sites.

Contents

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https://doi.org/10.1016/j.esd.2017.09.002
0973-08260973-0826/

Introduction

Global warming, the ongoing climate policy driven transition to renewable energy sources and technological change in the transport sector have rapidly increased interest in and demand of liquid biofuels (Abdulla et al., 2011; Achten et al., 2010). However, promotion of biofuel production has its own economic, social and environmental obstacles (Achten et al., 2010). Many researchers have considered the production of biofuel from *Jatropha curcas* (L.) as less risky and problematic with respect to the above mentioned problems than some proposed alternatives (Kumar and Sharma, 2008; Openshaw, 2000). The non-edible fruit of *J. curcas* has three seeds, which contain 35–60% oil that can be directly blended with a fossil fuel (Acevedo et al., 2016; Heller, 1996; Jongschaap et al., 2007; Kumar et al., 2012; Kumar and Sharma, 2008; Openshaw, 2000; Pandey et al., 2011). It has been suggested that *J. curcas* might provide high and predictable seed yields even in degraded and drought prone areas as it is able to grow in a wide range of agro-ecological conditions (Heller, 1996; Kumar and Sharma, 2008; Openshaw, 2000).

However, *J. curcas* is still a semi-wild plant and no consensus prevails on its economic viability in biofuel production (Pohl, 2010). Initially, it was assumed that *J. curcas* plantations could sustainably produce high seed yields also in arid and semi-arid sites without much agronomic effort (Achten et al., 2008; Kumar and Sharma, 2008; Openshaw, 2000). As a result, huge mono-plantations of *J. curcas* were established across the globe (GEXSI, 2008). However, seed yields turned out to be much lower than expected, and many farmers abandoned their plantations within a short period of time (Pohl, 2010). Despite these drawbacks, some researchers have taken an optimistic view on the economic viability of *J. curcas* plantations in biofuel production worldwide (Laviola et al., 2012). Obviously, the economic feasibility of plantations depends on local environmental and social factors. Furthermore, securing genetic diversity of the plant might be a way to ensure sustainable seed and oil yields, especially within the non-native range of *J. curcas*.

There is no comprehensive knowledge available on the crop size variability in *J. curcas* plantations, or on the importance of genetic diversity or specific environmental requirements on the observed yields (Hannan-Jones and Csurhes, 2008; Heller, 1996; van Eijck et al., 2010). Some studies performed within the non-native range indicate low genetic diversity in spite of observed relatively large phenotypic variability and variation in seed yield (Basha and Sujatha, 2007, 2011). Studies have also yielded contradictory results concerning genetic diversity even within a single country (Gupta et al., 2008; Kumar et al., 2009; Pioto et al., 2015; Rosado et al., 2010).

Likewise, no global review of seed yields of *J. curcas* has been published, although some studies have compared seed yields based on some data sets (Achten et al., 2008; Brittaine and Lutaladio, 2010; van Eijck et al., 2014). Wahl et al. (2012) studied seed yields of *J. curcas* plantations across the globe by interviewing farmers and other project stakeholders, and reported high seed yield variability even within individual countries (Wahl et al., 2012). Furthermore, because of low seed yields obtained in commercial plantations, many farmers have abandoned their *J. curcas* plantations in Africa, India and Latin America (Pohl, 2010; Wahl et al., 2012). This is not a surprise since some of these plantations had been established without sufficient knowledge about the biological requirements of the plant, and had apparently also been poorly managed (Pohl, 2010; Singh et al., 2013; Wahl et al., 2012). A study on Kenyan smallholder farms showed that 41% of farmers (out of 267) reported no seed yield at all from their plantations (Iiyama et al., 2013). All these studies show that more information is needed about factors affecting *J. curcas* seed yield in different parts of the world, and that there is also a need to educate farmers about appropriate species-specific farming practices.

The objectives of this review were (i) to extract worldwide data on genetic variability and seed yields of *J. curcas* from published and unpublished literary sources; (ii) to derive and analyze global patterns based on this data; and (iii) to review factors responsible for the observed genetic and seed yield variability.

Material and methods

Biology of J. curcas

J. curcas is a monoecious shrub that belongs to the family Euphorbiaceae; the genus *Jatropha* contains approximately 175 known species (Camellia et al., 2012; Heller, 1996; Raju and Ezradanam, 2002). Inflorescences rise from terminal branches (Heller, 1996). The ratio of male to female flowers (M/F) was reported to be 22:1–29:1 in the non-native range (Camellia et al., 2012; Raju and Ezradanam, 2002) and 60:1 in the native range of *J. curcas* (Rincón-Rabanales et al., 2016). Female flowers open before male flowers and the mating system is mixed (Rincón-Rabanales et al., 2016). Outcrossing is most common, but selfing and apomixis are also observed (Bressan et al., 2013). Outcrossing plants are insect pollinated and hermaphroditic flowers can self-fertilize but are rarely found (Heller, 1996). *J. curcas* flowers twice a year in average equatorial regions while in humid sites flowering has been reported throughout the year (Heller, 1996). Fruits require about three months to mature and one plant can produce fruit commercially for 50 years (Heller, 1996).

In appropriate growing environments, seeds germinate within 10 days (Heller, 1996). Seed germination rate at the soil surface is 6 times lower than at the depth of 2–3 cm inside soil (Negussie et al., 2015). *J. curcas* can be propagated from seed or vegetatively. Vegetative propagation is a more popular practice among farmers (Heller, 1996; Brittaine and Lutaladio, 2010). *J. curcas* was earlier planted as hedges or in degraded areas (Heller, 1996), but commercial mono-plantations have been started recently (GEXSI, 2008).

J. curcas is a deciduous shrub having C3 or CAM metabolism, a drought avoidance strategy (Maes et al., 2009a), and an opportunistic flushing behaviour (Maes et al., 2011; Neto et al., 2010). During drought, it reduces leaf size and its succulent stem balances small water losses in the leaves (Maes et al., 2009a). It is able to tolerate moderate drought and to recover quickly when water availability is improved (dos Santos et al., 2013; Fini et al., 2013). Under severe drought and herbivore stress, it produces flavonoids to protect leaf tissue from oxidative stress and photo-damage (Lama et al., 2016). It has one tap root and four lateral roots in plants raised from seed, whereas plants produced vegetatively lack tap roots (Heller, 1996). It grows from semi-arid (rainfall 150–300 mm y^{-1}) to humid (2700–3000 mm y^{-1}) climates (Achten et al., 2008; Iiyama et al., 2013). According to Trabucco et al. (2010) the optimal rainfall level for *J. curcas* is 1500 mm y^{-1} and the optimal temperature for growth is 26–27 °C. It is sensitive to water logging and frost but not to day length (Heller, 1996; Jongschaap et al., 2007; Kumar and Sharma, 2008). It prefers well-drained soils having a pH range of 6.0–8.5 and sound aeration; heavy clay soils are not suitable for *J. curcas* due to poor drainage (Brittaine and Lutaladio, 2010; Heller, 1996).

Data collection

All data were collected using various online search engines, especially Web of Science and Google scholar, with the key words and phrases

Please cite this article as: Lama AD, et al, Factors affecting genetic and seed yield variability of *Jatropha curcas* (L.) across the globe: A review, Energy Sustain Dev (2017), https://doi.org/10.1016/j.esd.2017.09.002