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Status of molecular breeding for improving *Jatropha curcas* and biodiesel

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ABSTRACT

Jatropha curcas is believed to be one of the potential biofuel crops, as it does not compete with planting lands for the edible oil plants. However, *J. curcas* has not been domesticated for producing biodiesel. Conventional breeding to increase the productivity of *J. curcas* has started since the early 2000s. Although some genetic improvement of oil yield has been made through conventional breeding, oil yield is currently still too low (≤2000 kg/ha/year) to make the biodiesel production from *J. curcas* sustainable. Due to the enormous potential of marker-assisted selection (MAS) and genomic selection (GS) to speed up genetic gain through early selection, genomic resources such as DNA markers, a linkage map, transcriptome sequences and a draft genome, have been developed and some are being used in genetic improvement for sustainable production of biodiesel. In this review, we present the recent advances in conventional breeding, as well as development and applications of genomic resources to improve the quantity and quality of biodiesel extracted from seeds of *J. curcas*. We also highlighted the requirement of a well-assembled reference genome of *J. curcas* and the potentials of next generation sequencing (NGS) for genome-wide association studies (GWAS) and GS to speed up the increase of the yield and quality of biodiesel from *J. curcas*.

Contents

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1. Introduction

Fossil fuel reserves are limited, while demand is ever-increasing worldwide [1]. Combustible fuels are the world's main energy resource and are at the center of global energy demands [2]. People are increasingly concerned about climate change [3], the dwindling supply of fossil fuel, as well as its unstable and rising costs, which has motivated researchers to seek alternative, renewable energy sources [3–5]. Biofuels are one of the solutions to energy security, the reduction of emissions of greenhouse gas and sustainable development [6]. Biodiesel has received considerable worldwide attention in the past years as it is environmental friendly [7]. However, many countries (e.g. China and Japan) do not allow the use of edible oils (e.g. soybean, palm and rapeseed oils) to produce biodiesel to ensure food security [8]. Therefore, alternative plant sources for non-edible oil for use in production of biodiesel have been extensively sought after [9].

The plant *Jatropha curcas* Linnaeus originated from Mexico and is an underutilized oil-bearing crop [10]. It was brought to Asia and Africa by Portuguese traders 350 years ago [10]. Its seeds can be processed into biodiesel and it is believed that *J. curcas* can grow on poor soils and areas of low rainfall (from 250 mm a year), hence, it has been promoted as the ideal plant for small farmers in countries such as India [11], China [12] Indonesia [13] and Africa [14]. However, *J. curcas* had never been domesticated for producing biodiesel before recent years [15]. Since 2008, several countries have started breeding programs to improve seed yield [16–19]. According to published reports, each mature tree produces an average of 4 kg of seeds per year when cultivated under optimal conditions [12,13,15]. Its oil yield is still much lower in comparison to other oil producing plant species, such as oil palm, which is the main bottleneck in plantation of *J. curcas* for production of biodiesel [20]. Besides seed yield, other traits such as the number of female flowers, later maturity, resistance to lodging, resistance to pest and disease, reduced plant height and high natural ramification of branches are also important for improving oil yield [21–23]. However, the genetic improvement for oil production with traditional breeding is very slow and tedious as phenotypes can only be measured after they are expressed.

Molecular breeding, also called marker-assisted selection (MAS), refers to the procedure of the use of DNA markers which are tightly linked to traits to assist phenotypic selection [24]. In comparison to traditional breeding, molecular breeding possesses several advantages such as selection at seedling stage, no influence of environment, and selection of preferred homozygotes, thus accelerating the genetic improvement. With the rapid development of next-generation sequencing (NGS) technologies, it is now easy to detect and characterize a large number of DNA markers using NGS and polymerase chain reaction (PCR) [24]. Molecular breeding has already been applied in important agronomic species to speed up genetic improvement, such as in rice, maize and corn [24]. In jatropha, molecular breeding is still in its infancy [25], although some reports on DNA markers [26,27], linkage map [28] and QTL mapping for seed yield [25,28,29] have been published.

Several important issues on jatropha biodiesel concerning plantation, tissue culture, biotechnological and biochemical engineering, biodiesel production and applications, economy and policy have already been reviewed [11–13,15,30]. However, this review is different from these excellent reviews, and combines relevant information about the recent advances of the development of genomic resources and their applications in accelerating genetic improvement of *J. curcas* for enhancing quantity and quality of biodiesel extracted from seeds of *J. curcas*. We also discussed the potentials of genome-wide association studies (GWAS) and genomic selection (GS) for speeding up the increase of the yield and quality of biodiesel from *J. curcas*.

2. Conventional breeding for increasing oil yield

2.1. Plantation and phenotypic variations

Jatropha curcas L. belonging to the Euphorbiaceae family is a perennial crop. Its seeds contain up to 35% oil [10]. *J. curcas* is traditionally used as a hedge plant and various parts of the tree have been collected for medicinal uses. However, *J. curcas* was not domesticated and extensively selected for oil yields before the 2000s [31]. As a result, *J. curcas* currently is still a wild plant with low oil yields. The oil yield of wild *J. curcas* is less than 1000 kg/ha/year [12,13], much lower than some major oil crops such as oil palm, coconut oil and rapeseed [32]. We have summarized the annual oil yield of major oil-producing plants in Fig. 1. Due to the realization of its potential for producing biodiesel to decrease the oil crisis, reduce pressure on the environment and control urban air pollution; and many claims about its advantages, *J. curcas* is believed to be an ideal plant for producing biofuel [33,34]. Thus, the plantation of *J. curcas* moved from small scale to large scale in India, China, Malaysia, Indonesia, Philippines, Burma, Saudi Arabia, Ghana, South Africa, Senegal, Nigeria, Tanzania, Ethiopia, Zaxmbia and Zimbabwe and other countries. In 2008, the total plantation area was 900,000 ha globally, among which 84.4% (760,000 ha) was in Asia, 13.3% (120,000 ha) in Africa and 2.23% (20,000 ha) in Latin America. According to a recent report of FAO [35], the total plantation area of *J. curcas* is expected to be 12.8 million ha by 2015. The largest producing country will be Indonesia in Asia, Ghana and Madagascar in Africa and Brazil in Latin America [35].

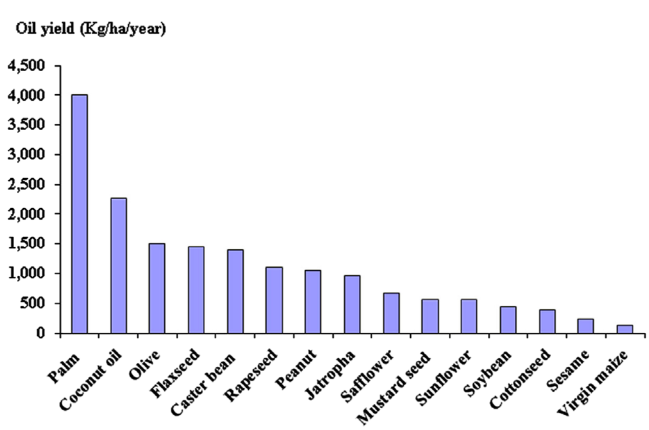

Fig. 1. Annual oil yield of major oil-producing plants. Data were extracted from several sources [32,44,45].