Nicolas Carels · Mulpuri Sujatha
Bir Bahadur *Editors*

Jatropha, Challenges for a New Energy Crop

Volume 1: Farming, Economics and Biofuel

Springer

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Nicolas Carels • Mulpuri Sujatha • Bir Bahadur
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Volume 1: Farming, Economics and Biofuel

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Foreword

In our world, where energy demand is increasing and access to fossil fuels becomes uncertain and expensive, a growing interest in renewable energy is developing. In particular, financial efforts and scientific investments have been made to find substitutes to replace gasoline in transportation. Plant sugars, oils, and, more generally, plant biomass are proposed as possible options to produce liquid bioenergy.

In this context, the 1980s saw the extensive cultivation of crops and wild species with high carbohydrate or fat content for biofuels. With the food price increase of 2007, partly attributed to the cultivation of crop plants for biofuels, renewed interest has been paid to exploit nonedible plants for their biomass, high sugar, or oil content.

Among a dozen of wild tropical plants, *Jatropha curcas* L. was designated as the best candidate, perhaps because of its pantropical distribution (a plant known to have more than 30 common names in Asia, Africa, and America), and certainly because of its already intense culture in Asia (India, China, Thailand, etc.) and Africa (Mali, Burkina Faso, Senegal, etc.). Thanks to its seed oil easily converted to liquid biofuel, which meets the American and European standards; its press cake used as fertilizer; and its ability to grow in extreme conditions (on marginal soils without irrigation), *Jatropha* was dubbed "the green gold of the desert" and taken by a lot of investors or project developers to tackle the challenges of energy supply and greenhouse gas (GHG) emission reduction. Such enthusiasm quickly replaced by negative feedback goes against all the advantages previously put forward for growing *Jatropha*.

Less than a century ago, nobody would have thought that this plant would be the source of so much interest and controversy. Originated from America, this multipurpose plant was introduced in the seventeenth century via the Cape Verde in African and Asian continents where it is generally grown as a living fence. Described by Linneus, its scientific name indicates a pharmacological potential (jatros = doctor, trophe = food) that is confirmed by the numerous traditional medicinal uses. The first intensive cultivation has been done in the early twentieth century on the Cape Verde islands, but it was intended to produce, from seed oil, soap and candles for Southern Europe. Its potential as a biofuel source was revealed later, triggering the cultivation in many tropical countries of this undomesticated plant. However, the returns from these experiences have never been collected.

The main objective of this work is to provide the reader with the most recent scientific studies on *Jatropha curcas*. This book gives an update on the economic importance of *Jatropha* in the parts of the world where its culture is well developed, especially in India, China, Brazil, and the Sahel region of Africa. In response to many questions, the second chapter is devoted to the physiology of the plant and presents its ability to grow and produce under extreme conditions of culture or in the presence of microbial inoculants. Finally, the last part presents all the advantages provided by the cultivation of *Jatropha*, from its by-product production, its use for rehabilitation of degraded lands to its potential as an energy crop.

Montpellier, France Claudine Campa

Preface

Jatropha, Challenges for a New Energy Crop—Volume 1 aims to report on the state of the art of scientific investigations that were made during the past 10 years on the new crop *Jatropha curcas*. The progresses obtained on the knowledge of this abstemious, semi-wild species are already impressive and were mainly achieved in just a decade (2001–2011). This knowledge extends from basic Jatropha physiology and biological reproduction to the basic agronomic practices and systems for its productive management, but also the complete set of biotechnological tools, such as in vitro culture, genetic transformation, genomic sequence, genetic map, and markers assisted selection that is necessary for Jatropha's selective breeding. These scientific and technological achievements pave the way for future technological management and domestication of Jatropha as an industrial oilseed crop able to contribute to the feeding of the transport system.

This first volume of a two-book series that forms the first comprehensive compilation by global experts appeared necessary to us in view of the importance that Jatropha demonstrated worldwide by its large-scale cultivation and emerging value for energy business as a biofuel. This reality contrasts with the difficult access to objective information scattered among science media eventually written in different languages. We thought it was necessary to gather the information scattered worldwide in a sort of summary or general agreement of what is known on Jatropha at the moment. The form of a compilation was also necessary because the knowledge on Jatropha is shared over the tropical belt by different teams, in different politico-economic realities, and with different technological and scientific backgrounds. A compilation was the best way to faithfully transmit the point of view of these experts with as few biases as possible. We believe and hope that this compilation will be a valuable source of inspiration for next-generation scientists investigating this new crop, for technologists invested in improving its profitability, as well as for decision makers and policy implementers involved in politics, economics, environment, or social management that are thinking and acting for the development of a world based on sustainability.

The book is presented in five units comprising 30 chapters covering the main aspects of the worldwide economic importance of Jatropha as well as its physiology, farming, oil processing, by-products, biodiesel, and biofuel combustion. It aims to give a kind of comprehensive picture on the whole *productive chain* of

Jatropha and is supposed to help the reader to make a mental representation concerning the potential of Jatropha as a crop. By contrast, volume two is dedicated to Jatropha as a *biological system* with the purpose of understanding what can be improved in Jatropha and how this can be achieved.

We wish to express our gratitude to all the contributors from all over the world for readily accepting our invitations for not only sharing their knowledge but for admirably integrating their expertise on scattered information from diverse fields in composing the chapters and enduring editorial suggestions to finally produce this venture that we hope to be a success. We greatly appreciate their commitment.

We also acknowledge the support received from many colleagues in the preparation of the manuscripts as well as to our family members and relatives for bearing with us, our commitment to the book.

We thank Ms Hannah Smith, Associate Editor at Springer Science Publishers, and her team for their help and excellent cooperation for bringing out the book in an excellent and readable getup.

Finally, we apologize for any mistakes, omissions, or failures that may subsist in this work.

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Author Biography

Nicolas Carels obtained his graduate degree in agronomy in Belgium and did a Ph.D. in plant pathology at *Faculté des Sciences Agronomique de Gembloux* (FSAGx, Gembloux) prior to working as a scientist on the elaboration of the first genetic map of sugarbeet at the end of the 1980s (ICIseed-SES, Belgium). He then moved to Paris at *Institut Jacques Monod* (IJM, CNRS, France) where he did a Ph.D. on the genome organization in plants. He continued his work on genomics in Italy at *Stazione Zoologica 'Anton Dohrn'* (SZN, Naples) and Spain at the *Centro de Astrobiología* of *Instituto Nacional de Técnica Aeroespacial* (INTA-CAB, Madrid, Torrejon de Ardoz) prior to moving to Brazil (Bahia, Ilhéus, UESC) where he contributed to the application of bioinformatics and genomics toward the improvement of cacao and rubber tree for resistance to fungal diseases. He took Jatropha at its beginning when it was declared a strategic crop for the Brazilian economy by President Lula. His investigations covered the measure of the genome size by flow cytometry and the application of reverse genetics to detect QTLs for oil production with the purpose of breeding Jatropha for this trait. He also published an extensive review (ABR) on Jatropha and more recently an overview on bioenergies (InTech) with special concern for climate change mitigation and biodiversity preservation. He is now a federal officer of Fiocruz (Rio de Janeiro, Brazil) and is interested in the exploration of genomics, bioinformatics, and natural products for human health benefit.

Mulpuri Sujatha graduated in plant sciences at the University of Hyderabad (UoH), India. She has a Ph.D. in genetics from Osmania University (OU), Hyderabad, and has worked on intergeneric and interspecific affinities between Ricinus and Jatropha. She has made significant contributions for the genetic improvement of oilseed crops through genetics, tissue culture, and biotechnological tools. Sujatha's important achievements include development of male sterility systems in safflower, sunflower, and niger, and reliable and efficient tissue culture and transformation protocols for sunflower, castor, niger, safflower, and Jatropha. The genetic transformation protocols developed are being used for the development of insect-resistant transgenics through deployment of suitable Cry genes in castor, development of transgenic male sterility and fertility restoration system in safflower and development of transgenics for resistance to necrosis disease in sunflower. Her experience in molecular markers resulted in mapping of downy mildew resistance gene (*Pl13*) in sunflower besides the development of appropriate molecular markers for distinguishing toxic and non-toxic accessions of *Jatropha curcas*.

Bir Bahadur graduated from Nizam College with a postgraduate degree from University College, Osmania University, Hyderabad, India. He obtained his Ph.D. in plant genetics from Osmania University and was closely associated with Prof. J.B.S. Haldane, FRS, renowned geneticist of the twentieth century. Prof. Haldane advised, guided, and encouraged Bahadur to study heterostyly and incompatibility in Indian plant species, a subject first studied by Charles Darwin in England about 160 years ago. He has made significant contributions in several areas of plant biology especially in incompatibility, mutagenesis, morphogenesis, tissue culture, organism asymmetry, and application of SEM in plant sciences. He has published over 250 research papers, which were well received and quoted in national and international journals, including a number of theses and several publications on Jatropha and Castor. He served Osmania and Kakatiya Universities as lecturer, reader, and professor, and has also served as chairman, head of department, dean of the Faculty of Science, Kakatiya University, Warangal. He has taught genetics, biotechnology, and reproduction of plants for over 40 years and accumulated research experience in these areas for about 50 years. He was a postdoctoral fellow at the Institute of Genetics of Hungarian Academy (Budapest); recipient of the Royal Society Bursary, London; and Honorary Research Fellow at the Birmingham University (UK). He has been invited speaker of over 100 conferences including Max Plank Institute, Koln (Germany); Institute of Genetics (Budapest), Birmingham (UK); University of Texas, Houston (USA); Missouri University, St Louis (USA); Sabrao conference, Szukoba, Tokyo (Japan); Indian Science Congress; etc. He has authored/edited eight books and was editor-in-chief of both proceedings of Andhra Pradesh Akademi of Sciences (Hyderabad, India) and Journal of Palynology (Lucknow, India). He is on the editorial boards of several journals in India. He is recipient of Best Teacher Award by AP state government and Prof. Vishwamber Puri Gold Medal from the Indian Botanical Society for his original contributions in various aspects of plant sciences. He is fellow of over dozen professional bodies in India and abroad including the Linnean Society, London; Institute of Biology and Chartered Biologist, London; and New York Academy of Sciences. He has been recently awarded the Bharath Jyoti Award for his sustained academic and research career at New Delhi. Presently he is on the Board of Directors of Sribiotech, Hyderabad, India and Emeritus Professor, Shandan Post-Graduate College, Osmania University, Hyderabad.

Contents

Part I Worldwide Importance of Jatropha

1 **The Birth of a New Energy Crop** 3
Nicolas Carels

2 **Importance of *Jatropha curcas* for Indian Economy** 13
Sunil Kumar, Alok Chaube, and Shashi Kumar Jain

3 **Status of Bioenergy Research and Jatropha in India: A Review** 31
Prathibha Devi

4 **Socio-Economy, Agro-Ecological Zones, Agronomic Practices and Farming System of *Jatropha curcas* L. in Sub-Saharan Africa** 53
Raphael Muzondiwa Jingura

5 **The Importance of Jatropha for Brazil** 71
Bruno Galvêas Laviola, Alexandre Alonso Alves, Rodrigo Barros Rocha, and Marcos Antônio Drumond

6 **Producing Jatropha Biodiesel in China: Policies, Performance and Challenges** 95
Zanxin Wang

Part II Physiology

7 **Physiological Mechanisms Involved with Salt and Drought Tolerance in *Jatropha curcas* Plants** 125
Joaquim Albenísio Gomes Silveira, Evandro Nascimento Silva, Sérgio Luiz Ferreira-Silva, and Ricardo Almeida Viégas

8 **Role of Microbial Inoculants on Growth and Development of *Jatropha curcas* L.** 153
Jamaluddin

Part III Farming

9 Cultivation Technology for *Jatropha curcas* 165
K.R. Karanam and J.K. Bhavanasi

10 Jatropha Pests and Diseases: An Overview 175
K. Anitha and K.S. Varaprasad

11 Phytosanitary Aspects of Jatropha Farming in Brazil 219
José Carlos Fialho de Resende, Nívio Poubel Gonçalves, Mário Sérgio Carvalho Dias, Carlos Juliano Brant Albuquerque, and Danielle de Lourdes Batista Morais

12 Phytotechnical Aspects of Jatropha Farming in Brazil 239
José Carlos Fialho de Resende, José Tadeu Alves da Silva, Fúlvio Rodriguez Simão, Rodrigo Meirelles de Azevedo Pimentel, and Danielle de Lourdes Batista Morais

13 Arbuscular Mycorrhizal Fungi for Jatropha Production 263
Supattra Charoenpakdee, Saisamorn Lumyong, and Bernard Dell

14 Diversity, Farming Systems, Growth and Productivity of *Jatropha curcas* L. in the Sudano-Sahelian Zone of Senegal, West Africa 281
Ibrahima Diédhiou, Papa Madiallacké Diédhiou, Khadidiatou Ndir, Roger Bayala, Bassiaka Ouattara, Banna Mbaye, Mohameth Kâne, Djiby Dia, and Idrissa Wade

Part IV Byproducts

15 Assessment of the Potential of *Jatropha curcas* for Energy Production and Other Uses 299
Siddhartha Proteem Saikia, Animesh Gogoi, Kalpataru Dutta Mudoi, Adrita Goswami, and Debashish Bora

16 *Jatropha curcas* Biodiesel, Challenges and Opportunities: Is it a Panacea for Energy Crisis, Ecosystem Service and Rural Livelihoods? 311
Suhas P. Wani and Girish Chander

17 Use of *Jatropha curcas* L. (Non-Toxic Variety) as Traditional Food and Generation of New Products in Mexico 333
Jorge Martinez Herrera, Cristian Jimenez Martinez, and Norma Guemes Vera

18 Jatropha Seeds Oil and Products: Important Properties with Respect to Uses 343
George Francis

19 Value-Addition of Jatropha Cake and Its Utilization as Manure in Jatropha and Other Crops 355
Arup Ghosh, Jitendra Chikara, and D.R. Chaudhary

20 Biopesticidal Properties of Seed, Seed Cake and Oil of *Jatropha curcas* L. Against the Polyphagous Lepidopteran Pest *Helicoverpa armigera* 369
D. Muralidhara Rao, S. Anitha, A. Aravinda, B. Karunakar, and N. Devanna

21 Phytochemicals in Jatropha Seeds and Potential Agro-Pharmaceutical Applications of *Jatropha curcas* Phorbol Esters 383
Rakshit K. Devappa, Harinder P.S. Makkar, and Klaus Becker

22 Jatropha Pharmacognosy, Phytochemistry and Pharmacology: A Review 403
Sujatha Samala and Ciddi Veeresham

23 Jatropha and Phytoremediation of Metal Contaminated Land 427
Asha A. Juwarkar, S.K. Yadav, and G.P. Kumar

24 Phorbol Esters and Other Toxic Constituents of *Jatropha curcas* L. 441
G. Raja Krishna Kumar, V.A. Bapat, and T. Sudhakar Johnson

Part V Biofuel

25 Biodiesel Production from *Jatropha curcas* Oil 463
P.P. Chakrabarti and R.B.N. Prasad

26 Performance, Emission and Combustion Characteristics of Preheated and Blended Jatropha Oil 491
Avinash Kumar Agarwal and Atul Dhar

27 Jatropha Oil Transesterification and Byproducts 509
Rosenira Serpa da Cruz, Ivon Pinheiro Lobo, José Faustino Souza de Carvalho Filho, Rafael Costa Amaral, and Felipe Oliveira Souza

28 The *In Situ* Biodiesel Production and Its Applicability to Jatropha 537
Keat Teong Lee and Steven Lim

29 Combustion of *Jatropha curcas* Oil, Methyl Esters and Blends with Diesel or Ethanol in a CI Engine 557
N.R. Banapurmath, V.S. Yaliwal, Y.H. Basavarajappa, S.S. Hiremath, S.V. Khandal, R.S. Hosmath, N.M. Girish, A.V. Tumbal, and P.G. Tewari

30 Potential of Jatropha as an Energy Crop 571
Sébastien Bonnet and Shabbir H. Gheewala

Index 583

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Part I
Worldwide Importance of Jatropha

Chapter 1
The Birth of a New Energy Crop

Nicolas Carels

Concerning the Socio-Economic Context of Biofuel Investigation

To live and enjoy life is surely a surprising experience in all times, but the particular moment where this book is being planned and written is certainly a very interesting and crucial period in the history of humanity. The main challenge for humanity is the auto-control of its worldwide population. Some experts argue that there will be no problem to feed nine billion people when we are already seven billion on earth now. This optimism sounds obsolete when one thinks objectively that the problem will be posed exactly in the same terms at the moment where the human population will effectively reach nine billions. Actually, resources will be far too less than they are now at seven billion and so what? Chinese people already understood that the size of human population is the real challenge and even if it still with a growing population, Chinese government took a long time ago the courageous initiative of an intensive family planning program that, among other things, is allowing only one child per couple without payment of deterrent taxes (Orleans 1975; Nathans 2010). Given the difficulties associated to the acceptance of this planning program, the Chinese population continued to grow, but at a much slower rate and it is expected to reach about 1.5 billion around 2030, before starting to decrease (Attané 2002). As an expected consequence, new problems are emerging, such as accelerated population aging (Hvistendahl 2010) or widening gap between rich and poor, but other positive effects were obtained, such as to bring the consciousness of everyone on the importance of the issues related to demography through education for all (http://www.china.org.cn/e-white/familypanning/). Education for all had the consequence to boost the Chinese economy despite the aging of the population. In turn, a more profitable economy should give a return to

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alleviate better life to the old people. The classical notion that it is the young people that should pay for the old ones is now obsolete. Actually, young people suffer unemployment because of substitution by machines, thus it is these machines that should be expected to pay for old people and not young ones. Again, there is some bias in the system just because basic economic rules are not respected. At this point, one would ask whether humanity should pay the price to go through wars or starvation to regulate its population density because the decision of making the simple accounting of how much square meters of earth planet is allowed for humans failed to be taken. Absence of human population size regulation by itself would have the mathematical consequence to be enforced in a way following the predator–prey equation (Lonngren and Bai 2008) just because earth's geometry will obviously not change.

Another disastrous consequence of an ever growing human population is the ever disappearing biodiversity, the so called ***sixth extinction*** (Wake and Vredenburg 2008). Biodiversity is an important integral component of the earth as we know it; it is a capital that has been accumulating during the past three billion years and that has been historically erroneously evaluated to ***zero*** by economists' procedures. Besides its invaluable environmental services associated, biodiversity offers a capital of tools that manage material transformation at very low energetic levels. These tools are the living cells and their enzymes enclosed in complex multifunctional organisms. These organisms are, thus, information systems that produce material transformations in various timescales. Genomics has recently shown that the most complex organisms, the higher eukaryotes, all host 15.000–25.000 units of information (genes) whatever, plant, insect, mammals or other higher eukaryotes. Thus, the similarity of quantitative information contrasts with the variety of shape/form and functions. We can draw from this observation that the capital given to us by nature is more in the state of the information network of an organism as an instantaneous picture of live processes than in its genes themselves. Through biodiversity, nature offers to us a book of variations on the way to coordinate the expression of genes to accomplish given functions and, this, on the basis of a content of information common to all life forms. In a sense, life is a quantum computing activity based on carbon chemistry that human technology is aiming to reproduce in the mineral paradigm with electronic components. When a species is extinct, this invaluable capital is destroyed for ever because humans do not have time in evolutionary scale, three billions years, to reconstruct it. Actually, we are just starting to investigate how these networks work when they are precisely entering a phase of extinction (Wake and Vredenburg 2008). For example, we can ask what would be medicine, and more generally biotechnology, today without ***polymerase chain reaction*** (PCR). PCR is a legacy from the biodiversity of Yellowstone National Park (USA), but did Yellowstone receive a fee for this gift to humanity? Certainly not! The tendency to consider gifts from nature for free is another general bias of economy in total contradiction with the theory itself and it can be seen as a human distortion in its mathematical context. Recently, this fact has been recognized and taxes on pollution have been started to be implemented in a number of countries. Thus, it is of central importance to keep the nature's capital alive and in its diversity at least to warrant our technological future and this without considering the environmental services that biodiversity offers to humans; services that are absolutely necessary to a healthy human living condition. It is unacceptable for humanity to lose the nature's capital for facts of ignorance, negligence or convenience. According to the concept of Gaia (Lovelock and Margulis 1974), earth is a living dynamic system and we cannot look at as it would not exist; this would be synonym of human extinction in a difficult to predict time delay (Lonngren and Bai 2008). Climate stabilization is one example of service from complex natural systems. Biodiversity has numerous stabilizing effects on the environment and climate (Odling-Smee 2007; Tomkiewicz 2006), ecosystems (Yue et al. 2011) and (consequently) human populations (Simões et al. 2010). Fortunately, even if slowly, the economical value of feral nature (Costanza et al. 1997) is starting to be recognized at economic level and *The* ***Economics of Ecosystems and Biodiversity*** (TEEB) has been created (http://www.teebweb.org/) with this objective.

World population regulation is possible as shown by China, but it is, at least, necessary to take the decision of its planning and management. The price of the disregard shown by the few later human generations around this issue will have to be paid by the future generations to come and there is no way to escape from this fact. Thus, the best strategy would be to reduce/stop the rate of population growth before entering overpopulation and suffering its deleterious consequences. China and India know the price to pay for people over crowding, but other countries unfortunately seem to have difficulties in learning their lesson. The politics that is followed by most if not virtually all countries is to adapt food resources to the needs of an ***ever growing population*** by technology adjustments. This strategy only has a limited future. Any normal person considering this question will definitely agree on the fact that it will not work for ever. The concept of ***infinite resource availability*** on which worldwide economies are based should never have existed and has been the major failure of economic theories (Nadeau 2006). It is on the basis of this concept that population size is growing worldwide. The concept of infinite resource availability does not hold good if it is not included in that of ***sustainability***, which limits the extent of the first to what is realistic, a concept that former economists from the period of ***industrial revolution*** intentionally forget to include in their calculations. This logic has been possible as far as resources were far from their ***peak production*,** but when resources are passing their peak production, a recession is to be expected if alternative resources are not found to maintain the *services* that their provide. This dynamics applies to the case of energy.

Considering energy, the ***infinitely available resource*** is not more crude oil since the one available at low price is probably reaching its peak, but rather the solar one. Experts believe that peak of world oil production should not occur before at least 30–40 years from now. The OPEC nations are currently operating at near full capacity. According to the expected solar life, solar energy will remain "*infinite*" during a large number of human generations. However, solar energy is still expensive and the transition to its exploration can only be partial in its present state of the art. Thus, the joining of a myriad of renewable energies, according to regional opportunities, will be necessary to the successful substitution of fossil and nuclear fuels to feed the energy grid (see Carels 2011 for a review). The model from de Vries et al. (2007) showed the following: (i) electricity from solar energy is typically available from Northern Africa, South Africa, the Middle East, India, and Australia; (ii) wind is concentrated in temperate zones such as Chile, Scandinavia, Canada, and the USA; (iii) biomass can be produced on vast tracts of abandoned agricultural land typically found in the USA, Europe, the Former Soviet Union (FSU), Brazil, China and on grasslands and savannas in other locations. In many areas of India, China, Central America, South Africa and equatorial Africa, these energy sources are found in areas where there is already a large demand for electricity (or there will be such demand in the near future). A combination of electricity from wind, biomass and/or solar sources (Eugenia Corria et al. 2006) may yield economies-of-scale in transport and storage systems. Regions with high ratios of solar-wind-biomass that potentially meet the current demand for electricity include Canada (mainly wind), African regions (solar-photovoltaic and wind), the FSU (wind and biomass), the Middle East (solar-photovoltaic) and Oceania (all sources). In other regions (such as Southeast Asia and Japan), the solar-wind-biomass supply is significantly lower than the demand for electricity. Ratios of around one are found in Europe and South Asia. The potentials just described depend on many parameters, and their achievement will depend on future land-use policies (de Vries et al. 2007; Miles and Kapos 2008).

Why Biofuels?

Numerous low emission scenarios have demonstrated that the goals of the Kyoto Protocol cannot be achieved without providing a large role for biofuels by 2050 in the global energy economy (Vertès et al. 2006). Among the reasons why biofuels are appropriate for such a transition, one may distinguish: (i) their simplicity; (ii) their production via well-known agricultural technologies; (iii) their potential for mitigation of climate warming without complete restructuring of the current working energy system; (iv) the use of existing engines for their transportation (even considering the conventional turbofan used in aviation) (Kleiner 2007; Rothengatter 2010); (v) their potential to facilitate worldwide mobilization around a common set of regulations; (vi) their potential as a directly available energy source with good public acceptance; (vii) their more uniform distribution than the distributions of fossil fuel and nuclear resources; and (viii) their potential to create benefits in rural areas, including employment creation.

Biodiesel from palm oil and bioethanol from sugarcane are currently the two leaders of plant bioenergy production per hectare. Palm and sugarcane are being grown in increasing amounts; however, the continuous increase in their production is not sustainable and will not resolve the enormously increasing demands for energy. Oil palm yields ~5,000 L ha^{-1}. In Brazil, the best bioethanol yields from sugarcane are 7,500 L ha^{-1}. Most of the energy needed for growing sugarcane and converting it to ethanol is gained from burning its wastes (i.e., *bagasse*). For every unit of fossil energy that is consumed by producing sugarcane ethanol, ~8 units of energy are recovered (Bourne 2007). Frequent droughts in many Asian countries have made difficult for them to replicate Brazil's success with sugarcane, which needs an abundant water supply. Thailand and Indonesia are tapping the potential with palm oil.

The general feeling is that first-generation biofuels are already reaching saturation because of the limited availability of arable lands. However, Brazil has additional lands available for sugarcane and *Jatropha curcas* L. (hereafter referred to as Jatropha) cultivation, whereas India is promoting Jatropha on its extensive wastelands. The development of these fuels has already been a success because they have demonstrated that engine running on ethanol or biodiesel is feasible without significant technological modification and can, at least, be used to power public transport.

Why *Jatropha curcas?*

Most traditional biofuels (such as ethanol from corn, wheat, or sugar beets and biodiesel from oilseeds) are produced from classic agricultural food crops that require high-quality agricultural land for growth. The biofuel economy will grow rapidly during the twenty-first century (Demirbas 2008). Currently, approximately 84% of the world biodiesel production is met by rapeseed oil. The remaining portions are from sunflower oil (13%), palm oil (1%), soybean oil and others (2%) (Gui et al. 2008). More than 95% of biodiesel is still produced from edible oils. In Brazil, ~85% of B5 (5% biodiesel in fossil diesel) is sustained by soybean oil. To overcome this undesirable situation, biodiesel is increasingly being produced from non-edible oils and waste cooking oil (WCO). Non-edible oils offer the advantage that they theoretically do not compete with edible oils on the food market.

Because of increased land use for biofuel production, biofuel crops are now competing with food crops (Odling-Smee 2007) and they are expected to have substantial effects on the economy. In addition, the use of food crop for biofuel production promote deforestation and creates a "*carbon debt*" by releasing 17–420 times more CO_2 than the annual greenhouse gas (GHG) reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels from waste biomass or from biomass grown on marginal lands planted with perennial species incur little or no carbon debt (Fargione et al. 2008; Searchinger et al. 2008).

Considering biofuels, Jatropha offers several advantages compared to other oilseeds: (i) Jatropha can thrive on wasteland, where poor populations are generally found. Thus, it is expected to have a positive social effect by attracting government's investment, stabilizing the population in rural areas, and providing the population with incomes and energy; (ii) the feasibility of its biodiesel has been proved (see Carels 2009 for a review); (iii) it can be burnt as neat oil or biodiesel in conventional ***compression ignition*** (CI) engines (see Carels 2009 for a review); (iv) its environmental impact is lower than that of palm oil as long as no natural ecosystems are removed for its implantation (Darussalam 2007; Laurance 2007; Malhi et al. 2008; Stone 2007; Venter et al. 2008). On the contrary, Jatropha is used for waste land reclaiming (Francis et al. 2005; Pandey et al. 2012); and (v) its life cycle justifies its exploitation (Pandey et al. 2011) even if it is still to be improved.

Regional Contributions and Development Worldwide

Scientific investigations on Jatropha started in the 1980s. In contrast to Brazil, where it stalled soon after its beginning and only recovered in 2006, it has been continuing in India. India, is certainly the country that most contributed to Jatropha's promotion worldwide. As summarized in the article title: "the little shrub that could – maybe" of Fairless (2007), the symbolic of a semi-wild species able to thrive in marginal conditions and give oil suitable for biodiesel production, has certainly drawn the attention of the scientific community on Jatropha. From 2008, the scientific community did a huge work and drawn Jatropha to the light by successively mastering its interspecific hybridization (Reddy et al. 1987; Sujatha and Prabakaran 2003; Sujatha 2006; Basha and Sujatha 2009; Parthiban et al. 2009; Popluechai et al. 2009; Karanam and Bhavanasi 2010), performing the transesterification of its oil (see Carels 2009 for a review), characterizing its biodiesel combustion in CI engines (see Carels 2009 for a review), determining it genome size (Carvalho et al. 2008), setting the bases for its DNA marker assisted selection (Sudheer-Pamidiamarri et al. 2009), sequencing the transcriptome of it seeds (Costa et al. 2010; Gomes et al. 2010; King et al. 2011; Natarajan and Parani 2011), sequencing and annotating its genome (Sato et al. 2011) and finally setting up a preliminary genetic maps (Wang et al. 2011); a set of victories that justified the preparation of this book.

Scientific community worldwide had different contributions to the development of Jatropha research mostly according to the technological profile of its regional specificities. Africa is developing an approach where Jatropha is considered on its own and managed with minimal care. Jatropha is taken for what it can release without significant investment, due to its ability to thrive in minimal conditions, and for its ability to thrive in semi-arid climate, which makes it a good candidate to struggle against desertification. As pointed above, India under the pressure of its large dependency on foreign importation of crude oil, has given a strong attention to the biological parameters of Jatropha and to the setting of first insides in its marker-assisted breeding for its rational improvement. Coming later, China also strongly invested in research due to its unsustainable long term dependency on coal for energy and its limited amount of lands suitable for food crops. Through Kazusa DNA Research Institute, Japan offered the genome sequence to the world. Due to its tradition as a world center of high technology, Singapore is investing in biotechnology to shape Jatropha through genetic engineering. Brazil, with its tradition for biofuel production looks for an integrated approach that would optimize the whole picture for the benefit of the whole chain. Mexico, "*late but not least*" is now giving strong attention to the description of genetic diversity of Jatropha in the country since it appears to be the diversification center of Jatropha and is preparing itself to release certified genotypes worldwide.

In Brazil, Jatropha cultivation (20,000 ha) has only been allowed by law in 2009, which explains that the significant interest for this new crop is only relatively recent. In China, the arable land area per capita is lower than the world average. As a result, most edible oils need to be imported. Since Jatropha is not too demanding in terms of soil quality, it is a good option for Southwest China (Yunnan, Sichuan and Guizhou provinces), which is the most suitable area for its cultivation, but with only a moderate potential since it is limited to ~100,000 ha of marginal lands not suitable for food crops (Wu et al. 2009). Such limited potential makes it difficult to expect significant contribution from biodiesel in this country (Yang et al. 2009); more is to be expected from biomass. In other Asian countries with high dependency (>80%) from foreign fuel, such as Thailand, Cambodia, Vietnam, Myanmar, Laos, Indonesia, and India, eroded land areas from deforested soil are also available for Jatropha cultivation. For over 7 years, the Indonesian government is supporting various national and international agencies as well as research institutes for the investigation of Jatropha with a target of biodiesel production covering 10% of the national fuel consumption. At moment, about 1.5 million hectares are effectively planted (Legowo 2007; Silitonga et al. 2011). Since India imports 70% of its fuel consumption (111 Mio t), any renewable energy is most welcome. Because India is a net importer of edible oil, it emphasizes non-edible oils from plants such as, Jatropha, karanja, neem, mahua, simarouba, etc. Jatropha and karanja are the two important leaders of the Indian plant list for biodiesel production and India has 33 million ha of degraded land available for Jatropha reclaiming because of improper use and population pressure over several years (Francis et al. 2005; Kumar and Sharma 2008; Misra and Murthy 2011). Pilot experiments for Jatropha implementation are also being carried out throughout Africa and this has been reviewed by Henning (2005), but government incentives are still few (Jumbe et al. 2009).

Challenges for Jatropha as a Successful Biofuel Crop

Even if a huge work has been done that allows scientists to have a comprehensive picture of Jatropha as a whole, it remains that this species is a semi-wild species in the process of domestication. There is no reason to complain about such status when one realizes that in ~4 years, the scientific community succeeded in going through the most part of a journey that took 5,000 years for a species such as wheat for being domesticated. In other words, if Jatropha is still far from an industrial crop, it is however rather sure that due to its amazing technological potentialities it went over a point of no return. The new crop Jatropha is now entering in the domain of scientific integration towards complete domestication for profitable biodiesel production. It is to be expected that within a short time scale the architecture and functionalities of Jatropha will be deeply affected by selective breeding and genetic engineering. Among the traits that should be affected in a feedback loop process along the whole chain of biodiesel production are: (i) short-term (few years) or long-term (perennial) system of exploitation; (ii) extensive (with resting period in semi-arid condition) or intensive system (ferti-irrigation) of exploitation; (iii) fertilization; (iv) plant architecture (semi-dwarf or dwarf); (v) discontinuous, but synchronous flowering and fruiting; (vi) dioecious plants to maximize out-crossing and yield/production per plant; (vii) increased seed production over 4 t ha^{-1}; (viii) plant tolerance to pests and diseases (especially to those of the rooting system); (ix) mechanical harvesting; (x) fatty acid composition; (xi) genetic engineering to facilitate the biofuel processing (triglyceride conversion into free fatty acids?, enzymatic conversion); (xii) low cost alkyl ester conversion; (xiii) biofuel composition for optimized combustion in CI engines; (xix) microeconomic modeling of suitable agro-systems of Jatropha growing and exploitation; (xx) life cycle modeling; (xxi) plant growth and fructification modeling according to climate conditions of culture.

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