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Communication

Opportunities and Constraints of Promoting New Tree Crops—Lessons Learned from Jatropha

Wouter M. J. Achten [1,*], Navin Sharma [2], Bart Muys [3], Erik Mathijs [4] and Paul Vantomme [5]

[1] Institute for Environmental Management and Land Use Planning (IGEAT), Université libre de Bruxelles (ULB), Avenue Franklin D. Roosevelt 50 CP 130/02, B-1050 Brussels, Belgium

[2] World Agroforestry Centre (ICRAF), CGIAR, Dev Prakash Shastri Marg Pusa Campus, New Delhi 110012, India; E-Mail: navin.Sharma@cgiar.org

[3] Division Forest, Nature and Landscape, KU Leuven - University of Leuven, Celestijnenlaan 200 E - 2411, BE-3001 Leuven, Belgium; E-Mail: bart.muys@ees.kuleuven.be

[4] Division of Bioeconomics, KU Leuven - University of Leuven, Celestijnenlaan 200 E - 2411, BE-3001 Leuven, Belgium; E-Mail: erik.mathijs@ees.kuleuven.be

[5] United Nations Food and Agricultural Organization, Viale delle Terme di Caracalla 00153 Roma, Italy; E-Mail: paul.vantomme@fao.org

* Author to whom correspondence should be addressed; E-Mail: wouter.achten@ulb.ac.be; Tel.: +32-2-650-4322.

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Abstract: It is not uncommon that new crops suddenly attract a lot and international attention from private and public actors based on their acclaimed potential to contribute to sustainable development. Such sharp increases in attention can lead to big investments and promotion campaigns to domesticate and commercialize these crops at industrial scale. However, in many cases the research of these plants is still in its infancy and investors generally lack sufficient insight into uncertainties and risks related to their investments, which consequently hold sustainability risks.

Keywords: *Allanblackia*; *Argania spinosa*; *Artemisia annua*; *Azadirachta indica*; *Jatropha curcas*; miracle crop; *Moringa oleifera*

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1. Introduction

On a regular basis, we can observe plant species receiving rapid increasing, international media attention based on their acclaimed potential to increase social, economic and/or environmental sustainability. This attention often triggers investments and promotion campaigns to domesticate the species, and to establish large-scale, commercial plantations. However, often these plants are still subject to fundamental research. Further, investors, but also promoting agencies or organizations, generally tend to focus on the promising aspects of the species, lacking a full insight into the constraints, uncertainties and risks. Too high expectations or commercial failures might then result in the termination or further development of the plant and its potential products. This is a typical description of a "boom and bust" cycle of so-called "miracle", or "rapidly emerging" crops or trees. (We define "emerging" species as species, which suddenly attract global attention (by the media, donors, academics, international organizations, researchers, industry) for large-scale commercial, developmental and/or environmental aims. Often these species have a local function or use before attention grows gradually at global levels by promoting institutes.)

These "boom and bust" cycles pose considerable sustainability risks (environmental, social and economic). Environmental risks can, for instance, relate to land-use changes and their consequences, or to the introduction of species which are invasive in their new environment and become pests [1]. Social risks might occur when investments in the booming crop are stopped and farmers are left idle with the plants, or when people have migrated, attracted by the booming business and associated labour demand. Economic risks are evident for the investments in a booming, but immature product or market. However, next to these sustainability risks the "boom and bust" cycles also hold the risk of losing opportunity, by throwing out the child with the bathwater as reaction to initial failures [2].

Initial failures (often measured in economic indicators) are, however, not the only constraints for an internationally emerging crop to become a success. In relation to both the native species and introduced species, e.g., the local knowledge and capacity is important. Local capacity is necessary to enhance activities around new species. In case of native species, local knowledge on these species is generally available. In case of introducing new tree species to new areas, capacity is necessary to handle the introduction and development (infrastructure, knowledge, *etc.*) of these species and their products. Along with the promotion of new species, it is therefore important to have or provide the instruments to use and/or build local capacity.

The broad attention given to these crops often prevents having a good view of the true opportunities and the false claims of the crops, and the potential constraints and risks of promotion. Therefore, it is very difficult for NGOs, policy bodies and development agencies to advise on the potential of such a crop and to decide whether to promote the crop or not. The purpose of this paper is (i) to raise awareness on the risks and constraints involved when promoting new large scale, commercial miracle species, and (ii) to provide agricultural, forestry, rural development and donor agencies advice for dealing with such rapidly emerging and widely publicized plant species in their decisions to promote or not.

In a first step, the paper describes and analyses qualitatively the case of *Jatropha curcas*, as this has been a very important and recent miracle tree which received a lot of attention globally. The Jatropha case is used to clarify general potential opportunities and constraints of emerging plants. In a second step, the lessons learned from the Jatropha case will be compared with, and evaluated against a

selection of other emerging species (*i.e.*, Allanblackia, Argan tree, Moringa). Based on this comparison and evaluation, communalities and differences will be identified. Further, the main driving forces of species emergence and the points of attention for promotion of emerging crops are qualitatively discussed (complemented with points-of-attention learned from other cases e.g. Neem, Artemisia).

2. The Case of *Jatropha curcas* L. in Retrospect

Jatropha is native to Mexico and continental Central America. Portuguese explorers learned about *Jatropha* and established plantations for soap and lamp oil production in Guinea Bissau and on the Cape Verde Islands. Later, this plant material was further spread across other Portuguese colonies on the African and Asian continent. Nowadays, Jatropha is spread pantropically [3].

Jatropha received some attention as a potential biofuel crop in the second half of the 1990s [4] and the interest in this plant received a new boost in 2003 when the Indian Planning Commission put Jatropha forward as the main crop for biodiesel production to reduce dependency on fossil fuel and reduce greenhouse gas emissions [5]. India planned to introduce *Jatropha* in wastelands and degraded lands only, to avoid conflict with food production and to simultaneously reclaim these unproductive areas, enhance rural socio-economic development and produce fuel [6]. From 2003 till 2007, several positive claims about Jatropha were spread globally through the internet, adding to the global hype around this crop [5]. At that time, this interest was further enhanced by emerging energy policies in Europe and elsewhere supporting renewable energy sources irrespective of their origin.

2.1. Jatropha Claims Contributing to the Hype

Besides the claim that Jatropha could reduce greenhouse gas (GHG) emissions through the production of biodiesel, it got the status of "miracle crop" based on [7]:

(1) Claims in relation to its yield: (i) Jatropha can produce up to 12 tons of seed (equivalent to 3 tons of oil) per hectare per year; (ii) Jatropha is not prone to pests and diseases. (iii) Jatropha does not require a lot of inputs (fertilizers and biocides) and management.

(2) Its escape from the food-*versus*-fuel debate: (i) Jatropha produces toxic oil and, as such, was considered not to compete with food production; (ii) Jatropha can reclaim "waste lands" unsuitable for agriculture (arid and semi-arid lands till average annual rainfalls of 250–300 mm), another reason why it does not compete with land for food production; (iii) Jatropha leaves are toxic and are not browsed by roaming animals, as such Jatropha can be used as living fence to protect food crops.

(3) The multipurpose nature of *Jatropha*: (i) Jatropha has a root structure consisting of four perpendicular lateral roots and one taproot, which makes Jatropha very suitable for soil erosion control and prevention; (ii) Jatropha seed cake is rich in nutrients and is suitable as organic fertilizer; the seed cake is also rich in essential proteins, and when detoxified, can be used as a high quality livestock feed; (iii) Jatropha improves soil fertility; and (iv) Jatropha oil can be used as a pesticide.

Based on these claims, Jatropha was depicted as a crop with enormous socio-economic and environmental development potential in degraded lands of arid regions.

2.2. Claims versus Facts

Although many claims were made, most of them were not based on scientific knowledge or were subject to large uncertainties. In 2007–2008, several scientific reviews showed that information on some essential production system parameters was (and some still are) very uncertain, like *Jatropha* growth requirements, the grain yield as a function of site, or effects on soil erosion. Of other essential parameters, no knowledge had so far been acquired, like genetic diversity and breeding, yield response to agronomic practices, impact of pest and diseases, and invasiveness [7–8]. Environmental impacts (e.g., energy balance, greenhouse gas balance, water balance) and economic potential were therefore almost impossible to evaluate.

Since then, the knowledge base has increased tremendously, and the mentioned knowledge gaps have been gradually filled. Some of the science done has confirmed the original claims; e.g., the multipurpose nature of the crop (e.g., soil erosion control potential [9]), whereas other studies contradicted some of the early claims, e.g. based on the distribution range of the species in its centre of origin it was concluded that the optimal annual rainfall range is 1200–2000 mm, instead of semi-arid conditions (250–300 mm) [10], and in combination with the scarce reported yields, a global yield prediction model showed yields up to 5 tons at the best locations, instead of 12 tons per ha per year, but in dry climates only up to 750 kg seed per ha per year [11]. The large need for more and better *in situ* yield measurement remains today [12]. These findings show that not all strong claims could be held, e.g., competition for land and/or resources in the food-*vs*.-fuel debate. Life cycle environmental impact evaluation showed a potential reduction in fossil energy consumption and greenhouse gas emissions, but also an increase in eutrophication and acidification risk [13]. In relation to land competition, the positive greenhouse gas balance can be easily neutralized by direct and indirect land use changes [14–16], meaning that Jatropha bioenergy is not *per se* climate friendly [17].

The economic potential of Jatropha remains very uncertain today [18], not only because of uncertainty in the yields and the inputs, but also in the variability of the Jatropha seed price (e.g., in Tanzania the seed price varies from 100–500 Tanzanian Shilling or 0.07–0.33 USD per kg). This is particularly problematic as it is expected to account for more than 75% of the total biodiesel cost [19]. Because markets are generally not yet established, it is very difficult to determine the seed price for economic analyses. For the case of Tanzania, Van Eijck and Romijn [20] identified additional important barriers: structural, infrastructural and logistic problems, technical skill and knowledge gaps, limited local research infrastructure, interests of powerful actors in the current energy regime, and the price disadvantage for Jatropha oil except in remote areas. Further, they also noticed cultural barriers associated with traditional uses of Jatropha. Obstacles emanated from the known poisonous characteristics of the crop which can be perceived as a barrier, but may only be a precaution based on local knowledge. Based on evaluations of Jatropha experiences in Mali, Tanzania and India, Brittaine and Lutaladio [21] concluded that the level of economic returns that would attract and retain private investments may not be attained on degraded land. They further showed that returns on labour are low for Jatropha compared to other biofuel feedstocks. Due to unequal flowering and fruit ripening, the harvesting period can stretch to several months. This low return on labour further weakens both the position in the food-*versus*-fuel debate and the claims on socio-economic development. However, this largely depends on the yield which could still be enhanced by addressing breeding and agronomic knowledge gaps [21].

2.3. Key Lessons Learned from the Jatropha Case

From the above-mentioned narrative, general applicable lessons on constraints and risks of early promotion of new crops are qualitatively identified and shown in Scheme 1. In the *Jatropha* case, three blocks of potential sources of constraints are identified: the information base, the market and the local capacity. For each block, several statements are provided which we consider to be necessary prior to embarking on a major promotion. For some statements, one or more specific questions and action points are listed as well.

Scheme 1. Key lessons learned from the *Jatropha* case.

INFORMATION BASE

Lesson 1. Reliable information on the species and its production system is primordial for further development of emerging species

- What information is available? What is the level of uncertainty of the information? What information is not available (knowledge gaps)?
  ➔ **Critical literature review**
- Knowledge on growth requirements and agronomy is essential for further species development
  ➔ **Check agroecological growing conditions in areas of natural distribution**
- Test plots and pilot plants are good sources of information and experience
  ➔ **In case insufficient knowledge is available or the uncertainty of it is too high, it is advisable to test different provenances of the new species** in test plots (common garden experiments along an environmental gradient) and pilot plants. **This allows science to be applied** to obtain reliable growth and production data to plan further expansion of the crop.

Lesson 2. Insight into the market situation through sufficient market information is primordial for further development of emerging species

Lesson 3. Reliable information on potential environmental and socio-economic impacts

MARKET

Lesson 4. Economic benefits depend on the position of the species' product or function in current value chains

- Are the species' products or functions marketable in an established market?
- Are there constraints (legal, physical, *etc.*) to access this market? If yes, which?

LOCAL CAPACITY

Lesson 5. Socio-economic potential or constraints will determine the adoption of the emerging species by local people

- Is there local information and capacity available to manage the species?
- Are necessary (policy) tools available to build up the needed local capacity?
- Does the species' product or function fits in a value chain local people can access?
- Does the species diversify local livelihood resources or rather the opposite?
- Does the species spread risks?
- Competition with land for food and nature or with labour?

3. Status of Other Emerging Species

In a second step, this paper aims to confront the lessons learned from the Jatropha case with the status of other emerging species. In the following sections, we describe a short history, the reason for increased interest and the current status of a selection of tree species, namely Allanblackia (*Allanblackia* spp.), the Argan tree (*Argania spinosa* (L.) Skeels.) and *Moringa* (*Moringa oleifera* Lam.).

3.1. Allanblackia Species

Allanblackia is a plant genus with nine undomesticated forest tree species [22]. The oil-rich seeds of these species have been harvested by local communities from the uplands of the Usambara Mountains in Tanzania to the Sierra Leone lowlands in West Africa for generations [23]. They used the seeds for food and to make cooking oil and soap. However, Allanblackia species know other uses too. Traditionally, their medicinal qualities have been used in Ghana. Further, the stem wood is used as timber. During the First World War, Allanblackia oil was used in Tanzania to substitute for cocoa butter. Later, in the 1970s and 1980s, export to Europe started in small quantities [24].

After oil samples had been analysed the specific characteristics of the Allanblackia oil got described. Composed almost entirely of stearic and oleic acids and having a sharp melting point around 34 °C, the Allanblackia proved to be extremely suitable as yellow fat or for cream-based spreads like margarines [23,24], without any further modification, unlike palm oil, reducing processing steps [24]. Based on this observation a major player in this sector decided to use Allanblackia in consumer products and therefore needed a regular, and large, supply.

In 2002, the "Novella Project" was established. The project was a public-private partnership founded to support a program of scaling up the production of Allanblackia in Ghana, Tanzania and Nigeria. At the same time, the project aimed at reducing poverty, promoting sustainable supply chains and biodiversity conservation. Upon the launch of this project, very little was known about the biology, autecology and production potential of Allanblackia. Therefore, the project started with making an inventory on the availability and natural distribution of Allanblackia trees. By 2003, the surveys indicated that Tanzania had 1 million Allanblackia trees accessible for harvesting which were assumed to provide an annual yield of 40,000 ton seeds, or 13,000 ton oil [24]. The local farmers were convinced that there was good money to be earned by gathering the Allanblackia seed [24], as the investing company guaranteed to buy every seed available at a fixed price [25].

However, in 2004 only 4 tons seeds (10,000 times less than the estimated potential) were collected. The inventories had largely overestimated the number of trees that could be harvested [25]. In order to achieve the Novella project goals, it was clear that Allanblackia would need to be brought out of the forest to the farmers' fields [24].

With this new approach, the project faced several problems impeding domestication: low germination rates of seeds, long gestation period of plants propagated from seeds, difficult determination of the sex of the seeds, dwindling Allanblackia populations and loss of genetic diversity in the wild. Several of these problems could be solved by using vegetative propagation, but this still needs considerable research. Elite material is only to be expected in the 2020s [24].

In the first half of 2008, over 40,000 Allanblackia trees were planted on small rural farms. Fifteen large nurseries, called regional resource centres, have been established to grow Allanblackia trees and teach farmers how to grow their own trees. In Tanzania, 5000 farmers in 55 villages are taking part. In Ghana, 5500 farmers are taking part in over 200 hamlets [26].

If the African continent would need to produce enough Allanblackia oil to meet the demand, it will need to plant tens of millions of trees [24]. Therefore, still a lot of research and development is needed on reproductive biology and characterization, vegetative propagation, growth conditions, cultivation practices, selection and breeding, socio-economic effects. Furthermore, this big demand can become a challenge to the partnership in keeping the principle of sustainable supply chains, as new actors in the partnership might see large-scale plantings of Allanblackia as a more attractive option [23].

3.2. Argania spinosa

The Argan tree (*Argania spinosa* (L.) Skeels) (Sapotaceae) is endemic to Morocco, where Argan forests cover about 8000 km^2 [27]. It is a slow growing spiny tree and grows either with shrubby architecture or up to 10 m when standing alone in favourable environments. The Argan tree's life span frequently exceeds 200 years [27]. As its root system reaches in deep soil horizons, the Argan tree can resist severe drought [27]. It can survive in areas with an annual rainfall down to 120 mm and maximum temperatures up to 50 °C [28]. The Argan tree is claimed to protect the soil against heavy rain or wind induced erosion and maintains soil fertility [27,29]. Based on these properties, the Argan tree is often seen as a suitable tool to combat desertification [27,29]. The Argan trees produce wood suitable as fuel wood and have leaves known as "hanging forage" suitable for feeding goats and camels [27].

The Argan groves have been severely degraded and fragmented due to: (i) clear cutting for fuel wood and agriculture, (ii) urbanization and population growth, (iii) overgrazing, (iv) loss of ecosystem productivity and (v) systematic collection of Argan fruits which causes problems in the natural regeneration of the Argan populations [30].

The Argan fruits are mainly collected for the oil bearing seeds they contain. The oil is part of the traditional alimentary medicine [29,31]. The oil is used as edible oil, but also for medicinal purposes. It can be used against rheumatism and for the healing of burn wounds [31]. Argan oil also has its cosmetic uses. It is advocated as moisturizing oil. The pericarp is mainly used for tanning hides [31].

Currently, the Argan oil attracts attention from the oil market as one of the rarest and most expensive edible oils in the world. Furthermore, there is increasing notice of the cosmetic and nutritional properties of the oil, as it is very rich in unsaturated fatty acids and has a high level of natural tocopherols (Vitamin E), phenols, phenolic acids, carotenes and squalene [32] in [33].

In the mid-1990s, the domestic Argan oil market slowed down and the non-traditional, high-value oil markets expanded significantly in the late 1990s and beginning of 2000s [34]. New innovation activities in Argan oil products date back to the mid 2000s. Argan oil use started in skin care supplements particularly in France, followed by use in culinary oils in USA, UK, Germany, France and Switzerland. Between 1996 and 2006, the price of one litre of Argan oil at producers gate increased by 570% (€ 3.5–20/L) [34].

Based on the economic successes of Argan oil, the idea of growing Argan trees outside its centre of origin has emerged [27]. This could take *Argania spinosa* to a next step as emerging tree species. In a

first stage, this could affect the Argan oil business in Morocco and could inhibit the efforts made to save the Argan forests. Therefore, the Moroccan government applied to obtain a Geographical Indication (GI) for Argan oil (initially intended for European products such as Parmesan cheese, Roquefort cheese or Champagne, but now extended to non-European countries) [34]. A granted GI would mean that only Argan oil prepared from seeds collected in Morocco and following strict production rules can be sold as such [27]. In this way, Morocco tried to preserve the traditions connected to Argan oil (women making the oil, old extraction techniques, *etc.*).

3.3. Moringa oleifera

Moringa oleifera Lam. (Moringa) is a small fast-growing tropical tree originating from India, but nowadays grows pantropically (tropical Africa, South East Asia, Central and South America). This multipurpose tree has many uses of which the nutritional and medicinal properties are initially considered the most important. It is considered as one of the world's most useful trees [35] and has often been labelled as a "miracle tree" [36–37].

Although Moringa is considered a drought-resistant pioneer species, it grows in areas with annual average rainfall between 750 and 2250 mm. Preferring well drained sandy soils, Moringa is claimed to adapt easily to various soil conditions. However, it is very sensitive to water logging and frost [35].

There is evidence that the cultivation of this tree for its edible and medicinally active seeds in India dates back several thousand years ago. Today, there is broad scientific consensus on the nutritional and medicinal properties of Moringa leaves, fruits, flowers and immature pods [38].

Moringa leaves are reported to be a rich source of protein, Vitamin C, calcium, potassium, β-carotene and natural anti-oxidants [38]. The leaves are generally dried and then ground to powder which is then used in sauces [35]. Based on these nutritional properties, leaves are intensively produced in a horticultural fashion [39].

Moringa seeds contain up to 40% edible oil which can be used in the kitchen, but can also be used as lubricant for fine machinery or in cosmetics. Medicinal properties have been ascribed to Moringa's roots, bark, gum, leaves, fruits, flowers, seed and seed oil, such as, e.g., treatment of inflammation and infections, cardiovascular and gastrointestinal disorders [38].

Anwar *et al.* [38] concluded that Moringa hosts a lot of medicinal potential and that more research is necessary on isolation of compounds with medicinal properties, certainly the potential anti-tumour compounds. Therefore, they called to cultivate Moringa widely in the areas where environmental conditions favour optimal growth [38].

Besides the nutritional and medicinal properties, Moringa has been promoted for the water purifying attributes of its seeds as well [37]. Crushed seeds are considered a replacement of synthetic coagulants [38]. Moringa seeds are very effective for high turbidity water (reduction of 92%–99%) and shows similar effects to alum. Further, the seeds have pH lowering and natural buffering capacities which could neutralize alkaline surface or ground water. Last, but not least, the seeds have antiseptic properties valuable for the treatment of drinking water [38]. Although this might be an interesting economic property, no evidence could be found of the activities of industrial players in this field.

4. Discussion

4.1. Similarities and Differences between the Emerging Crops Covered

The overview given on *Jatropha curcas*, *Allanblackia* species, *Argania spinosa,* and *Moringa oleifera* shows that these species are in different stages of emergence. Moringa is already cultivated widely. Allanblackia is promoted in Africa by a large industrial player on the edible oils market, while Argan oil is offered to the high-value oil market as a traditional and exclusive product. Jatropha triggered a very strong and rapid hype worldwide, which is currently fading, while Moringa has been promoted for decades but did not reach a level of interest comparable to Jatropha (yet).

This short overview of four emerging tree crops also shows that there are many dimensions to the status and potential of an emerging crop. As mentioned above, it is about marketing (products for big global markets or products for small exclusive markets, products for rudimentary local markets, *etc.*), scale (local *versus* global, native species *vs.* introduced species), governance issues (institutional capacity, labelling, patenting, intellectual property, and geographic indication), plant resources and the easiness of cultivation/domestication and the type of growing conditions.

These topics will be further discussed in the following sections.

4.2. Jatropha Lessons Applied to Selected Emerging Crops

Table 1 shows some constraints and opportunities for each crop. For Allanblackia, currently used through wild collection, the major constraint is the lack of information on key issues about domestication, crop production and development, certainly when cultivation in farmers' fields is promoted. However, there was a significant initiative from the Novella project to fill those knowledge gaps. The fact that a big industrial player is interested might look promising as it might indicate the potential of the plant. However, the single company market created for Allanblackia may also hold risks. In the countries where Allanblackia production is promoted, Allanblackia is currently not cultivated and its oil is not widely available as edible oil. To whom will the farmers sell their seeds when the company is no longer interested in Allanblackia? On the international oil market Allanblackia would have to compete with sunflower, rapeseed and olive oil. On the other hand, the attention that the company gives to Allanblackia can also trigger attention from other industrial groups. In such cases, the farmers might benefit from a potential price competition.

Argania spinosa cultivation is not as heavily promoted as Allanblackia. This is probably due to the type of product it delivers and the type of market it fits. The oil is too rare and too expensive for large-scale application in the edible oils industry. Although there are economic incentives that trigger the promotion of both Argania as Allanblackia, Argania promoters aim at small but high value markets, while the Allanblackia promoter aims at a large (global) lower value market. Argania was picked up from the local market and slowly brought to the high value niche markets (health and cosmetics), which is also different from Allanblackia oil for which there actually is no considerable locally established market. These issues give the impression that *Argania spinosa* is a success story. However, its current economic successes on the international niche market also trigger initiatives outside Morocco (e.g., Spain and Israel) which might affect the exclusive and traditional status, and consequently the economic value, of the "real" Moroccan Argan oil. Furthermore, the upcoming interest in Argania's medicinal properties might trigger a new boost in its promotion.

Table 1. Overview of key issues of the five discussed emerging crops, based on the key lessons learned from the Jatropha case (Section 2.3).

	Product(s) of main interest	**Climate**	**Information**	**Market**	**Local capacity**
Jatropha curcas	Biofuel oil for global energy market	Tropical savannah and monsoon climates Distribution: Global	Lack of information on genetics, cultivation, economics.	Biodiesel market is in development both local as international	Cultivation: No (numerous initiatives try to build local capacity); Processing: Yes; Marketing: No
Allanblackia species	Edible oil for global margarine market	Tropical humid climates Distribution: Africa	Lack of information on reproductive biology, vegetative propagation, genetics, growth conditions, cultivation practices	No substantial local market. One-company-market: The company buys all seeds	Gathering: Yes; Domestication, Cultivation: No, Novella Project is building capacity; Marketing: No
Argania spinosa	High value oil (as edible oil and in cosmetics)	Mediterranean arid climates Distribution: Morocco	Information available on growth conditions, ecology, cultivation outside centre of origin, genetics and research is still ongoing.	Established international niche market	Gathering: Yes; Domestication, Cultivation: No; Marketing: Yes
	Potential Anti-malaria, anti-cancer and anti-oxidant compounds		Research on medicinal compounds is emerging	-	-
Moringa oleifera	Food (leaf powder)	Tropical semi-arid climates: Distribution: India and East Africa	Most topics have been studied and scientific attention is still very strong	Subsistence use or Local central American markets	Gathering: Yes; Processing: Yes; Planting and cultivating: Yes
	Oil (Cosmetics)			Entering international market	
	Water purification (seed powder)			No formal market established yet	
	Medicinal compounds			-	-

Moringa has long been promoted as a nutritional tree suitable for semi-arid regions. The nutritional products (leaf powder and oil) of Moringa are interesting. As the spread of Moringa worldwide was mainly based on its ability to produce food and fodder in semi-arid regions, the more recent attention from an international cosmetics company seems not to have triggered a significant boost in cultivation promotion. Recent promotions for its water purification capacities seem to have encountered a marketing problem. Although biological water purification could be a growth market, there is no evidence of such market yet. In some places where Moringa has been introduced, farmers have no access to markets where there is Moringa product demand.

4.3. Key Driving Forces in the Emergence of New Crops

The evaluation of Jatropha and three other emerging crops indicates that financial incentives are the most important drivers for crop emergence. However, there are other drivers as well, such as local socio-economic development and environmental drivers. Often different drivers are active in complex interaction. For instance, Jatropha was brought to the attention as a potential crop that could simultaneously produce sustainable energy (financial and environmental driver), enhance rural socio-economic development in developing countries (socio-economic development driver) and could reclaim waste lands (environmental driver). Further, it was claimed to be easily cultivated on almost every site. On top of that, Jatropha biodiesel was assumed to host economic potential for industrialized countries as well. In these countries, bound by GHG emission reduction and fuel blending targets, financial incentives created a market for biodiesel and cogeneration, contributing to the triggering of a global cultivation hype. This illustrates that hypes on species and their products do not necessarily originate in their countries of origin or cultivation, but can start off-site in faraway markets. Actors may also actively trigger or stimulate hypes in order to attract investors. In the case of Jatropha, economic incentives in a few industrialized countries triggered big Jatropha investments, which in turn increased Jatropha's attention which further enhanced the promotion and investments. In this way, this became a non-linear self-enhancing process.

The extent to which these drivers influence the emergence of a certain species depends on the products and the functions these species can deliver and the markets where these products or functions can possibly fit in and the scale of these markets (local *versus* global). Jatropha oil, Allanblackia oil and Argan oil are good examples of that. Jatropha oil has properties suitable for biofuel production and attracts the attention of the global energy market; Allanblackia oil is suitable for margarine production and attracts attention from the international edible oil market; whereas Argan oil is a rare oil with a traditional and exclusive character and attracts attention from the high value oil markets in rich countries. It is clear that these three markets are very different and also have different driving or promoting potential. This also applies to the other drivers, environmental and socio-economic drivers.

The contribution of the different drivers to the emergence of a species depends on the products and functions that the species can deliver as well. However, in case a species delivers products and functions with clear economic value, generally the economic driver is the biggest driver (depending on the market scale—local *vs.* global).

The existence of a market or the type of market where the product or function of an emerging crop can fit in is an important aspect of the potential success of a species. However, in terms of economic

drivers, this is not the only important aspect. The ability to access such markets is important as well. Therefore, the species and the location where the species is promoted rely on some other resources and assets as well. Enough high quality plant resources (available populations, genetic diversity, nursery capacity), suitable land area, labour (human resources, both in number and in skills) and logistics (e.g., transport infrastructure, input availability, land rights) are necessary to bring a species to a certain market. However, when the market is big enough and hosts high economic potential, these resources and assets can be created. As an example, during the rubber boom in the Amazon, numerous people within Brazil, and beyond, migrated to the Amazon in search of jobs in this booming business. The same applies to the plant resources. The strong increase in investment in Jatropha genetics, breeding and cross-breeding is exemplary to improve Jatropha performance.

4.4. Additional Points of Attention

4.4.1. Governance Issues

A range of issues dealing with the legislative framework that governs the production and trade of these products, such as labelling as well as the institutional capacity to implement and review product legislation is critical, and should be well assessed when considering the introduction of a "new" product or miracle tree. Legal issues linked to emerging crops are related to intellectual property rights, patenting, and geographic indication. Besides these more general legal issues, several sector-dependent standards, certification and labelling procedures are important as well. Strong regulations exist for food, nutrition and health for respective products. It is important to note that a product from an emerging crop also has to comply to such national and international regulations in order to access the respective market.

The two first issues, intellectual property and patenting, are often linked with biopiracy. "Biopiracy" is a term in the fields of biotechnology, pharmaceuticals, and intellectual property law meaning "*the commercial development of naturally occurring biological materials, such as plant substances or genetic cell lines, by a technologically advanced country or organization without fair compensation to the peoples or nations in whose territory the materials were originally discovered*" [40]. In order to protect their materials and indigenous knowledge, governments try to obtain plant variety protection, patents and geographic indications of their indigenous, local plant varieties, genetic lines and products. The story of neem (*Azadirachta indica*) can be cited as an example here (see [40–42]). Such protection measures try to guarantee that upon commercial use, the original sources are acknowledged and/or credited. On the other hand, companies that are developing new plant varieties through breeding or new products, try to protect their intellectual property (/investments) as well, by patenting transgenic plants, genes or DNA markers. It is in this context that the *Convention on Biological Diversity* (Nagoya, 2010) tries to regulate the access to genetic resources and traditional knowledge.

4.4.2. Is there a Durable and Established Market for Emerging Tree Products?

The existence of a market is very important for the emergence of a tree species, as explained in previous sections. However, the durability of the market is important for the future viability of the developed activities of the tree species. This applies to both local markets and international markets.

The durability of the market is particularly important for tree species as they are perennial. Very often planting trees is a long term investment. Furthermore, most trees have a gestation period which can take several years. In case the market for the tree products collapses, or shifts, the investment fails. Additional to the failed investment, the trees are still there which means that the land has to be cleared, before it can be used for other activities, which represents an extra cost. Therefore, it is preferable that there is a considerable established local market for the tree product(s).

In the case of Jatropha, a market for seed and oil had to be created; even the supply chain and the market for biodiesel was not available in many countries. The creation of supply chains and markets takes time, time in which eventual harvest might get lost and disappointed farmers start leaving the activities and (re)start other activities.

In this respect, it is important to start and continue developing the local and/or regional markets and supply chains for the promoted products as well. In that way, there is a back-up offset option in case international interest is decreasing. In that sense, it is important to assess if the promoted product has local or regional market possibilities. Local market development also entails local capacity building on technical issues (crop, harvest, processing), business development and policy forming.

4.4.3. Are There Sufficient Assets to Accommodate the Aimed Market?

Several assets or resources are necessary to establish and access a market. Generally, this involves (i) natural, (ii) human and (iii) infrastructural resources. (i) Is there sufficient suitable land for the activity? Can this land be converted without severe social and environmental impacts? Are there sufficient plant resources (selected provenances, improved genotypes, tree nursery capacity)? (ii) Is there sufficient labour available? Can the labour be allocated to the new activity? Dislocation of people for labour might lead to severe social disruption. (iii) Is sufficient infrastructure available or sufficient assets to establish the infrastructure?

4.4.4. Is Agro-Based Production Suitable for the Aimed Market?

In case an industry needs a certain product which could be produced by trees, the market could be considered durable. However, precaution is still necessary. Will the tree product fulfil the wishes of the market and the industry and is the tree product the best option for the industry to work with? Agro-based production is generally variable. Because of variations in climate the production will generally not be stable. For some industries, steady supply is very important. In general, agronomic and agro-ecologic research should not only focus on yield increase, but also on increasing yield stability. As an example of this issue the story of *Artemisia annua* can be cited [43].

4.5. Will the Tree Crop Grow and Produce?

This seems to be a trivial question. However, it is not. Tree species growing and producing well in their centre of origin might not grow or produce in areas where it is introduced outside their centre of origin, even if the growth conditions (soil and climate) resemble the conditions of the centre of origin. Problems can arise with pest and disease which have no natural counterpart, absence of pollinators, germination problems, *etc.* The same applies for bringing wild species from the forest into cultivation.

Sufficient knowledge on genetics, reproductive biology, growth conditions and agronomy is necessary to provide a reliable answer to this question. Even though a trivial question, precaution is necessary.

5. Participatory Tree Domestication in Agroforestry Systems

Although the main scope and focus of this paper is on new tree species promoted as cash crops for large and international scale, it is important to shortly show another current trend in which locally-important traditional tree species are introduced and domesticated in agroforestry systems in a participatory way [44].

Tree domestication is a "process by which a species becomes adapted to man and the captive environment by some combination of genetic changes occurring over generations and environmentally induced developmental events recurring during each generation" [45]. Domestication involves taking a plant from its natural habitat, for specific needs, to agro-ecosystems where plants are nurtured and protected against environmental risks [46]. In agroforestry, important trees with productive value are therefore brought into farmers' fields. This model, combining annual and perennial species, is not an alternative of the current agricultural systems, but a means to diversify them, rendering them more sustainable [44]. In this context, agroforesters have been for the last 20 years starting to domesticate tree species, producing locally important food and non-food products, in farmers' fields. Therefore, well-known horticultural practices, like vegetative propagation, are used [47]. Vegetative propagation host several important domestication advantages [48], e.g. based on mature tissue, it can significantly reduce the length of the unproductive period, which tree crops generally know [47,48]. To link the needs of the local community with the potential of the species in a long and durable way, and to ensure that the farmers are the first to benefit from the domestication, the whole process of domestication should be participatory, involving the local communities and agriculturists [44,47]. This involvement, but also the reliance on indigenous and local knowledge, empowers the farmers and community [47].

There is a long list of plant species that have been domesticated this way [49] offering their contribution to local livelihoods, without further evolution towards a larger scale economic level [50]. In India, for example, some of the underutilised fruit trees which have gained prominence in recent years are tamarind (*Tamarindus indica*), custard apple (*Annona squamosa*), Indian gooseberry (*Emblica officinalis*), ber (*Zizyphus mauritiana*), and kokum (*Garcinia indica*). A participatory tree domestication project in Cameroon showed positive impact on income generation in less than five years after the project started. Furthermore, next to the income generated, the participants also signalled other positive spill-over effects, such as the local empowerment and the demonstration that the local community is yet to host future opportunities [47].

Although these numerous species, unlike the ones discussed in this paper, do not attract global attention, or are not promoted towards large-scale commercial implementation, successful, participatory, small-scale domestication in agro-forestry systems directly contributes to the livelihood of the local communities [44,47].

6. Conclusions

In this discussion paper, short overviews are given on large-scale, internationally emerging tree crops (*Jatropha curcas*, *Allanblackia* spp., *Argania spinosa*, *Moringa oleifera*). The Jatropha case was

reviewed more intensively. From Jatropha, we retain some important lessons which could be interesting for land use planners, investors and policy makers dealing with other emerging tree species. These lessons can be summarized in three groups: (i) availability of information, (ii) availability of a market, (iii) availability of local capacity. Based on these lessons, it could be concluded that before promotion it should be verified if reliable information on growth conditions, agronomic practices, potential market, potential environmental and socio-economic impact is available. For the potential market, it should be checked if the market is established and accessible or not, and which (natural, human and logistic) assets are available to access and further develop the (local) market. Issues relating to local capacity are mainly the local availability of information on the species, the availability of local processing and marketing capacity. Last but not least, it is important to verify if the species' properties and related activities suit the local socio-cultural situation. In a second step of this paper, Allanblackia, Argania, and Moringa were further evaluated and discussed against these lessons learned from Jatropha.

The qualitative discussion on these species revealed the complex mechanisms driving the emergence of a crop. Economic (potential profitability, market scale, sector/industry, *etc.*), socio-economic (poverty reduction, rural development, *etc.*), environmental (climate change, reforestation, desertification, *etc.*) and agronomic and ecological drivers (easiness to cultivate, wide range of growth conditions, *etc.*) were identified and discussed. Further the discussion showed the importance of governance issues, market durability issues and market position issues for emerging tree crops and their products. Next to binding regulations to which products or production processes have to comply, it is important to verify other legal aspects like labelling, patenting, geographical indication, intellectual property rights, *etc.*, as these can considerably influence the price, accessibility and competition of products. The durability of the target markets is very relevant in the case of perennial species, as they require prolonged investments and imply prolonged land occupation. Further, it is also important to take into account the ability of the species to satisfy the market expectations in terms of production quantity and quality.

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Author Contributions

Paul Vantomme, Bart Muys and Wouter M.J. Achten conceived and designed the paper. Wouter M.J. Achten executed the literature review and drafted the manuscript. Erik Mathijs contributed to and verified the socio-economic aspects of the paper. Navin Sharma contributed to the participatory tree domestication section. All co-authors contributed to the writing of the final version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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