DISADVANTAGES OF HERBACEOUS OIL-BEARING PLANTS AS FEEDSTOCK IN THE BIODIESEL PRODUCTION

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(REVIEW PAPER)

UDC 662.756.3: 633.85

DOI: 10.5937/savteh2002088T

The cultivation of non-edible oil-bearing plants as feedstocks for the biodiesel production can aggressively take advantage of natural environments. Herbaceous non-edible oil-bearing plants have been significantly favored as an ideal feedstock for biodiesel fuel, though little is known about its industrial feasibility and environmental impact. The items with the greatest sensitivity in capital and ecology are land acquisition, plant life cycle, mechanical harvesting, fertilizer, control of weed, pests and diseases, seed yield and oil content. This study aims at analyzing the disadvantages of herbaceous non-edible oil-bearing plants and suggests impeding their industrial cultivation for the biodiesel production. The source of information for the proper selection of non-edible oil-bearing plants suitable as biodiesel feedstocks has been the recent relevant literature. Herbaceous non-edible oil-bearing plants have a low phytoremediation potential and oil yield, but high weed potential. They occupy a large arable area while demand harder cultivation conditions and mechanical harvesting. Non-edible oils from woody plants are promising biodiesel feedstock. However, the weed potential of woody oil-bearing plants must also be considered to prevent their invasiveness.

Keywords: biodiesel; non-edible oil; herbaceous oil-bearing plants; trees; phytoremediation; weed.

Introduction

The energy crisis is a burning global problem. The world's energy demands progressively rise while natural energy resources diminish since replenishing them takes centuries. Wars, deliberate manipulation with human society about over-consumption of goods, nationalization and privatization of energy companies cause a rising energy demand. To prevent an energy crisis, it is crucial to reduce the energy use and replace old with new, sustainable energy resources with a healthy life cycle of several decades. As a sustainable energy source, biodiesel drives attention in the scientific community for more than 60 years.

Moreover, the world population is becoming more environmentally aware, so the call for biodiesel is on the rise. The cost of biodiesel is the most influenced by the price of the feedstocks. Various feedstocks compete for the most suitable one, including oleaginous oil-bearing plants, microalgae, waste edible oils (WEO), agro-industrial seed waste (AISW) and rendered animal fats. A suitable biodiesel feedstock must supply high yields of non-edible, low-cost, monosaturated oil. Furthermore, its cultivation brings no risks to the natural environment [1]. In the light of economic and environmental issues, WEO [2,3] and AISW are the most suitable biodiesel feedstocks, while the oil obtained from the seed of non-edible oil-bearing plants should be used only during shortfalls as a supplement [2].

Many herbaceous and woody non-edible oil-bearing plants have been tested as a potential supplement during

WEO and AISW shortfalls. The non-edible oil biorefinery concept is relatively new. Based on a Scopus search, the first appearance of non-edible oil-bearing plants (*Jatropha curcas* and *Pongamia pinnata*) as a biodiesel feedstock in technical journals was in 2006 [4]. It can be observed that the studies dealing with herbaceous are more dominant than those using woody non-edible oil-bearing plants. Thus, many published articles are focused on oil content, oil/biodiesel characterization, extraction techniques and transesterification. However, the choice of plant for the biodiesel production should not depend only on the properties of the oil or biodiesel but also on the economic and environmental impact of cultivating that oil-bearing plants.

This study compares various herbaceous and woody oil-bearing plants receiving enough attention to become feedstock in the biodiesel production. Our list is not comprehensive since 300 oil-bearing plants compete for the most suitable biodiesel feedstock. However, this study includes 64 oil-bearing plants receiving enough attention to be nominated as the ones with the highest potential to be used in the biodiesel production. The oil-bearing plants were assessed considering their inedibility, annual seed yield/availability, land occupation, cultivation/harvesting demands, lifecycle, phytoremediation and weed potential. For the selected non-edible oil-bearing plants, the land occupation for its cultivation was calculated based on arbitrarily selected biodiesel production capacity of 10000 tones/year. This review should

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The manuscript received: October, 30, 2020.
Paper accepted: December, 03, 2020

exemplify why some oil-bearing plants that are potentially invasive should not be speculatively planted for the biodiesel production. To the best author's knowledge, such a review paper covering the mentioned topics has not been published before.

Inedibility of oil-bearing plants

Non-edible oils are not for human consumption due to the presence of toxic components [5]. However, not all oils declared as non-edible contain known hazard effects and therefore are not very poisonous. For example, an oil obtained from *Brassica carinata*, herbaceous weed with phytoremediation potential, is edible [6,7], but it has been widely tested for the biodiesel production because its oil content is 33-38% [8]. Similar edible oil is obtained from the seed of weedy annual herbaceous *Camelina sativa* with phytoremediation potential [6,9-13]. *Cuphea viscosissima* contains up to 30% oil [14], of which 76% is capric acid, so it can replace palm kernel and coconut oil and be used in foods [15]. The oil obtained from *Erica sativa* (weed with phytoremediation potential) is a substitute for rapeseed oil [16]. Herbaceous annual *Guizotia abyssinica* has low phytoremediation potential [17], while seeds are the source of edible oil, a substitute for olive, rape and sesame oil [18]. *Linum usitatissimum* seed oil is edible too. This annual herbaceous plant is not a weed but has phytoremediation potential [19]. The seeds of *Michelia champaca* contain about 30% edible, semi-solid oil [20]. Herbaceous perennial *Nicotiana tabacum* is a plant with phytoremediation potential [21]. This plant seed oil can be edible after refining, besides being used in soap, paints, lubricants, fuel [22]. Herbaceous annual *Onopordum acanthium* is a weed with phytoremediation potential [23]. Its seeds provide an edible oil of good quality [9,24]. *Ricinus communis* oil is often used as a biodiesel feedstock due to toxic ricin in this weedy plant with phytoremediation potential. However, its oil is edible after ricin deactivation with heat or milk [25]. *Silybum marianum* seeds provide edible oil, often named as luxury and healthy food oil [26]. *Solanum nigrum* seed oil has high contents of linoleic acid and it can be used as frying oil [27]. Furthermore, fully ripe fruits of this plant can be eaten, too [6,28,29].

Some seeds oil of herbaceous oil-bearing plants, such as *Raphanus sativus* var. *oleifera*, *Thlaspi alliaceum*, *Asclepias syriaca*, *Portulaca oleracea*, *Cannabis sativa* and *Sinapis alba* are rather named as non-edible. However, their seed is edible. Seeds of *Raphanus sativus* var. *oleifera* [24] and *Asclepias syriaca* [6] can be eaten raw or sprouted. Although *Asclepias syriaca* is a good phytoremediation candidate [30], it is an aggressive weed and poisonous to sheep, cattle and horses [31]. The powder of grounded *Thlaspi alliaceum* seeds is used as a mustard substitute [6,11], while sprouted seeds can be eaten as a salad [6]. Herbaceous annual weed with phytoremediation potential *Portulaca oleracea* L. produces oily seeds that can be used grounded into flour [6]. Annual herbaceous *Cannabis sativa* L. seed can be eaten raw or cooked. It can be parched and eaten as a condiment or made into cakes and fried [6,9,13,32]. Consuming large amounts of white mustard *Sinapis alba* seed can be danger-

ous, but diluted by hot water, vinegar, salt, wine and other spices became a food flavoring [33]. Weed seeds of *Thlaspi arvense* are a mustard substitute or can be a salad ingredient [6,11].

Similarly, not all woody oil-bearing plants can be used for the biodiesel production. *Attalea speciosa* tree is a weed, while seeds can be eaten raw, cooked, or made into nut milk. Seed oil can be used to make butter [34]. Phytoremediation potential woody weed of *Balanites aegyptiaca* [35] is also used as biodiesel feedstock due to the high oil content of 30-60%. However, this oil is edible and used for cooking [36]. Edible oil can be obtained from the seeds of *Bombax ceiba* [6] and *Caryocar coriaceum* [34,37]. *Ceiba pentandra* tree produces seeds whose edible properties are suspicious. One report says that seeds could be eaten raw or cooked, roasted and ground into a powder in soups as a flavoring [6], while the other claims it is toxic [33]. However, a common opinion is that its oil is pleasant tasting and used for cooking [6,33]. Seeds and oil of *Celastrus paniculatus* abound in medicine. Kokam butter is made from seeds of *Garcinia indica* [6]. Seeds from phytoremediation tree *Hevea brasiliensis* contain cyanic acid which can be destroyed by soaking or boiling seeds for a prolonged period [38,39] and used as food. *Hibiscus sabdariffa* is an annual/perennial shrub with phytoremediation potential [40]. Roasted seeds are a coffee substitute and when grounded into powder they could be used in oily soups and sauces [6,13,18]. *Simarouba glauca* is an evergreen tree, the fruit of which is edible, while seeds contain 60 - 75% of edible oil [41]. The seed of *Sterculia foetida* can be eaten [6,42] or a source of non-drying edible oil [43]. *Zanthoxylum bungeanum* is a shrub/tree in which fruit is a Sichuan pepper source, while the seed's oil (27% - 31%) is considered a high nourishing and healthy edible [44]. Raw seeds of *Ziziphus mauritiana* can be eaten as a snack [45]. Macassar oil, obtained from seed of *Schleichera oleosa* may be used for human consumption but only after removing some cyanogenic compounds from it [46,47].

Most biodiesel research studies deal with non-edible woody oils from *Annona muricata* [48], *Annona squamosa* [49], *Idesia polycarpa* var. *vestita* [50], *Madhuca longifolia* [51], *Mesua ferrea* [52], *Salvadora persica* [53], *Ximenia americana* [54]. However, these oils are derived from non-edible kernels seeds of edible fruits and therefore are classified as AISW.

The oil-bearing plants mentioned so far were in some way edible, and further discussion about their use in the biodiesel production is expelled. This review focuses on the non-edible oil-bearing plants (toxic) seed oil tested as a promising feedstock for the biodiesel production. Oil contents for woody oil-bearing plants *Joannesia princeps*, *Melia azedarach*, *Putranjiva roxburghii*, *Samadera indica* are of 37%, 40%, 43% and 33%, respectively [55-58]. However, to the best author's knowledge, no seed yield information was available and therefore are not used in comparison for suitable biodiesel feedstock. The potential use of these oil-bearing plants (Table 1) as alternative medicaments are also noticed.

Table 1. Non-edible oil-bearing plants suitable for biodiesel production

Plant	Plant type	Phytoremediation potential	Weed potential	Seed yield (t/ha)	Seeds ripen month	Oil (%)	Seed uses	Land ^a , ha
<i>Aleurites trisperma</i> ^b	Tree	NA	No	25–30 ^c	VII–VIII	38–40	Laxative, for paints, varnishes, soaps, coating boats	8
<i>Aphanamixis polystachya</i>	Tree	NA	No	8–10	II–IV	33.3	Anthelmintic, anti-hepatotoxicity, antimicrobial, anti-rheumatism and spleen diseases	30
<i>Argemone mexicana</i>	Herbaceous perennial	Yes	Yes	0.5	VII–IX	30–35	Demulcent, emetic, expectorant and laxative	571
<i>Calophyllum inophyllum</i> L.	Tree	Yes	No	8–40	V–VI, X–XI	50–70	Sunburn lotion and moisturizer	4
<i>Carapa guianensis</i>	Tree	NA	No	0.2–1.9	VI–VII	70	Ointment for the skin and hair, mosquito repellent	75
<i>Cerbera odollam</i> ^d	Tree	NA	No	NA	NA	54	Seed is used for lighting and for anointing the head	-
<i>Crambe abyssinica</i>	Herbaceous annual	Yes	No	0.5–2.5	VIII–X	32	Oil is used for lighting, making plastics and nylon	125
<i>Croton tiglium</i>	Tree	Yes	No	0.2–2	XI–XII	30–45	As an insecticide, Anti-HIV-1 medicament	111
<i>Datura stramonium</i>	Herbaceous annual	Yes	Yes	0.5–0.6	VIII–X	10.3–23.2	Used in Tibetan medicine with extreme caution	718
<i>Euphorbia lathyris</i>	Herbaceous annual	NA	No	1.5–2.5	VII–VIII	48	Used as a violent purgative	83
<i>Madhuca indica</i>	Tree	Yes	No	2.7	V–VII, VIII–IX	30–45	As ointment, in rheumatism and to moisturize skin	82
<i>Milletia pinnata</i> ^e	Tree	Yes	Yes	0.9–9	II–V	27–40	Lubricant, varnish, water-paint binder, soap ingredient	28
<i>Sapium sebiferum</i>	Tree	Yes	Yes	14	XI	20	Candles and soap, varnishes and native paints machine oils and crude lamp oil	36
<i>Simmondsia chinensis</i> (Jojoba) ^f	Shrub	Yes	No	0.3	VIII–IX	50	Cosmetics, antibiotics production, leather industry	667
<i>Terminalia bellirica</i>	Tree	NA	No	15–20	VIII–XII	40	Manufacture of soap, for hair-oil	13
<i>Thevetia peruviana</i>	Tree/shrub	Yes	Yes	52.5	XII–II, V–VIII	60–65	Highly poisonous, as a purgative, to treat skin infections, abortifacient, insecticide	3
<i>Vernicia montana</i>	Tree	NA	No	1.8–3.5	IX–XI	14–20	Paints and inks, soap, linoleum	143
<i>Vernicia fordii</i> ^g	Tree	Yes	Yes	2–3	IX–XI	58	Paints, resin, leather, lubricants, cleaning agents	57

^a Calculated for maximum seed yield, oil content, total conversion of oil and biodiesel production rate of 10000 t/year; ^b Synonym of *Reutealis trisperma*; ^c Calculated from seeds/tree and tree/ha; ^d The species known as the „suicide tree“ is often confused with *Cerbera manghas* (Sea mango); ^e Also known as *Pongamia glabra*, *Pongamia pinnata* or *Karanja*; ^f There is a debate on Jojoba seeds and oil use for human consumption; ^g Also known as Tung tree.

Figure 1. Woody vs. herbaceous non-edible plants for biodiesel production

Seed yield and availability

The highest seed yield of 52.5 t/ha was noticed with woody *Thevetia peruviana* [59]. Generally, both seed yield and oil content were higher in woody oil-bearing plants than

in herbaceous (Figure 1). This could be the consequence of higher seeds weights of woody oil-bearing plants. The duration and period for seeds ripening are mostly the same, i.e., approximately two-three months, late spring, summer and early fall. The exception was trees *Calophyllum inophyllum* L., *Jatropha curcas*, *Madhuca indica* and *Thevetia peruviana* with more than one seed ripen seasons per year.

Land occupation

Proponents of the herbaceous non-edible oil bio-diesel idea advocate marginal abandoned land to cultivate such oil-bearing plants with a minimum of fertilization and irrigation. Disadvantages in exploiting such scattered locations are high quality of planting seed material and lack of post-harvest technologies [60]. Also, herbaceous oil-bearing plants do not naturally occupy large, abounded areas suitable for mechanization, but the new arable area must be used for commercial sowing. Among selected oil-bearing plants (Table 1), woody needed smaller area for cultivation comparing to herbaceous types. It is because woody oil-bearing plants pro-

vide higher seed yields and the oil content. The vast land occupation was noticed for Jojoba, which made this tree inappropriate as biodiesel feedstock. On the other side, *Calophyllum inophyllum* and *Thevetia peruviana* trees needed the smallest cultivation area. However, seed ripening season for both woody oil-bearing plants is annually twice, which may increase its price of harvesting. Among herbaceous oil-bearing plants, *Euphorbia lathyris* needed the smallest cultivation area of 83 ha.

Instead of using marginal lands, another scientific community suggests a plant rotation technique where the same land can be used for different plant cultivation. A rotation technique improves the soil condition and plant nutrition, influencing the increased yield, quality and a reduced pest pressure. However, negative aspects of the plant rotation are often overlooked [61]. Cultivating two or more oil-bearing plants on one site means building a system. It is complicated for the system to maintain the different time of propagation, flowering, seed ripping, the excess or decreased fertility, increased or decreased pest pressure, herbicide residues, the same soil compaction. For these reasons, farmers can have a lowered income of the plant yield and quality. For example, *Cuphea viscosissima* can be in rotation cultivation with corn every three years. It has been suggested that *Cuphea viscosissima* breaks the rootworm cycle, so corn yields increase. However, *Cuphea viscosissima* shows to be intolerant to stress since it stopped growing [62], or its roots can provide the rootworm larval development [63]. Wheat can be in plant rotation with *Argemone mexicana*. However, the wheat yield losses of 17% and 22% have been noticed [64]. *Crambe abyssinica* can be cultivated in rotation with soybean [65] to suppress the growth of weed and fertilize the soil. However, it was shown that other oil-bearing plants, such as radish (*Raphanus sativus*) could suppress higher amounts of weed, while the absolute deposited amount of straw (post-harvest dry mass, deposited on the soil surface which stood as a good fertilizer) was obtained at the area with *Brachiaria ruziziensis* [66]. *Datura stramonium* is a weed, so its use in plant rotation cultivation was not recorded. Rotation technique cultivation of *Euphorbia lathyris* was mentioned as a possibility [67], while its further investigation is missing. Rotation cultivation among woody oil-bearing plants was noticed with shrubs and grasses. *Croton tiglium* is rotated with cacao or coffee to provide shade [18]. Woody *Madhuca indica*, *Pongamia pinnata* and *Azadirachta indica* are intercropped with *Ricinus communis* (shrub) and grasses like *Miscanthus giganteus* and *Panicum virgatum* [68].

Cultivation and harvesting

Water requirements, fertile soil and pests/disease control strategies increase the biodiesel plant cultivation costs. As it can be seen (Table 2), both herbaceous and woody oil-bearing plants required regular irrigation. The application of fertilizers was not noticed only among two woody oil-bearing plants *Aphanamixis polystachya* and

Calophyllum inophyllum L., while other oil-bearing plants grew better with fertilizers. Organic fertilizers were the most common, such as farmyard manure [69] and green manure plants [70]. Seed cakes of *Madhuca longifolia*, *Pongamia pinnata*, *Azadirachta indica* and *Ricinus communis*, can be applied as fertilizers [71] during the *Terminalia bellirica* growth. Besides *Aleurites trisperma* [72], *Aphanamixis polystachya* [73], *Datura stramonium* [74] and *Millettia pinnata* [18], most of the oil-bearing biodiesel plants were the host for recognized pests and pathogens and numerous insect attacks.

Harvesting techniques of herbaceous oil-bearing plants used in the biodiesel production could mainly be mechanized. An exception is manual collecting of *Argemone mexicana* seed, which must be taken with caution since it is poisonous and irritating [75]. Combine-harvester with the available equipment for cereal can be used for *Crambe abyssinica* harvesting [76]. *Datura stramonium* can be harvested with hay or silage. Standard harvesting equipment is applied. *Euphorbia lathyris* harvesting by combine is not yet reported.

Millettia pinnata can be mechanically harvested with a Colossus harvester [77]. *Vernicia fordii* seeds are harvested by field labor or mechanical methods [78]. Except for these two woody plants, harvesting of the rest of the woody plants is manual. The matured fruit of *Aleurites trisperma* drops to the ground so its harvesting method is by hand [79]. *Calophyllum inophyllum* seeds are usually harvested after mature fruits fall to the ground, but picking, lopping off branches with pruning poles are also recorded [80]. Human harvesting by picking seeds of *Carapa guianensis* from the ground has also been noticed [81]. However, a desiccant must be applied before harvesting to avoid difficulties in collecting and cleaning the seeds. Currently, the harvesting of *Jatropha curcas* fruits is mainly manual [82]. *Madhuca indica* and *Terminalia bellirica* harvesting technique is handpicking [83]. However, due to the increased market demand, illegal, destructive ways of lopping and cutting fruits-bearing twigs replaced traditional ones. Fruits and seeds of *Sapium sebiferum* are harvested by hand when leaves have fallen [18]. *Simmondsia chinensis* can be harvested by implementing various methods, such as raking from under the bushes followed by suction, pruning the lower branches and handpicking [18]. Harvesting of the fallen fruits by hand and picking from the trees are the most common methods of collecting *Vernicia montana* seeds in China [84]. However, harvesting is not complicated since it represents fruit collection from the ground. Also, mechanized harvesting could be implemented very easily since fruit picking machines could be used.

Quantitative data on harvesting methods of *Aphanamixis polystachya*, *Cerbera odollam*, *Croton tiglium*, and *Thevetia peruviana* harvesting seeds lack in the literature, probably since seeds of these trees were not commercially used.

Table 2. Conditions for non-edible oil-bearing plants cultivation

Plant	Plant type	Annual rainfall range (mm)	Fertilization	Pests, insects
<i>Aleurites trisperma</i>	Tree	>100	Mud and the surfactant agricol	Not known
<i>Aphanamixis polystachya</i>	Tree	2000–5000	No	Not known
<i>Argemone mexicana</i>	Herbaceous perennial	Moderate irrigation	Low	Bacterial leafspot, fungus, nematodes and budworms
<i>Calophyllum inophyllum</i> L.	Tree	750–5000	No	A vascular wilt disease caused by the fungus
<i>Carapa guianensis</i>	Tree	>3000	Yes	Numerous insect seed attack
<i>Cerbera odollam</i>	Tree	Moderate irrigation	Yes	Pests control
<i>Crambe abyssinica</i>	Herbaceous annual	Irrigation similar to those used for small grains cultivation	Fertilization similar to those used for small grains cultivation Yes	Fungi, insects, nematode, maggots, and viruses attack
<i>Croton tiglium</i>	Tree	600–1200	Yes	Mealybugs, scale, spider mites and thrips as pests
<i>Datura stramonium</i>	Herbaceous annual	>597	Organic fertilizers	Not known
<i>Euphorbia lathyris</i>	Herbaceous annual	Weekly irrigated	Organic fertilizers	Known host for recognized pests and pathogens
<i>Jatropha curcas</i>	Tree	520–2000	Organic fertilizers	Few pest and disease
<i>Madhuca indica</i>	Tree	550–1500	Farmyard manure	Fungi, insects and parasites
<i>Millettia pinnata</i>	Tree	500–2500	Low	Not known
<i>Sapium sebiferum</i>	Tree	1300–3700	Yes	Root-knot nematode and fungi
<i>Simmondsia chinensis</i> (Jojoba)	Shrub	250–800	Yes	Fungi, parasites, a microlepidopterous insect
<i>Terminalia bellirica</i>	Tree	Irrigation regularly	Organic fertilizers	17 types of microorganisms
<i>Thevetia peruviana</i>	Tree/shrub	720–1200	Yes	Parasitic weed <i>Cuscuta</i> sp, scale insects, mealy bug, red spider mite and aphids
<i>Vernicia montana</i>	Tree	850–2000	Yes	Fungi
<i>Vernicia fordii</i>	Tree	>1120	Green manure plants and fertilizers	Black spot, anthracnose, blight and the insects (longicorn beetle, scarab stinkbug)

Plant lifecycle

Most of the herbaceous oil-bearing plants used as a biodiesel feedstock are annual (Table 1 and 2), which means they need to be replanted from seed on marginal land every year or in rotation with other plants every second, third year. Replantation of this short lifecycle oil-bearing plants increases cultivation costs. Annual and perennial oil-bearing plants grow faster than trees. *Argemone mexicana* sowing takes place in spring and the seeds can be ripen from July to September. *Crambe abyssinica* is cultivated as a spring-sown plant while the seed can be harvest in late summer. *Datura stramonium* and *Euphorbia lathyris* annual oil-bearing plants take five and six months from sowing to harvesting the seeds, respectively [85]. These annual herbaceous oil-bearing plants grow faster than trees, but not among other edible plants. For example, *Euphorbia lathyris* is challenging to grow without irrigation and its growth is very slow, twice slower than sunflower [67].

On the other hand, trees are long living, with a lifecycle of more than forty years. Trees provide soil support, shade for grazing animals, trapped air dust and reduced wind/rain damaging effects. The growth of trees is slow during the first three years of life, and trees are not hermaphrodites. Seedling and trees raised from root suckers bear fruits (seeds) after 5 to 6 and 7 to 9 years from planting, respectively. A faster option in instant biodiesel production would be to use the existing seeds capacities of already planted trees. The growth rate of the evergreen tree of *Aleurites trisperma* is fast but the first seeds can be collected 8 to 10 years after planting [72]. *Aphanamixis polystachya* evergreen tree growth is rapid [86] and it is flowering 3–4 years after plantation [87], pro-

viding the fruits and seeds. The growth rate of *Calophyllum inophyllum* is slow and gives fruits (seeds) at the 10 years of life [88]. *Carapa guianensis* tree is fast-growing and generally begin to fruit during 10–12 years old [81,89]. *Croton tiglium* plants take three years from sowing to harvesting the seed [90,91]. *Jatropha curcas* average full seed productivity is at about 3 years, while under preferred rainfall conditions, it can be after the second rainy season [46,92]. The *Mahuna indica* starts bearing 8 to 15 years from plantation [93]. The growth of young trees of *Millettia pinnata* is relatively slow, but seed production starts when trees are 5 - 7 years old [46,94]. A fast-growing tree of *Sapium sebiferum* requires from 3 - 8 years to bear seeds [18,95]. The jojoba growth rate is a slow tree and provides full bearing in 7 - 8 years from plantation [96]. The harvesting time of *Terminalia bellirica* seed is done after 7–8 years of growth [97]. *Vernicia montana* gives seeds in a 3-year-old period [84]. *Vernicia fordii* start bearing fruit the third year after planting, with the maximum production in 10 - 12 years [70].

Phytoremediation and weedy potential

Most oil-bearing plants listed in Table 1 are bioaccumulators of heavy metals and some toxic substances, so they are used in phytoremediation. Weed plants are soil bioindicators, as well. The trees have higher accumulation capacities because of the extensive and deep rooting system [98]. Furthermore, trees have a long lifecycle to constantly remediate soil for a long time, for example, at barren tailing dumps. *Argemone mexicana* uptake heavy metal by entire plant parts [99]. Eight months old seedlings of *Calophyllum inophyllum* accumulate lead and copper [100], while *Crambe abyssinica* leaves have

an excellent potential in arsenic phytoremediation [18]. The efficient cadmium, mercury, and zinc phytoremediation plant is *Croton tiglium*. The order of these heavy metals' sensitivity towards the roots, stem and leaves of this plant is zinc > cadmium > mercury [101]. Seedlings of *Datura stramonium* contains cadmium [102]. After the 90-day phytoremediation, the roots, stems and leaves remove iron and arsenic from the soil mixture [103]. Simultaneously, heavy metals are not detected in the *Jatropha* seeds, implying no metal emissions from such biodiesel [104]. The roots of most of the *Madhuca indica* accumulate a higher concentration of chromium, nickel, and cadmium [105]. *Milletia pinnata* accumulates copper in seed coats from 1220 ppm to 26 ppm [106]. *Sapium sebiferum* contains mercury and zinc in its roots [107]. The phytoremediation potential of *Simmondsia chinensis* biomass is reported by cobalt, copper, nickel and iron [108]. Chromium followed by lead and nickel are found in leaves and roots of *Thevetia peruviana* [109].

Although numerous papers deal with phytoremediation with oil-bearing plants, which could be used in the biodiesel production, the influence of such a contaminated soil on the heavy metal presence and concentration in seeds and derived oils is contradictory. Baudh et al. [110] report a low concentration of metals in oil seeds, but contaminated oil's combustion is not clearly explained. Other authors report that phytoremediation does not improve the environmental situation since heavy metals concentrations in seeds are above the maximum allowed and hazardous metal emissions from biodiesel are questionable [111].

No commercial cultivation of weedy oil-bearing plants is advised for the biodiesel production. Weeds are harmful to the environment because they are hard to control, alter the habitats and lead non-invasive species into extinction. Birds and wind are spreading the seeds, while mechanically harvesting rarely exists. The lack of risk assessments for weed plants used in the biofuels production is already criticized [112,113]. Furthermore, Australia loses \$4 billion annually to cultivate weedy biodiesel *Mimosa pigra*, while *Rubber vine* takes \$27 million every year [114]. Based on Table 1, only *Euphorbia lathyris* posed no weed threat among herbaceous oil-bearing plants. Woody oil-bearing plants, such as *Jatropha curcas*, *Milletia pinnata*, *Sapium sebiferum*, *Thevetia peruviana* and *Vernicia fordii*, often promoted as the ideal biodiesel plants, were weeds, too.

Conclusions

In a world affected by various environmental disasters, biodiesel feedstock sources should be WEO, AISW and rendered animal fats. During shortfalls, oil obtained from non-edible oil-bearing plants could be used as a supplement. The woody oil-bearing plants were recommended as they provide a higher yield and oil content than herbaceous oil-bearing plants. However, the drawback was hand seed harvesting. Trees occupied

small marginal land areas, with low or without fertilization support. Rainfalls were the only type of required irrigation for woody oil-bearing plants. Some trees were without pests/disease control strategies. Trees have a slow but long lifecycle. Furthermore, trees were gaining momentum over herbaceous plants in phytoremediation trials because of their greater effectiveness. However, further studies must be performed to determine if and how much heavy metals would be accumulated in seeds. What concerns attention was that some of the listed biodiesel woody oil-bearing plants had a substantial history as weeds. Therefore, weed risk must be assessed to ensure that woody oil-bearing plants do not add biodiesel to the invasive species fire.

Acknowledgments

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under the Program of financing scientific research work, number 451-03-68/2020-14/200133.

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Izvod

NEDOSTACI ZELJASTIH ULJARICA KAO SIROVINE U PROIZVODNJI BIODIZELA

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UDK 662.756.3: 633.85
DOI: 10.5937/savteh2002088T

Uzgoj nejestivih uljarica kao suplementa sirovini za proizvodnju biodizela može agresivno uticati na životnu sredinu. Nejestive zeljaste uljarice su značajno favorizovane kao idealna sirovina za biodizel, iako se malo zna o njihovoj isplativosti korišćena na industrijskom nivou i uticaju na životnu sredinu. Stavke sa najvećom osetljivošću na kapitalne troškove i ekologiju su otkup zemljišta, životni ciklus biljaka, mehanička berba, đubrivo, suzbijanje korova, štetočina i bolesti, prinos semena i sadržaj ulja. Cilj ovog istraživanja je analizirati nedostatke zeljastih nejestivih uljarica i predložiti prekid njihovog industrijskog uzgoja za proizvodnju biodizela. Izvor informacija za pravilan odabir nejestivih uljarica kao sirovine za proizvodnju biodizela bila je referalna naučna literatura novijeg izdanja. Rezultati ovog istraživanja pokazali su da su zeljaste nejestive uljarice imale visok korovski, ali nizak prinos ulja i potencijal fitoremedijacije. Zauzimali su velike obradive površine dok su zahtevali teže uslove obrade. Nejestive drvenaste uljarice pokazale su se povoljnijim sirovinama za proizvodnju biodizela. Međutim, i kod drvenastih uljarica mora se voditi računa o korovskom potencijalu da bi se sprečila njihova invazivnost.

Gljučne reči: biodizel; nejestivo ulje; zeljaste uljarice; drveće; fitoremedijacija; korov.