Bioresource Technology 249 (2018) 1044–1051

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Review

A review on moringa tree and vetiver grass – Potential biorefinery feedstocks

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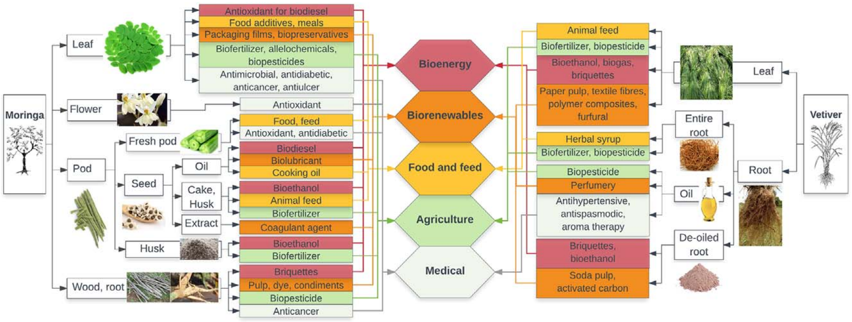
GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Bioenergy
Biorefinery
Food
Moringa
Sustainable agriculture
Vetiver

ABSTRACT

Plants and derivatives have been explored for unlimited purposes by mankind, from crop cultivation for providing food and animal feed, to the use for cosmetics, therapeutics and energy. Moringa tree and vetiver grass features, capabilities and applications were explored through a literature review. The suitability of these plants for the bioenergy industry products is evidenced, namely for bioethanol, biogas and biodiesel, given the lignocellulosic biomass content of these plants and characteristics of moringa seed oil. In addition, moringa leaves and pods are an important source for food and animal feed industries due to their high nutrient value. Thus, the co-cultivation of moringa and vetiver could provide energy and food security, and contribute to more sustainable agricultural practices and for the development of rural areas. Policymakers, institutions and scientific community must engage to promote the cultivation of multipurpose crops to cope with energy and food industries competition for biomass.

1. Introduction

Moringa is a fast-growing tree native to India and largely spread across tropical and subtropical regions (Pereira et al., 2016). Moringa tree parts are suitable for a large number of applications and commercial purposes, which can provide countless benefits to the communities (Paliwal et al., 2011). Moringa fresh leaves, fruit pods, extracts and meals have high nutritional value including proteins, vitamins, minerals and phytochemicals (Ramachandran et al., 1980; CBI, 2016). Moringa tree cultivation has been greatly encouraged in order to increase food security and reduce undernourishment, particularly for infants and women of child-bearing age in developing regions (Boateng et al. 2017). Besides its use in food and animal feed industry, moringa tree parts have been used in other relevant industries such as energy, biorenewables, agriculture and medical (Baptista et al., 2017; Ahmad et al., 2016; Agboun et al., 2016; Gupta et al., 2012; Al-

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https://doi.org/10.1016/j.biortech.2017.10.094
Received 15 September 2017; Received in revised form 26 October 2017; Accepted 29 October 2017

Asmari et al., 2015).

Vetiver grass, also indigenous to India, is able to tolerate a large range of climatic conditions such as drought, flood, submergence, extreme temperatures, pH and high contaminants concentrations in the soil (Darajeh et al., 2016; Meyer et al., 2017). Vetiver is known for its long and dense root system that reaches large soil volumes and provides soil shear strength, reinforcement and stability (Donjadee and Tingsanchali, 2016; Gnansounou et al., 2017). Vetiver grass hedgerows can effectively reduce soil erosion and water runoffs, being used as a tool for soil and water conservation (Oshunsanya, 2013a; 2013b). Given its high tolerance to agro-fields contaminants, vetiver grass is a widely used phytoremediation instrument, contributing to the recovery of degraded lands and decontamination of water bodies (Dousset et al., 2016; Phusantisampan et al., 2016). Both moringa and vetiver products are also suitable for the production of natural mulch, which may be applied as fertilizer minimizing the use of chemicals in the agro-fields.

Given the large spectrum of application of moringa and vetiver derivatives, the co-cultivation and strategic intercropping of these two fast-growing plants could be implemented in the context of a biorefinery. Besides enhancing agriculture and supply of food and feed, moringa-vetiver co-cultivation could yield significant amounts of biomass and oil with large potential as raw materials for bioenergy, biochemicals and other biorenewables. The current review covers an inside look at the literature on the use of moringa and vetiver plant derivatives as feedstock for biorefineries. Additionally, a brief overview is presented on other relevant uses of these two plants as instruments for enhancing agriculture, reducing environmental burdens and mitigating climate change (see Table 1).

2. Origin and features of moringa tree and vetiver grass

The most known and cultivated species of moringa tree is *Moringa oleifera*, native from the southern Himalayas region. In the last centuries, such tree was spread along the tropical belt, from South India to the Southeast and West Asia, Arabian Peninsula, sub-Saharan Africa and Central America. Previous generations used moringa tree leaves mostly for cattle feed, and, gradually, they have started to include it in human diet due to its nutritional value. *Moringa oleifera* is a perennial softwood tree with relatively low demand for nutrients and water, being an easily exploitable crop (Paliwal et al., 2011; Pereira et al., 2016). Moringa tree stem grows straight until 2 m height, the moment it starts branching (Paliwal et al., 2011). The tree can achieve until 12 m of height; however, it is usually kept pruned shorted for an easier harvest of the leaves. The lifespan of moringa tree can reach 20 years with a high production of leaves, pods and seeds, products which can be valorized in different markets. The optimal temperature conditions for moringa cultivation are 25–35 °C. Moringa tolerates arid and semi-arid soils and stands a soil pH range of 4.5–9 (Pereira et al., 2016). Moringa flowers have white and yellowish sepals placed in panicles and give origin to pod-like fruits (Ramachandran et al., 1980; Paliwal et al., 2011). Moringa pods contain round shape moringa seeds. Paliwal et al. (2011) reported that one tree can produce 15,000–25,000 seeds y^{-1} and an average seeds/pod of 0.5 g g^{-1}. Moringa seeds have 30–40% of oil, which is edible for human consumption. Finally, moringa roots are relatively short, tough and fibrous.

Vetiveria zizanioides, known as vetiver, is a rapidly growing perennial grass native from tropical and subtropical India, Pakistan, Sri Lanka Bangladesh and Malaysia (Dousset et al., 2016). Due to its versatility and interesting properties, vetiver expanded along the equatorial region and it is cultivated in the entire globe. Vetiver major producers are India, Indonesia, China Haiti and Brazil, mainly for exploiting the vetiver root essential oil. Vetiver is known for its resistance to pests, tolerance to pollution, low maintenance, and for being capable to grow under harsh conditions of soil and climate (Meyer et al., 2017). Vetiver optimal root growth occurs at the soil temperature of 25 °C and the annual rainfall of 1000–2000 mm. Vetiver stems are stiff, thin, up to 150 cm long and typically grow in clusters building dense hedges. Vetiver stems can stand up in deep water streams. Vetiver fibrous root system is dense and extensive, in some cases reaching up to 3–4 m deep in the first year of plantation. In the root system surroundings, conditions are favorable for nutrient exchange and growth of symbiotic microbial communities. Del Giudice et al. (2008) provided evidence of the involvement of vetiver root-associated bacteria in the essential oil biosynthesis.

3. Industrial applications of moringa tree and vetiver grass

3.1. Bioenergy

Renewable energy production is one of the main targets for countries policy measures to mitigate climate change and fuel price fluctuations. Among the energy produced from renewable resources (e.g. solar, wind), energy from biomass residues and vegetable oils in the form of solid fuels (e.g. briquettes, charcoal), gas fuel (e.g. biogas) and liquid fuels (e.g. bioethanol, biodiesel) could fulfill the local energy demand, generate economic development through agriculture activities and promote rural employment. Vetiver and moringa biomasses can be processed to fuel due to the well-growing properties of these plants in harsh conditions with less water and fertilizer resources in degraded land, favoring erosion control, land rejuvenation, reforestation and biomass supply. Vetiver is planted in many parts of the world for soil conservation or root oil production. In either case, the leaves could be valorized to give economic returns. Vetiver leaves have significant energy content: ~16.3 GJ ton^{-1} (Pinners, 2014). Thus, charcoal and briquettes could be produced from vetiver leaves and sold locally for cooking and heating purpose. In a feasibility assessment report from UNEP, vetiver biomass production capacity was found to be 120 tons (dry matter) per hectare and charcoal produced from vetiver leaves proved to be an effective source for urban and rural energy demand in Haiti (UNEP, 2015). In addition, the enterprise Unikode in Haiti is commercially producing briquettes from vetiver grass procured from the local community and vetiver oil distilleries. Vetiver leaves biomass is also a potential raw material for biogas production. Li et al. (2014) studied the effect of harvest time in biogas production from vetiver with anaerobic fermentation. A volumetric gas yield of 140,434 (m^3 m^{-3} ton^{-1}) was obtained after 26 days fermentation with 58.46% biomass utilization. Sun et al. (2014) reported biogas production from transgenic vetiver with 300 mL g^{-1} biogas yield in 45 days anaerobic treatment. Whereas Xiao-ming et al. (2008) reported 471 mL g^{-1} TS biogas after 90 days of anaerobic treatment. The vetiver leaves residues remaining from biogas production are rich in nutrients and can be used as fertilizer (Li et al., 2014).

Cellulose (32.6%), hemicellulose (31.5%) and lignin (17.3%) composition in vetiver biomass make it a suitable raw material for bioethanol production via pretreatment, saccharification and fermentation. The lignin remaining can be used as boiler fuel in the bioethanol industry for steam and electricity generation. Wongwatanapaiboon et al. (2012) studied the bioethanol production capacity from cellulose and hemicellulose using alkaline pretreatment method. Out of several kinds of grass tested, vetiver grass from Sri Lanka showed the highest performance with bioethanol/biomass yield up to 0.14 g g^{-1}. Restiawaty and Dewi (2017) investigated a comparison on pretreatment methods for ethanol production from vetiver leaves and concluded that alkaline pretreatment was better compared to liquid hot water and dilute acid pretreatment followed by simultaneous saccharification and fermentation using *Neurospora* sp. Whereas, Kuhiran and Punnapayak (2000) used fungi and yeast for simultaneous saccharification and fermentation to produce ethanol from vetiver grass. In addition, Raman and Gnansounou (2015) conducted a prospective life cycle assessment on utilizing vetiver leaves for bioethanol in the Indian geographical context. Compared to petrol fuel as the reference system, greenhouse gas emissions and fossil depletion impacts were 95% and 23% lower for