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Invasiveness of biofuel crops: implications for energy research and policy in Botswana

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ABSTRACT

In developed countries, biofuel development was largely driven by a desire to reduce greenhouse gas (GHG) emissions and increasing energy security, whereas in developing countries, in addition to energy security, the quest for rural development and employment creation incited an interest in biofuel production. Notwithstanding the benefits of biofuels, there are reservations about their potential invasiveness. These concerns stem from the fact that the traits that characterize an ideal biofuel crop such as rapid growth rate, tolerance to drought and low soil fertility as well as pest and disease resistance, match those of invasive plants. The objective of this paper was to review literature on experiences of other countries on invasiveness of biofuel crops, with a view to providing lessons for biofuel production in Botswana. The review has revealed that most plants proposed for biofuel production are classified as invasive. The review concludes with recommendations for the Government of Botswana: Improve the cultivation of indigenous wild plants with high oil content for biodiesel production, screening of exotic species through a science-based risk-assessment procedure to evaluate their invasive potential before embarking on large-scale cultivation, and development of appropriate management practices and regulations to mitigate risk of invasion.

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Introduction

In response to an unreliable fossil fuel supply, unstable fuel prices and increasing greenhouse-gas (GHGs) emissions, the global community is promoting biofuels as an alternative climate-smart and environmentally friendly energy source. Global consumption of biofuel annually is projected to increase exponentially from 7 Mt in 2010 to 29 Mt by 2030 (Alexandratos & Bruinsma, 2012). In the developed world, biofuels are promoted to reduce GHG emissions and ensure a sustainable fuel supply, whereas, in the third world, in addition to fuel security, biofuel development was largely driven by desire for rural development, employment and income generation (Blanchard et al., 2011). These factors are all motivated by the creation of international markets, particularly in the European Union, where member countries are mandated to blend 10% biofuel into conventional transport fuel (Von Maltitz et al., 2014). Furthermore, international conventions on

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mitigating climate change, such as Kyoto Protocol also ignited global interest in biofuels. Europe started research on potential biofuel crops in the 1960s followed by the United States in the 1970s (Lewandowski et al., 2003)

The global interest in biofuels has resulted in an increase in the use of a number of crops and wild plants for biofuel production. The first generation of biofuels is dominated by food crops such as grains and sugarcane where starch and glucose are fermented to produce bioethanol, and vegetable oils are used to produce biodiesel through the process of transesterification (Ziolkowska, 2014). In the European Union, the crops mostly used to produce bioethanol include wheat, barley and sugar beet whereas in southern Africa they include sugarcane (Malawi, Zimbabwe and Zambia) and maize (South Africa). Traditionally, biodiesel has been mostly produced from edible oil plants such as rapeseed, soybean oil, palm oil and sunflower oil (Silitonga et al., 2015). However, due to the debate about food security versus fuel production, non-edible biodiesel feedstocks are gaining momentum worldwide. Some of the candidate for non-edible biodiesel feedstocks are *Moringa oleifera* (drumstick tree), *Croton megalobotrys* (croton), *Azadirachta indica* (neem), *Jatropha curcas* (jatropha), *Calophyllum inophyllum* (undi) and *Thespesia populnea* (milo) (Jain et al., 2018).

The use of food crops for biofuel production sparked debate and questions in light of food insecurity, particularly in developing countries. These concerns led to the pursuit of non-food crops, which require fewer inputs (e.g., water and fertilizer) and can be grown on marginal land not suitable for agricultural production (DiTomaso et al., 2013). A variety of herbaceous and woody species emerged as candidates for biofuel production. For instance, *Arundo donax* L., *Phalaris arundinacea* L. and *Miscanthus sinensis* in the United States (Flory et al., 2012) and *Prosopis* species, *Leucaena leucocephala* (Lam.) de Wit and *Azadirachta indica* A. Juss in Africa (Witt, 2010). Plant breeding programmes for biofuels are focused on selecting and breeding for low susceptibility to pests and diseases, ability to grow in marginal conditions and to produce vigorous monoculture plantations (Barney & DiTomaso, 2008). The majority of biofuel crops intrinsically possess these desirable traits; prolific growth rates, high yields with minimal inputs, tolerance to drought and low soil fertility and resistance to pests and diseases (Barney & DiTomaso, 2008; Chimera et al., 2010).

It is important to note though that these traits closely match those of invasive species (Raghu et al., 2006), and there are fears that biofuel crops may escape cultivation and invade natural or other land use systems (DiTomaso et al., 2007). The debate about the potential invasiveness of biofuel crops sheds light on how a well conceptualized innovation, informed by new policy initiatives, with good purpose may have collateral damage with devastating socio-economic and environmental impacts (Ferdinands et al., 2011). Despite these reservations, biofuels continue to be promoted and cultivated worldwide (Buddenhagen et al., 2009). For instance, *A. donax, Panicum virgatum* L. and *Prosopis* spp. are promoted for biofuel production in the United States but are known to be invasive in other countries (McCormick & Howard, 2013). *Jatropha curcas* L. is currently being promoted for biodiesel production in Africa, India and Southeast Asia despite being classified as invasive in South Africa and Australia (Von Maltitz et al., 2014).

The potential risk is exacerbated firstly by the fact that most biofuel crops are exotic to the country or region proposing cultivation (Barney & DiTomaso, 2008), and secondly, the anticipated large-scale cultivation heightens propagule pressure and further increases the probability of escape and invasion (Davis et al., 2011). The number of propagules correlates positively with the risk of invasiveness, i.e. an increase in the number of propagules will result in an increase in the risk of invasiveness (Holle & Simberloff, 2005). Biofuel feedstocks are likely to be transported over long distances during planting, harvesting and processing further increasing the probability of propagules escaping into natural systems or hybridizing with adjacent natural populations (Barney & DiTomaso, 2010; Richardson & Blanchard, 2011).

Invasive species are those when introduced to a new habitat or ecosystem grow vigorously and displace native species resulting in damages to the economy, biodiversity and human health (IUCN (International Union for Conservation of Nature), 2009). No continent, region or country can claim to be free from invasive species (Molina-Montenegro et al., 2012). The demand for exotic species has traditionally been influenced by desire for high yielding species that would generate better economic benefits for agricultural, horticultural and fibre production industries (Ferdinands et al., 2011). Human activities are largely responsible for transporting alien invasive species around the world either intentionally or accidentally (Van Wilgen & Richardson, 2014). They can be introduced purposely to be used as research trials, ornamental plants, agricultural crops and forestry species (Drew et al., 2010; Lockwood et al., 2005). Under conducive environments, any alien species is capable of growing vigorously and spreading extensively to outcompete native species (Chimera et al., 2010). Once established, invasive species are difficult and costly to remove or contain (Pimentel et al., 2005, 2000). They are only surpassed by habitat destruction as drivers of biodiversity loss (McCormick & Howard, 2013). The economic costs of invasive species can be quite substantial, with the global cost estimated at 5% of the global Gross Domestic Product (GDP). The cost per year to the United States, United Kingdom, Australia, South Africa, India and Brazil amounted to more than 100 billion USD (Convention on Biological Diversity [CBD], 2017). The costs were mainly due to a reduction in the productivity of agricultural and forest sector. Other costs include human health problems, hampered recreational access and aesthetic qualities, damage to ecosystem services as well as management and eradication costs (Pejchar & Mooney, 2009; Young et al., 2011).

To avoid the invasiveness risks, the production of biofuel must be guided by appropriate management, legal and regulatory frameworks to judiciously integrate these crops into the agro-ecosystem with minimal risk of invasion. Blanchard et al. (2011) and Richardson and Blanchard (2011) suggested that a biofuel strategy should have a framework designed to evaluate and determine the impacts of potentially invasive species. Most countries in Africa are yet to produce a policy or strategy to inform biofuel development (Maltsoglou et al., 2013). However, South Africa and Mozambique have established comprehensive regulatory frameworks for biofuel (Janssen & Rutz, 2012). The biofuel strategy in South Africa was enacted in 2007 as the Biofuels Industrial Strategy of South Africa of 2007 (Department of Minerals and Energy (DME), 2007). Other countries, including Botswana, are currently drafting their legal and regulatory frameworks for biofuel development (Janssen & Rutz, 2012). It is worth noting that the current policies regulate traditional edible biofuel feedstocks (e.g., corn, soyabean and sugarcane), and may need reforms to regulate emerging non-edible biofuel feedstocks such as croton, jatropha and castor oil plant (Quinn et al., 2015).

Biofuel development in Botswana, like in other developing countries, was triggered by a desire to secure energy for rural development and a lack of foreign exchange. In an attempt to reduce reliance on fossil fuels, the government undertook a feasibility study in 2007 to explore the possibility of producing ethanol from sweet sorghum and biodiesel from *Jatropha curcas* L. (EECG, 2007). The Botswana Government had planned to start biofuel production in 2012 (Kgathi et al., 2012) and sweet sorghum and Jatropha were listed in the National Development Plan 10 (NDP, 10) as candidates for biofuel production (Ministry of Finance and Development Planning (MFDP), 2009). Jatropha was preferred as it was perceived to have more potential than sweet sorghum (Kgathi et al., 2012). To this effect the Government of Botswana formed a collaborative research project (2012–2017) with The Government of Japan to develop technical protocols and knowledge for production and utilization of Jatropha biodiesel and biomass in Botswana (Mmopelwa et al., 2017). Despite its potential for biodiesel production, Jatropha has been classified as an invasive in Australia, USA and neighbouring South Africa (Negussie et al., 2013). The invasive risks of biofuel crops have received little attention and are rarely considered as part of biofuel policy.

The objective of this study was to assess the invasiveness of plants proposed for biofuel production in Botswana. The paper begins by presenting background information on drivers of biofuel development and impacts of invasive species, followed by research methods section. Next section is on invasiveness of biofuel crops in Africa. The impact of *Prosopis* in Botswana is then used to demonstrate the impact that a second generation biofuel crop can have on biodiversity and livelihoods. The paper, then, describes different methods for evaluating invasiveness risk, followed by the final section on conclusions and policy implications.

Materials and methods

Botswana is a semi-arid landlocked country with a land surface area of 582000 km^2 and an average rainfall of 416 mm, ranging from 250 mm in the south-western to over 650 mm in the north-eastern part of the country (Ministry of Finance and Development Planning (MFDP), 2009). The rain falls in one distinct season from October to April, with May to September being the dry season (Batisani, 2011). About two thirds of the country is covered by Kalahari Desert with sandy soils up 120 m deep (Burgess, 2006). The country almost lacks surface water sources (Batisani, 2012) and water is sourced by drilling boreholes to a depth of 200 m (Burgess, 2006). The vegetation in the sandy soils comprises of scrubs and grasses, and woodlands (Batisani, 2012; Burgess, 2006).

The country is classified by the World Development Indicators (2018) as an upper middle-income economy with a gross national income per capita of USA 7 USD 750 in 2018 (World Development Indicators, 2018). However, poverty reduction is still a major development challenge in Botswana. In 2015/2016, the proportion of households living below the poverty datum line was estimated to be relatively high in rural areas at 24.2% higher than the national figure of 16% (Statistics Botswana, 2018).

The information for this study was collected from a review of historic to recent literature and publications on energy and biofuel development, invasive species and invasiveness of crops proposed for biofuel production. Data sources included academic journals, books, feasibility studies, government reports and development plans. The review covered countries in the Americas, Europe, Australia, New Zealand and Africa, but most of the information was gathered from the USA as it has an advanced biofuel industry and many invasive biofuel crops. While the USA and Europe have a well-developed biofuel sectors and policies, information on their experience with invasiveness of biofuel crops, and their strategies in addressing invasion risk provide valuable lessons for Botswana as it plans to venture into biofuel production.

Biofuel crop invasiveness in Africa

Although there is a world-wide movement to produce biofuels, biofuel development in Africa is still at an inception stage (Kgathi et al., 2012). The region has some potential, but the production is limited by a lack of capacity, infrastructure and the need to meet food security (Food and Agriculture Organisation of the United Nations (FAO), 2008). Sub-Saharan Africa (SSA) has been suggested as a region with great potential for bioenergy production (Hoogwijk et al., 2005), owing to large tracts of agricultural land that are failing to produce to their maximum potential (Van Eijck et al., 2014). Southern Africa in particular, has great potential for biofuel production (Smeets et al., 2007). This is supported by favourable rainfall and tropical to sub-tropical climate, which characterizes the region (Von Maltitz & Setzkorn, 2012).

Biofuel development in Africa is still at inception stage (Kgathi et al., 2012; Maltsoglou et al., 2013). An increase in fuel prices in recent years positioned biofuels as an economically viable alternative source of energy (Campbell et al., 2009) and attracted several international investors into southern Africa (Von Maltitz et al., 2014). Most of the investment, however, was on production of biodiesel from Jatropha (Kgathi et al., 2017). This was mainly because Jatropha was herald as a ‘miracle crop’ that is not edible and could grow in marginal areas with limited inputs (Kant & Wu, 2011). However, recent literature showed that Jatropha like any other crops requires good rainfall, inputs and fertile land to produce economically viable seed yields (Edrisi et al., 2015). The assumptions about Jatropha high yields are partly responsible for the collapse of most Jatropha projects in southern Africa (Von Maltitz et al., 2014). In addition, Jatropha is classified as invasive and its cultivation is prohibited in South Africa (Global Invasive Species Programme (GISP), 2019) and Australia (Pacific Islands Ecosystems at Risk (PIER), 2008).

Countries in SSA are currently producing biofuels from traditional food crops. For example, Malawi and Swaziland produce bioethanol from sugarcane molasses (Maltsoglou et al., 2013). In recent years, there are research and development initiatives aimed at shifting from the use of biofuel feedstocks of food crops to those of lignocellulosic biomass in the form of non-food crops, agricultural and forest residues, and industrial wastes to produce ‘second generation’ biofuels. The production of second-generation biofuels is still at research and development stage, and not yet commercialized as a result of high production costs (Eisentraut, 2010; Escobar et al., 2009). However, several pilot and demonstration projects of second-generation biofuels exist in developed countries as well as in emerging economies of Brazil, India, China and Thailand (Eisentraut, 2010). The economic, social and environmental challenges for the implementation of second-generation biofuels are expected to be lower than those of first-generation biofuels, depending on the types of feedstocks used. These challenges may include limited funding for financing these biofuel projects, high production costs, conflict with food production and GHG emissions (Eisentraut, 2010; Mitchell, 2011; Mohr & Rahman, 2013; Royal Society, 2008).

Biofuels and biodiversity

Biodiversity plays a central role in ecosystem functioning (Quijas et al., 2010) and, thus, is a source of provision of a suite of services to mankind. Any threat to biodiversity puts livelihoods of humans at risk (Pysěk et al., 2017). Land-use change has been cited as the main driver of biodiversity loss associated with biofuels production (Immerzeel et al., 2014), followed by second generation biofuel feedstocks with invasive traits (Barney et al., 2012; Gasparatos et al., 2015). The impact of land-use change on biodiversity is greater when large tract of natural forest, grasslands, shrubland and woodlands are cleared for cultivation and production of biofuels (Kgathi et al., 2017). It results in negative impacts on species, habitat, species richness, abundance and composition (Calviño-Cancela et al., 2012). Overall, the effects of the production of biofuels on biodiversity are difficult to quantify and often explained by various spatial scales, production systems and regions, and biodiversity indicators used (Immerzeel et al., 2014).

Biofuels and food security

Biofuel projects may negatively impact food supplies if factors of production (land, labour and capital) and other resources are diverted away from food production to the production of biofuels (Kgathi et al., 2017). For instance, when first-generation biofuels use cereals (e.g., maize and sugarcane) as feedstocks food availability is threatened because cereals are an essential component of most diets in the world (Food and Agriculture Organization of the United Nations – (FAO), 2003). Therefore, changes in availability and prices of cereals would influence availability of adequate food supplies (Escobar et al., 2009). Biofuel production may also limit access to food by influencing food commodity prices (Mitchell, 2008). There is a general sentiment that biofuel production is responsible for an increase in commodity prices and may thus exacerbate food insecurity in developing countries (Mitchell, 2008). To address this problem, the Government of Botswana may need to develop national policies with legal and regulatory frameworks to ensure that development of biofuels is in tandem with sustainable food security (Fischer et al., 2009). For instance, given that agricultural land is scarce, it may be necessary to indicate the proportion of farmland that could be allocated for the production of biofuels (Escobar et al., 2009).

Biofuels and the environment

Biofuels are promoted as climate-smart and cleaner source of energy in the transport sector (Koçar & Civaş, 2013). Their climate change mitigation benefits are exhibited during the combustion in the engines, whereby emissions of carbon dioxide (CO_2) are equivalent to the amount that was absorbed during the process of process of photosynthesis (Puppañ, 2002).

Agro-chemicals from biofuel production systems can impact on the environment, particularly vertebrate biodiversity and may thus negatively affect native ecosystems (Correa et al., 2019). Excessive use of fertilizers pollute soils with heavy metals (Atafar et al., 2010). Large-scale biofuel systems are associated with application of large amounts of pesticides and fertilizers. Such applications contribute to accumulation of heavy metals (cadmium, lead and arsenic) in the soil and can be absorbed by plants and cascade through food chain to animals and humans (Taylor & Percival, 2001). Eutrophication of aquatic systems as a result of run off causes rapid growth and reproduction of phytoplankton and lead to algae blooms which deplete oxygen for other aquatic organisms such as fish (Anderson et al., 2002).

Biofuels and water resources

Accelerated growth in biofuel production may result in an increase in the demand for fresh water especially during the cultivation stage and therefore threatens water availability particularly in countries already experiencing water scarcity (Gheewala et al., 2011). Therefore, sustainable biofuels production requires understanding of the impact of these crops on water resources (Yimam et al., 2014). Globally, agriculture consumes 80–90% of all freshwater and a larger volume of it is used in irrigation of crops (Morison et al., 2008). Increasing demand for water through biofuel production is likely to impact negatively on water resources particularly in areas where water is already scarce (De Fraiture et al., 2008). In a simulation study by Beringer et al. (2011), water consumption for irrigation of biofuel plantations ranged between 1481 and 3880 km^3 $year^{-1}$. Using CropWat Model in semi-arid Botswana, Moseki et al. (2019) suggests that *Jatropha curcas* as a feedstock for biodiesel production will need additional irrigation. They also showed that it requires more water compared to most first-generation biofuel crops such as maize and sorghum. In the US Southern Great Plains, Yimam et al. (2014) showed that under rainfed conditions, bioenergy production from sorghum biomass may require less water per unit land area than perennial grasses system. Large-scale irrigated biofuel system is likely to reduce groundwater aquifers and rivers (where surface water is used for irrigation) in the long run and thus affect the hydrological cycle (De Fraiture et al., 2008). Finally, the amount of water consumed depends on type of crop, area cultivated and management practices (Logan & Jurkowski, 2008).

In addition to the above discussion about the environmental impacts of biofuels, the pitfalls of using energy crops for producing second generation biofuels is their morphological and ecological traits that may confer invasiveness. A number of woody invasive species in Africa (Table 1) which are candidates for second generation biofuels were previously introduced for horticultural and agro-forestry purposes (Witt, 2010). This implies that cultivation of such crops for biofuel production must be carried out under the best management practices and regulations to limit the risk of invasion (Barney, 2014). Otherwise, one problem will be solved by creating another. The challenge facing the biofuel industry is how to achieve sustainable production of biofuel without exacerbating the risk of invasion (Blanchard et al., 2015; Quinn et al., 2015).

Invasive biofuel crop in Botswana

A number of woody species that are candidates for 'second generation' biofuel crops have already been introduced to Botswana to stabilize sand dunes and restore vegetation in the arid southwest part of the country. These include species such as *Prosopis* spp.

Table 1. Invasiveness and distribution of selected second-generation biofuels in Africa.

Species	Common name	Family	Species origin	Region where species is invasive	Source
Acacia saligna (Labill.) H. L. Wendl.	Port Jackson wattle	Fabaceae	Southwestern Western Australia	Asia, Africa, North America, South America Europe and Oceania.	Richardson and Rejmánek (2011)
Ailanthus altissima (Mill.) Swingle	Tree-of-heaven	Simaroubaceae	Northern and central China	Asia, Africa, North America, South America, Europe and Oceania	Iverson et al. (2019)
Azadirachta indica A. Juss.	Neem tree	Meliaceae	Afghanistan, Pakistan, India, Sri Lanka, Bangladesh, Myanmar and China	Asia, Africa, North America, Central America and Caribbean, South America and Oceania	Gupta (1993) Benelli et al. (2017)
Broussonetia papyrifera (L.) L'Herit ex Vent.	Paper mulberry	Moraceae	East Asia	Asia, Africa, North America, Europe and Oceania	Matthews (1996) González-Lorca et al. (2015)
Casuarina cunninghamiana Miq.	Australian beefwood	Casuarinaceae	Australia	Asia, Africa, North America, Central America and Caribbean, South America and Oceania	National Research Council (1984) Wilson & Johnson (1989) Henderson (2001)
Cedrela odorata L., 1759	Spanish cedar	Meliaceae	Northern Mexico, Argentia and Caribbean	Asia, Africa, North America, Central America and Caribbean, South America and Oceania	Estrada-Contreras et al. (2016)
Eucalyptus camaldulensis	Red gum	Myrtaceae	Australia	Asia, Africa, North America, Central America and Caribbean, South America, Europe and Oceania	Richardson and Rejmánek (2011)
Gleditsia triacanthos L.	Common honey-locust	Fabaceae	North America	Asia, Africa, North America, South America, Europe and Oceania	Ferreras et al. (2015)
Leucaena leucocephala (Lam.) de Wit	Leucaena	Fabaceae	Mexico	Asia, Africa, North America, Central America and Caribbean, South America, Europe and Oceania	Dana et al. (2003)
Melia azedarach L.	Chinaberry	Meliaceae	India and Pakistan	Asia, Africa, North America, Central America and Caribbean, Europe and Oceania	Chinnasamy et al. (2019)
Populus alba	Silver-leaf poplar	Salicaceae	Morocco, China, central and southern Europe, North Africa, Western and central Asia	Asia, Africa, North America, Central America and Caribbean, South America, Europe and Oceania	Dickmann and Kuzovkina (2008) Balestrazzi et al. (2014)
Prosopis species	Mesquite	Fabaceae	Mexico, Central and northern South America	Asia, Africa, North America, Central America and Caribbean, South America and Oceania	Ayanu et al. (2015) Shackleton et al. (2014)
Psidium cattleianum Afzel. ex Sabine	Strawberry guava	Myrtaceae	Southeast Brazil and northern Uruguay	Asia, Africa, North America, Central America and Caribbean, South America, Europe and Oceania	Patel (2012) Dos Santos Pereira et al. (2018)
Robinia pseudoacacia L.	Black locust	Fabaceae	Eastern North America	Asia, Africa, North and South America, Europe and Oceania	Li et al. (2014) Vítková et al. (2020)

(*Continued*)

Table 1. (Continued).

Species	Common name	Family	Species origin	Region where species is invasive	Source
Salix fragilis	Crack willow	Salicaceae	Central Europe	Asia, Africa, North America, Europe and Oceania	Buss (2002) Serra et al. (2013)
Schinus molle L.	False pepper tree	Anacardiaceae	South and Central America	Asia, Africa, North America, Central America and Caribbean, South America, Europe and Oceania	Ravindran (2017)
Senna spectabilis (DC.) H. S. Irwin & Barneby	White bark senna	Fabaceae	South America	Asia, Africa, North America, Central America and Caribbean, South America and Oceania	Fortunato et al. (2019)
Spathodea campanulata P. Beauv.	African tulip tree	Bignoniaceae	Africa	Asia, Africa, North America, Central America and Caribbean, South America, Europe and Oceania	Sangeetha et al. (2016)
Tecoma stans (L.) Juss. ex Humb., Bonpl. & Kunth	Yellow bells	Bignoniaceae	Argentina	Asia, Africa, North America, Central America and Caribbean	Faleiro et al. (2015) Gentry (1992)
Toona ciliata M. Roem.	Toon	Meliaceae	South and Southeast Asia	Asia, Africa, North America, Central America and Caribbean, South America and Oceania	Sahni (1999) Rodrigues et al. (2016)

Source: Table constructed from Henderson (2001); CABI (2007); DEA (Department of Environmental Affairs) (2015); Taylor et al. (2018)

(Fabaceae), *Eucalyptus camaldulensis* Dehnh (Myrtaceae), *E. sideroxylon, Leucaena leucocephala* (Lam) de Wit (Fabaceae, *Acacia saligna* (Labill.) H.L. Wendl. (Fabaceae) and *Casuarina cunninghamiana* Miq. (Casuarinaceae) (Lepetu, 1998). Other species such as *Schinus molle* L., *Melia azedarach* L., *Ailanthus altissima* (Mill.) Swingle, *Spathodea campanulata* P. Beauv, *Tecoma stans* (L.) Juss. ex Humb., Bonpl. & Kunth and *Senna spectabilis* (DC) H. S. Irwin & Barneby are present as garden or street tree.

Most woody invasive species in Botswana contain large amounts of non-edible lignocellulosic biomass and, therefore, are suitable as 'second-generation' biofuels. However, the impacts of these species in Botswana, with the exception of *Prosopis* species, have not been studied. Botswana is yet to develop a list of invasive plant species, let alone the legislature to regulate trading and cultivation of these species. The only legislature is the 1916 noxious weed act (CAP 35:04) which requires that listed plant species may not be allowed to grow on a property or the land owner is guilty of an offence; however, the list of species is quite old and does not include most invasive plant species. The impact of *Prosopis* species has been studied in Botswana (Muzila et al., 2011) and these studies can be used to provide lessons on how a proposed 'second-generation' biofuel crop can have an impact on biodiversity and ecosystem services.

Biology of Prosopis *spp*

Prosopis spp. is a woody weed adapted to arid and semi-arid regions and was introduced in these regions primarily for erosion control, fodder production, shade and fuelwood (Boy & Witt, 2013; Zimmermann, 1991). In Botswana, these species were intentionally introduced in Kgalagadi District to control desertification and stabilize sand dunes (Muzila et al., 2011). The species present in Botswana are *Prosopis chilensis, P. juliflora, P. glandulosa* and their hybrids. They have now escaped from cultivation and invaded the adjacent areas of Gantsi District. They are estimated to cover an area of 5,110 ha in both districts (Thobega, 2013). They also hybridize and form impenetrable dense thorn-thickets that prohibit any agricultural production in the invaded area (Schachtschneider & February, 2013). Interspecific hybridization which has been observed by Muzila et al. (2011) in southern Botswana also confers invasiveness (Zimmermann, 1991). In Australia, *Prosopis* species are declared noxious weeds and 1 of the 20 problematic weeds (Thorpe & Lynch, 2000), whereas in South Africa they are ranked second to Australian Acacia species as the worst invasive genus (Shackleton et al., 2017). They are also classified as invasive in Kenya, Ethiopia, Sudan, Pakistan and India (Food and Agriculture Organisation of the United Nations [FAO], 2006). *Prosopis* species are double-edged sword as they provide environmental, social and economic benefits (Shackleton et al., 2014) and also have a negative impact on biodiversity, ecosystem services and livelihoods (Shackleton et al., 2016). Such conflicting impacts present a challenge for the management of *Prosopis* species as one has to reduce the negative impacts as well ensuring some benefits (Shackleton et al., 2017).

Prosopis is drought tolerant and grows in hot dry climates with fluctuating temperature extreme and annual rainfall of 150–750 mm (Pasiecznik et al., 2001). Adaptability to low rainfall is facilitated by a deep tap root system of about 53 m that allows it to extract groundwater and nutrients from deeper soil profiles (Dzikiti et al., 2013). Due to wide ecological adaptability, *Prosopis* species are widely distributed in arid and semi-arid zones. As leguminous plants, they fix nitrogen in their root system, thus, are able to survive in sandy soils with low soil fertility (Smit, 2005). *Prosopis* species are prolific seed producers with effective dispersal mechanism (Shiferaw et al., 2004). The pods containing seeds are consumed by animals and pass through the digestive tract where the acid scarifies the seeds and enhances their germination upon excretion through droppings (Noor et al., 1995).

Ecological impacts of Prosopis *species*

The impact of *Prosopis* species in Botswana has not been extensively studied as in South Africa, Kenya, Ethiopia (Shiferaw et al., 2004) and many other countries in Africa and worldwide. However, the communities in the affected four villages of BORAVAST (Bokspits, Rapplespan, Vaalhoek and Struizendam) cited blockage of boreholes and depletion of groundwater and nutrients due to a deep and extensive root system (Muzila et al., 2011). The communities also complained about blocked noses or ‘flu like symptoms’, especially during windy weather. The dense thickets of *Prosopis* species along the road sides obscure driving visibility, resulting in road accidents that involve vehicles hitting livestock and wild animals (BCAPR, 2004). It has also been reported that *Prosopis* species form dense monoculture stands in areas it invades, resulting in loss of grazing areas. Chilume (2016) reported that *P. juliflora* significantly reduced species evenness, richness and density in Gantsi District. They also observed a reduction in species diversity and a change in species composition.

When livestock lose palatable fodder species due to *Prosopis* species invasion, they are moved long distances away from their area to other areas free of *Prosopis* species (Witt, 2010). However, this movement can result in conflict as the resident communities may deny the livestock grazing in fear of spreading of *Prosopis* into their area through droppings. Livestock droppings also improve soil fertility and subsequently growth and spread of Prosopis. Similar conflict has been reported by Mwangi & Swallow (2005) in Kenya where livestock was driven about 50 km from their area. *Prosopis* species are also reported to have allelochemical effects on other plants. In Botswana, Mosweu et al. (2013) reported that *Prosopis* species secretes allelochemicals that inhibit the growth of other plants and reduce biodiversity. In neighbouring South Africa, *Prosopis* invasions were found to significantly reduce the cover of native grasses and herbaceous plants (Shackleton et al., 2015). Given that these negative impacts have been extensively studied and are well known in South Africa, it is probable that the *Prosopis* species invasion in Botswana has also negatively affected ecosystem services such as water supply and grazing potential.

Methods for evaluating invasiveness risk of biofuel crops

Several studies have raised concern about the potential invasiveness of biofuel crops (DiTomaso et al. 2010; Flory et al., 2012; Raghu et al., 2006; Schnitzler & Essl, 2015; Smith et al., 2015). Despite concerns about their adverse environmental impact, there are limited efforts to quantify potential invasiveness of biofuel crops (Buddenhagen et al., 2009). In an attempt to minimize the introduction of invasive species, the scientific community has designed pre-introduction screening protocols as a pro-active measure to classify exotic species on the basis of risk-assessment criteria (Barney & DiTomaso, 2008). Species identified to be posing an invasion risk can, then, be cultivated under the guidance of the appropriate national biofuel framework (Buddenhagen et al., 2009).

Pheloung et al. (1999) developed a Weed Risk Assessment (WRA) for determining species with a high probability of becoming invasive, which is currently used in Australia and New Zealand to regulate new plant imports. Additionally, WRA can be used as a management tool to prioritize eradication and control programmes of invasive species already present (Kato et al., 2006), and limit their spread from one area to another. Reliability of this risk assessment tool can be enhanced by experimental or survey data (Hulme, 2012). In Hawaii and Japan, it was found to correlate positively with index from local botanists and weed scientists (Daehler et al., 2004; Kato et al., 2006). The WRA tool consists of 49 questions about domestication/cultivation, climatic requirements and distribution, use and weediness elsewhere, biology and ecology. The responses are used to decide on whether a species is accepted or declined for importation, or whether there is a need for further evaluation. Based on the answers, the tool assign the evaluated species to one of the three categories: 'accept', for score of less than one (< 1) as it implies the risk of invasion is low; 'reject', for score of greater than six (> 6), it implies the risk of invasion is high; and 'evaluate further', for score of (1–6), it requires field experiment or additional information to make a decision.

This WRA has been used world-wide either as the standard Australian Weed Risk Assessment or a modified one. It has been used in the United States (Barney & DiTomaso, 2008; Daehler et al., 2004; Jefferson et al., 2004; D. R. Gordon et al., 2012), Canada (McClay et al., 2010), Italy (Crosti et al., 2010), Japan (Kato et al., 2006; Nishida et al., 2009), Australia (Pheloung et al., 1999; Walton, 2001; Weber et al., 2009) and New Zealand (Champion & Clayton, 2001) (Table 2). In Czech Republic, Křivánek and Pyšek (2006) used the tool on 180 alien species, and it rejected 100% of known invasive and accepted 83.8% of non-invasive. When used in 230 exotic species in East Africa, Tanzania, it rejected 83% of known invaders and accepted 74% of non-invaders (Dawson et al., 2009).

Table 2.. Weed Risk Assessment (WRA) for crops proposed for biofuel.

Species	Region for cultivation	WRA score	Source
Panicum virgatum	California	10 (reject)	Barney and DiTomaso (2008)
	Italy	4 (reject)	Crosti et al. (2010)
	Hawaii	11 (reject)	Low et al. (2007)
Arundo donax	Florida	8 (reject)	Barney and DiTomaso (2008)
	United States	11 (reject)	D. R. Gordon et al. (2011)
	Hawaii	12 (reject)	Turn et al. (2005)
E. camaldulensis	Florida	12 (reject)	D. R. Gordon et al. (2011)
	United States	12 (reject)	D. R. Gordon et al. (2011)
E. grandis	Florida	7 (reject)	D. R. Gordon et al. (2011)
	United States	8 (reject)	D. R. Gordon et al. (2011)
	Hawaii	11 (reject)	Turn et al. (2005)
Prosopis juliflora	Hawaii	19 (reject)	Howard and Ziller (2008)
Jatropha curcas	Florida	19 (reject)	D. R. Gordon et al. (2011)
	United States	19 (reject)	D. R. Gordon et al. (2011)
	Hawaii	17 (reject)	Poteet and Number (2006)
	Zambia	18 (reject)	Negussie et al. (2013)
L. leucocephala	Florida	21 (reject)	D. R. Gordon et al. (2011)
	United States	21 (reject)	D. R. Gordon et al. (2011)
	Hawaii	15 (reject)	Turn et al. (2005)
Sorghum bicolour ('sweet')	United States	3 (accept)	D. R. Gordon et al. (2011)
Saccharum officinarum	United States	5 (accept)	D. R. Gordon et al. (2011)
Moringa oleifera	Hawaii	1 (accept)	Poteet and Number (2006)
Mimosa pigra	Florida	27 (reject)	D. R. Gordon et al. (2008)

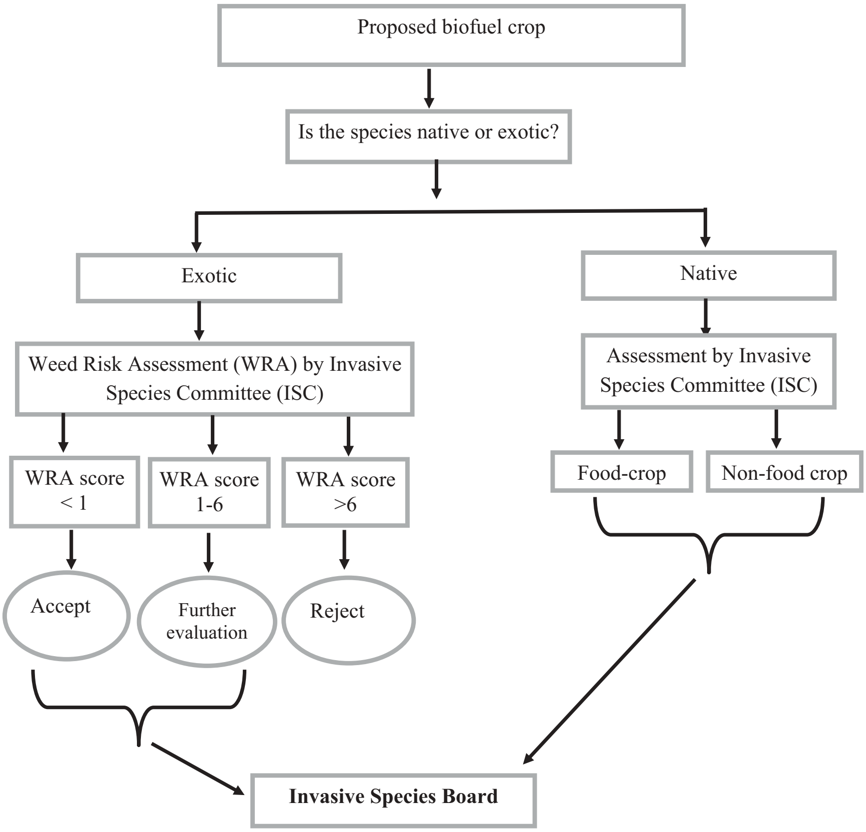

Figure 1. Proposed framework for selecting non-invasive biofuel crops in Botswana.

From the foregoing discussion on the usefulness of WRA, it is recommended that a framework for selecting non-invasive biofuel crops in Botswana be developed. Crops proposed for biofuel production in Botswana need to be assessed for invasiveness before their introduction and cultivation. Such a screening tool will ensure that only non-invasive crops are used for biofuel production. A framework for selection of biofuel crops in Botswana is proposed (Figure 1) and it suggests that:

(1) Exotic species should be subjected to Weed Risk Assessment (WRA) protocol by Invasive Species Committee (ISC) composed of scientists, private sector (environmentalists) and international expert on invasive species. Based on the score the committee make recommendations to either accept, evaluate further or reject. Recommendations for acceptance and further evaluation are then submitted to Invasive Species Board (ISB) for final decision. The ISB should be formed by invasive species experts from Ministry of Agriculture and Environment, and universities, biofuel industry, private sector and the community.

(2) Native species should be assessed based on whether it is a food-crop or non-food. The recommendations should similarly be submitted to the ISB for final decision

Conclusion and policy implications

The results of these reports (Table 2) have demonstrated that most plants proposed for biofuel production are either invasive or have the potential to become invasive when introduced outside their native range. The challenge besieging the biofuel industry is the production of biofuel crops with limited risk of escape into adjacent land use systems or natural areas. Invasions by alien invasive species lead to a variety of environmental, social and economic impacts. They reduce species diversity, affect livelihoods and damage national economy. They are also costs associated with a reduction in productivity of the sectors of agriculture and forestry, and other production systems can be extremely high

The Botswana Government is currently conducting an evaluation of *Jatropha curcas* L. for biodiesel production. Such trials should be subjected to an environmental impact assessment inclusive of an assessment of their invasive potential. A scientifically proven WRA should be used as a screening tool by ISC and recommend to ISB to reject any proposed biofuel crop that is predicted to be invasive. Most food-crops (e.g., maize, sorghum, millet and beans) are cultivated globally outside their native ecosystem and are not invasive, thus more research is needed to identify or develop biofuel crops with minimal invasion traits that will reduce the risk of potential invasiveness in their new habitats.

The invasion risk of biofuel crops is not limited to the plantations or cultivation fields but follows the supply chain including harvesting, transportation and storage of feedstock. It is, therefore, important that the Government of Botswana develops a national strategy and related regulations to manage risk along the supply chain from production in the field through to feedstock storage. Managed or natural systems along the supply chain most susceptible to invasion should be identified and prioritized for risk management. Management of the invasion risk can be improved by adopting the IUCN Guidelines on Biofuels and Invasive Species which recommend the use of feedstock with minimal risk, capacity building to enforce regulations, development of Environmental Management Plans, and the extension of planning to monitor and assess beyond the site of production.

Eradication of established invasive species is costly and may not be possible. Given the expected large-scale cultivation of biofuel crops, it is highly possible that some plants may escape and invade other ecosystems. Therefore, mitigation strategies should be in place to prevent invasion and successful establishment. Some biofuel plantations may not be economically viable leading to their abandonment. Such plantations should be properly terminated and eradicated, and then sites should monitor over years.

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