Importance of *Lupinus albus* in agricultural and food-related areas: A review

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Received: 27 May 2018 / Accepted: 9 October 2018 / Published online: 12 October 2018
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Abstract

The purpose of this review is to assist readers in understanding the importance of *Lupinus albus* to nature, farmers, and scientists. *L. albus* is mostly found in Argentina, Uruguay, Paraguay, and in “Campanha, Litoral and Missões” regions of State of Rio Grande do Sul (Brazil). Therefore, this review presents information and discussion on this plant that can encourage novel studies in a near future for exploring evermore the biological and physicochemical properties of *L. albus*. The plant presents adaptive characteristics of soils with low content of nutrients, being an important plant for the recovering of degraded areas. In the last few years, there was an increase in scientific interest for exploring its chemical composition and biological activities. All plant matrices (i.e., roots, leaves, seeds, and stalks) are rich in antioxidant and antifungal compounds, especially stigmasterol. For example, the extracts obtained from the roots are reported with more than 50 wt% stigmasterol and 25 wt% ergosterol. Furthermore, the extracts present remarkable fungicide effects, especially against *Fusarium oxysporum* and *Fusarium verticillioides*.

Keywords *Lupinus albus* · Chemical composition · Extract · Antioxidant · Antifungal · Degraded areas

Introduction

Brazilian biodiversity has a high variety of species and biomes rich in different plants (Coradin et al. 2011). This biodiversity is considered as a source of biologically active substances that present immense potential for the production of secondary compounds with important biological activities (Marangoni et al. 2012). However, it is necessary to encourage studies on this natural heritage, because this biodiversity is still a few studied.

The species belonging to the genus *Lupinus* are highly tolerant to dry habitats and are normally found on nutrient-poor soils (Elbandy and Rho 2014; Martínez-Alcalá et al. 2010). Among the species present in Pampa biome in the State of Rio Grande do Sul, there is the *Lupinus albus*. It belongs to Fabaceae family and is still a few investigated in relation to its secondary constituents (Simoes 2006). *L. albus* is a species of “New World” (Granada et al. 2015), native from the northwest region of Argentina, Uruguay, Paraguay, and southern Brazil (Planchuelo and Dunn 1984). In most of the countries, the plants are being used as a cover crops tool to improve the quality of the soil (Martínez-Alcalá et al. 2010; Vázquez et al. 2006).

The plant extracts, as well as essential oils, are bioactive substances that can be used as antibacterial, antioxidant (Ben Lajnef et al. 2018; Bouyahya et al. 2017a, b; Nile et al. 2017; Suluvoy and Berlin Grace 2017), antifungal (Fadel et al. 2013), repellents, insecticides, and herbicides, or even altered to improve their biological action (Bakkali et al. 2008). Essential oils and plant extracts are complex mixtures of various compounds, as terpenoids (Singh and Sharma 2015), monoterpenes, sesquiterpenes, alcohols, aldehydes, ethers, esters, ketones, and phenols,

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among others, which are primarily responsible for aroma and odor (Dhakad et al. 2018). These bioactive substances (secondary metabolites) are complex molecules with various functional structures (Lahlou 2013) and can be produced in all plant tissues such as leaves, flowers, fruits, roots, rhizomes, stalks, and seeds. The presence of such substances may vary in quantity and quality and from species to species, once their occurrence and synthesis are influenced by genetic and environmental factors (Li et al. 2011; Senica et al. 2017).

Considering the biological importance of extracts from *L. albens*, the objective of this work is to review the importance and biological properties of different parts of *L. albens*. Information and discussion on the recovery of degraded areas and nitrogen fixation, chemical composition, and bioactivity are presented.

Lupinus sp. genus

The *Lupinus* sp. genus is composed of annual herbaceous or herbaceous and shrubby perennials divided in the “Old World” and “New World” (Durán et al. 2013). Among the different species found in the “Old and New World”, some of them are used to human feed: *L. angustifolius*, *L. albus*, *L. luteus*, and *L. mutabilis* (Fig. 1) (Islam and Ma 2016). *Lupinus* sp. is known popularly as lupine and it belongs to the Fabaceae family. It has more than 400 species found worldwide (Fig. 2), but the characteristics of only a few species have been explored (Khan et al. 2015).

According to data from the “Flora of Brazil”, there are 31 species of *Lupinus* sp. cataloged in Brazil with confirmed geographic distribution: Northeast (State of Bahia), Center-West (Federal District and State of Goiás), Southeast (States of Minas Gerais, Rio de Janeiro and São Paulo), and South (States of Paraná, Rio Grande do Sul and Santa Catarina).

Fig. 1 Cultivated lupine species: *L. albus* (white lupine), *L. angustifolius* (narrow-leaved lupine or blue lupine or Australian sweet lupine), *L. luteus* (yellow lupine), and *L. mutabilis* (pearl lupine). Font: Islam and Ma (2016) (reproduced with permission)

Fig. 2 Geographical distribution worldwide of genus *Lupinus* sp. The dots show the location of populations. (Source: <http://eol.org/pages/27789/names>) (reproduced with permission)

The phytogeographical domains are in “Caatinga”, “Cerrado”, “Mata Atlântica”, and “Pampa” (Fig. 3).

Lupine presents an important role for farmers in soil nitrogen fixation for crop rotation (Pettersen 2016), becoming one of the main grain crops in Australia (Thambiraj et al. 2015). *L. albus*, *L. angustifolius*, *L. luteus*, and *L. mutabilis*

are the main four species of lupine with agricultural interest (Uzun et al. 2007). Another characteristic of lupine is the high protein level (French 2016) and nutritional value (Sbihi et al. 2013), being used to feed cattle through nutritive forages (Wink 1992) and for human consumption (Villarino et al. 2016). Some species of lupine are rich in compounds

Fig. 3 Distribution of some species of genus *Lupinus* sp. in Brazil

such as polyphenols, alkaloids, and phytosterols, and are beneficial to humans and animals (Khan et al. 2015). They have biological activity but are unfit for consumption due to the lacking of nutritional properties (Trugo et al. 2016). The bioactive compounds are formed by secondary plant metabolism and may cause different pathologies (Wink 1992). In a recent study, Farag et al. (2018) identified 107 metabolites from different species of *Lupinus*, comprising organic compounds, sugars, and sterols. However, different approaches must be carried out to explore other factors related to the composition such as collection site, seasonal variation, and extraction conditions.

Lupinus albens

Lupinus albens can be found in the Southern regions from Brazil, Northwestern Portugal, Venezuelan mountains, and Northern Australia, where a sandy, degrading, and nutrient-poor soil (Fig. 4) is found. In South America, *L. albens* is a legume found in the “New World” and with natural occurrence in Argentina, Uruguay, Paraguay and in the regions of “Campanha, Litoral and Missões” of State of Rio Grande do Sul (Granada et al. 2015).

Popularly known as a native lupine, *L. albens* presents leaflets and very hairy branches. Some resinous substances compose lupine, which can be a mechanism of adaptation to the edaphoclimatic conditions of the region, demonstrating

its evolution parallel to a paleo-environment. These characteristics and the high rusticity of the species have beneficial effects on their use in soil recovery strategies and make *L. albens* unsuitable for animal consumption. The high pilosity acts to decrease transpiration, an important factor in soils with low water retention (Suertegaray et al. 2005).

Lupinus albens is an herbaceous plant with erect growth, digested leaves, and racemic inflorescences of lilac flowers and fruits in pod form, with up to seven seeds (Fig. 5) (Planchuelo and Dunn 1984). It is a native species that has not undergone genetic improvement processes and has variability at some stages of its development, such as unequal inflorescence emission and irregular flowering within the racemes (Rovedder 2007).

The germination of native lupine takes from 10 to 20 days, forming a bank of seedlings with high density (Rovedder 2007). The lupine presents seed dormancy; that is, it does not present germination capacity under favorable conditions (Finch-Savage and Leubner-Metzger 2006). It suggests that the dormancy may be associated with a decrease in metabolism, which may be due to different mechanisms such as changes in temperature, light, water, and others (Xia et al. 2018). According to the rules of seeds analysis (Brasil 2009), it is recommended to store the seeds at low temperatures (pre-chill of 5–10 °C). The chromosome number of *L. albens* was first reported by Perissé et al. (2000), as well as its karyotype: $2n=36$. It presents 15 pairs of metacentric and 3 pairs of submetacentric chromosomes, varying in size from 1.17 to 2.87 (Fig. 6).

Fig. 4 Degraded area of natural occurrence of *L. albens*—State of Rio Grande do Sul, Brazil

Fig. 5 Qualitative characteristics of *L. albens* species occurring in the State of Rio Grande do Sul, Brazil

Recovery of degraded areas and nitrogen fixation

In sandstone areas, the soil is very fragile and degraded, where there are excessive clay and nutrient losses (Roesch et al. 2009). Therefore, the use of resistant cover plants is a good strategy for recovering these sites. Rovedder and Eltz (2008a) emphasize the use of *L. albens* as a plant for preventing the expansion of sand, because it has presented high efficiency in the reduction of sand transport.

Biological nitrogen fixation is a natural process of nitrogen uptake and transformation into ammonia (Hungria et al. 2007). This process is carried out by specialized bacteria that interact with the plants, forming structures in roots as

nodules (rhizobia). These nodules are the sites specialized in transforming atmospheric N_2 into ammonia, which is distributed to plants and incorporated into nitrogenous components such as ureides, amino acids, and amides (Hungria et al. 2007; Rascio and La Rocca 2013).

Legumes are one of the species of plants that have the ability to associate with bacteria and to perform the fixation of atmospheric N_2 (Furlan et al. 2017). Due to its high rusticity and adaptability to sandy soils, native lupine is also being studied for its use for biological nitrogen fixation and soil cover. However, only a few studies focused on the identification and selection of rhizobia strains in association with *L. albens* (Table 1).

Secondary metabolites are related to adaptive processes of plant defense, which are considered as final products

Fig. 6 Image of identification of chromosome (a) and karyotypes (b) of *L. albens*. Font: Perissé et al. (2000) (reproduced with permission)

Table 1 Main remarks of studies dealing with *Lupinus albus* and its applicability on degraded areas

Objectives	Main factors evaluated	Main results and conclusions	References
Evaluating revegetation with cover species, <i>Avena strigosa</i> Schieb. and <i>Lupinus albus</i> , in order to contain the transport of soil particles by wind erosion	Treatments of degraded areas and revegetated degraded areas were evaluated with covering plants	Black oat + native lupine cover crops showed a 93% efficiency on the reduction of sand transport	Rovedder and Eltz (2008a)
Evaluating the development of <i>Pinus elliotii</i> Engelm (Pinus) and <i>Eucalyptus tereticornis</i> Sm. (Eucalyptus) in association with cover plants <i>Avena strigosa</i> Schieb. (black oats) and <i>L. albus</i> H. et Arn. in the revegetation of sandstone areas	Different treatments were evaluated: pinus and eucalyptus planted in plots of the native field with cover plants; degraded soil with cover crops; native field without cover plants and degraded soil without cover plants. The survival rate of the pinus and eucalyptus plants at 12 months after planting was also evaluated	The use of eucalyptus to contain the sandstone can be started on the soil already sanded and in consortium with cover plants. In planting of pinus, a specific care should be taken with a consortium with herbaceous species, due to interspecific competition	Rovedder and Eltz (2008b)
Studying the revegetation with <i>L. albus</i> on the edaphic environment, based on the abundance and diversity of epigene groups of soil organisms as bioindicators of soil quality	The treatments consisted of soil with a natural cover of <i>L. albus</i> , sandstone area that received revegetation with <i>L. albus</i> a year ago, 3 years ago, sandstone soil and native field	The arenization reduced the development of soil populations, while revegetation showed positive effects on recolonization of the area	Rovedder et al. (2009)
Testing the best way to cultivate <i>L. albus</i> in order to contain the sandstone	Seed density and spacing between different lines were evaluated	The spacing between lines of 17 cm favored the production of biomass and the one of 51 cm had a better seed production; the number of plants per linear meter did not interfere on the characteristics analyzed	Rovedder et al. (2010)
Isolating and characterizing bacteria associated with <i>L. albus</i> in sandy soils of the State of Rio Grande do Sul, Brazil	Bacteria from the <i>L. albus</i> rizoplane were isolated and characterized genotypically and phenotypically as morphology, motility and electron microscopy, growth rate	The inoculation of <i>L. albus</i> with the RPIp and RP2p strains resulted in a significant increase in the weight of the dried plants; these bacteria have properties that favor plant growth	Giongo et al. (2010)
Characterizing a rhizobium strain isolated from <i>L. albus</i> using phenotypic, symbiotic and molecular approaches	The strain UFSM LA 1.3 was tested in vitro according to the parameters: colony size; color and growth rate; acid or basic reaction in yeast medium mannitol supplemented with bromothymol blue; production of gum. Molecular characterization was also performed	The isolate UFSM LA 1.3 showed high efficiency in the biological fixation of N to <i>L. albus</i> , presenting phenotypic and molecular characteristics that allow locating this isolate in the genus <i>Bradyrhizobium</i>	Roberto et al. (2010)
Characterizing the bacterial communities of the soil in a sandstone area under different management regimes and evaluating the potential of growth of native plants of <i>L. albus</i>	Bulk soil samples were collected from a sandstone site, and rhizosphere soil and roots of <i>L. albus</i> plants grown at this sandy site. Microbial biomass, respiratory activity, and metabolic index were evaluated and characterized by microbial diversity and identification of isolated bacteria	Independent and dependent methods of culture showed convergent results in relation to diversity indexes; rhizospheric environments increased bacterial diversity and biomass when compared to granular soils. The growth characteristics of the plants were affected by the environmental conditions	Granada et al. (2013)
Evaluating the level of fertilization most appropriate for production of <i>L. albus</i> seeds, rationalizing their cultivation in degraded areas	The influence of different doses of P ₂ O ₅ (25%, 50%, 75%, 100%, 125%, and 150%) in the form of triple superphosphate and K ₂ O in the form of KCl was evaluated in terms of plant height, number of pods per plant and percentages of survival	The dose of 75% was the one that obtained plants with higher heights and numbers of pods per plant	Abrão et al. (2013)

Table 1 (continued)

Objectives	Main factors evaluated	Main results and conclusions	References
Evaluating bradrihizobial communities present in the root nodules of <i>L. albenscens</i> and characterizing these communities	A multilocus phylogenetic analysis was performed, allied to genetic diversity indexes in 74 bradrihizobial isolates	<i>Bradyrhizobium</i> spp. plant symbionts of <i>L. albenscens</i> were genetically different in sandstone and non-sandstone areas, showing that the environment affected the selection of the most efficient plant growth promoters to support plant growth	Granada et al. (2015)

(Anarat-Cappillino and Sattely 2014). The plants, although autotrophic, are immobile and unable to escape the attack of phytopathogens, pests or invasion by other plants. For this reason, the main function of these metabolites is the protection against the attack of their enemies (Oliveira et al. 2012). Therefore, it can be stated that secondary metabolites are the form found by plants to communicate or respond to external stimuli (Pavarini et al. 2012).

Chemical composition and bioactivity of *Lupinus albenscens*

Several metabolites act as antibacterial or antifungal, immunosuppressant, antiparasitics, herbicides, and cholesterol-lowering agents (Vaishnav and Demain 2011). There are approximately 10,000 secondary metabolites with allelopathic action (chemical interaction of plants and microorganisms) (Barbosa et al. 2008). The chemical composition of leguminous crops is a primary factor for using the legumes as food (Jawed et al. 2015) or for agronomic purposes. Only a few studies demonstrated the composition of some species of *Lupinus* (Confortin et al. 2017; Planchuelo-Ravelo and Wink 1993). Although the information is scarce in the scientific literature, the knowledge that is available is really important to understand the structural diversity of compounds and to demonstrate their related biological activities.

Planchuelo-Ravelo and Wink (1993) is considered the first report that analyzed the alkaloids of seeds and leaves of *L. albenscens* from South American with the combination of liquid chromatography of high-resolution and gas chromatography coupled to mass spectrometry. The samples were collected near the city of Santa Fe (Argentina). As a result of the extraction of alkaloids, ten types were identified for leaves and seeds in a very similar way (Table 2), as multiflorine (86.7%).

Regarding the chemical composition of extracts from *L. albenscens*, only another report was found in the literature (Confortin et al. 2017). The authors have determined the yields and chemical composition of extracts obtained from different parts of *L. albenscens* (roots, stalks, leaves, and flowers) using gas chromatography. Ten different compounds were identified in high quantity (Table 2). Stigmasterol and ergosterol are the major ones, which have antioxidant, anti-inflammatory (Hamdan et al. 2011), and antifungal (Mbambo et al. 2012) activities.

The control of diseases in agriculture caused by pathogenic fungi of plants has been carried out basically through the use of synthetic products (Feng et al. 2015). In recent years, there has been an increasing interest in agricultural methods that are environmentally and economically viable. Therefore, constant studies and the search for new chemical

Table 2 Chemical composition of *Lupinus albus*

Matrices	Compounds and their mean percentages ^a (mass basis)	Extractive methods	References
Leaves and seeds	Anmodendrine (0.05%); albine (8.5%); dehydromultiflorine (1.4%); lupanine (0.1%); 11,12-seco-12,13-didehydromultiflorine (0.8%); multiflorine (86.7%); 13-tigloyloxymultiflorine (1.5%)	Solid liquid extraction using an Extrelut column and methylenechloride as eluent	Planchuelo-Ravelo and Wink (1993)
Seeds	C16:0 (palmitic 7.7%), C18:1 (oleic 27.8%), C18:2 (linoleic 56.7%), C18:3 (linolenic 5.3%), C20:0 (arachidic 0.1%), C20:1 (eicosenic 0.3%), C22:0 (behenic 1.2%), cholesterol (0.51%), campesterol (17.39%), stigmasterol (17.70%), 24-methylcholest-/-enol (2.45%), β -sitosterol (59.75%), A7-stigmasterol (2.20%)	Soxhlet (<i>n</i> -hexane)	Fuentes and Planchuelo (1997)
Roots, stalks, leaves and flowers	Stigmasterol (34.8%); ergosterol (11.8%); vitamin E (1.3%); methyl commate (6.0%); pentadecanoic acid (3.0%); eicosanol (1.5%); octadecanoic acid (3.0%); neophytadiene (1.0%); epiergostanol (1.2%); tetracosanol (7.8%)	Supercritical CO ₂ , pressurized LPG and Soxhlet (<i>n</i> -hexane)	Confortin et al. (2017)

^aThe mean percentages are related to all matrices reported in each study

Table 3 Antioxidant activity of compounds from *L. albus*, described by Confortin et al. (2018)

	Antioxidant activity ($\mu\text{g/mL}$)	
	Extract obtained by supercritical CO ₂	Extract obtained by compressed LPG
Flowers	189.65	192.96
Leaves	115.65	118.56
Stalks	101.29	102.56
Roots	29.25	32.94

LPG liquefied petroleum gas

groups with fungicidal effects are considered of fundamental importance.

Considering the chemical composition found in different matrices by Confortin et al. (2017), our research group evaluated the extracts obtained from *L. albus* against the growth of two fungi pathogens: *Fusarium oxysporum* and *Fusarium verticillioides*, as well as its antioxidant potential (Table 3). All matrices presented a high inhibition power for both fungi: 70.1% inhibition against *F. oxysporum* and 67.8% inhibition against *F. verticillioides*. The root matrix was highlighted, because its extracts presented the best results for both tests (antifungal and antioxidant activities) (Confortin et al. 2018). The authors infer that their outcomes were promising in terms of antioxidant activity. They recommend a possible use of the extracts as a biological control for agricultural diseases caused by phytopathogenic fungi, which the activities are higher if compared with the studies of other plant extracts.

Lupinus albus has an important role in nature and for farmers, which is used as a recovering plant in degraded areas and for fixation of nitrogen. In addition, the identification of its chemical compounds shows the potential biological properties of this plant for a biological control. Recently, there has been an increasing interest in agricultural methods that are environmentally and economically viable. In such trends, promising antifungal results were reported for two pathogenic fungi (*Fusarium oxysporum* and *Fusarium verticillioides*). However, there are only a few studies about this plant up to now. Consequently, as future outlooks, new projects are expected to be performed to find new chemical groups with the other biological effects for the agricultural and food-related areas.

Acknowledgements The authors thank Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarships, and Research Support Foundation of the State of Rio Grande do Sul (FAPERGS), and National Counsel of Technological and Scientific Development (CNPq) for the financial support.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding this work.

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