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Review Article

Atriplex canescens (Pursh) Nutt. una especie multifuncional de las zonas semiáridas de Norteamérica: una revisión

Atriplex canescens (Pursh) Nutt. a multifunctional species of the semi-arid zones of north America: a review

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Resumen

Atriplex canescens es una especie nativa ampliamente distribuida en las zonas semiáridas de Norteamérica, desde el norte de México hasta el oeste de Estados Unidos de América. La presente revisión de la información publicada sobre esta especie durante los últimos 25 años pretende mostrar su taxonomía, distribución geográfica, hábitat, usos actuales y potenciales, así como las amenazas para su hábitat. Los resultados evidenciaron que el uso más amplio de *A. canescens* es el forrajero, en la alimentación de ganado bovino, caprino y ovino. También, destacó su empleo en la rehabilitación de suelos degradados, la captura de carbono, la prevención de la erosión y la fitorremediación de suelos contaminados por desechos industriales. Además, tiene un amplio potencial en el campo biotecnológico, como control biológico, biocombustible y fuente de genes tolerantes a la sequía y salinidad; asimismo, el consumo de flores, frutos, hojas y raíces de *A. canescens* ha sido muy importante para las comunidades indígenas. Sin embargo, a pesar de su amplia distribución enfrenta algunas amenazas, como el cambio de uso de suelo, la competencia con especies invasoras y la reducción de la conectividad entre poblaciones naturales. En síntesis, *A. canescens* es un taxón con una gran diversidad de usos, por lo que es necesario generar conocimiento para su manejo sustentable y conservación.

Palabras clave: *Atriplex canescens* (Pursh) Nutt., forraje, manejo forestal, biotecnología, restauración ecológica, zonas semiáridas.

Abstract

Atriplex canescens is a native species widely distributed in semi-arid areas of North America, from northern Mexico to the western United States. This review aims to present the information published for the last 25 years on its taxonomy, geographic distribution, habitat, current and potential uses, and threats to its habitat. This review shows that the main use of *A. canescens* is the production of forage for the feeding of bovine, goat and ovine livestock. Equally prominent is the use of this species in the rehabilitation of degraded soils, carbon sequestration and the prevention of soil erosion, as well as in phytoremediation of soils contaminated by industrial wastes. In addition, *A. canescens* has a wide potential in the biotechnological field, as biological control, biofuel and source of drought- and salinity-tolerant genes. The consumption of flowers, fruits, leaves and roots of this species has also been important for the indigenous communities. However, despite its wide distribution, this species faces threats, such as land-use change, competition with invasive species and reduction of connectivity among populations. In summary, *A. canescens* is a multifunctional species, that demands further knowledge for its sustainable management and preservation.

Keywords: *Atriplex canescens* (Pursh) Nutt., forage, forest management, biotechnology, ecological restoration, semi-arid zones.

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Introduction

The semi-arid zones of North America are ecosystems that harbor high biodiversity and provide a wide range of environmental services to human communities (Bradley and Colodner, 2020). They are characterized by limited water resources, extreme temperatures and the recurrence of prolonged droughts (Chambers *et al*., 2008). The shrub component is the main existing form of plant life, with a predominance of genera such as *Larrea*, *Prosopis*, *Flourensia,* and *Atriplex* (Granados *et al*., 2011).

Prominent among the shrub species is *Atriplex canescens* (Pursh) Nutt., considered a multifunctional taxon due to its wide distribution and importance (Sanderson and McArthur, 2004). *A. canescens* is perennial, evergreen, ashy or grayish in color, with deep roots and a large number of adventitious roots adapted to absorb water at great depths (Romero and Ramírez, 2003).

Furthermore, *A. canescens* is an excellent green biomass producer (up to 1.24 kg plant^{-1}) under low rainfall conditions (Echavarría *et al*., 2009). Therefore, its main use is the production of fodder for livestock feed for grazing in semi-arid areas of the world (Mellado *et al*., 2006; Allison and Ashcroft, 2011).

However, it has a wide range of current and potential uses, some of which are little known among the scientific community and the managers of its populations. Therefore, the objective of this study was to compile and synthesize the information published during the last 25 years on the taxonomy, distribution, ecology, current and potential uses, as well as threats to the habitat of *A. canescens*. The following bibliographic databases were consulted: Scopus, Google Scholar, and other sources of information, such as theses and technical brochures.

The information will be very useful for determining the current state of knowledge about this taxon, as well as for disseminating and contextualizing its importance as a multifunctional species.

Traditional and binomial nomenclature

A. canescens is known in Mexico by several names: *cenizo*, in the states of *Chihuahua* and *Sonora*; *costilla de vaca*, in the states of *Zacatecas* and *Coahuila*, and *chamizo*, in the states of *Baja California, Chihuahua* and *San Luis Potosí* (Urrutia *et al*., 2014). In the United States of America, it is called four-wing saltbush, grey sage brush, and saltbush (Sanderson and McArthur, 2004). According to its etymology, *Atriplex* corresponds to its ancient Latin name, while *canescens* is the Latin epithet meaning "hoary, gray" (Dictionary of Botanical Epithets, 2019).

The species was described by F. T. Pursh in 1814 as *Calligonum canescens*; later, in 1818, T. Nutall repositioned it in the *Atriplex* Nutt. genus, which is currently accepted. Its synonyms are: *Atriplex linearis* S. Watson, *A. nuttallii* S. Watson, *Obione canescens* (Pursh) Moq., and *Pterochiton canescens* (Pursh) Nutt. It formerly belonged to the Chenopodiaceae family, but in recent years it was relocated to the Amaranthaceae family (The Plant List, 2020; Tropicos, 2020). Since the original description of the species in 1814, it has undergone modifications at both the genus and the family level; today, the valid scientific name is *Atriplex canescens* (Pursh) Nutt. Table 1 shows its complete taxonomic classification.

Table 1. Taxonomic classification of *Atriplex canescens* (Pursh) Nutt.

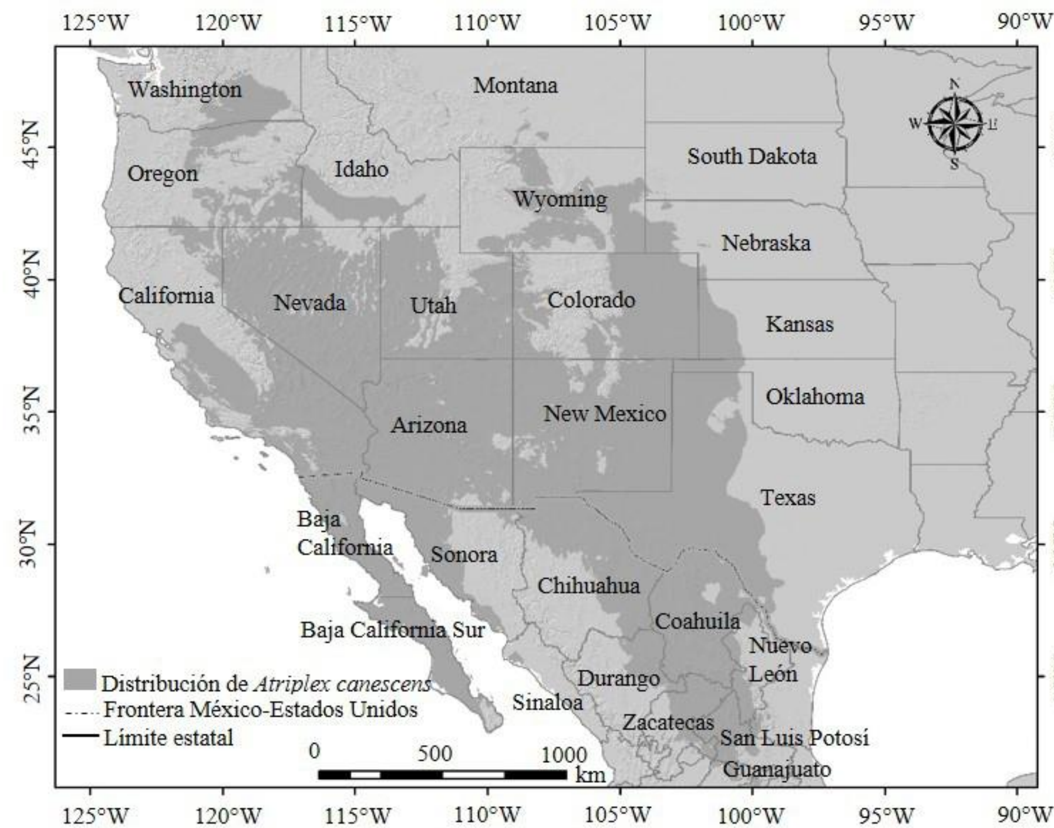
Taxonomic category	Taxon
Kingdom	Plantae
Division	Magnoliophyta
Subclass	Magnoliidae Novák ex Takht.
Class	Equisetopsida C. Agardh
Superorder	Caryophyllanae Takht.
Order	Caryophyllales Juss. ex Bercht. & J. Presl
Family	Amaranthaceae Juss.
Subfamily	Chenopodioideae
Genus	*Atriplex* L.
Species	*Atriplex canescens* (Pursh) Nutt.

Source: Tropicos (2020).

Accepted infraspecific taxa include: *Atriplex canescens* var*. canescens*, *Atriplex canescens* var. *linearis* (S. Watson) Munz, *Atriplex canescens* var. *aptera* (A. Nelson) C. H. Hitchc., *Atriplex canescens* var. *garrettii* (Rydb.) L.D. Benson, and *Atriplex canescens* var. *gigantea* S.L. Welsh & Stutz (Tropicos, 2020).

Distribution of *Atriplex canescens*

Atriplex canescens is the most widely distributed species of the genus in North America (Sanderson and McArthur, 2004) (Figure 1). In Mexico, it grows in the states of *Chihuahua, Coahuila, Nuevo León, San Luis Potosí, Zacatecas, Durango, Tamaulipas, Guanajuato, Querétaro,* and *Aguascalientes*, in the so-called Chihuahuan Desert (Gutiérrez *et al*., 2012), as well as in *Sonora* and *Baja California*, within the Sonoran Desert (Romero and Ramírez, 2003).



Source: Prepared by the authors.

Figure 1. Distribution area of *Atriplex canescens* (Pursh) Nutt. in Mexico and the United States of America.

In the United States of America, it is located on the Pacific coast in California, Oregon and Washington; in the Mojave Desert in Nevada; in the Sonoran Desert in Arizona; in the Chihuahuan Desert in Colorado, New Mexico and Texas; in the Great Basin of Utah, Wyoming, Idaho, Nebraska, Oklahoma, Kansas, and in certain parts of South Dakota and Montana (Sanderson and McArthur, 2004).

Habitat

A. canescens predominates on soils with a high content of calcium carbonate, phosphorus, potassium, gypsum and salts, and a low content of organic matter and nitrogen (Glenn and Brown, 1998; Granados *et al*., 2011). It usually grows on Calcisol, Solonchak, and Solonets soils with a silty-sandy, sandy-clay, sandy-gravelly, and sandy-loam texture; on slopes between 1 and 3 % (Saucedo, 1998; Segura *et al*., 2014), and at altitudes of 0-2 600 m; an average annual rainfall of 100-500 mm, with hot, dry summers and cold winters, and an average annual temperature of 3 – 25 °C (Enríquez *et al*., 2011; Ogle *et al*., 2020).

This species forms monodominant stands, or stands associated with shrubs and grasslands, within the desert microphyllous and rosetophyllous scrub, low subspiny scrub, halophytic and open grasslands, and dunes in coastal areas (Enríquez *et al*., 2011; Granados *et al*., 2011). These characteristics allow this taxon to adapt to extreme environmental conditions, low nutrient contents, and high salt concentrations; therefore, it is very suitable for establishment in various environments.

Uses of *A. canescens*

Forage

A. canescens is the most important native forage species in the semi-arid zones of North America drom its characteristics, including: a high crude protein content in the leaves (16–20 %) (Enríquez *et al*., 2011); high concentrations of calcium (Ca), fiber, fat, and digestible nutrients (Romero and Ramírez, 2003); high forage availability all year round, as it is able to recover its aerial biomass in 100 days if the removal does not exceed 60 % of the foliage (Saucedo, 1998), and its high palatability. Therefore, it represents an important source of food for domestic livestock and wildlife in the semi-arid zones of northern Mexico, the United States of America, North Africa and Southeast Asia (Le Houérou, 2000; Mellado *et al*., 2006; Allison y Ashcroft, 2011).

The species can be used both in natural populations and in high density plantations (Gutiérrez *et al*., 2012; Ríos *et al*., 2012). Its consumption as fodder is considered an alternative to improve the nutritional status of grazing cattle, particularly during the dry season and winter, as well as in critical periods to avoid animal mortality due to lack of feed (Kronberg, 2015).

In northern Mexico, 60 % of the goats are fed with *A. canescens* (Romero and Ramírez, 2003) and have a productivity of up to 53 kg yr^{-1} of milk and 7 kg yr^{-1} of meat (Mellado *et al*., 2006). In addition, *A. canescens* results in a higher mass gain than other forage species (e.g. oats), since kids fed with this species have gains of 100 g day^{-1} versus 80 g day^{-1} when consuming forage oats (Echavarría *et al*., 2014).

Yields are also high, ranging between 4.2 and 9.5 t ha^{-1} of green matter, equivalent to 1.3 - 3.1 t ha^{-1} of dry matter, in agricultural soils under irrigation (Gutiérrez *et al*., 2012); while, in sites with a low annual rainfall (166 mm), yields can reach up to 1.8 t ha^{-1} of dry matter (Echavarría *et al*., 2014).

For the *Zacatecas* area, Echavarría *et al.* (2009) recorded that biomass production averages 1.24 kg of dry matter per plant in a six-year old plantation established on agricultural soil without irrigation and with an average annual rainfall of 407 mm. Enríquez *et al.* (2011) report that with a plant density of 1 800 individuals ha^{-1}, forage production fluctuates from 3 582 kg ha^{-1} to 4 955 kg ha^{-1}.

In combination with other forage sources, it improves digestive and productive qualities; for example, mixed with nopal cactus [*Opuntia ficus-indica* (L.) Mill.], it reduces water consumption during drought events and doubles the milk production in goats (Urrutia *et al*., 2014), and the incorporation of oak acorns (*Quercus* *havardii* Rydb.) reduces the concentration of tannins and saponins in the rumen, thereby improving the digestive process of cattle (Deeds *et al*., 2010).

A. canescens is a rustic plant, since it does not require fertilizers or irrigation for its establishment (Petersen and Ueckert, 2005). This makes it a forage resource with high potential for planting —especially on saline agricultural soils (Enríquez *et al*., 2011); in regions where the market for goats is important (Gutiérrez *et al*., 2012), and in pastures degraded by overgrazing (Pinales, 2008)—, alone or in association with grasses and mesquite (Ríos *et al*., 2012).

Among the North American wildlife that consume the foliage of *A. canescens* are the white-tailed deer (*Odocoeilus virginianus* Zimmermann), reindeer (*Cervus canadensis* Erxleben), pronghorn (*Antilocapra americana* Ord), bighorn sheep (*Ovis canadensis* Shaw), and hares (*Lepus californicus* Gray) (Ogle *et al*., 2020). In addition, its biomass provides shade and shelter for endangered species, such as the desert tortoise (*Gopherus agassizii* Cooper) and the mountain plover (*Charadrius montanus* Townsend) (Grover and De Falco, 1995; Smith and Keinath, 2004).

Given its importance as a forage species that is available green all year round and adaptable to extreme environmental conditions, it should be promoted for livestock feeding in pastures and abandoned agricultural areas; this would represent important savings for livestock producers, especially in places with recurrent droughts.

Restoration of degraded soils

A. canescens has a wide potential for the restoration of degraded soils; therefore, from its great capacity for propagation by seeds and to its growth characteristics, it has been successful in the reconversion of agricultural soils (McLendon *et al*., 2012) and overgrazed lands (Newman and Redente, 2001), and in the reforestation of abandoned mines (Booth *et al*., 2002), roadsides, and areas affected by fires (Ogle *et al*., 2020).

The roots of *A. canescens* reach up 6 m deep and they help prevent and reduce the process of soil erosion; for this reason, it is considered an important species for restoring vegetation cover (Sanderson and McArthur, 2004; Ogle *et al.,* 2020), as well as for stabilizing steep slopes and mitigating the risk of landslides (Hu *et al*., 2013).

The ability of *A. canescens* to grow in sodic saline soils and other ecosystems has made it possible to restore the vegetation cover and facilitate the establishment of native flora, conserving local biodiversity (Newman and Redente, 2001). It also has a high potential for carbon sequestration, capturing up to 5 t year^{-1} of carbon dioxide in sites with low rainfall and infertile soils (Lailhacar *et al*., 1995).

The establishment of *A. canescens* plantations has demonstrated a great capacity to desalinate soils irrigated with brackish groundwater (Flores *et al*., 2017). In New Mexico, where 75 % of the groundwater is saline, this species has been able to retain such salts as Ca and Mg, thus improving the quality of water for agricultural use (Sarpong *et al*., 2019).

The characteristics described above make *A. canescens* an excellent option for use in programs for restoring degraded soils and overgrazed pastures, a situation that is increasingly recurrent in the semi-arid zones of North America.

Remediation and phytoremediation of contaminated soils

A. canescens is used in soil remediation at sites contaminated by mining, with oil and by-products of industrial production in the southwestern United States of America. Its growth on tailings dam substrate stabilizes the chemical residues from mining and prevents their spread through wind and rain (Rosario *et al*., 2007). Its tolerance to high selenium (Se) and uranium (U) contents allows it to grow on soils irrigated with water from the energy industry, which helps their rehabilitation or decontamination (Baumgartner *et al*., 2000).

It is also used to reduce the mobility of such contaminants as nitrate (NO_3^{-2}), ammonium (NH_4^{+1}), and sulfate (SO_4^{-2}) generated in uranium mines, thereby eliminating their propagation into the surrounding aquifers (Brestoff *et al.,* 2013).

A. canescens has the ability to retain, recover and extract industrial pollutants from soils with high plutonium (Pu) content and NO_3^{-2} (McKeon *et al*., 2006; Caldwell *et al*., 2011). Its biomass is capable of absorbing and removing particles of heavy metals from soils contaminated with cadmium (Cd), chromium (Cr), zinc (Zn), lead (Pb), and copper (Cu) in polluted water (Sawalha *et al*., 2009).

Its roots can extract NO_3^{-2} from contaminated aquifers (McKeon *et al*., 2006; Jordan *et al*., 2008), as well as recover sodium (Na) and phosphorus (P) from wastewater (Howe and Wagner, 1999). This represents a low-cost method for the remediation of soil and water contamination with industrial by-products (Rosario *et al*., 2007).

Based on the above characteristics, *A. canescens* has a wide potential for the remediation and phytoremediation of contaminated soils, much more than annual herbaceous plants such as *Thlaspi caerulescens* J. Presl & C. Presl, *Sedum alfredii* Hance, and *Alyssum murale* Waldst. & Kit, or than very complex and costly physicochemical and thermal methods (Delgadillo *et al*., 2011).

Household consumption

The household use of *A. canescens* has been very important for the indigenous people of northern Mexico and the southwestern United States of America. The seeds are used in the preparation of flour to make bread; the macerated leaves are used to season food, and the burnt branches, to color tortillas (Beck, 2016). Medicinal use: the roots and flowers are used to relieve insect bites, treat coughs, nasal congestion, headaches and stomach aches (Kuznar, 2001). Other relevant uses are ornamental, as an abrasive, as a cleaner, and as a dye for basketry and textiles (Sinenski, 2013).

Although information is still very scarce, it is mandatory to assess the medicinal and food properties and traditional uses of *A. canescens* in a systematic way, since this species could prove very useful and beneficial for society if used on an industrial scale.

Biotechnology

A. canescens has a significant role in the biotechnological field; for example, leaf extracts possess secondary metabolites with potential for inhibition of bacteria like *Staphylococcus aureus* Rosenbach, which causes skin, bone, cardiac and respiratory infections (Castro *et al*., 2001). Extracts from the seeds are used for the control of the larvae of the common mosquito (*Culex quinquefasciatus* Say) (Ouda *et al*., 1998). In addition, its biomass has a large potential as biofuel (Castellanos *et al*., 2012). Recently, the incorporation of *A. canescens* genes on soybean that induce tolerance to drought and salinity has been evaluated (Qin *et al*., 2017; Guo *et al*., 2019).

It is necessary to continue exploring the potential applications of *A. canescens* in biotechnology, as this may lead to important advances in bioenergy, agriculture, as well as in pest and disease control.

Threats to the conservation of *Atriplex canescens*

Natural populations of *A. canescens* face threats to their utilization and conservation. Overgrazing generates adult shrub mortality, limits natural regeneration of seedlings (Gibbens *et al*., 2005) and induces the propagation of species such as *Larrea tridentata* (DC.) Cav. and *Prosopis glandulosa* Torr., potential competitors of *A. canescens* (Mata-González *et al*., 2007).

Cattle have a preference for consuming female flowering plants, which alters flowering patterns and long-term reproductive success (Cibils *et al*., 2003). *A. canescens* is vulnerable to invasive exotic species; thus, in southern Texas, it has been displaced by African grass, *Eragrostis lehmianna* Nees (Leavitt *et al*., 2010). In addition, lagomorphs consume up to 99 % of the seedlings in *A. canescens* plantations (Clements and Harmon, 2017).

Urban sprawl is a major disturbance factor in the semi-arid areas of the southwestern United States of America in cities such as Phoenix, Arizona and Los Angeles, California (Bohn *et al*., 2018). In Mexico, this has been less of a problem in cities with agroindustrial activity, such as *Torreón, Coahuila* (Ballesteros-Barrera *et al*., 2007). Expansion of the agricultural frontier and overgrazing of native grasslands constitute the greatest threats in the north of the country (Pool *et al*., 2014).

Road construction contributes to the fragmentation of the habitat of *A. canescens* by altering the genetic and ecological connectivity between populations (Ballesteros-Barrera *et al*., 2007). Expansion of open pit mining concessions in northern Mexico (Téllez and Sánchez, 2018), combined with the long history of this type of mining in the southwestern United States of America (Ingram *et al*., 2020), can also drastically reduce its habitat.

Climate change will reduce seasonal precipitation in the southwestern United States and northern Mexico, potentially altering the phenological cycle of this species (Cázares *et al*., 2010). In addition, the expansion of highly flammable exotic grasslands is likely to induce very severe fires and thus generate a high mortality rate of *A. canescens* (Underwood *et al*., 2019). Thus, despite the great capacity of this taxon to develop under extreme environmental conditions, it is also very susceptible to changes in habitat, and, therefore, efforts must be made to preserve it.

Conclusions

A. canescens represents an important non-timber forest resource in the semi-arid zones of North America, with a wide variety of current and potential uses, including forage, rehabilitation of degraded and contaminated soils, and with various biotechnological and domestic applications. Although this species is widely distributed, it is threatened by a variety of human activities. Therefore, its wild populations must be preserved, given its multiple uses in the areas where it is naturally distributed, as well as its potential utilization in other parts of the world.

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Conflict of interests

The authors declare no conflict of interest.

Contribution by author

David Castillo Quiroz, Ramón Gutiérrez Luna, Diana Yemilet Ávila Flores and Francisco Castillo Reyes: information search, drafting and review of the manuscript; Jesús Eduardo Sáenz Ceja: information search and drafting of the manuscript.

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