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Morphological characterization of four invasive species of Solanaceae in the southern region of Saudi Arabia

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Abstract
After locale loss due to human activities, invasive plants are considered the second greatest threat to plant diversity. Invasive species pose a threat to plant diversity hotspots and islands, as well as farmlands, woodlands, forests, grasslands, and populated areas. They endanger native biodiversity at the genetic, species, and ecosystem levels. Agriculture, aquaculture, forestry, transportation, recreation, and construction activities all encourage the intentional and unintentional spread of species across their natural boundaries. Trade and travel have increased dramatically over the last centuries, particularly in the last few decades, resulting in an acceleration of the introduction of alien species. An average of two species were found in many of Saudi Arabia's most troublesome habitats in the southwestern region of Saudi Arabia, where the presence of invasive species was significant. The presence of aggressive or unfamiliar plants was defined in the southwestern region. A total of 37 strange florae have been reported from various locales in the southwest. Among these species that are likely to harm biodiversity or change ecosystems in general are the Solanaceae species *Datura innoxia*, *Datura stramonium*, *Nicotiana glauca*, and *Withania somnifera*, which are widespread in Southern Saudi Arabia.

Keywords: invasive- species- alien - solanaceae- *datura innoxia- datura stramonium- nicotiana glauca- withania somnifera*

Introduction

Invasive plant species are defined as those that spread into local plant classifications, establish self-sufficient residents, and become dominant within those systems (Reichard and White, 2001) [26]. Around the world, invasive plants are widely recognized as major threats to Biodiversity conservation (Reichard and White, 2001) [26]. Biodiversity loss is mainly caused by invasive alien species (Boy and Witt, 2013) [9]. Invasive plants are following only to habitat loss and degradation in endangering native plants (Wilcove *et al*., 1998) [32]. They also exhibit rapid growth rates, powerful production capabilities, and a high tolerance for environmental stress (Geesing *et al*., 2000) [15]. It is valued that up to 50% of invasive species, in general, can be classified as environmentally destructive, based on their actual effects (Richardson *et al*., 2000) [27]. Globally, invasive alien plants threaten agricultural and natural systems. Many invasive species are not dominant competitors in their natural systems, but they competitively exclude their new neighbors in their new environments (Keane & Crawley, 2002) [19]. Offensive species are a growing concern in local ecologies. Their overview may destroy the ecosystems that take possession of them, which can have environmental and economic consequences (Solorzano, 2018). In some areas of Saudi Arabia lacking in plant information collection, one can find many unexpected species that have not been previously recorded in Saudi Arabia and the emergence of some plant samples collected during recent field explorations. However, some species are not yet known to Saudi Arabia and are invasive plants (Thomas *et al*., 2016) [30]. The southern region of Saudi Arabia is unique in its nature, land shape, water availability, and climate (Abulfatih, 1981) [1] and is remarkable for the relatively high diversity of plant species. This diversity results from a diversity of geomorphological characteristics, including islands, dunes, sand plains, low rocky hills, and high mountains (Masrahi, 2015) [23]. The region maintains a diverse topography and as a result, the climate changes dramatically from hot dry in the lowlands to cold in the highlands (Hosni and Hegazi, 1996) and according to Hosni & Hegazi (1996), a total of 218 species belonging to 48 species of southern Saudi Arabia have been included. One of these species is Solanaceae, a large plant variety of trees, shrubs, and grasses that is a widespread family of about 40 genera and 5, 424 species, spread in the tropics and temperate regions of the world (Laika *et al*., 2018) [22]. *Solanum, Atropa, Capsicum, Datura, Withania, Hyoscyamus, Nicotiana,* and *Miscellaneous*. These species are widely used for medical purposes worldwide and are widely used as an important source of food and spices (Shree *et al*., 2020) [29]. Forty-eight alien species have been recorded from Saudi Arabia, some of which have been introduced and settled for decades.

Among these species that are likely to harm biodiversity or change ecosystems, in general, are widespread in southern Saudi Arabia, which follows the species of the Solanaceae species *Nicotiana glauca, Physalis acuminate, Datura forex, Datura stramonium, Datura metel,* and *Datura innoxia* (Thomas *et al*., 2016) [30]. In this research paper, we present some plant species that were recorded in southern Saudi Arabia as invasive plants and some of them are recorded for the first time.

Studies Plants

Solanaceae is considered one of the huge and financially most vital families of angiosperms, counting important nourishment, spice, and drug plants *its* nearly cosmopolitan in distribution and include more than 3000 species. The family is almost cosmopolitan in dispersion, found all through tropical and mild locales, but with a concentration of differing qualities in Australia and Latin America. (Ganaie *et al*., 2018) [14]. *Four* species in Three *genera recorded* invasive plants in Southern Saudi *Arabia:*

***Datura* Mill:** Which comprises about 10 species distributed mainly in tropical and warm temperate regions, especially tropical American and Australia (Ibrahim *et al*., 2016) [18] in this paper, two species of Datura records in southern Saudi Arabia have been studied, *Datura innoxia Mill. (Syn. Datura meteloides Dunal), also known as Downy thorn apple and Datura stramonium* (Maslo and Šarić, 2019). *D. innoxia* a traditional Chinese herbal medicine, produces tropane alkaloids such as hyoscyamine and scopolamine. Scopolamine has a larger demand than hyoscyamine due to its stronger pharmacological effects and fewer side reactions. It is extracted from Solanaceae species. However, the content of scopolamine is lower than hyoscyamine in *D. innoxia* (Li *et al*., 2020) [21]. D. stramonium produces the highest concentration of tropane alkaloids. Scopolamine, atropine (hyoscyamine), and anisodamine are the main tropane alkaloids of *D. stramonium*. Historically, scopolamine and atropine have been used for asthma, rheumatism, and spasmolytic drug. Scopolamine is one of the essential active medicinal compounds according to the World Health Organization (De-la-Cruz et al, 2021) [12].

***Nicotiana* L:** is one of the largest within Solanaceae, with 76 naturally occurring species, according to Knapp *et al*. (2004) [20], it is divided into 13 sections. *Nicotiana* species are widespread in South and North America and Australia, with one species in Africa (Bogdanovi *et al*., 2006) [8]. *N. glauca* has been ranked among the top six invasive plants that are damaging biodiversity and altering the ecosystems in Saudi Arabia (Alharthi *et al*., 2021) [2], *Nicotiana glauca* Graham, also known as wild tobacco or tree tobacco, is a multi-branched perennial shrub of up to 5 m high with smooth green hairless branches, glaucous leaves, and tubular yellow flower (Alharthi *et al*., 2021; Alsenidi *et al*., 2018) [2, 4] Leaves of *N. glauca* are large, alternate, ovate, and blue-green In Sothern Saudi Arabia, the plant is found along walls, on debris, or growing along with sandy areas, its characterized by the presence of pyridine alkaloids in leaf and root tissues, the four most abundant being nicotine, nornicotine, anabasine, and anatabine. Its content varies among various parts of the plant, being highest in the leaves and the bark. This highly toxic alkaloid is responsible for clinical toxicology (Furer *et al*., 2011) [13].

***Withania* (L.) Dunal:** twenty-three known *Withania* species are widely distributed in the drier parts of tropical and subtropical zones, ranging from the Canary Islands, the Mediterranean region, and northern Africa to Southwest Asia. Among them, only two species, *Withania somnifera*, and *Withania coagulans* are cultivated in several regions due to their economical and medicinal significance (Tole & Saifu, 2019). *Withania somnifera* (L.) Dunal (Solanaceae) commonly known as 'ashwagandha' 'winter cherry' or 'Indian ginseng' is an erect branching under-shrub, widely distributed in all dry parts of subtropical India (Ghimire and Ghimire, 2012) *Withania somnifera* has also been included in the list of invasive plant species (Ashraf, *et al*., 2012), the plant It is important in the indigenous medical system for over 3,000 years and extract of leaf, bark, and root of this plant is used for a multipurpose medical agent. It stimulates the immune system and believes to improve memory. It has anti-tumor, anti-inflammation, anti-cancer, and anti-stress effects (Ghimire and Ghimire, 2012).

The climate of the study area

The study area is in the southwestern part of the Kingdom of Saudi Arabia between longitudes 41 25' and 44 37' east and latitudes 17' 25' and 20 57' north. It extends for 380 km from the northeast at the point 20'55 6" and 43' 45" 44 to the southeast of the point 17' 23" 00 N and 43' 30' 41" E. the western mountainous heights are considered one of the most important features of the terrain in the Kingdom of Saudi Arabia. This region is characterized by low temperatures, with an annual average of 17 m, a rainfall rate of 250 mm, and average relative humidity of 65% (Chowdhury & Al-Zahrani, 2013) [11]. As for the western plains, they are in the west of the Kingdom of Saudi Arabia east of the Red Sea, along the Tehama plain, as it extends between Sarawat Mountains and the Red Sea beach (Al-Awdat et al., 1997; Almazroui *et al*., 2012) [5, 3]. In an arid climate and rain sparse country such as Saudi Arabia, rainfall plays a crucial role in several important socio-economic aspects, including water resources management and agriculture (Athar, 2015) [5]. From (fig. 1) the annual rainfall in the southwestern region of Saudi Arabia varies greatly between the years 2010-2020. It reached 243.9 mm/year in 2016 as the highest rainfall rate, while 2015 was the lowest, reaching 25.9 mm/year. Through temperature data in the period between 2010-2020 in the southwestern region of the Kingdom, the lowest average temperature was recorded in 2010, where it was between 8.4-21 °C, while in 2017 the highest average temperature was recorded between 18.5-31.2 °C (fig. 2).

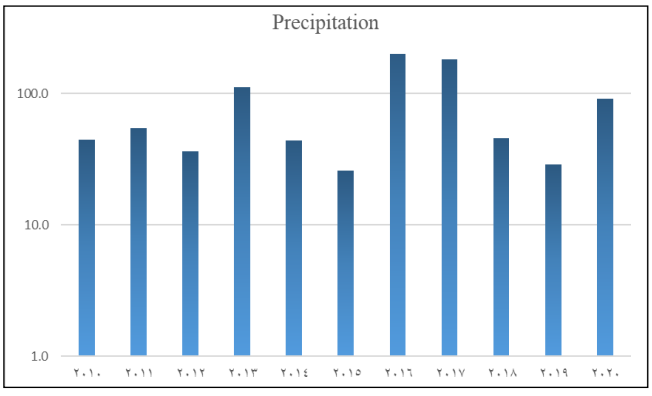

Fig 1: Average annual rainfall in the southwestern region of the Kingdom between the years 2010-2020

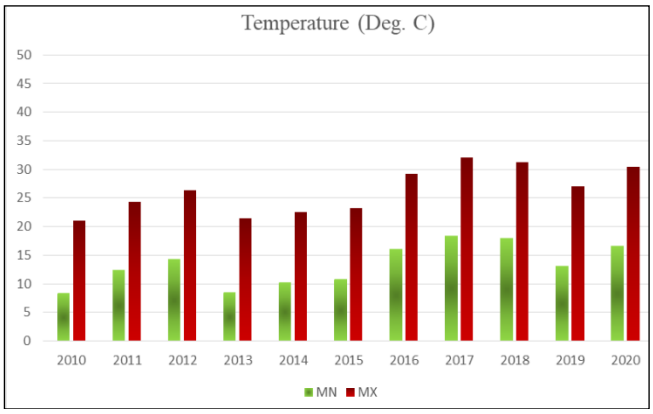

Fig 2: Average Temperature in the southwestern region of the Kingdom between the years 2010-2020

Material and Methods

Preparation of plant samples

Plant samples were collected from their natural locations in the southwestern region of the Kingdom of Saudi Arabia, and the place of the collection was determined as shown in Table (1), fig (3).

Study of morphological characteristics

The plant samples of the species under study were collected from their natural habitats, then the appearance of the shoot system of each of the stem and leaves was examined in terms of the shape, edge, base, and tip of the blade, Then the inflorescence and flower density on the axis were examined, the calyx, corolla, stamens, and pistils were examined, and all results were recorded, measurements of parts of all plant samples.

Table 1: Plant species and their places of collection

Taxa	Collected location	Coordinates
Datura innoxia	Tehama (Bellow the obstacle logo)	18.2615426, 42.3876575
Datura stramonium	Tabbab Village	18.4129811,42.3452565
Nicotiana glauca	Extension of Soda Park Road	18.2615426,42.3876575
Withania somnifera	Abha Valley	18.2631911,42.5601736

Fig 3: Study plants in their natural locations (a) *D. innoxia* (b) *D. stramonium* (c) *N. glauca* (d) *W. somnifera*

Results

Datura innoxia is an annual to perennial herb 1-2 m high, with a spreading crown up to 2 m in diameter. Stem with dense, spreading glandular hairs. Mature leaves broadly ovate, the lamina up to 20 cm long, almost entire, slightly sinuate, or irregularly lobed towards the base. Solitary terminal or axillary flowers, pentamerous hermaphrodite, peduncles height is up to 10 mm. Cylindrical Calyx, 8-9cm long, Corolla white with green veins, infundibuliform, 17-19 cm long. Stamens not exerted, anthers 8-10 mm long. Style 10-14 cm long, stigma well below anthers. The fruit is a globose or ovoid spiny capsule with numerous slender spines, about 3-5 cm in diameter, deflexed, spiny; spines numerous, slender, sharp, all about equal in length, to 10 mm long; the persistent base of the calyx to 20 mm long, very prominent. Capsule breaking irregularly when ripe, releasing brown seeds. Seeds D-shaped Table (2), fig (4).

Datura stramonium: is an annual to perennial herb 1-1.5 m high, with a spreading crown up to 1.5 m in diameter. Stems smooth. Mature leaves ovate, the lamina is up to 20 cm long, almost dentate, slightly lobed, or irregularly lobed towards the base. Solitary terminal or axillary flowers, pentamerous hermaphrodite, peduncles height is up to 9-10 mm, solitary terminal or axillary flowers, pentamerous hermaphrodite, peduncles height is up to 9-10 mm. The calyx is narrowly cylindrical. Corolla is white, infundibuliform, with a tube 14-15 cm long. Five epipetalous stamens, anthers 7-9 mm long. Style 10-14 cm long, stigma well below anthers. The fruit is a globose or ovoid spiny capsule with numerous slender spines, about 3-5 cm in diameter, deflexed, spiny; spines numerous, slender, sharp, all about equal in length, to 10-15 mm long; the persistent base of the calyx to 20 mm long, very prominent. Capsule erect breaking irregularly when ripe, releasing black seeds Table (2), fig (5).

Nicotiana glauca: is a shrub or small tree, up to 6 m tall, with stems that are laxly branched, smooth green hairless branches, glaucous leaves. The leaves are alternate, elliptical to lanceolate or oval, pointed, bluish, or greyish green. The tubular flowers are greenish yellow 30–40 mm long. Many are borne in a lax panicle. The corolla is tubular with a short-lobed limb. The fruit is an egg-shaped, two-valved capsule, 7–10 mm long and slightly longer than the persistent papery calyx. It produces many small seeds, which can be dispersed by wind and water Table (2), fig (6).

Withania somnifera: is an erect, branched, grayish, stellate-tomentose under-shrub, 90- 150 cm high. Leaves are simple, petiolate with the leaf blade varying in shape from elliptic-ovate to broadly ovate, entire along margins, acute to obtuse at apex, cuneate or oblique at base, clothed with a persistent grayish tomentum on sides, 4-10 cm long and 2-7 cm broad. Leaves on vegetative shoots are alternate and large and those floral branches are opposite, arranged somewhat laterally in pairs of one large and one small leaf, bearing in their axile a cymose cluster of 5-25 inconspicuous pale green bisexual flowers. *W. somnifera* has exhibited stigma-another proximity caused by elongation of filaments to cover the bilobed stigmatic surface with dehiscing anthers. High pollen load on the stigma and stiff pollen competition within a flower strongly favor self-pollination. Table (2), fig (7).

Table 2: Morphological characteristics of the plant species understudy

Taxa	Life form		Height of the Plant M	The Plan Color	Stem					Leaf shape	Inflorescence	Pedicel Height (mm)	Calyx Height (mm)	Corolla Height (mm)	fruit		
	Herbaceous	Shrub			An erect	glabrous	Pubescent	branched	unbranched						surface	Color	Type
D. innoxia	+	-	1.2	gray green	+	-	+	+	-	ovate	-	20-25	80-90	17-19	spiny	brown	Capsule
D. stramonium	+	-	1.5	Yellowish green	+	+	-	+	-	ovate	-	10-15	70-80	14-15	spiny	brown	Capsule
N. glauca	-	+	4.3	bluish to gray-green	+	+	-	+	-	ovate-elliptic	raceme	10-15	13-15	13-15	smooth	brown	Capsule
W. somnifera	+	-	0.6	gray green	+	-	+	+	-	ovate-broadly ovate	axillary	2-4	11-15	5-15	smooth	red	Beery

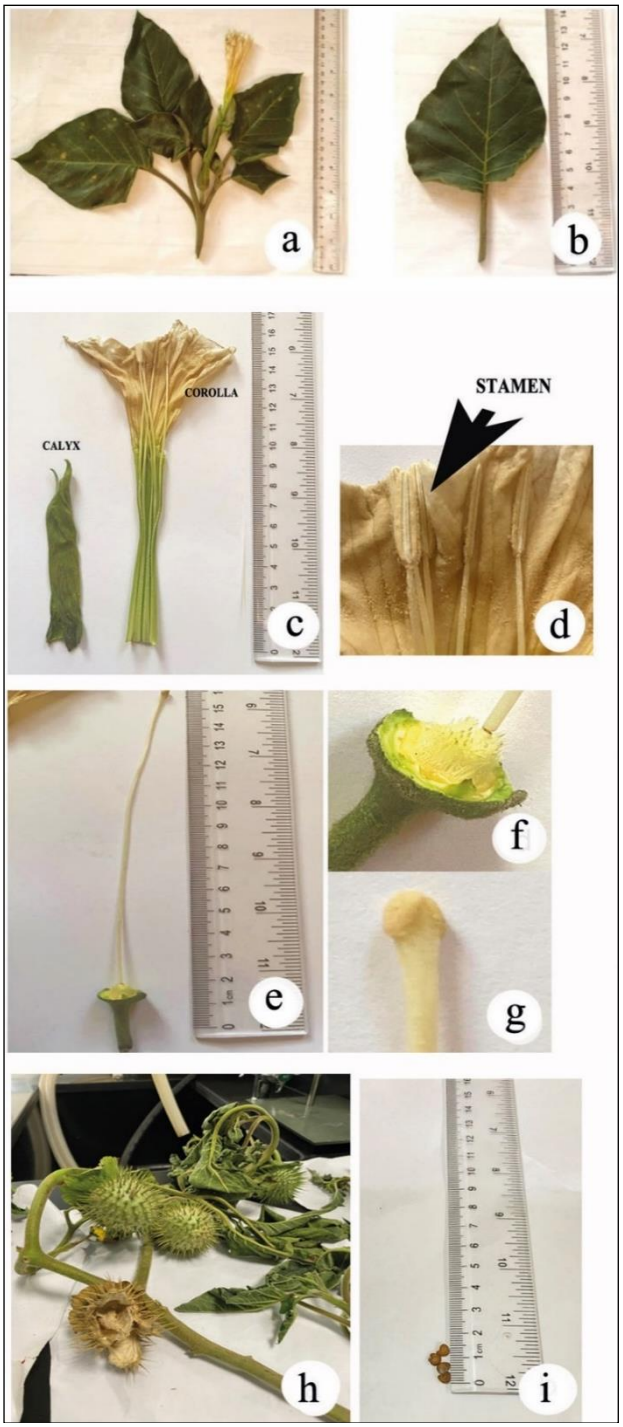

Fig 4: *D. innoxia* (a) Branch of a plant (b) leaf (c) Calyx and Corolla (d) stamens (e) gymnasium (f) ovary (g) stigma (h) Fruits (i) seeds

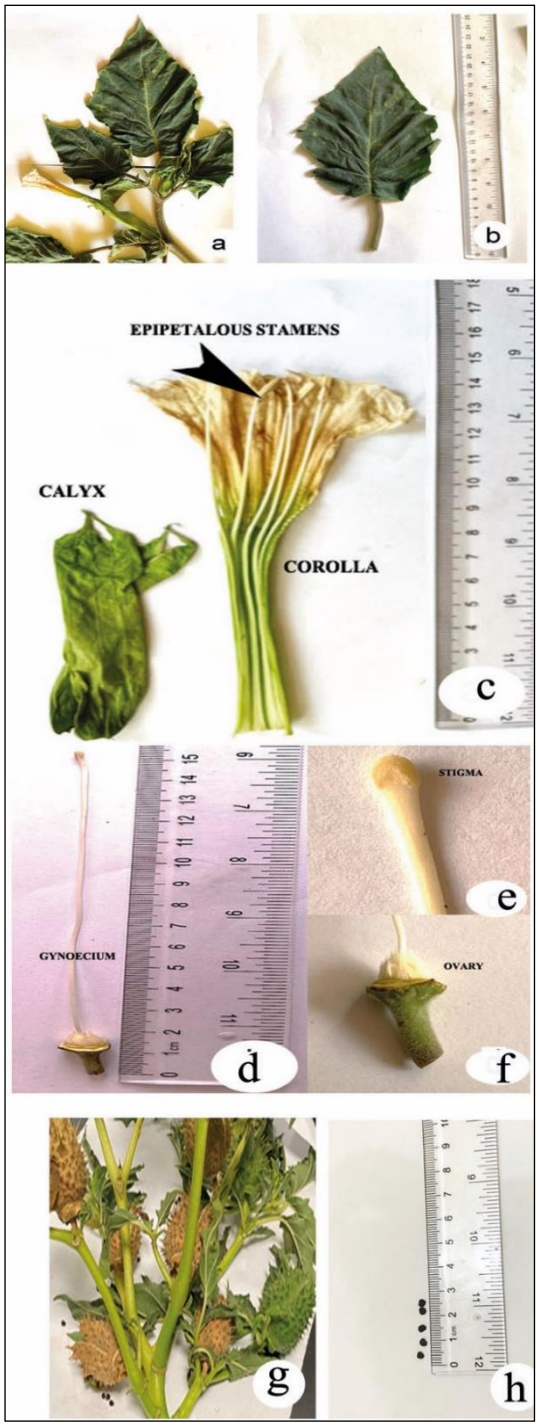

Fig 5: *D. stramonium* (a) Branch of a plant (b) leaf (c) Calyx, Corolla, and stamens (d) gymnasium (e) stigma (f) ovary (g) Fruits (h) seeds

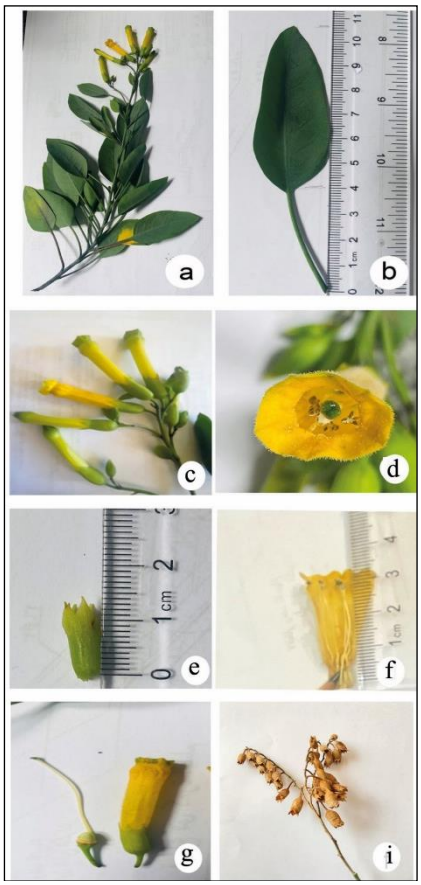

Fig 6: *N. glauca* (a) Branch of a plant (b) leaf (c) inflorescence (d) flower (e) calyx (f) corolla and stamens (g) gynoecium (h) Fruits

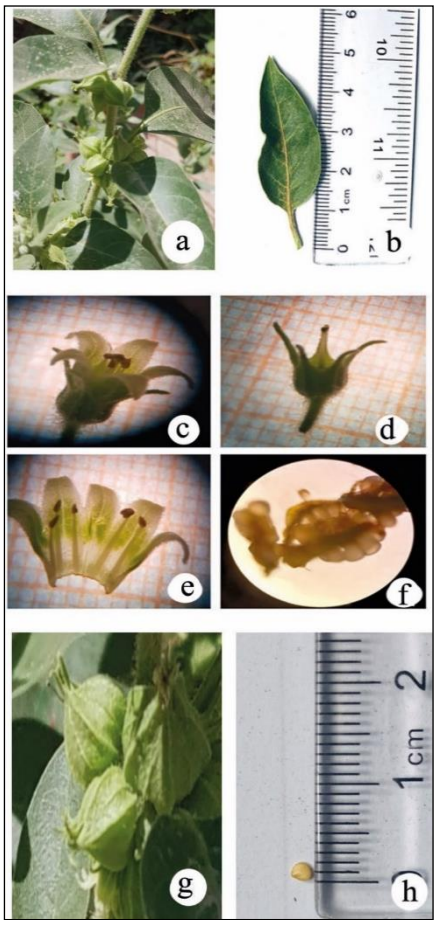

Fig 7: *W. somnifera* (a) Branch of a plant (b) leaf (c) Corolla (d) Calyx (e) stamens (f) ovary (g) Fruits (h) seeds

Discussion

The invasive species of the different studied genera of Solanaceae spread in their environments in the form of close individuals, and are always seen in monodominant stands, and form dominant groups that compete or disappear with the local species and this is consistent with the nature of invasive plants where the rates of fruiting and seed vitality are high Which leads to an increase in the rate of seed growth and this was supported by the studies on the nature of invasive plants, including what was mentioned in the study of Alsenidi *et al*. (2018) [4] Whereas the low plains such as the Tehama plains, which are located between the valleys, dunes, and coastal areas, have the Datura innoxia, while in the highlands, which are between 800-2700, other species such as *Datura stramonium* and *Withania somnifera* are found, and this is consistent with a study (Alsenidi *et al*., 2018) [4]. As for *Nicotiana glauca*, it grows between 0.000 to 3700 meters above sea level and this is consistent with what was mentioned in the study (Alharthi *et al*., 2021; Ibrahim *et al*., 2016; Maslo & Šarić, 2019) [2, 18, 24]. On average, all species were found in most habitats, but they differ in terms of abundance and density, as they were common in neglected lands, valleys, and on the sides of high roads. It was noted that the extent of plant growth, its size, and the speed of its detection were related to the amount of rain in the plant growth environment, and this is consistent with what was mentioned in the study (Olmstead *et al*., 2008) [25]. Invasive plant species increased their distribution range in both lowlands and highlands and are therefore considered the most troublesome in Saudi Arabia (Thomas *et al*., 2016) [30]. The studied invasive species have adapted to drought and salinity, some of them are sparsely hairy plants in species *D. Innoxia* and *W. somnifera*, to reduce water loss, these results agree with the study (Alharthi *et al*., 2021; Ibrahim *et al*., 2016) [2, 18]. Whereas in other species, *D. stramonium*, *N. glauca*, the appearance of the plant was smooth, glabrous, and consistent with what was mentioned in the study (Chaudhary, 2001) [10], the leaves of *N. glauca* are covered with a waxy substance to preserve the water inside (Alsenidi *et al*., 2018) [4].

Conclusion

It is difficult for observers to be sure about the status of invasion in the field, especially as these are often side observations made while performing other work in restoration, animal, or plant surveys or just field expeditions. The lack of expertise on biological invasions in Saudi Arabia may also lead to confusion between invasive, established knowledge available on invasive alien floras and plant species is highly heterogeneous in the country. Also, historical differences among regions and differences in land use might explain some differences in the number of invasive species. When a country is as large as Saudi Arabia, has challenges, assessing its biota due to its size and diversity of ecosystems. This research assessment of plant invasions in Saudi Arabia is far from complete or fully accurate. However, it is an initial step towards better understanding of biological invasions and provides much-needed information for managers and scientists working on invasion issues in Saudi Arabia. The publication of official invasive species lists is important to provide support to managers and institutions to build up prevention and early detection techniques and regional strategies to mitigate the threats posed by biological invasions.

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