



Geographical distribution and phenotypic characteristics of *Lythrum salicaria* L. growing in Nineveh Governorate /Iraq

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Lythrum salicaria L. was reported as a new record in Nineveh Governorate, Iraq. The distribution and localities of *Lythrum salicaria*, also known as purple loosestrife, were ascertained using digital categorization. The spectral reflection properties of the *Lythrum salicaria* samples were measured using an ASD field spectroradiometer. The spectroscopic analysis was performed on these materials using a full range wavelength scale of roughly 400 to 500.

The phenotypic analysis revealed that *Lythrum salicaria* was an upright herb with whorled leaves and a woody, four-sided stem. The surface soil layer contains a broad, lignifying root with several branches. A soft down coated the plants. The lance-shaped leaves were rounded at the base or heart-shaped, hairy, sessile, and inserted directly onto the stems. They were either opposite or grouped in whorls of three leaves, four to seven cm long.

Mature plants featured multiple stems growing from a single rootstock; the smaller stems were quadrangular, while the bigger ones had three to five longitudinal ridges. The plants reached a height of 170cm. Bright purple blooms with five to six petals were seen during the sampling period. The flowers remained on the branches all the summer season, forming dense spikes 35cm long. The calyx is a ribbed, hairy, somewhat reddish tube.

Keywords: Botany, Ecology, Invasive plants, *Lythrum salicaria*

INTRODUCTION

Lythraceae is a large tropical to subtropical angiosperm family with a few temperate species. Although most plants are terrestrial, several are semiaquatic or aquatic. (Graham et al., 1993). Taxonomically, Lythraceae has approximately 31 genera (Gu et al. 2019), and 700 species are currently classified in the Malvids clade within Eudicots in the order Myrtales (Cavalcanti et al., 2022), according to the (Angiosperm Phylogeny Group (APG), 2009 and 2016). Myrtales form a monophyletic group (organisms with a common ancestor) with Geraniales. This group relationship was freshly supported by Berger et al. (2016).

According to Lempe et al. (2001), many of these taxa exhibit flooding tolerance, and one of the members of this family is *Lythrum salicaria*, which comprises 38 perennial and annual herbaceous

species (Torres & Puntieri, 2015). Primarily found in temperate regions of North America, Asia, and Europe, *L. salicaria* is widespread across southern and central Europe, as well as the coastal margins of the Mediterranean Basin, with the exceptions of Crete and the Balearic Islands. "Some key characteristics used to identify purple loosestrife include its square stem, which becomes woodier with age (Munger, 2002), opposite or whorled leaves, and plants often having multiple shoots. Typically, the plant grows to be 60-120cm tall and produces an average of 1-15 flowering stems.

Studies indicate that *Typha angustifolia* and other hardy species are competitively excluded by the noxious weed *Lythrum salicaria* (Mal et al., 1997). Due to its significant threat to various aquatic ecosystems, its widespread spread is contributing to the reduction of biodiversity in

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riverine areas. For this reason, several regions of the United States classified *Lythrum salicaria* as a harmful invasive species in 201. (Knezevic et al., 2018).

It is worth noting that the transport and establishment of invasive species, such as *L. salicaria*, are among the greatest threats to biodiversity. For example, the US is experiencing over \$125 billion in annual economic losses due to the extensive environmental damage caused by approximately 50,000 invasive exotics. (Allendorf & Lundquist, 2003). The US has an estimated 5,000 introduced plant species in its natural ecosystems, significantly more than the 17,000 native plant species. (Pimentel et al., 2000).

Invasive species are non-native species that can have potential environmental and human-unpleasant consequences, including economic, health, and ecological harm (Kiruba-Sankar et al., 2018). Introducing diverse species complicates the distinction between native and non-native species, allowing non-native species to adapt and develop in their new environment. (Andriyono & Fitriani, 2021). Human activities, such as agriculture, urbanization, encampments, and irrigation projects, have dramatically reduced natural vegetation. In Egypt, for example, these activities have led to the massive decrease in OMAIED Biosphere Reserve flora from 253 to 145 taxa and an increase in the number of invasive plants such as *Herniaria hemistemon*, *Reseda decursiva*, and *Trigonella corniculata*, which recorded by El-Sakaty et al. (2022). Significantly, weeds reduce production, especially when soil moisture is the limiting factor for productivity (Anter, 2005). Also, the spread of Exotic species threatens ecosystems, habitats, and biodiversity, as recognized by the Convention on Biological Diversity, requiring control and monitoring to protect native fauna and flora.

Invasive plants alter soil chemistry and ecosystem function, impacting plant communities and nutrient cycles. Where leaf litter and root exudates can alter soil structure and cause long-term mobilization, some invasive species gain a competitive advantage by releasing specialized substances that harm native plants. Additionally, herbicides used to control these species can indirectly affect non-target plants. At sublethal concentrations, herbicide drift may impact the secondary metabolism of non-target plants and slow their growth (Weidenhamer & Calloway,

2010). One of the most important reasons for the spread of *Lythrum salicaria* is its use by beekeepers in North America during the 1940s. The deliberate dispersal of seeds along streams and rivers was a strategy to increase the number of *Lythrum* plants that bloomed.

The ability of the *Lythrum salicaria* to tolerate different environmental conditions and to produce a large number of seeds during one season (An estimated 2.7 million seeds can be produced annually by a single plant.) has led to habitat loss, reduced nesting sites, shelter, and bird food, and a decline in biodiversity. These changes are attributed to a large seed bank, containing 410,000 seeds per square meter of soil 5 meters deep (Skinner et al., 1994).

Estimates on seed viability range from 2 to 3 years to 20 years or longer (Warne, 2016). Germination rates decrease from 93% after one year to 80% in the second year. *L. salicaria* seeds germinate at 20°C. They can tolerate various conditions, including flooding, high and low water nutrients, and low pH, and when rooted in moist soil, they can grow up to 1m tall. (Angela et al., 2022).

Lythrum salicaria can adapt to various physical and chemical conditions in disturbed habitats, such as nitrogen and phosphorus deficiencies. Due to its high competitiveness, the growth of *Lythrum salicaria* decreases biodiversity, which in turn reduces the populations of native plants that wetland wildlife uses for food and shelter (Malecki, 1993). In some wetlands, purple loosestrife displaced up to 50% of the biomass (Balogh & Bookhout, 1989). Notable wildlife that is impacted include waterfowl, due to the aforementioned impact on food resources and shelter, as well as restricted access to open water. This provides poor cover for waterfowl and harmful nesting material (Mal et al., 1992).

Lythrum salicaria, a medicinal plant with a long history of use in traditional European medicine, offers numerous health benefits due to its phenolic compounds, particularly tannins. (Humadi & Istudor, 2009).

According to Bencsik et al. (2011), *Lythrum salicaria* is an astringent herb used for strengthening weak or bleeding gums, treating diarrhea, dysentery, eczema, sores, hemorrhoids, promoting wound healing, and alleviating varicose veins. Additionally, the entire plant possesses antibacterial properties and is particularly effective against the bacterium that

causes typhus (Chevalier, 1996). *L. salicaria* leaves contain tannins, preserving wood and natural fibers. Red dye from flowers is used as a hair coloring agent, while the flowers and stems are used as food (Roia, 1966).

Taxonomy

The order Myrtales has 14 families, including the Lythraceae, which belong to the subclass Rosidae. While many species in this dicotyledonous family inhabit watery or semi-aquatic environments, most are tropical. According to Morris (2007), the Lythraceae comprises approximately 600 species, with 35 species in the genus *Lythrum*. Purple loosestrife is now known scientifically as *Lythrum salicaria* L. (Lythraceae). (Hitchcock and Cronquist, 2018) list purple loosestrife and spiky loosestrife as additional common names. The taxonomic ranks of *Lythrum salicaria* are as follows:

Division: Magnoliophyta

Subdivision: Rosophytina

Class: Rosopsida

Subclass: Rosidae

Superorder: Myrtales

Order: Myrtales

Suborder: Lythrineae

Family: Lythraceae

Species: *Lythrum salicaria* L.
(Tímea, 2014).

Because *Lythrum salicaria* was first discovered at the Tigris River in Mosul during this study, its purpose was to shed light on the species' expansion in Nineveh Governorate, as well as to investigate its most essential anatomical and morphological characteristics.

MATERIALS AND METHODS

Lythrum salicaria specimens were collected from Mosul city at the Tigris River (the major river in Iraq that, along with the Euphrates River, forms the basin of Mesopotamia) (Al-Mandeel et al., 2024).

To achieve the study's objectives, the following were done:

1- More than 30 short pieces of the plant parts were soaked with a solution consisting of water, alcohol, and glycerol (1:1:1 by volume) for 48h to anatomical consideration, which was conducted

on sections of root, the upper part of flowering stems, and leave. Thin hand-made sections (ca. 0.05mm) were made by a razor blade under a stereo-microscope, then stained by ethanol solutions of ammonical fuchsin and Astra Blue, and studied directly using an Olympus microscope and a Sony 7.2 Megapixel digital camera (Kaplan & Symones, 2005; Al-Mandeel, 2013).

2- Under controlled and standardized settings to ensure accurate and repeatable spectral measurements, some of the *Lythrum salicaria* samples were selected, and their spectral reflection properties were measured in laboratory conditions using an ASD Field spectroradiometer with spectral resolution ranging between (400–2500nm). Typically, samples are placed flat and uniformly under the light source, with a consistent distance (25cm) between the sample, light, and sensor (Cavender-Bares et al., 2020).

RESULTS AND DISCUSSION

Spread of *Lythrum salicaria* in Nineveh Governorate

Remote sensing, advanced by technologies such as hyperspectral imaging spectroscopy and light detection and ranging, enables the identification and differentiation of plant species within the same functional groups (Cavender-Bares et al., 2020).

Remote sensing has long been preferred for mapping invasive plants because it can offer synoptic views over broad geographic areas. This benefits field surveys, which are sometimes restricted to small areas and may be in challenging-to-reach places (Bolch et al., 2020).

This study used digital classification to determine the locations and spread of *Lythrum salicaria*. According to the data, the species under study emerged on both sides of the Tigris River, extending to the village of Munira, 34 kilometers south of Mosul. As seen in (Figure 1), the red dots on the Landsat image demonstrate the presence of *Lythrum salicaria*.

Morphology and histology

Lythrum salicaria L. can adapt to a wide range of ecological situations, including increased aerenchyma production, alterations in leaf morphology, and submerged stems (Thompson et al., 1987). As a result, *L. salicaria* can alter some morphological characteristics depending on its habitat.

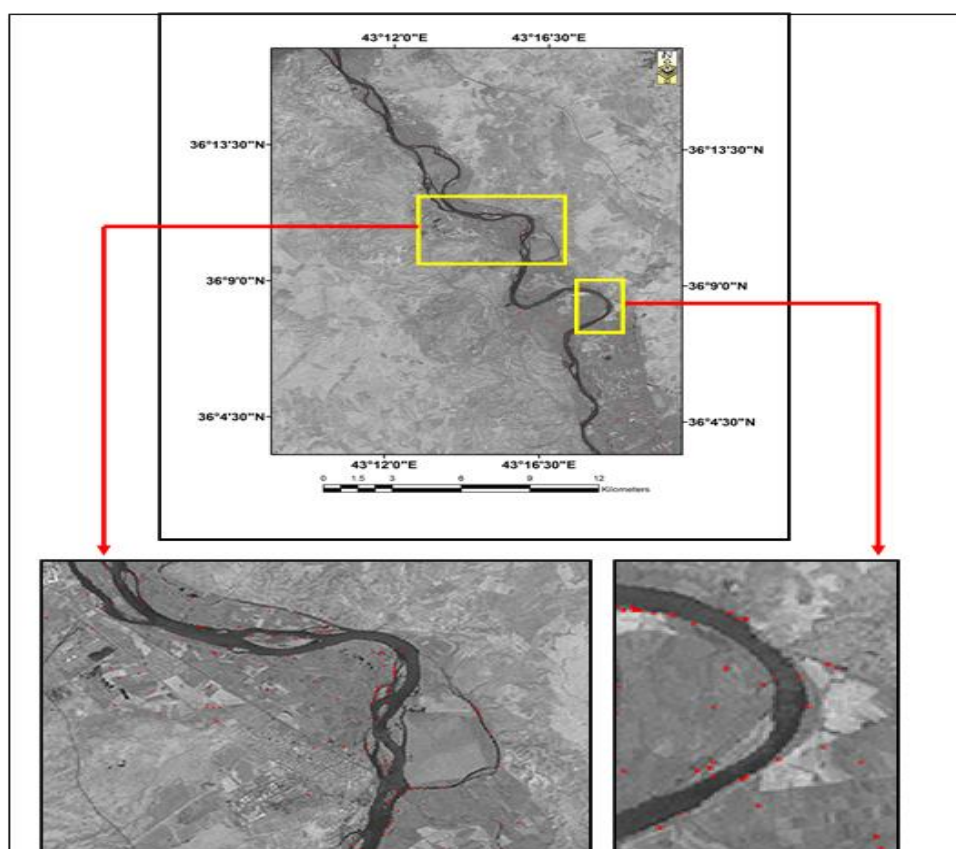


Figure 1. *Lythrum salicaria* locations in some areas are delineated by red dots on the Landsat image

Lythrum salicaria was an upright herb (erect) with whorled leaves and a woody four-sided stem. It has a thick, lignifying root with many branches in the surface soil layer (Table 1). The plants were hairy and their leaves were heart-shaped or

rounded bases with lance-shaped sessile inserted directly on the stems, without a developed petiole, opposite or gathered in whorls of three leaves and 4 to 7cm long (Figures 2, 3).

Table. 1 Phenotypic characteristics of *Lythrum salicaria*

Plant parts	Phenotypic characteristics
Stem	Many stems (more than 10) emerge from a single rootstock (solid root), with erect, hairy, woody, four-sided stems that reach a height of 170cm. The lateral branches of the stem grow from the leaf axils and are arranged alternately in some cases and oppositely in others. The alternating and opposing branches were not the same length.
Leaves	Whorled leaves were heart-shaped or rounded bases with lance-shaped, sessile it is inserted directly on the stems, without a developed petiole, opposite or gathered in whorls of three leaves and 4 to 7cm long. The secondary veins form arcs that connect at the leaf margin.
Root	Develops a strong taproot, a thick, lignifying root with many branches located in the surface soil layer.
Flowers	The inflorescence is spike-like, reaching a length of 35cm, and features bright purple flowers with five to six petals. The calyx takes the form of a hairy, ribbed tube, more or less tinged with a reddish hue. The calyx is composed of 12 sepals that are fused over most of their length, terminating in 12 small, sharp teeth, six internal and six external. (6 sepals with 3-7mm length bearing six small, triangular teeth alternating with six large acute teeth; the petals are alternate with sepals). <i>L. salicaria</i> exhibits tristily, with stamens and styles in three lengths.



Figure 2. Morphology of *Lythrum salicaria*, A: Stem, B: Flower spike, C: Flowers with 5 to 6 petals

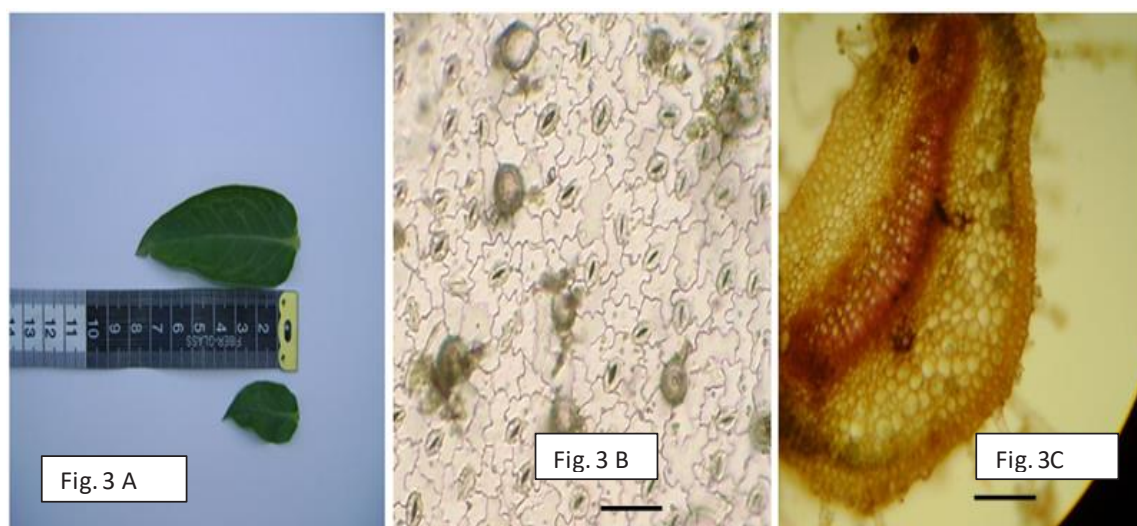


Figure 3. A: leaf of *Lythrum salicaria*, B: epidermal cell shapes and stomatal types, C: Transverse section micrograph of leaf midrib tissue, scale bar for B and C is 50µm

The secondary veins form arcs that connect at the leaf margin. Mature plants exhibited multiple stems emerging from a single rootstock (solid root); the thicker stems had 3-5 longitudinal ridges, while the smaller ones were quadrangular. During the current study, the plant height reached 170cm (Figure 2), and the woody stems of the plants remained erect throughout the winter. Some articles reported specimens as tall as 2.7 meters (Mal et al., 1992).

The lateral branches of the stem grow from the leaf axils and are arranged alternately in some cases and oppositely in others. It was noted that both the alternating and opposing branches were not at the same length. Short branches were observed below the long branches. Consequently, the stems' lower

branches are not required to develop before its upper branches.

Branching is a key component that affects plant form because branching is so sensitive to environmental factors. A plant growing in areas with high density of growth may have a single stem without branches. Still, when it grows alone, it may produce several branches and may acquire a dense character (Evers et al., 2011).

During the sampling period, bright, purple flowers with five to six petals were observed (Figure 2). The flowers were gathered in dense spikes that reached a length of 35cm. They remained on the stems throughout the summer. The calyx is a hairy, ribbed tube, more or less tinged with a reddish hue.

The phenotypic results obtained in the current study are in agreement with those reported by Balogh (1986).

Plant anatomy is crucial for understanding the functions, characterization, taxonomic identification, and phylogenetic analysis of plant tissues (Raman et al., 2017). Research at the level of morpho-anatomy has gained momentum at a time when morphological and anatomical characters provide basic, adequate information. In this regard, it must be said that the importance of anatomical studies lies in their connection with the external appearance of the plant.

Regarding the anatomical study of the stem of *Lythrum salicaria*, the outline of the cross-section is quadratic, with four visible protuberances. The epidermis consists of quadratic or rectangular cells that are slightly tangentially elongated, with a thick outer layer. The cortex is thick (Figure 4). Significantly, the size of epidermal cells varied across all plant parts (higher on the adaxial than the abaxial surface). The cortex, which lies between the epidermal and vascular layers, comprises isodiametric cells. The phloem cell layers are followed by xylem elements, which create several concentric circles throughout the stem. The pith

comprises several isodiametric parenchyma cells with intercellular gaps in the core of the stem.

Also observed is a thick xylem ring, with vessels and numerous fibers having extremely thick external walls; the secondary xylem is penetrated by numerous parenchymatic rays (Figure 4).

Studies indicate that Plant survival in various settings can be enhanced by morphophysiological tactics implemented at the root level (Eshel & Beeckman, 2013). For example, water is stored, oxygen is provided, and photosynthesis is performed (Armstrong & Drew, 2002).

The root exhibits a secondary structure, as indicated by a relatively thick cortex and a thin secondary ring of phloem (Figure 5), featuring a few sieve tubes and an abundance of phloem tissue.

In shrubs and herbaceous plants, the vessel diameter ranges from 50 to 100µm, with simple perforations opposite each other. Thin or thick-walled fibers may have tiny pits.

Sometimes, the axial parenchyma is paratracheal. The transverse parts of the phloem's sieve tubes and parenchyma contain numerous crystal druses, making them difficult to differentiate from one another.

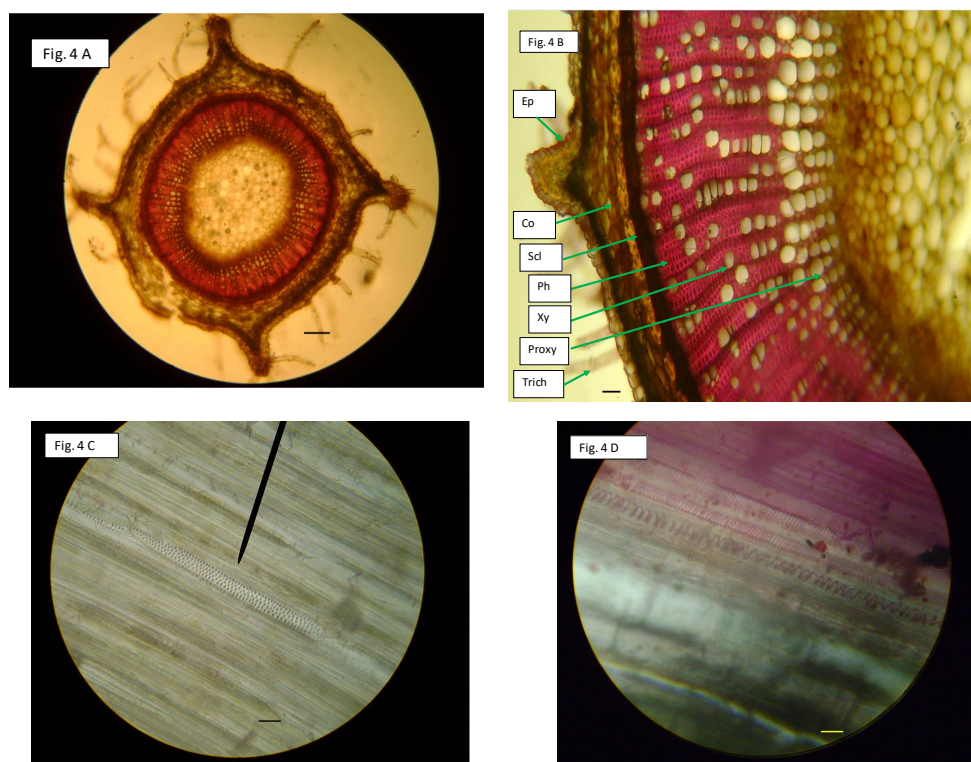


Figure 4. A: Cross-section of *Lythrum salicaria* B: Stem structure; Ep (Epidermis), Co (Cortex), Scl (Sclerenchyma), Ph (Phloem), Xy (Xylem), Proxy (Protoxylem), Trich (Trichome), C & D: Thickening of xylem tissue [scale bar for A is 100µm; for B, C and D is 50µm]

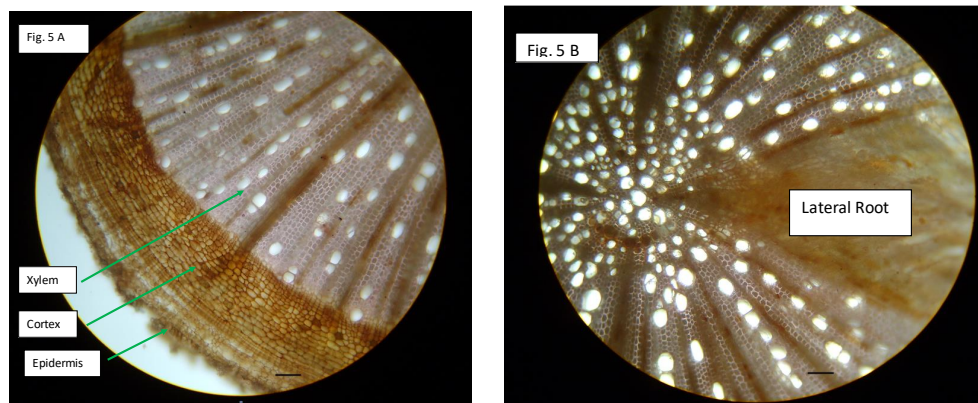


Figure 5. A & B: Root structure in cross-section of *Lythrum salicaria*. scale bar is 50μm

The leaf cross-section revealed that the upper side of the lamina contains large cells with a thick outer wall, covered by a cuticle.

The mesophyll consists of two layers of very high-walled cells, separated by spongy tissue in the form of a large equal-diameter cell.

The results of the current study were consistent with the view that leaves grown in the sunshine have more palisade layers, characterized by long, large, and closely packed palisade cells, compared to those in shade. Because the level of mesophyll differentiation is greatly reliant on the degree of exposure to sunlight. (Hanson, 1917; Ryder, 1954; Haron & Taha, 2007).

The flowers are grouped at the end of the stems in elongated clusters (Figure 2). The calyx takes the form of a hairy, ribbed tube, more or less tinged with reddish; it is made up of 12 sepals fused over most of their length, and ending with 12 small sharp teeth, six internal and six external. (6 sepals with 3-7mm length bearing six small, triangular teeth alternating with six large acute teeth; the petals are alternate with sepals). The same result was also reported by Mal et al. (1992).

The corolla comprises six oval-lanceolate petals with wavy margins, spaced apart from each other, of bright purplish pink, more or less veined with purple. The flowers have 12 stamens with curved filaments, divided into two sets of 6 stamens of different lengths.

The pistil comprises a globular ovary, surmounted by a curved style of variable length from one plant to another; it ends with a globular stigma covered with sticky papillae. The ovary develops after pollination into a small oblong capsule, releasing numerous seeds.

L. salicaria exhibits tristyles, with stamens and styles in three lengths, a rare plant phenomenon studied by Darwin in 1877 and observed in the Oxalidaceae and Pontederiaceae families (Bencsik, 2014).

In natural populations of purple loosestrife, three morphological categories are distinguished by the relative lengths of the stamens and the pistil

- A long style morph, with a long style, six short stamens, and six medium stamens
- A medium style morph, with a medium style, six short stamens, and six long stamens
- A brevistylous morph with a short style, six medium, and six long stamens.

Within the flower, the arrangement of the stamens may prevent pollen from reaching the stigma of the same flower, thus introducing an obstacle to self-pollination and making cross-pollination by a pollen carrier obligatory. For example, Long-styled flowers cannot receive pollen from a long-styled flower. Since *Lythrum salicaria* has three different lengths of styles (Figure 6), there are three possible cross-fertilization combinations (Barrett & Glover, 1985).

Tristyly has long been described in purple loosestrife by great British naturalist Charles Darwin, who elucidated the particular pollination mechanism associated with strictly in purple loosestrife, which he explained in 1877 in his work *Forms of Flowers*, from which the original illustration in Figure 6 is taken. Thus, Darwin showed that not only was pollination possible between flowers borne by distinct individuals but also that a style of a given length would only be receptive to pollen grains from stamens of the same length as its own.

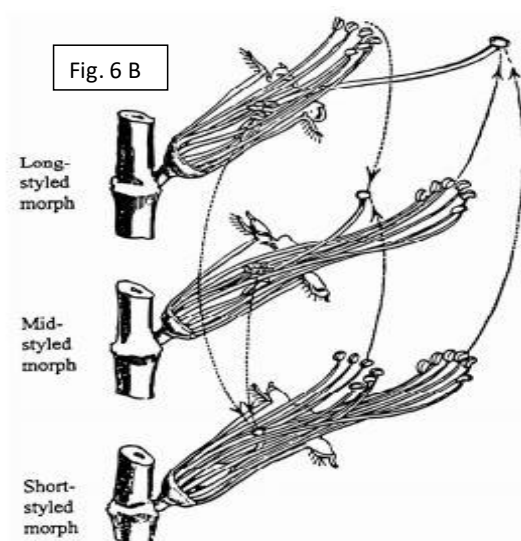


Figure 6. A: Three morphs of purple loosestrife flowers and the compatible pollen exchanges, represented by arrows, B: from Darwin (1877).

For example, the pistil of a longistyl flower can only be fertilized by pollen grains from the six long stamens of medistylous or brevistylous flowers.

Fertile pollen exchanges are shown schematically by dotted arrows in Figure. Genetically determined, this complex mechanism enables the avoidance of self-pollination while increasing genetic diversity within purple loosestrife populations.

According to Shamsi & Whitehead (1974), Thompson et al. (1987), and Darwin (1877), Seed production in *L. salicaria* depends on age, size, and vigor. A single stem can produce 900-1000 capsules, with 83-130 seeds per capsule. The average seed production per plant is approximately 2 700,000 stems arising from root buds.

CONCLUSION

This study aimed to explore the distribution of *Lythrum salicaria* in Nineveh Governorate and its essential characteristics. *Lythrum salicaria*, a plant previously unknown in the Tigris River region, has been found on both sides, reaching Munira 34 km south of Mosul, indicating that environmental and climatic changes have facilitated its spread. The study is the first one that documents the discovery of this species in Mosul. *Lythrum salicaria* has three different styles. Therefore, the stamen arrangement in flowers can hinder self-pollination, making cross-pollination obligatory through a pollen carrier. The proliferation of *Lythrum salicaria* adds to prior evidence of the spread of invasive species in the Nineveh Governorate environment,

including *Hydrilla verticillata* and *Potamogeton* species. It is well understood that the expansion of invasive species into a new area has a negative impact on endemic species, causing genetic alterations and reducing biological diversity.

Ethical approval: Not applicable.

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