Selection of Shrubs for Urban Environments—An Evaluation of Drought Tolerance of 120 Species and Cultivars

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Abstract. **Shrubs comprise a very large proportion of the plant material used in public as well as private green spaces. Yet, there is currently a lack of quantitative assessments of stress tolerance in a large proportion of available species and cultivars of shrubs, thus complicating any design process involving shrubs. The aim of this study was to evaluate drought tolerance of many common and less traditional shrubs intended for public planting. Through this compilation, a first contribution (dataset) to species selection to obtain expected ecosystem services of shrubs is offered. As water stress is a major constraint for landscape plants in urban environments and is likely to increase in many regions under future climate scenarios, the quantitative drought tolerance of a species or genotype must be a fundamental consideration for plant selection for urban environments. In this study, we used water potential at the turgor loss point (Ψ_{P0}) as a key trait for evaluating drought tolerance of different species of shrubs. Ψ_{P0} is a highly instructive trait because it represents a quantifiable measure of physiological drought tolerance. More negative Ψ_{P0} values represent greater drought tolerance by allowing the leaf to maintain physiological function over a greater range of leaf water potentials. Ψ_{P0} was estimated for a wide range of shrubs, representing a total of 44 genera and 120 species and cultivars. The mean Ψ_{P0} value for all 120 shrub species and cultivars was −2.76 MPa, with the overall species Ψ_{P0} value ranging from −1.48 MPa to −4.23 MPa. Intraspecific variation (variation between cultivars) was evaluated using five cultivars of *Spiraea japonica* and one wild collected genotype. Within this species, there was a range of Ψ_{P0} values of 1.66 MPa, with *S. japonica* 'Little Princess' having the highest estimated drought tolerance (Ψ_{P0} = −2.78) and the wild-type *S. japonica* having the lowest (Ψ_{P0} = −4.44 MPa).**

It is not a farfetched claim that trees are a dominant field of interest within horticulture and landscape professions, with multiple horticultural organizations, societies, and publishing journals focusing on trees (Götmark et al. 2016). Shrubs, which comprise a vast and interesting plant group, are much less well-represented in research and the literature. In Sweden, nursery production and sales of shrubs comprise a large proportion of the national total. The latest available statistics from the Swedish Board of Agriculture refer back to 2005 (Jordbruksverket 2006), reflecting a general lack of up-to-date information, but the total value of domestic nursery production in that year was 40.1 million euros, of which ornamental shrubs and hedge and landscape plants accounted for 8.27 million euros (20%). Similar data about shrubs only do not exist within Europe, but the total production of ornamental plants in the union (with the United Kingdom) had a turnover of 22,099 million euros in 2019 (European Commission 2020).

Even at the user level (designers, landscape architects, landscape engineers, gardeners), shrubs comprise a very large proportion of the plant material used. As an example, a recent assessment of typical use of different categories of plant material in landscape design work in a residential area (Augustenborg) in Malmö, Sweden, showed that the costs of low shrubs comprise almost 48% of all plant costs (Slagstedt Johan, personal communication 2022). Therefore, shrubs constitute a very large proportion of the green infrastructure in urban environments and should merit a substantial research focus, especially toward site-specific guidance for selecting the correct shrubs for a particular site, that is currently lacking.

Some previous studies have focused on shrubs in their native context (Adelman and Schwartz, 2016; Kolbeck et al. 2003; Leuschner et al. 2017), thus providing guidance for the capacity of different species for survival and success in different climates and growing habitats. Based on findings in these publications, shrubs are important components in at least 9 of 11 global biomes (Archibold 1995; McKell 1989), shaping much of the vegetation in tropical savannah, arid regions, Mediterranean ecosystems, polar tundra, and high mountain tundra. They are also widespread in terrestrial wetlands, forest understory, and gaps in the forest canopy, where both shade-tolerant and pioneer (shade-intolerant) shrubs occur. The broad tolerance of shrubs for different climates and growing conditions in nature widens their use potential for urban environments compared with trees, indicating a need for site-related research of shrubs in urban environments.

Moreover, recent research of shrubs and the provision of ecosystem services (Blanusa et al. 2019) has demonstrated that shrubs and hedges are becoming particularly important in an urban context because of city densification, which may place pressure on space for parks and large-stature trees in the future (Haaland and van den Bosch 2015). Shrubs and hedges use less space than trees, at least in terms of width, and together with green walls and roofs may be critical to the future provision of effective green infrastructure in cities, particularly considering recent re-evaluations of the role of trees in the urban context (Abhijith and Kumar 2019; Blanusa et al. 2016; Pugh et al. 2012). However, those seeking to maximize the delivery of ecosystem services by shrubs need to use species that are capable of performing well in challenging urban sites, thus making site-specific selection of shrubs absolutely crucial.

There is currently a lack of quantitative assessments of stress tolerance in a large proportion of available species and cultivars of shrubs, which complicates any design process involving shrubs. The aim of this study was to evaluate drought tolerance of many common and less traditional shrubs intended for public planting to make a first contribution (dataset) to species selection. As water stress is a major constraint for landscape plants in

urban environments and is likely to increase in many regions under future climate scenarios (Caretta et al. 2022), the quantitative drought tolerance of a species or a genotype must be a fundamental consideration in plant selection for urban environments. Previous research has demonstrated great intraspecific variation in drought tolerance within the same species for trees (Hannus et al. 2021; Hirons et al. 2021), another fundamental research aim is to determine whether this is also the case within species of shrubs.

In this study, we used water potential at the turgor loss point (Ψ_{P0}) as a key trait for evaluating drought tolerance of different species of shrubs. Ψ_{P0} is a highly instructive trait because it represents a quantifiable measure of physiological drought tolerance. More negative Ψ_{P0} values represent greater drought tolerance by allowing the leaf to maintain physiological function over a greater range of leaf water potentials (Lenz et al. 2006; Sack et al. 2003). Ψ_{P0} has also been demonstrated to differentiate a wide range of species and cultivars with respect to drought tolerance and has helped to inform plant species selection guidance for green infrastructure (Hirons and Sjöman 2019). The current technique for determining Ψ_{P0} uses vapor pressure osmometry to predict osmotic potential at full turgor ($\Psi_{\pi100}$) and is sensitive enough to resolve differences in drought tolerance between closely related genotypes (Hannus et al. 2021).

Materials and Methods

Sample collection and processing. The methodology followed the protocol developed by Bartlett et al. (2012a). One sun-exposed branch with no symptoms of abiotic or biotic damage was collected from five to seven individual shrubs of each selected species during early evening, when transpiration was relatively low. Excised branches were immediately recut under water at least two nodes distal of the original cut and placed in a tube of water without exposing the cut surface to the air. Shoot material was rehydrated overnight in a dark chamber with more than 95% relative humidity. After overnight rehydration, one leaf disc per leaf was taken from fully expanded leaves using an 8-mm cork borer. All discs were tightly wrapped in aluminum foil to limit condensation or frost after freezing. The foil-wrapped leaf discs were submerged in liquid nitrogen for 2 min to fracture the cell membranes and walls. Next, the leaf discs were punctured 10 to 15 times with sharp-tip forceps to allow evaporation through the cuticle and decrease equilibration time (Kikuta and Richter 1992). Finally, each leaf disc was sealed in a vapor pressure osmometer (Vapro 5600; Westcor, Logan, UT, USA) using a standard 10-μL chamber. Initial readings of the solute concentration (mmol·kg^{-1}) were performed after 10 min of equilibration time; then, the solute concentration was recorded as repeated readings at ∼2-min intervals while the value remained less than 5 mmol·kg^{-1}. Solute concentration values were converted to

osmotic potential (Ψ_{P0}) using the Van't Hoff equation:

$$\Psi_{P0} = -RTc_s \qquad [1]$$

where R is the gas constant, T is temperature in Kelvin, and c_s is the solute concentration in the leaf disc.

An equation developed by Bartlett et al. (2012b) allowing the prediction of Ψ_{P0} from osmotic potential at full turgor ($\Psi_{\pi100}$) is based on a global dataset that includes data from tropical biomes. Because the present study was limited to the temperate biome, an equation developed by Sjöman et al. (2015) for deriving Ψ_{P0} from $\Psi_{\pi100}$ of temperate species based on a subset (woody temperate, Mediterranean/temperate-dry, and temperate conifer species) of the supplementary data provided by Bartlett et al. (2012a) was used:

$$\Psi_{P0} = -0.2554 + 1.1243 \times \Psi_{\pi100} \qquad [2]$$

This equation provided a higher coefficient of determination ($R^2 = 0.91$) than that of Bartlett et al. ($R^2 = 0.86$); therefore, it provided a more reliable means of predicting Ψ_{P0}.

Plant material was taken from the following two botanical collections: Swedish University of Agricultural Sciences Campus Arboretum in Alnarp (55°65′N, 13°08′E) and Gothenburg Botanical Gardens (57°42′N, 11°58′E) in southwestern Sweden. Alnarp and Gothenburg are considered to have a fully humid, oceanic, temperate climate, with warm summers (category Cfb in the Köppen-Geiger climate classification system) (Kottek et al. 2006). The soil composition at the two sites was postglacial clay in Gothenburg, with a clay content of 15% to 25% and 3% organic material, whereas Alnarp has a loam with a clay content of 15% and 3% organic content. The shrubs sampled during this study were all established for more than 10 years in unconstrained rooting space, grew in full sun or only subjected to short periods of partial shade, and had no visual symptoms of stress, indicating that the shrubs were fit for the ambient climate. The numbers of shrub species and cultivars included in the study were based on available plant material of the two botanical collections for which at least five to seven different individuals of each species/genotype were available, providing sufficient samples to allow satisfactory replicates.

A total of 120 species and cultivars of shrubs were sampled. For one species (*Spiraea japonica*), six different cultivars were evaluated to determine intraspecific differences within the species. The data collection was performed during 10 d in August. Each day, 12 species/genotypes were analyzed; each species/genotype was collected and analyzed at the same time. The data of the selected shrubs were also compared with turgor loss data for trees previously reported by Sjöman et al. (2015, 2018a, 2018b) and Hirons et al. (2021).

All statistical analyses and data visualizations were conducted using R software (R Core Team 2020). A one-way analysis of variance was used to determine whether differences

between genera, species, and cultivars were statistically significant, whereas a post-hoc Tukey's honest significant difference test was used to determine statistically significant differences across groups.

Results

The leaf Ψ_{P0} was estimated for a wide range of shrubs, representing a total of 44 genera and 120 species and cultivars. The mean Ψ_{P0} value for all 120 shrub species and cultivars was -2.76 MPa [standard error (SE) $\pm$ 0.02 MPa], with the overall species Ψ_{P0} value ranging from -1.48 ± 0.05 MPa for *Clethera alnifolia* to -4.23 ± 0.09 MPa for *Spiraea japonica* (Fig. 1). For a total overview of the Ψ_{P0} value of species and genera in the study, see Supplemental Tables 1 and 2.

Of the nine genera with four or more representative species in the dataset, *Rhododendron* had the lowest mean drought tolerance ($\Psi_{P0} = -2.42 \pm 0.02$ MPa), and *Spiraea* had the highest ($\Psi_{P0} = -3.47 \pm 0.04$ MPa) (Fig. 2).

To illustrate the range within a single genus, *Rhododendron* and *Spiraea* were chosen as cases. Across *Rhododendron*, there was a range of 0.53 MPa between the lowest and highest Ψ_{P0} values. *Rhododendron yeodensis* had the lowest drought tolerance ($\Psi_{P0} = -2.19 \pm 0.05$ MPa), and *Rhododendron luteum* had the highest ($\Psi_{P0} = -2.72 \pm 0.06$ MPa). Across *Spiraea,* there was a range of 1.63 MPa, with *Spiraea miyabei* having the highest ($\Psi_{P0} = -2.80 \pm 0.03$ MPa) and *Spiraea japonica* having the lowest ($\Psi_{P0} = -4.43 \pm 0.09$ MPa). Both *Rhododendron* and *Spiraea* showed significant differences ($P < 0.05$) across the intrageneric species evaluated (Fig. 3).

Intraspecific variation (variation between cultivars) was evaluated using five cultivars of *Spiraea japonica* and one wild collected genotype. Across the species, the range of Ψ_{P0} values was 1.66 MPa, with *S. japonica* 'Little Princess' having the lowest estimated drought tolerance (less negative) ($\Psi_{P0} = -2.78 \pm 0.01$ MPa) and the wild-type *S. japonica* having the greatest (most negative) ($\Psi_{P0} = -4.44 \pm 0.12$ MPa) (Fig. 4).

To assess whether there was a systematic variation in the turgor loss of temperate woody plants according to type (shrub/ tree), the 120 shrubs in the dataset were compared against 166 trees species using data derived from previous publications. The mean Ψ_{P0} value for all shrubs and trees combined was -2.73 ± 0.03 MPa, whereas shrubs had a mean value of -2.76 ± 0.05 MPa and trees had a mean value of -2.75 ± 0.05 MPa. The difference in turgor loss between shrubs and trees was not significant. The range and density distribution of these two types of woody plant are also very similar (Fig. 5).

Discussion

In natural environments, shrubs have a crucial role in delivering many types of functions, such as climate control, soil stabilization, carbon uptake and storage, and habitats
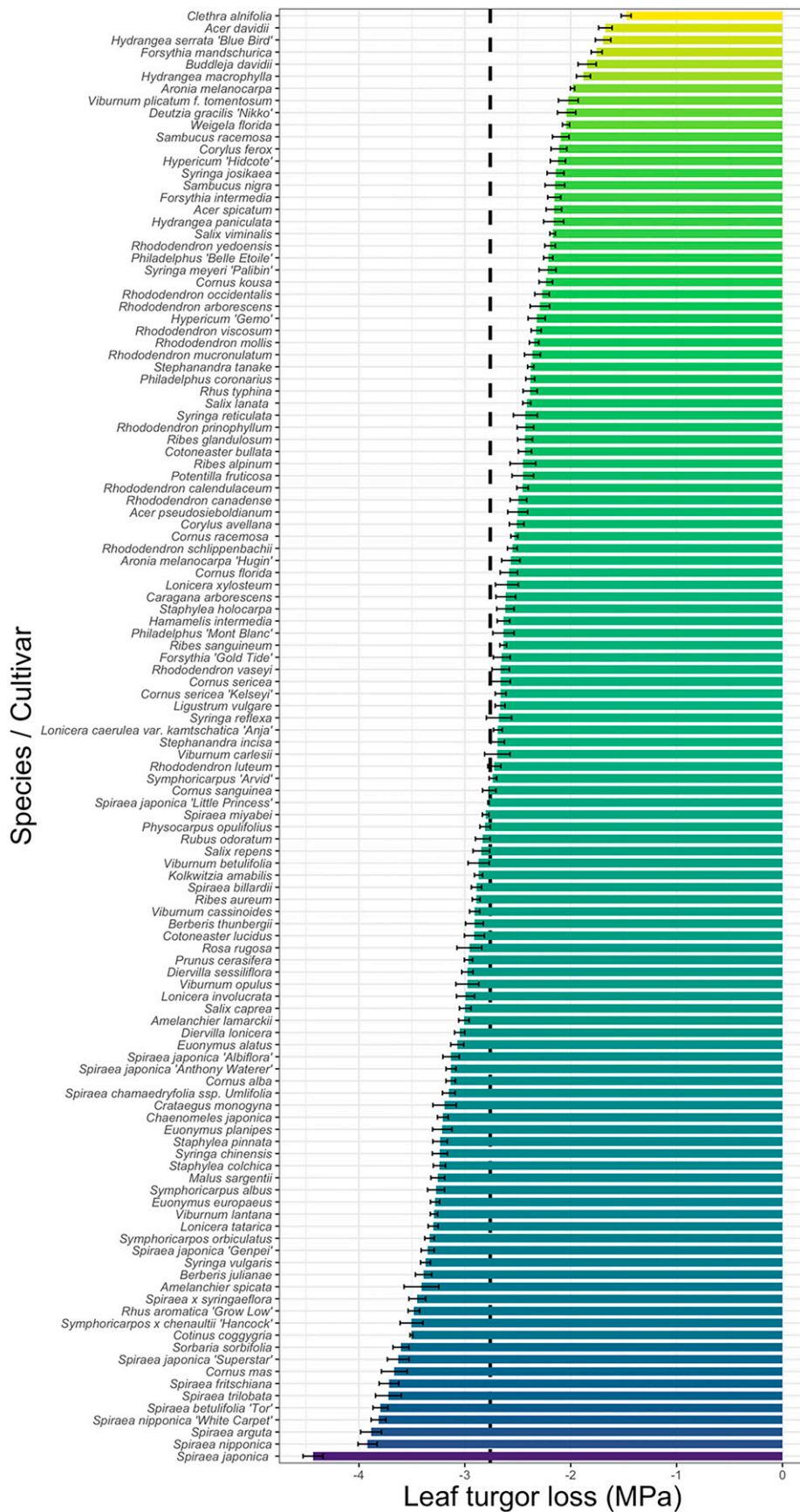
Fig. 1. Estimated water potential at leaf turgor loss (Ψ_{P0}, MPa) of the 120 shrub species and cultivars evaluated during this study ranked in order of increasing drought tolerance, i.e., decreasing Ψ_{P0} (mean, −2.76 MPa; range, −1.24 to −4.23 MPa). Bars represent the *SEM*. Vertical dashed line indicates the mean of all species represented in the plot.
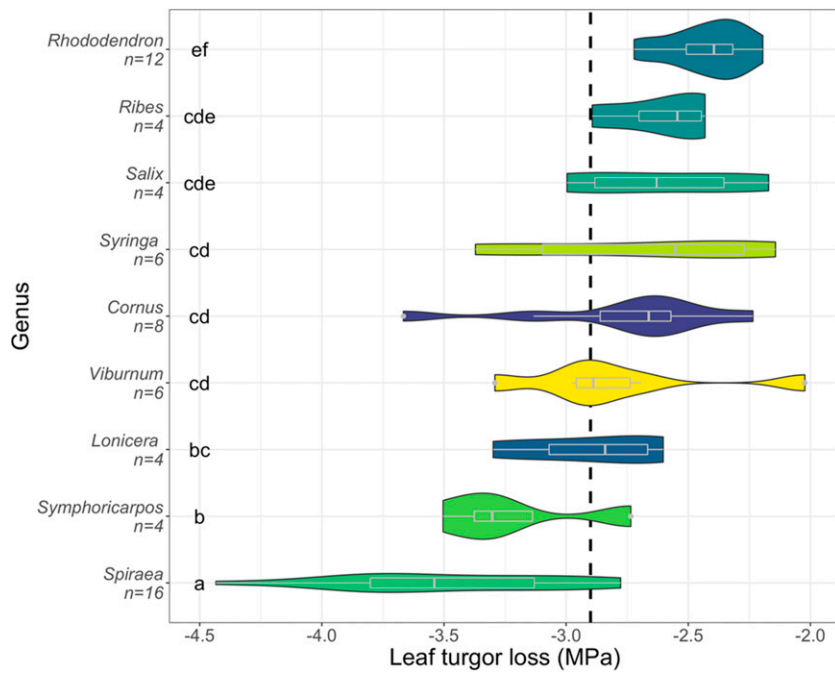
Fig. 2. Estimated genus-level water potential at leaf turgor loss (Ψ_{P0}, MPa) of the nine genera with four or more species represented in this study displayed using a violin plot (with boxplot). The median line is shown in the box representing the first and third quartiles [interquartile range (IQR)]. The upper whisker extends to the largest value no more than 1.5 times, and the lower whisker extends to the smallest value no less than 1.5 times. Outliers are plotted as individual points beyond the range of the whiskers. A smoothed density trace surrounds the boxplot, where the relative amplitude indicates the density of data. The vertical dashed line indicates the mean of all species represented in the plot. Different letters (a–f) indicate significant differences ($P < 0.05$) between the genera.

trampling by animals, whereas a shrub can afford to lose some of its stems and still survive (Götmark et al. 2016; Sheffer et al. 2014; Wilson 1995). Shrubs also have a greater bark area for sprouting and potential development of new organs than trees with the same aboveground woody volume, which is an advantage in disturbed habitats. Epicormic and dormant adventitious buds underneath the bark of stems, stem bases, and branches are responsible for this higher sprouting potential of shrubs compared with trees. In stressful environments (resource-limited habitats), the low and multi-stemmed growth form of shrubs is an additional advantage. According to Wilson (1995), shrubs follow a strategy of producing relatively small, low-investment, low-risk stems that are expendable in high-stress environments, which makes them successful in more resource-limited environments. Furthermore, according to Götmark et al. (2016), the lower height of shrubs compared with trees reduces the risk of cavitation in stems caused by drought and freezing. The maximum height of trees is partly determined by the problem of getting water to tall canopies. Water shortages can cause embolism in the xylem (Tyree and Sperry 1989), and the risk of cavitation increases with stem height because of gravity (Ryan and Yoder 1997).

All these research findings demonstrate that shrubs are capable of handling and tolerating challenging growing conditions in their natural environments through their ability to form low and multi-stemmed plants. In the urban context, this makes them valuable in the most challenging sites. As indicated, there is some existing evidence and guidance regarding how shrubs handle challenging conditions, such as hot and dry environments, in their natural habitat, but there is a lack of clear guidance regarding how these properties are expressed in the planting conditions prevailing in urban environments. In this study,
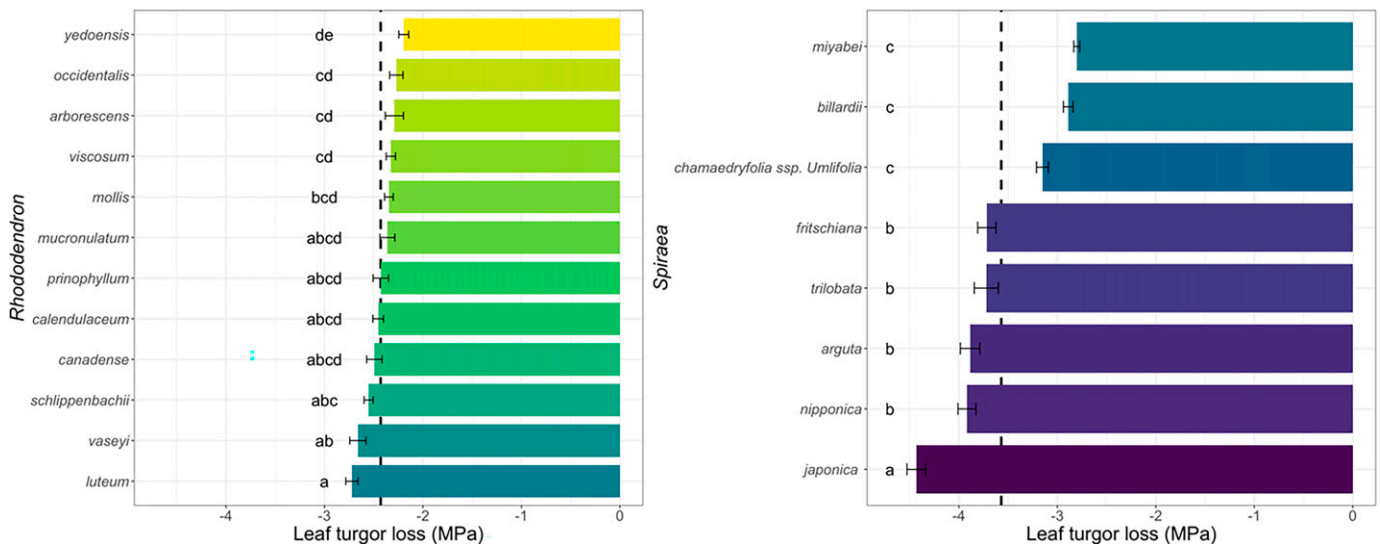
for mammals, birds, fungi, and invertebrates. Within their natural environments, shrubs also act as important "nursery plants" for other plants, including trees. In a review by Filazzola and Lortie (2014), shrubs were identified as the dominant nurse lifeform and, therefore, an important element of forest succession and forest species composition. Moreover, shrubs are present in most vegetation systems globally and have a more extensive range than trees, occupying treeless habitats such as high mountain areas, deserts, steppes, and habitats subjected to recurrent disturbances (Rundel 1991). Shrubs have the advantage of being low and multi-stemmed in form, thus creating resilience to browsing by deer (Tanentzap et al. 2012). A single-stemmed tree faces the risk of mortality if the stem breaks and dies because of harsh weather conditions, falling trees/branches, drought, disease, browsing, or

Fig. 3. Estimated water potential at leaf turgor loss (Ψ_{P0}, MPa) of species within the least drought-tolerant genus (*Rhododendron*) and most drought-tolerant genus (*Spiraea*) evaluated during this study. (**Left**) Twelve species of *Rhododendron*. (**Right**) Eight species of *Spiraea*. Bars indicate the *SEM*. The vertical dashed line indicates the mean of all species represented in the plot. Different letters (a–e) indicate significant differences ($P < 0.05$) between the species.
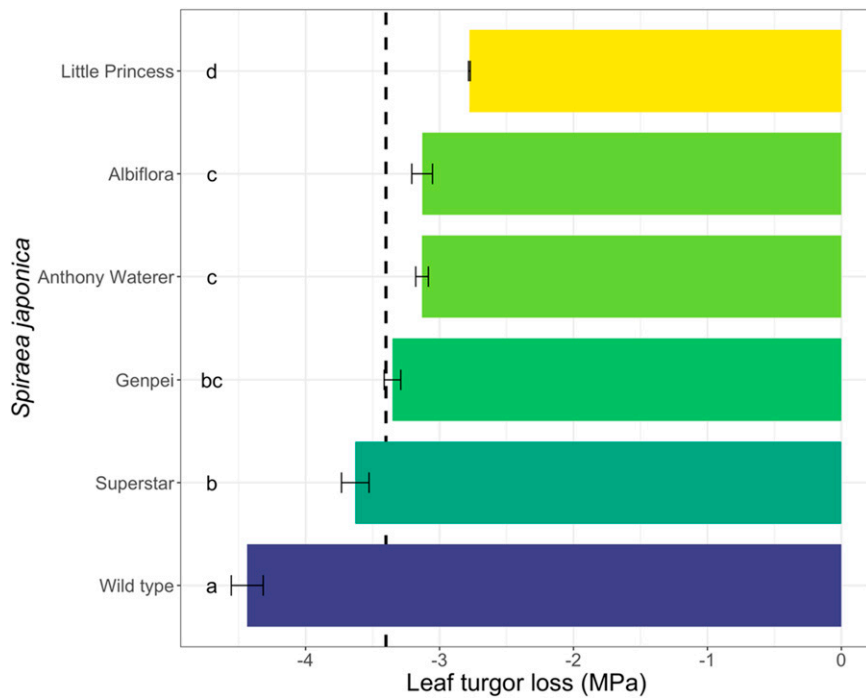
Fig. 4. Estimated water potential at leaf turgor loss (Ψ_{P0}, MPa) of six *Spiraea japonica* cultivars evaluated during this study. Bars indicate the *SEM*. The vertical dashed line indicates the mean of all cultivars represented in the plot. Different letters (a–d) indicate significant differences ($P < 0.05$) between the cultivars.

a first attempt was made to obtain such information. To this end, 120 species and genotypes of shrubs were evaluated in terms of their water potential at the turgor loss point (Ψ_{P0}), which is a key trait for evaluating drought tolerance. The Ψ_{P0} value of a species is a highly instructive trait because it represents a quantifiable measure of physiological drought tolerance, thus making it possible to

rank and compare species and genotypes and determine their use potential in challenging urban environments.

The results of this study showed that species such as *Clethra alnifolia*, *Hydrangea macrophylla*, and *Aronia melanocarpa* were sensitive to drought, with Ψ_{P0} values of -1.48, -1.88, and -1.98 MPa, respectively (Fig. 1). This was not an unexpected finding because these species

all originate from moist, cool forest habitats (Dirr 2011; Thomas 1992). Species such as *Rhus aromatic*, *Cotinus coggygria*, and *Cornus mas*, which originate from exposed and dry habitats, were found to have high drought tolerance, with Ψ_{P0} values of -3.48, -3.5, and -3.67 MPa, respectively (Dirr 2011; Thomas 1992) (Fig. 1).

The ranking of the different species in terms of drought tolerance was predictable based on their natural habitat, but the results obtained during this study showed not only whether a species was tolerant or sensitive but also the degree of tolerance or sensitivity. In the horticultural literature on shrubs, guidance for drought tolerance is mainly qualitative, with lists of tolerant and sensitive species, but no in-depth descriptions (Krüssmann 1982; Stoecklein 2001). These qualitative conclusions are usually based on the researchers' own assessments, which are based on observations rather than plant-based empirical measurements during studies such as this. When using plants in urban environments experiencing densification and global warming today, and especially in future climates, qualitative conclusions are insufficient. Instead, more quantitative compilations are needed to determine the capacity of plant material for a specific site by predicting the potential of different species to develop successfully and deliver all the features expected of them. An interesting finding during this study was the large difference in drought tolerance within different genera such as *Cornus*, *Viburnum*, and *Spiraea*. Based on the Ψ_{P0} values (Fig. 2), within each genus there is a large variety of species with varying tolerance to drought determined by the different natural environments from which they originate.
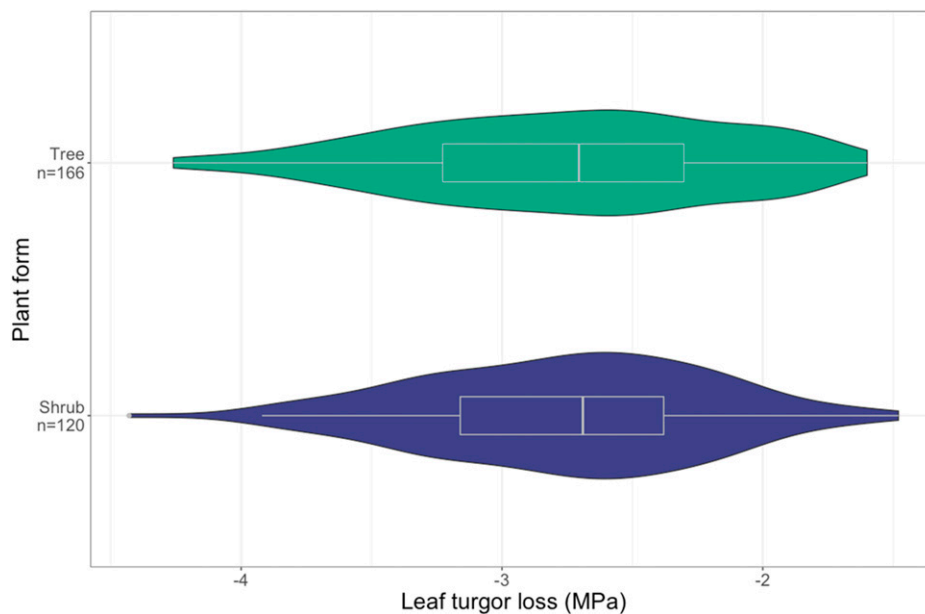

Fig. 5. Estimated water potential at leaf turgor loss (MPa) of tree and shrub species for which data are available (this study and the literature) displayed using a violin plot (with boxplot). The median line is shown in the box representing the first and third quartiles [interquartile range (IQR)]. The upper whisker extends to the largest value no more than 1.5 times, and the lower whisker extends to the smallest value no less than 1.5 times. Outliers are plotted as individual points beyond the range of the whiskers. A smoothed density trace surrounds the boxplot, where the relative amplitude indicates the density of data. *Tree data are from Sjöman et al. (2015, 2018a, 2018b) and Hirons et al. (2021).

Another important observation was that there can be great variation in drought tolerance even within the same species. Our evaluation of six genotypes of *Spiraea japonica* revealed large intraspecific variations. Such variations have been demonstrated by studies of trees, with large differences being reported for drought tolerance between different ecotypes within the same species (Hannus et al. 2021; Hirons et al. 2021; Sjöman et al. 2015). The findings of previous studies of trees and of the present study of shrubs indicate the need to extend descriptions of stress-related guidance and plant use and move away from simply talking about the capacity of different species to handle "hot" and "dry" urban environments. In the future, we must discuss different genotypes/ecotypes within the capacity of a species to handle dry planting environments. This perspective is likely to become increasingly important to future climates and urban environments that will become challenging for shrubs and in which the genetic material used must have the best possible capacity to manage conditions while maintaining good development. Therefore, there is an urgent need to start screening the genetic range of shrubs currently in commercial use to assess how well-equipped they are for urban environments today and in the future. Additionally, more nontraditional species and genetic material with different origins than those currently on the market must also be evaluated to identify more species and ecotypes with the capacity to be reliable plant material for future urban environments. This will require screening of plant collections such as botanical gardens and arboretums, which may already contain some of the most successful shrubs for future climates. An example was found during this study: a genotype of *Spiraea japonica* of wild origin from the botanical collection in Alnarp had much greater drought tolerance ($\Psi_{P0} = -4.43$ MPa) than the common cultivar *S. japonica* 'Little Princess' ($\Psi_{P0} = -2.78$ MPa). This suggests that the ornamental perspective has been prioritized for cultivar selection, in this case at the expense of drought tolerance. Therefore, botanical gardens and botanical institutions must recognize an obligation to participate in the necessary horticultural development work to ensure that towns and cities in a future climate can continue to use varied and durable shrub material that delivers many important ecosystem services.

To create a more detailed and reliable guide for shrubs, it is necessary to develop similar site-related guidance such as that available for trees. This guide should have a strong focus on trait-based suitability and the natural properties that different species and ecotypes have developed through evolution to handle different competitive contexts, climates, and growing conditions. Through trait-related research, it may be possible to develop an understanding of *what* makes shrub species successful or sensitive to different types of environments and *how* they deal with these conditions. Extensive trait-based research of trees involving many different species and ecotypes has created clear and comprehensive tree selection guides (Hirons and Sjöman 2019). To our knowledge, trait-based data of shrubs are currently lacking; therefore, the present study represents an important first step to creating similar trait-based compilations for shrubs. To assess drought tolerance, we used Ψ_{P0}. It is known that species with low (more negative) Ψ_{P0} values tend to maintain leaf gas exchange, hydraulic conductance, and growth at lower soil water potential (Ψ_{soil}); therefore, they are at an advantage when soil water deficits occur during the growing season (Blackman et al. 2010; Mitchell et al. 2008). The Ψ_{P0} value also acts as a surrogate for the critical Ψ_{soil} value below which the plant cannot recover from wilting (Bartlett et al. 2012a). It is also related to leaf and stem conductivity, which are hydraulic traits reflecting drought impacts on the water supply for transpiration and photosynthesis (Bartlett et al. 2016). Therefore, Ψ_{P0} is a trait that provides information about the capacity of a species for growth in dry environments and is particularly relevant for urban environments characterized by restricted soil volumes and impermeable surfaces (Sjöman et al. 2015). It is of significant interest as a quantifiable measure of drought tolerance, and species with lower values (i.e., with a greater tolerance to drought) are more likely to survive in challenging sites and have a greater ability to deliver the ecosystem services sought by urban forest professionals. The technique used during this study, originated from Bartlett et al. (2012a), enabled simplified screening of a larger number of species than is possible with the more traditional method using pressure–volume curves. Moreover, it is important to consider this study as one of the first steps toward a greater understanding and overview of the traits that shrubs have developed to deal with hot and dry growing environments. Further studies of other traits and how they are connected to each other will provide a gradually increased understanding of this widely used plant group for public plantations.

Another objective of this study was to evaluate several species and cultivars, including common and nontraditional species, to create the first overview of species/ecotypes that have the capacity to handle dry growing conditions. For both trees and shrubs, there is limited diversity available for urban environments, with a limited catalog of species and varieties used as public plantings. Many cities worldwide have produced extensive inventories of their urban tree populations (Cowett and Bassuk 2017; Sjöman and Östberg 2019; Yang et al. 2012), but similar inventories of their shrub populations are missing. However, it can be suspected that a limited number of shrub species dominate in public plantations; in northwestern Europe, there has been an excessive reliance on *Spiraea*, which is found in large numbers in many public shrub plantations. This one-sided use of shrubs naturally entails risks if these overused shrubs are exposed to serious diseases or pests, which can result in large ecological losses and costly replanting programs. During this study that evaluated 120 species and genotypes of shrubs, we identified two species of *Staphylea* with high Ψ_{P0} values, *S. colchica* ($\Psi_{P0} = -3.24$ MPa) and *S. pinnata* ($\Psi_{P0} = -3.23$ MPa). This indicates good drought tolerance, but these two species rarely occur in public plantings and are currently generally restricted to exclusive plant collections and botanical gardens. The findings of this study advocate for their increased use in urban planting contexts, as well as the use of shrub species that are currently under-represented.

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Supplemental Table 1. Total overview of the Ψ_{P0} value of species in the study.

Species	Ψ_{P0}, MPa	$\pm SE$
Acer davidii	−1.67	0.06
Acer pseudosieboldianum	−2.50	0.09
Acer spicatum	−2.16	0.07
Amelanchier lamarckii	−3.01	0.05
Amelanchier spicata	−3.41	0.16
Aronia melanocarpa	−1.98	0.02
Aronia melanocarpa 'Hugin'	−2.57	0.09
Berberis julianae	−3.39	0.08
Berberis thunbergii	−2.91	0.08
Buddleja davidii	−1.84	0.09
Caragana arborescens	−2.61	0.09
Chaenomeles japonica	−3.21	0.05
Clethra alnifolia	−1.48	0.05
Cornus alba	−3.13	0.05
Cornus florida	−2.58	0.08
Cornus kousa	−2.24	0.06
Cornus mas	−3.67	0.12
Cornus racemosa	−2.53	0.03
Cornus sanguinea	−2.77	0.06
Cornus sericea	−2.66	0.09
Cornus sericea 'Kelseyi'	−2.66	0.05
Corylus avellana	−2.51	0.07
Corylus ferox	−2.11	0.07
Cotinus coggygria	−3.50	0.01
Cotoneaster bullata	−2.43	0.06
Cotoneaster lucidus	−2.91	0.09
Crataegus monogyna	−3.19	0.11
Deutzia gracilis 'Nikko'	−2.04	0.09
Diervilla lonicera	−3.05	0.05
Diervilla sessiliflora	−2.98	0.05
Euonymus alatus	−3.07	0.06
Euonymus europaeus	−3.28	0.04
Euonymus planipes	−3.21	0.09
Forsythia 'Gold Tide'	−2.65	0.08
Forsythia intermedia	−2.16	0.06
Forsythia mandschurica	−1.75	0.05
Hamamelis intermedia	−2.63	0.06
Hippophae rhamnoides 'Spire'	−1.87	0.06
Hydrangea macrophylla	−1.88	0.07
Hydrangea paniculate	−2.16	0.09
Hydrangea serrata 'Blue Bird'	−1.69	0.07
Hypericum 'Gemo'	−2.32	0.08
Hypericum 'Hidcote'	−2.12	0.07
Kolkwitzia amabilis	−2.87	0.04
Ligustrum vulgare	−2.67	0.05
Lonicera caerulea var. *kamtschatica* 'Anja'	−2.69	0.04
Lonicera involucrate	−2.99	0.09
Lonicera tatarica	−3.30	0.05
Lonicera xylosteum	−2.60	0.11
Malus sargentii	−3.26	0.07
Philadelphus 'Belle Etoile'	−2.21	0.04
Philadelphus 'Mont Blanc'	−2.64	0.10
Philadelphus coronarius	−2.38	0.04
Physocarpus opulifolius	−2.81	0.05
Potentilla fruticosa	−2.45	0.10
Prunus cerasifera	−2.97	0.04
Rhododendron arborescens	−2.29	0.09
Rhododendron calendulaceum	−2.45	0.05
Rhododendron canadense	−2.49	0.08
Rhododendron luteum	−2.72	0.06
Rhododendron mollis	−2.35	0.04
Rhododendron mucronulatum	−2.36	0.08
Rhododendron occidentalis	−2.27	0.07
Rhododendron prinophyllum	−2.43	0.08
Rhododendron schlippenbachii	−2.55	0.05
Rhododendron vaseyi	−2.66	0.08
Rhododendron viscosum	−2.33	0.05
Rhododendron yedoensis	−2.19	0.05
Rhus aromatica 'Grow Low'	−3.48	0.05
Rhus typhina	−2.38	0.07
Ribes alpinum	−2.45	0.12
Ribes aureum	−2.89	0.04
Ribes glandulosum	−2.43	0.07

(Continued on next page)

Species	Ψ_{P0}, MPa	$\pm SE$
Ribes sanguineum	−2.64	0.03
Rosa rugosa	−2.96	0.12
Rubus odoratum	−2.83	0.07
Salix caprea	−3.00	0.05
Salix lanata	−2.41	0.04
Salix repens	−2.84	0.08
Salix viminalis	−2.17	0.03
Sambucus nigra	−2.15	0.09
Sambucus racemosa	−2.09	0.08
Sorbaria sorbifolia	−3.60	0.08
Spiraea arguta	−3.89	0.10
Spiraea betulifolia 'Tor'	−3.80	0.07
Spiraea billardii	−2.89	0.05
Spiraea chamaedryfolia ssp. *umlifolia*	−3.15	0.06
Spiraea fritschiana	−3.72	0.09
Spiraea japonica	−4.43	0.09
Spiraea japonica 'Albiflora'	−3.13	0.08
Spiraea japonica 'Anthony Waterer'	−3.13	0.05
Spiraea japonica 'Genpei'	−3.35	0.06
Spiraea japonica 'Little Princess'	−2.78	0.01
Spiraea japonica 'Superstar'	−3.63	0.10
Spiraea miyabei	−2.80	0.03
Spiraea nipponica	−3.92	0.09
Spiraea nipponica 'White Carpet'	−3.82	0.07
Spiraea trilobata	−3.72	0.12
Spiraea × syringaeflora	−3.45	0.08
Staphylea colchica	−3.24	0.06
Staphylea holocarpa	−2.62	0.08
Staphylea pinnata	−3.23	0.07
Stephanandra incisa	−2.69	0.06
Stephanandra tanake	−2.38	0.03
Symphoricarpos orbiculatus	−3.33	0.05
Symphoricarpos × chenaultii 'Hancock'	−3.50	0.11
Symphoricarpus 'Arvid'	−2.74	0.04
Symphoricarpus albus	−3.27	0.08
Syringa chinensis	−3.24	0.07
Syringa josikaea	−2.14	0.08
Syringa meyeri 'Palibin'	−2.22	0.08
Syringa reflexa	−2.68	0.12
Syringa reticulata	−2.43	0.11
Syringa vulgaris	−3.37	0.05
Viburnum betulifolia	−2.87	0.10
Viburnum carlesii	−2.69	0.12
Viburnum cassinoides	−2.91	0.05
Viburnum lantana	−3.29	0.04
Viburnum opulus	−2.98	0.11
Viburnum plicatum f. *tomentosum*	−2.02	0.09
Weigela florida	−2.04	0.03

Supplemental Table 2. Total overview of the Ψ_{P0} value of genera in the study.

Genus	Ψ_{P0}, MPa	$\pm SE$
Acer	−2.11	0.08
Amelanchier	−3.21	0.10
Aronia	−2.27	0.09
Berberis	−3.15	0.08
Buddleja	−1.84	0.09
Caragana	−2.61	0.09
Chaenomeles	−3.21	0.05
Clethra	−1.48	0.05
Cornus	−2.78	0.06
Corylus	−2.31	0.07
Cotinus	−3.50	0.01
Cotoneaster	−2.67	0.08
Crataegus	−3.19	0.11
Deutzia	−2.04	0.09
Diervilla	−3.01	0.04
Euonymus	−3.19	0.04
Forsythia	−2.19	0.08
Hamamelis	−2.63	0.06
Hippophae	−1.87	0.06
Hydrangea	−1.91	0.06
Hypericum	−2.22	0.06
Kolkwitzia	−2.87	0.04
Ligustrum	−2.67	0.05
Lonicera	−2.90	0.06
Malus	−3.26	0.07
Philadelphus	−2.41	0.05
Physocarpus	−2.81	0.05
Potentilla	−2.45	0.10
Prunus	−2.97	0.04
Rhododendron	−2.42	0.02
Rhus	−2.93	0.15
Ribes	−2.60	0.05
Rosa	−2.96	0.12
Rubus	−2.83	0.07
Salix	−2.61	0.06
Sambucus	−2.12	0.06
Sorbaria	−3.60	0.08
Spiraea	−3.47	0.04
Staphylea	−3.03	0.07
Stephanandra	−2.53	0.05
Symphoricarpos	−3.21	0.06
Syringa	−2.67	0.08
Viburnum	−2.80	0.07
Weigela	−2.04	0.03