Woody Ornamental Plants in Mediterranean Climate

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The native flora of different Mediterranean countries, often woody species, was widely recognized for its ornamental potential. The shrubs, in particular, are a typology of plants very widespread in the Mediterranean environment and constituent the 'Macchia', the typical vegetation of this ecosystem. These plant species could be used to improve the ornamental value of urban and peri-urban green areas. Since urban areas can suffer from low-quality soil and limited resources, the selection of plants must be carefully considered. The most commonly used plants should have adequate tolerance to abiotic stress.

Keywords: urban environment ; shrubs ; green areas ; landscape ; abiotic stress

1. Introduction

Woody plants, trees or shrubs, represent the most common plants in many natural and semi-natural environments [1]. Almost all these plants have characteristics, such as being perennial or the same structure of ramifications, that allow their use for ornamental purposes [2]. All 'woody ornamental plants' can be used in gardens and landscaping, thanks to the presence of flowers, more or less showy, of different colours, the colour and morphology of leaves, and the shape of the plant (height, shape, and width) [2]. The species of woody ornamental plants belong to numerous botanical families and genera; within a single species, there are numerous cultivars, expressing enormous variability [3]. An indication of the wide biological diversity of woody plants used for horticultural purposes is the "List of Names of Woody Plants" by Naktuinbouw, which contains the 'preferred botanical names and common synonyms and trade names of almost 45,000 woody nursery plants' [4]. The new edition (2021–2025) contains more than 8200 new names of woody plants. Shrubs, in particular, are a category of woody plants widespread above all in the Mediterranean Basin, where they form the so-called in Italian 'Macchia', i.e., the vegetation typical of this environment.

The diffusion of this plant typology in the Mediterranean regions is justified by its adaptability to stressful climatic conditions, characterized by hot summers and low rainfall, which determine a long and droughty summer [5]. Climatic conditions of the Mediterranean environment are also found in four other regions of the Earth (California, Chile, South Africa, and some areas of Australia). The frequency of abiotic stresses, and in particular water and saline stresses due to the poor quality of the water, has selected the plants of all these environments, leading to the convergence of the morphophysiological traits of the various species, determining that all the plant communities of the Mediterranean climate are dominated by sclerophyllous evergreen shrubs. In the Mediterranean regions, water stress and poor water quality (high salt content) are among the main problems hindering the use of ornamental plants. Global climate change will certainly accentuate problems associated with water deficits and salt levels, especially in urban areas [6]. The possibility of the use of native Mediterranean shrub species can be a solution for drought [7] and saline stress [8]. It is of interest to increase the sustainability of the landscape. Native Mediterranean shrubs are able to adapt to conditions of accentuated drought, which is one of the most important factors influencing plant survival and species distribution [9]. Many woody ornamental plants and native Mediterranean shrubs are particularly suitable to use in landscape planning. These plants, in addition to their high aesthetic value, are characterized by wide biodiversity. Indeed, the Mediterranean Basin is one of the Earth's areas with the greatest biodiversity, as it hosts 10% of the world's higher plants in an area that is just 1.6% of the Earth's surface [10]. Of the approximately 25,000 species recorded in the Mediterranean area, half are endemic to the region [11]. Hotspots represent about 22% of the total area of the Mediterranean Basin and host about 5500 restricted endemic species [12].

Thanks to their particular morpho-physiological characteristics, woody plants are very suitable to be used for ornamental purposes. Since shrubs are characterised, as Givnish [13] recalled, by a high number of active meristems, which are potential sites for stem regeneration, they are able to tolerate abiotic stresses more than trees. It is no coincidence, in fact, that shrubs are associated with degraded environments, where abiotic stresses are very frequent, for these reasons. They are plant species suitable for low-maintenance green infrastructures. Shrubs, perennial plants with numerous branches that branch out at or near the ground [1], are widespread in the different biomes of the Earth; their tolerance to numerous stresses allows them to ensure numerous ecosystem services [14]. These plant species are able to control temperatures, stabilize the soil, and ensure the water balance of the ecosystem, absorption, and carbon storage. The capacity to assure ecosystem services is crucial in the choice of ornamental plants for sustainable green infrastructures. From an ornamental point of view, shrubs are characterised by different features (high number of twigs, which influences their growth pattern; pulvinate shapes, which reduces their transpiration and improves the visual qualities of the green infrastructures; leaf characteristics; different blooming periods; and colours of flowers) that add interest and variety to the landscape [15].

2. Ornamental Shrubby Plants in the Urban Environment

Urbanisation significantly modifies the physical environment, biological components, and ecosystem processes of cities [16]. Woody plants, trees, and shrubs become essential components of urban green infrastructures for their numerous ecosystem services and, in particular, for the reduction of pollution [14]. Another aspect linked to urban environment quality is heat island reduction, determined by green areas and vegetation, particularly important in relation to increasing global warming. Plants, thanks to their shade [17] and transpiration, are able to improve urban conditions for the inhabitants but also for tourists who favour areas with green infrastructure to spend their time outdoors [18][19]. It is well-known that urban areas have temperatures 5–7 °C higher than rural areas. Mitigation of the high temperatures is obtained by the transpiration of plants, and the efficiency depends on water availability. Ornamental shrubs are able to maintain environmental quality and offer pleasant landscape effects, even if urbanisation, with its environmental changes, exerts negative effects on plants, which mainly affect the characteristics of the leaves [20]. At the same time, the variations that, due to the stressful effects of urbanisation, are observed in plants, such as leaf thickness, unit leaf area, specific leaf area, etc., can be used as indicators of the urban environment quality [20].

3. Mechanism of Tolerance and/or Resistance of Ornamental Shrubs to Abiotic Stress

Abiotic stresses are the major limiting growth factor in urban and peri-urban areas. The identification and use of tolerant ornamental species allow the reduction of management costs and preserve the aesthetical value of green areas. Urban environments can be subjected to more stressful conditions than rural areas [14].

Drought tolerance is most important for agricultural production, as most of the plants are obtained in Mediterranean, semi-arid, and tropical regions [21]. Soil water limitation during drought affects evaporation, evapotranspiration, and ultimately, precipitation [22]. Plants have developed various adaptive strategies to cope with drought stress [23]. Plants adapt to drought in several ways, such as drought escape, tolerance, and avoidance mechanisms [24]. Perennials especially rely on drought tolerance [25], which can be achieved through morphological adaptations of roots, stems, and leaves. Tolerant plants have a high-water potential with higher water uptake or physiological adaptations through the reduction of transpiration [26]. Plant adaptation varies among plants depending on species, genotype, phenological development, or organ type (leaves) [27]. Optimisation of carbon assimilation with minimisation of water loss, i.e., improvement of intrinsic water use efficiency, has been described as an adaptive trait for plants that are exposed to severe drought, like, for example, the Mediterranean woody plant species [28][29].

Woody species are particularly important in this context, due to their longevity and the possibility of studying long-term adaptation mechanisms. To understand the tolerance level, many physiological traits such as the measurement of leaf water potential before sunrise and at midday, photosynthetic rate, stomatal conductance, transpiration rate, and intercellular carbon dioxide concentration were analysed. Biochemical characteristics, such as ascorbic acid, glutathione, chlorophyll content, tocopherols, amino acids, carotenoids, and soluble sugar, have also been used to control the tolerance level of plants to drought stress [30]. It has been observed that species that can retain a greater quantity of water and therefore lose less through the stomata are more tolerant to drought [31]. As reported by Galmes et al. [32], shrubs have a better ability to regulate transpiration than herbaceous plants [30].

Many of the favourable characteristics for resisting drought are present in shrubs; it is not a coincidence that in semi-arid environments, most of the plants are sclerophyllous evergreen shrubs, or deciduous or seasonally dimorphic shrubs, which possess the main adaptive approaches of perennial species to drought stress [33]. The main role of shrubs in semi-arid ecosystems lies in the fact that these plants can grow under conditions of environmental stress where trees cannot survive [34][35]. Some perennial species, such as *Euphorbia dendroides* L., a Mediterranean shrub, keep their leaves during the winter and/or spring and drop them with the onset of the hot season.

The use of Mediterranean shrubs for revegetation in semi-arid areas has increased because of their ability to adapt to severe drought conditions, which is considered to be one of the most important factors influencing plant survival and species distribution [36]. In the case of Mediterranean evergreens, leaves undergo several drought events that can further hinder photosynthetic capacity [37][38]. One of their most distinctive characteristics is a higher water use efficiency (WUE) at the leaf level, due to the reduced stomatal conductance but higher carboxylation capacity of Rubisco compared to evergreens of other biomes [39]. Hence, stomatal and mesophyll diffusion constraints are the most important factors limiting photosynthesis in evergreens [40]. However, Mediterranean sclerophylls are able to sustain positive CO_2 assimilation rates at relatively low leaf water potentials compared to Mediterranean deciduous species [39]. This increased drought tolerance has been partly attributed to the robustness of sclerophyll leaves [41], which tend to sustain shrinkage and collapse, thus preventing negative effects on photosynthesis and water transport [38][42]. Beyond the response mechanisms to drought stress, ornamental plants used in landscaping must ensure an aesthetic value that can be influenced by a reduction in the number of flowers, an excessive decrease in plant growth, and a worsening of foliage quality [30]. The analysis of the mechanisms adopted by different species to overcome drought stress and reduce water loss could allow the identification of the most tolerant species to be used in arid and semi-arid environments, thus increasing the sustainability of ornamental green infrastructures (**Table 1**).

Table 1. Effect of drought on ornamental plant quality and traits associated to tolerance.

Target Organs	Stress Effects	Tolerance or Adaptation Response	References
Roots	**Increase of root biomass**	**Increase the functional roots and architectures**	[30]
Stem	**Decrease the growth, elongation, diameter and biomass**	**Increase the lignification process (chi lo dice?)**	[30][43][44]
Leaves	**Reduction of size and leaf number**	**Increase the wax or thickness, and trichome number**	[27][45]
Flowers	**Reduction of flower production and longevity**	**Increase the flower longevity and turnover**	[46]

Salt stress is another important abiotic stress that ornamental plants and shrubs in landscaping can be exposed to. There are not numerous studies on the effects of saline stress [47]. Salinity can affect the growth of ornamental shrubs by reducing leaf growth and expansion due to osmotic effects or by toxicity due to the high concentration of Na^+ and Cl^- in saline water [48]. In ornamental plants, the aesthetic value can be compromised by salinity inducing leaf necrosis or abscission [49][50]. In many ornamental species, salinity usually induces dry shoot biomass and leaf surface. Morphological adaptations such as resinous buds, and waxy leaves and stems in tolerant species allow woody plants to cope with salinity stress. The salt exclusion mechanisms are represented by smooth twigs, sunken buds, and low surface area to volume ratios (as occurs, for example, in pine needles) [51][52].

Exposure to salt can affect plant metabolism through an osmotic effect, causing water deficit, or through a specific ion effect, causing excessive ion accumulation [53]. Under saline conditions, plants must activate various physiological and biochemical mechanisms to cope with saline stress, which include water relationships, photosynthesis rate, hormonal profiles, toxic ion distribution, antioxidant metabolism, and soil response [54]. In particular, the changes in leaf tissue cell walls and factors limiting photosynthesis under these conditions and their possible interactions with leaf tissue damage are not well understood [29]. Plants that have some degree of tolerance to salinity may show quality reductions when exposed to this stress, and this is an important factor in the selection of ornamental plants for use in gardens and landscaping [55].

The ionic composition of irrigation water can influence the response of shrubs and trees to salt stress. Chloride salts appear to be more harmful than SO_4^{2-} salts, and Mg^{2+} associated with Cl^- is more harmful than Na^+ with Cl^- [56]. Among many salinity tolerance mechanisms [57], the ability to limit the entry of saline ions through the roots and to limit the transport of Na^+ and/or Cl^- to the aerial parts, retaining these ions in the root and in the lower part of the stem, is one of the most important characteristics associated with salt tolerance [58]. Species that maintain acceptable growth rates under saline conditions have effective mechanisms for excluding Na^+ and Cl^- from roots or leaves, thus maintaining good aesthetics and are ideal for landscaping. The low reduction and absence of symptoms of salt damage in *Eugenia myrtifolia* L. was associated not only with the root storage of Na^+ and Cl^-, but also with their limited uptake with increasing salinity [59]. An important aspect of salt tolerance is related to a plant's ability to compartmentalise toxic ions, such as Na^+ and Cl^-, in roots or stems [60][61].

The response of plants to salinity depends not only on the intensity of the salt treatment but also on the time of exposure to the salt treatment [62]. These aspects are of primary importance, especially in the Mediterranean area when saline water is used for irrigation of perennial species, such as woody plants, as the interaction between intensity and duration of exposure to salt will determine physiological and molecular changes. At nursery level, the selection of plants tolerant to salinity stress can be carried out by the evaluation of plants' responses to salinity treatments (**Table 2**).

Table 2. Effect of salinity on ornamental plant quality and traits associated to tolerance.

Target Organs	Stress Effects	Tolerance or Adaptation Response	Reference
Roots	**Increase of roots biomass**	**Increase the water uptake and exclusion of some toxic ions such as Na^+ or Cl^-**	[63]
Stem	**Decrease the growth and biomass**	**Increase the extrusion or storage**	[64]
Leaves	**Reduction of size, necrosis, or abscission**	**Increase the storage of ions in vacuole**	[49]
Flowers	**Reduction of flowers production and longevity**	**Increase the flower longevity and turnover**	[65]

In urban areas, hypoxia is an abiotic stress that ornamental plants can be often exposed to in compacted soil. Compaction is determined by physical degradation, which reduces the volume of a given mass of soil and decreases porosity. This promotes the formation of urban flooding [66]. An excess of water is usually considered to be deleterious to plant health and growth, and total submergence rapidly kills most plant species. Hypoxia/anoxia conditions have negative effects on several biological processes such as plant respiration and water and nutrient absorption [67][68][69]. The most common symptoms in the aerial part of a plant under hypoxia/anoxia conditions include leaf curling (epinasty) and stem twisting, leaf chlorosis and wilting, marginal browning of the leaf and shedding/defoliation, as well as fruit drop. The physiological consequences of hypoxia are a decrease in stomatal conductance [70] and a reduction of water potential [71]. In woody plants, waterlogging tolerance responses are associated with hypertrophied lenticels, new adventitious roots, and aerenchyma development [72]. These morphological and anatomical changes depend on the intensity, duration, and timing of the flooding cycle [68]. The presence of hypertrophied lenticels is a common anatomical change observed in many woody species [73]. The development of hypertrophied lenticels is supposed to simplify the downward diffusion of O_2 as well as the potential discharge of compounds produced in the roots as by-products of anaerobic metabolism [74].

Oxygen depletion is one of the most important events during flooding. The diminishing in gas diffusion to the root environment as a result of the presence of excessive water in the soil or deprived aeration in soilless cultivations, accompanied by reduction of available oxygen by aerobic processes (i.e., root and microbial respiration), will deprive the rhizosphere of available O_2.

A flood-tolerant plant can overcome the adverse effects of flooding through numerous morphological modifications, such as hyponasty (upward bending of leaves), improved shoot extension, aerenchyma formation, the development of barriers against radial O_2 loss (ROL) in roots, the development of adventitious roots, leaf anatomical changes, and the formation of a gas film on leaf surfaces [75][76]. The formation of adventitious roots improves the plant's adaptation to flooding stress, effectively transports atmospheric O_2 into the roots, and may support or replace the primary root system [75].

Urban environment pollution is also a source of stress in ornamental plants. Urban areas can be highly polluted by human activities. Pollution can be represented by heavy metals derived from heating systems, vehicular traffic, and industrial emissions [77]. Combustion of engines and tire emissions can represent a mobile pollutant source, while industries and heating systems represent fixed sources of pollution [14]. Around pollution sites, the concentration of heavy metals increases. Ornamental plants can have different degrees of pollution tolerance or ability to uptake and degrade them if they are organic pollutants. The use of suitable plant species can recover the visual appearance of polluted areas. The success of green area establishment depends on the tolerance of ornamental plants to the pollutant concentrations. Heavy metals are represented by different elements such as aluminium (Al), arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), mercury (Hg), and zinc (Zn). The tolerance of ornamental plants to heavy metals is strictly connected with the ability of these species to exclude the toxic heavy metals from the uptake or the ability of plants to uptake and translocate heavy metals to organs that can be released, such as older leaves or even fruits [78].

The identification of tolerant ornamental plants at nursery level can be performed by exposing the interested species to increasing concentrations of heavy metals. The biochemical and physiological response of plants allows their classification to different levels of tolerance. The specific markers for the evaluation of tolerance to heavy metals can be the production and accumulation of some protection molecules such as phytochelatins. These proteins can protect the plants by removing metals from the active cell metabolism by chelation, and their biosynthesis is induced by heavy metals accumulation. The phytochelatin biosynthesis is mediated by phytochelatin synthase and starts from glutathione [79]. The activity of this enzyme is regulated by the heavy metals post-translation activation [80]. Heavy metals induce plant stress with the accumulation of free radicals and damage to the cell membrane. The most common radicals are represented by reactive oxygen species (ROS), reactive nitrogen species (RNS), or reactive sulfur species (RSS). The non-specific response can be represented by the increase of the detoxification enzymes such as those belonging to the ascorbate–glutathione cycle.

Free radicals are highly reactive and can damage the cell membrane and the phospholipid double layers. The damage of ROS on the cell membrane is specifically due to loss of compartment integrity and enzymes coming into contact with substrates generating products that can be responsible for several physiological disorders, compromising the visual appearance [81]. Membrane integrity and low lipid peroxidation are also good markers for the estimation of ornamental plant tolerance to heavy metal concentrations. At the nursery level, the selection of plants tolerant to heavy metals is carried out by exposing the plants to increasing doses and monitoring the lipid peroxidation, phytochelatin accumulation, and enzymatic response. The distribution of plants in the planning area must be done considering the concentration and distribution of pollution in the soil.

The shadows of buildings or tall plants in green areas can have negative effects on other plants. Therefore, the combination of different plant species such as herbaceous plants, shrubs, and woody ornamentals must be carefully considered. The visual appearance and aesthetical quality of the area depend on the health status of plants and their correct distribution. It is important to identify the correct exposure to ensure adequate light intensity. Plant distribution and combination must be carried out considering their shading tolerance. Buildings and trees can be responsible for shading and light limitations. Many ornamental plants can have a plasticity degree that allows the adaptation of plants to lower light intensities. At the nursery level, the ornamental plants can be prepared for low-light environments by progressive light reduction using black nets with a shading percentage from 50 to 90%. The intensity of shading depends on the shading in the urban area. The shade adaptation must be achieved by slow light intensity reduction [82]. Plants under shade contribute to the ornamental value through the increase of chlorophyll concentration. At the physiological level, leaves under progressive shading intensity reduce the light compensation point (**Figure 1**). This means that a lower amount of light is required to compensate the respiration process [83]. Ornamental plants that have good light plasticity can be used for green planning in the shaded areas inside urban and peri-urban environments. If plants are not tolerant to shade, under shading conditions, the respiration can be higher than photosynthesis with a negative sugar accumulation balance in a 24 h period. This negative balance, if prolonged, can lead to plant death.

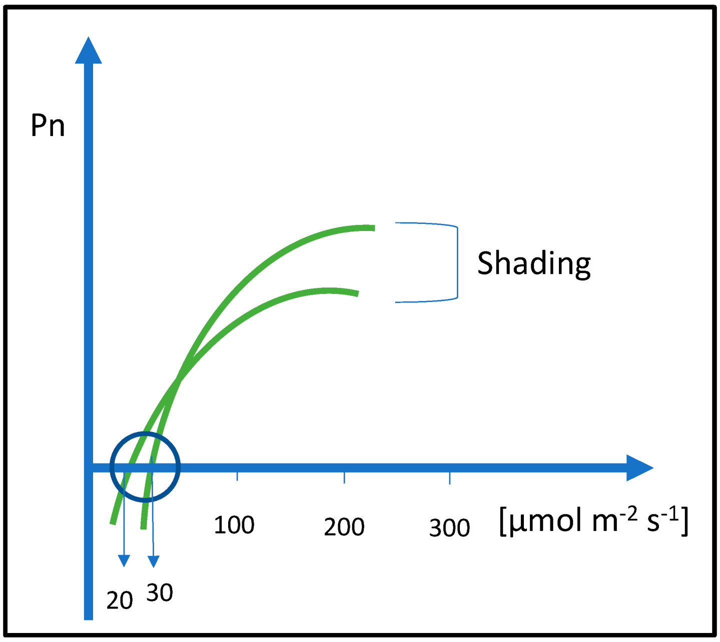

Figure 1. Schematic of light saturation curves and light compensation points lowered by shading treatments. Shading lowers the light compensation point from 30 to 20 µmol m^{-2} s^{-1}. The lowering of light compensation point can require several days or weeks.

High and low temperatures can induce damages that compromise the ornamental value of plants. Temperature is an important environmental parameter that can induce speciation and affect plant distribution in diverse geographical areas. Plant growth and development are tightly correlated with temperature, and many species are synchronised with the environment for foliation and flowering. Each species has an optimal range of development; the minimum and maximum temperatures must be considered in the selection of plant species to use in certain regions or geographical areas. The temperature has a direct impact on primary and secondary metabolism. In an urban context, the reduction of growth is not a problem if there is any change of visual or external quality. In fact, slow growth can reduce the cost of management due to pruning. Unfortunately, the wrong ornamental plant selection exposed to low temperature can suffer cold stress or chilling injury during winter. On the contrary, plant species sensitive to high temperature, as well as for low temperature, can also show some physiological disorders such as leaf abscission or senescence.

Cold stress can be dramatically deleterious depending on the phenological stage of plants. Deciduous ornamental plants are strongly tolerant to low temperatures during winter when they are in the dormant stage. In spring, if new vegetation appears early, eventual low temperatures can induce chilling injury. Based on temperature data recorded in recent years, it is possible to distribute plants in areas considering their sensitivity to low temperatures. The combination of ornamental species from woody trees, shrubs, and herbaceous plants can protect each other.

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