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To cite this version:

Frederic Lens, Catherine Picon-Cochard, Chloé E. L. Delmas, Constant Signarbieux, Alexandre Buttler, et al.. Herbaceous angiosperms are not more vulnerable to drought-induced embolism than angiosperm trees. Plant Physiology, 2016, 172 (2), pp.661-667. 10.1104/pp.16.00829 . hal-02638426

Plant Physiology Preview. Published on June 7, 2016, as DOI:10.1104/pp.16.00829

short title: Embolism resistance in herbs

Herbaceous angiosperms are not more vulnerable to drought-induced embolism than angiosperm trees

Frederic Lens[a], Catherine Picon-Cochard[b], Chloé E. L. Delmas[c], Constant Signarbieux[d,e], Alexandre Buttler[d,e], Hervé Cochard[f], Steven Jansen[g], Thibaud Chauvin[f,h], Larissa Chacon Doria[a], Marcelino del Arco[i], Sylvain Delzon[j]

[a]Naturalis Biodiversity Center, Leiden University, P.O. Box 9517, 2300RA Leiden, the Netherlands; [b]INRA UR874 Grassland Ecosystem Research, F-63039 Clermont-Ferrand cedex 2, France; [c]UMR SAVE, INRA, BSA, Univ. Bordeaux, 33882 Villenave d'Ornon, France; [d]School of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Ecological Systems Laboratory (ECOS), Station 2, 1015 Lausanne, Switzerland; [e]Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Site Lausanne, Station 2, 1015 Lausanne, Switzerland; [f]PIAF, INRA, Univ. Clermont Auvergne, 63100 Clermont-Ferrand, France; [g]Institute of Systematic Botany and Ecology, Ulm University, Albert-Einstein-Allee 11, D-89081, Ulm, Germany; [h]AGPF, INRA Orléans, 45166 Olivet Cedex, France; [i]Department of Plant Biology (Botany), La Laguna University, 38071 La Laguna, Tenerife, Spain; [j]BIOGECO INRA, Univ. of Bordeaux, 33610 Cestas, France.

Corresponding author

dr. Frederic Lens; email: frederic.lens@naturalis.nl; tel: 0031 683172643

Author contribution

F.L., H.C. and S.D. designed research; F.L., C.P.C., C.S., A.B., S.J., T.C., L.C.D., and M.D.A. performed experiments; C.E.L.D., H.C. and S.D. analysed data; and F.L. wrote the paper with contributions from all the authors.

Funding information

This project was funded by the Climagie project within the Metaprogramme Adaptation of Agriculture and Forests to Climate Change (AAFCC) of the French National Institute for Agriculture Research (INRA), and by the programme 'Investments for the Future' (ANR-10-EQPX-16, XYLOFOREST) from the French National Agency for Research. The Swiss contribution was part of the project GrassAlt, funded by the Swiss National Science Foundation (SNF CR31I3_156282/1). FL received support from the Alberta Mennega Foundation.

One sentence summary

Herbs display a wide range of embolism resistance, and do not show pronounced embolism formation throughout the growing season.

Summary

The water transport pipeline in herbs is assumed to be more vulnerable to drought than in trees due to the formation of frequent embolisms (gas bubbles), which could be removed by the occurrence of root pressure, especially in grasses. Here, we studied hydraulic failure in herbaceous angiosperms by measuring the pressure inducing 50% loss of hydraulic conductance (P_{50}) in stems of 26 species - mainly European grasses (Poaceae). Our measurements show a large range in P_{50} from -0.5 to -7.5MPa, which overlaps with 94% of the woody angiosperm species in a worldwide, published dataset, and which strongly correlates with an aridity index. Moreover, the P_{50} values obtained were substantially more negative than the midday water potentials for five grass species monitored throughout the entire growing season, suggesting that embolism formation and repair are not routine and mainly occur under water deficits. These results show that both herbs and trees share the ability to withstand very negative water potentials without embolism formation in their xylem conduits during drought stress. In addition, structure-function trade-offs in grass stems reveal that more resistant species are more lignified, which was confirmed for herbaceous and closely related woody species of the daisy group (Asteraceae). Our findings could imply that herbs with more lignified stems will become more abundant in future grasslands under more frequent and severe droughts, potentially resulting in lower forage digestibility.

Terrestrial biomes provide numerous ecosystem services to humans, such as biodiversity refuges, forage supply, carbon sequestration and associated atmospheric feedbacks (Bonan et al., 2008). Drought frequency and severity are predicted to increase across various ecosystems (Dai, 2013), and its impact on the fate of terrestrial biomes has aroused great concern for stakeholders over the past decade. For instance, world-wide forest declines have been associated with drought events (Allen et al., 2010), and the sustainability of grasslands - one of the most important agro-ecosystems representing 26% of the world land area - is threatened due to increasing aridity in the light of climate change (Tubiello et al., 2007; Brookshire and Weaver, 2015). Since the maintenance of grasslands is of prime importance for livestock, and several of the most valuable crops are grasses, herbaceous species deserve more attention from a hydraulic point of view to understand how they will cope with shifts in precipitation and temperature patterns.

During water deficit, hydraulic failure in trees has been put forward as one of the primary causes of forest decline (Anderegg et al., 2015, 2016). Drought exacerbates the negative pressure inside the water conducting cells, making the liquid xylem sap more metastable, and thus more vulnerable to air-entry (i.e., gas embolism; Lens et al., 2013). Extensive levels of embolisms may lead to desiccation, leaf mortality, branch sacrifice and ultimately plant death (Barigah et al., 2013; Urli et al., 2013). Plant resistance to embolism is therefore assumed to represent a key-parameter in determining the drought tolerance of trees and is estimated using so-called vulnerability curves (VCs), from which the P_{50} - i.e. the sap pressure inducing 50% loss of hydraulic conductivity - can be estimated (Cochard et al., 2013). P_{50} values are therefore good proxies for drought stress tolerance in woody plants and have been published for hundreds of angiosperm and gymnosperm tree species (Delzon et al., 2010; Choat et al., 2012), illustrating a wide range from -0.5 to -19MPa (Larter et al., 2015).

Studies focusing on P_{50} values of herbs are limited to stems of circa 14 angiosperm species (see Table S1 and references cited therein). Half of the herbaceous angiosperms studied so far (see Table S1) have a stem P_{50} between 0 and -2MPa, indicating that many herbs are highly vulnerable to embolism. Moreover, positive root pressure has been reported in various herbs – including many grasses (Poaceae) with hydathodes in their leaves (Evert, 2006) – and root pressure is hypothesised to refill embolized conduits overnight when transpiration is low (Miller et al., 1985; Neufeld et al., 1992; Cochard et al., 1994; Macduff and Bakken 2003; Saha et al., 2009; Cao et al., 2012). This could suggest that embolism formation and repair follow a daily cycle in herbs. In other words, the midday water potential that herbs experience in the field may often be more negative than P_{50}, which would result in an extremely vulnerable hydraulic pipeline characterised by a negative hydraulic safety margin (expressed as the minimum midday water potential - P_{50}). In contrast to herbs, most trees operate at a slightly positive hydraulic safety margin (Choat et al., 2013), and woody plants are often too tall to allow refilling by positive root and/or pressure in the upper stems (Ewers et al., 1997; Fisher et al., 1997). It could therefore be postulated that herbaceous species possess a hydraulic system that is more vulnerable to embolism than that of woody species. In this study, we want to underpin possible differences in embolism resistance between stems of herbaceous and woody angiosperms.

The scarcity of P_{50} measures in herbaceous angiosperms – including grasses and herbaceous eudicots – is mainly due to their fragile stems and low hydraulic conductivity, making VCs technically more challenging. Using minor adaptations to existing centrifuge techniques (see Supplemental Text S1), we obtained a P_{50} stem dataset of 26 herbaceous angiosperm species (mainly grasses) from various collection sites in France and Switzerland. In addition, we compared our dataset with published data from woody (gymnosperm and angiosperm) species, confronted some of our herbaceous eudicot measurements with original P_{50} data from derived, woody relatives, and we performed anatomical observations in grasses to investigate a possible link between stem anatomical characters and differences in P_{50} among the species studied. Three main research questions are central in our paper: (i) are stems of herbaceous angiosperms more vulnerable to embolism than those of woody angiosperms?; (ii) do grasses operate with highly vulnerable, negative hydraulic safety margins?; and (iii) do grasses show structure-function trade-offs in their stems with respect to embolism resistance?

RESULTS AND DISCUSSION

Comparable P_{50} Range in Herbs Compared to Woody Species

Our herbaceous dataset including 26 angiosperm species reveals a broad range in P_{50} from -0.5MPa to -7.5MPa (Fig. 1). If we compare the overlap between the range of this herbaceous dataset and the range observed in a large, published woody dataset (including P_{50} values of 404 woody angiosperm and gymnosperm species, see Material and Methods, Table S2), 89% of the woody species fall within this 0.5-7.5MPa range. This P_{50} overlap further increases to 94% when only the woody angiosperms are taken into account (301 species). Since herbaceous species (N = 28, Spearman's r = 0.6003, P = 0.0007) as well as woody species (N = 124, Spearman's r = 0.6006, $P < 0.0001$) with a more negative P_{50} grow in drier environments (lower aridity index; Fig. 2), we expect that further sampling of herbs from (semi-)desert-like environments will further increase the P_{50} range towards more negative extremes. This would generate an even stronger overlap in P_{50} between herbaceous and woody plants. Generally, we find that herbaceous angiosperms (mean P_{50} = -2.93MPa, CV = 57%) are significantly more vulnerable to embolism than woody species, including angiosperms and gymnosperms (mean P_{50} = -4.07MPa, CV = 62%; $F_{1,441}$ = 7.64, P = 0.0059; Fig. S1). However, when splitting up the dataset into grasses (Poaceae, mean P_{50} = -3.37MPa, CV = 57%), herbaceous eudicots (mean P_{50} = -2.3MPa, CV = 43%), woody angiosperms (mean P_{50} = -3.57MPa, CV = 59%), and woody gymnosperms (mean P_{50} = -5.55MPa, CV = 55%), only the woody gymnosperms are different from the rest (Fig. 3, Tables S1 and S2), while the differences between grasses, herbaceous eudicots and woody angiosperms are not significant (Table S3); especially the similarity in stem P_{50} between grasses and woody angiosperms is remarkable (LS-Means differences P=0.98; Table S3). These results emphasise that both herbaceous and woody angiosperms share the ability to withstand low water potentials without experiencing embolism formation in their xylem conduits during water deficit (Fig. 3).

Hydraulic Safety Margins in Stems of Grasses are Positive

We assessed the range of native embolism in five grass species with a P_{50} between -3 and -4.5MPa from the Swiss field sites (Table 1). Therefore, we measured the midday leaf water potential throughout the entire growing season from April to October, and related these values with their VCs in order to estimate native embolism over the operating range of water potential. Interestingly, midday leaf water potentials in spring were substantially less negative than P_{50}, suggesting very low levels of native embolism (< 16% loss of hydraulic conductance; Tables 1, S4). This contradicts the general assumption that grasses undergo daily or short-term embolism/repair cycles during mild conditions. Furthermore, the most negative leaf water potential (Psi min), experienced by the plants during the driest period of the year (July), corresponded to low levels of native embolism in the stems, ranging from 10 to 22% loss of hydraulic conductance, which is far below 50% as defined by P_{50} (Table 1). Consequently, midday leaf water potential data in the five grass species studied show evidence for positive hydraulic safety margins varying from 1.40 to 2.19MPa (Table 1).

In summary, our data suggest that daily embolism/repair cycles in grasses are not the rule throughout the growing season, at least not in stems, despite ample evidence for positive root pressure in grasses (Neufeld et al., 1992; Cochard et al., 1994; Miller et al., 1995; Saha et al., 2009; Cao et al., 2012). The broad range in embolism resistance of the grasses studied, in combination with these low levels of native embolism in the moderately resistant grasses studied suggest that embolism refilling may play a less significant role for grasses than previously thought (Cao et al., 2012). In other words, our findings suggest that frequent cycles of xylem embolism and repair are not pronounced in grasses, which is in agreement with observations in woody plants (Wheeler et al., 2013; Sperry, 2013; Delzon and Cochard, 2014). If the Psi min monitoring in our five grass species studied could be confirmed in a broader sampling of herbaceous species, this would raise questions about the generally accepted role of root pressure in repairing embolised conduits. Root pressure may simply be a byproduct of nutrient absorption by roots, allowing water transport via a leaky hydraulic pipeline with hydathodes. Evidently, root pressure needs to be quantified in relation to P_{50} and midday leaf/stem water potentials across a broad sampling of herbaceous species to better understand this enigmatic phenomenon. Moreover, we should know more about the specific climatic conditions under which root pressure development is physically possible, since drought will decrease the soil water content (Table S4), making root pressure more challenging.

Despite the observed conservative nature of embolism/refilling cycles in the grass stems studied, Holloway-Phillips and Brodribb (2011) showed that *Lolium perenne* – one of our Swiss species studied – operates very close to its hydraulic limits based on whole leaf hydraulic data, suggesting a hydraulic decoupling between stem and leaves. While the stem P_{50} reaches -3.21MPa in the individuals we studied (Table S1), the authors found a vulnerable whole leaf P_{50} (leaf P_{50}: -1MPa; leaf P_{95}: -2.2MPa), and complete stomatal closure happened very late at -2.35MPa. In other words, while our stem observations for *Lolium perenne* indicate no or low levels of native embolisms throughout the growing season in combination with a positive safety margin, leaf hydraulic measures suggest much narrower or even negative hydraulic safety margins. This contradicting result could be explained by recent papers on leaf hydraulics, showing that the observed decrease in hydraulic conductance in needles and leaves is not due to xylem embolism but rather to a conductivity drop in the extra-xylary pathway (Bouche et al., 2016; Scoffoni, personal communication). This suggests that there are no robust assessments of leaf vulnerability to embolism so far, but it is expected that the new optical technique developed by Brodribb et al. (2016) will shed new light into better understanding the hydraulic connection between stems and leaves.

Embolism Resistance in Herbs Comes at a Lignification Cost

Based on our 20 herbaceous species for which we have anatomical observations (mainly based on internode cross sections of grasses; Tables S1, S5, S6), Fig. 4 shows that the more resistant herbs have a higher proportion of lignified tissue in their stems (*P* =

0.0066, partial $R^2 = 0.40$; Figs. 4 a-d) and develop thicker cell walls in the fibres of this lignified zone ($P = 0.0005$, partial $R^2 = 0.57$; Figs. 4 a-c, e). When only the grass dataset is analysed, the relative proportion of lignified tissue becomes marginally significant ($P = 0.0457$, partial $R^2 = 0.32$), while the relative proportion of cell wall per lignified fibre remains highly significant ($P = 0.0014$, partial $R^2 = 0.62$; Table S6). Therefore, we argue that developing embolism resistant stems in herbs requires upregulation of the energy-consuming lignin pathway, which is a costly process. The relative size of the pith, and the hydraulically weighted (metaxylem) vessel diameter did not significantly contribute to variation in P_{50}. Likewise, there was no trade-off between P_{50} and the intervessel pit membrane thickness between adjacent metaxylem vessels in vascular bundles of six selected grass species, which ranged from on average 131nm in *Lolium perenne* to 313nm in *Elytrigia repens* ($F_{1,4} = 0.03$, $P = 0.87$). This is unexpected considering the strong evidence for functional relevance of intervessel pit membrane thickness amongst woody angiosperms (Jansen et al., 2009; Lens et al., 2011, 2013; Li et al., 2016).

The distribution pattern of lignified tissues between grasses and herbaceous eudicots is completely different. In grasses, lignification is mainly confined to the outer parts of the stems along the entire axis (Fig. 4A–C), and is related to provide mechanical strength and perhaps also to avoid water loss during periods of drought. Lignification in the herbaceous eudicots, however, is concentrated in the narrow wood cylinder at the base of the stem (Lens et al., 2012ab; Kidner et al., 2016; Fig. S2A, B). Our anatomical dataset, including mainly grass species, shows that lignification scales positively with embolism resistance. The link between increased embolism resistance and increased lignification has also been experimentally demonstrated in the herbaceous eudicot *Arabidopsis thaliana* (Lens et al., 2013; Tixier et al., 2013), in several transgenic poplars modified for lignin metabolism (Awad et al., 2012), and is further corroborated in this study by comparing the vulnerable, herbaceous daisies *Chamaemelum* (P_{50} -2.6MPa) and *Leucanthemum* (P_{50} -2.5MPa) with closely related members of the derived, more embolism resistant, woody genus *Argyranthemum* (P_{50} between -3 and -5.1MPa; Fig. S2A, C). Based on these observations, it seems that plants invest more energy resources to develop a mechanically stronger, embolism resistant stem (Lens et al., 2013), which is in agreement with previous studies linking embolism resistance with higher wood densities and thickness-to-span ratios of water conducting cells (Hacke et al., 2001), and thicker interconduit pit membranes (Jansen et al., 2009; Lens et al., 2011, 2013; Li et al., 2016). Likewise, intervessel pit membranes of the embolism resistant, woody *Argyranthemum* species are thicker than in the more vulnerable, herbaceous *Leucanthemum* and *Chamaemelum* (between on average 370-485nm vs 290-350nm, respectively).

However, more lignification/wood formation is not per definition needed to obtain a higher level of embolism resistance across flowering plants: the Gentianaceae sister pair *Blackstonia perfoliata* (herbaceous) and *Ixanthus viscosus* (woody) shows a similar P_{50} value (-4.5MPa), despite the marked difference in wood formation (Fig. S2B, D). Likewise, some other woody eudicot lineages that have evolved from herbaceous relatives grow in extremely wet environments, such as *Cyrtandra* (Cronk et al., 2005) or *Begonia* (Kidner et al., 2016). Also in ferns, where a thick ring of sclerenchyma fibres is located just below the epidermis of the leaf rachis – comparable to the situation in grass stems – no structural investment trade-offs in vulnerability to embolism were found (Watkins et al., 2010; Pittermann et al., 2011).

In conclusion, there is a remarkable range in P_{50} amongst 26 herbaceous species, overlapping with 94% of woody angiosperm species in a published dataset. The large variation in P_{50} in herbs and trees scales tightly with climatic conditions. Despite the potential refilling capacity by root pressure, embolism formation in grasses does not seem to be common throughout the growing season. This suggests that herbs and woody plants are more similar in their ability to avoid drought-induced embolism than previously expected, especially within the angiosperms. We also found that embolism resistance generally comes at a lignification cost in herbs. This could lead towards selection for species with more lignified stems in future grasslands that have to cope with more frequent and intensive droughts, potentially resulting in a lower forage digestibility.

MATERIAL AND METHODS

Sampling Strategy

In total, 26 herbaceous angiosperm species, including 18 grass species (family Poaceae) and eight eudicots, and four woody angiosperm species were investigated. Details about species and sampling sites are given in Supplemental Text S1 and Table S1. Canary Island species were collected in order to compare stem anatomy and P_{50} values of some of the herbaceous eudicots with closely related, woody descendants. Examples are *Argyranthemum* species that have evolved within the largely herbaceous daisy group including amongst others *Chamaemelum* and *Leucanthemum* (Fig. 1). Likewise, we studied *Ixanthus viscosus*, a woody Canary Island species that is derived from the herbaceous *Blackstonia* native to continental Europe (Lens et al., 2013; Fig. 1, Table S1). To expand the wood dataset, we used an updated version of the Xylem Functional Traits Database (Choat et al., 2012; Table S2 and references cited therein), in which we removed the angiosperms with long vessels and high P_{50} values (> -1MPa) to account for the vessel length artefact (Cochard et al., 2013), and adopted the P_{50} values with those published in Brendel and Cochard (2011) for 18 species that showed more than 40% intraspecific variation compared to other studies (mainly because of vessel length issues). In addition, we updated the wood dataset with more recent references and with four Canary Island species measured in this study (Table S2).

The variation in habitat among the herbaceous species and the adjusted dataset of Choat et al. (2012) was captured by the Julve index, an aridity index characterizing the edaphic humidity environment that was specifically designed for the French flora (Julve, 1998; http://perso.wanadoo.fr/philippe.julve/catminat.htm, download "French Flora Database (baseflor)", column AD "Humidité_édaphique" corresponding to edaphic humidity). "Baseflor" is a floristic database indexing about 11,000 taxa from the French vascular flora. For each taxon, the database includes phytosociological characteristics and chorological, ecological and biological descriptions. In the "Baseflor" database, the Ellenberg's "F"-values are modified to take into account the French ecological context of each taxon, describing xerophytic to aquatic species (from small to high values). The Julve index was documented for 28 herbaceous species and 124 woody species present in our datasets (Table S2).

Embolism Resistance Measurements

All the species were measured using the centrifuge technique. The static centrifuge technique (Alder et al., 1997) was applied when the conductance was too low (most of the grass species from France), while the cavitron (in-situ flow centrifuge) technique (Cochard et al., 2005) was used for the other species because the hydraulic conductivity was high enough (Table S1). Both centrifuge techniques are explained in

Supplemental Text S1, and S-shaped VCs were fitted according to a sigmoid function (Pammenter and Vander Willigen, 1998).

Leaf Water Potential Measures

For the species of the Swiss collection, midday leaf water potential was determined using a Scholander pressure chamber (SKPM, Skye instruments Ltd, Powys, UK) along the entire growing season 2015 (from April to October) between 11 a.m. and 1 p.m. on sunny days and every two weeks. Then, the minimum midday leaf water potential value experienced in the field for each species was used as minimum water potential (Psi min), which in all cases corresponded to the driest period of the year, i.e. in July.

Anatomical Observations

For all the French (*N* = 20) and Canary Island (*N* = 4) species, cross sections of three individuals per species were made at the level of the internodes according to resin embedding (Hamann et al., 2011) or standard wood sectioning (Lens et al., 2005), respectively, observed with the light microscope, photographed with a digital camera, and measured with ImageJ (Table S5). Details are given in the Supplemental Text S1. We also investigated intervessel pit membrane thickness based on transmission electron microscope (TEM) observations for six selected grass species from the French site with a P_{50} range between -0.5 and -6.2MPa (*Anthoxanthum odoratum*, *Brachypodium pinnatum*, *Elymus campestris, Elytrigia repens*, *Lolium perenne, Phalaris arundinacea*; stored in -20°C freezer before fixation, transverse sections through the nodes), and all the eight eudicot species belonging to the daisy and Gentianaceae lineage. After hydraulic measures, we immediately submerged the stems in Karnovsky fixative (Karnovsky, 1965), and followed the protocol explained in the Supplemental Text S1.

Statistics

The correlation between P_{50} and the aridity index (Fig. 2) was tested using Spearman correlation for herbaceous species ($N = 28$) and woody species ($N = 124$ species) separately (PROC CORR, in SAS Software, SAS University Edition). To assess differences between embolism resistance across plant groups (Fig. 3), we compared P_{50} variability (i) among angiosperms (including grasses, herbaceous eudicots, woody angiosperms) and gymnosperms, and (ii) between herbaceous species and woody species using General Linear Models (PROC GLM). For the first type of analysis (i), we used post-hoc least squares means using the ‘Tukey-Kramer’ approximation adapted for multiple comparisons with unbalanced sample sizes (Table S3).

We used multiple regression analyses (PROC REG) to test the contribution of anatomical features (independent variables) to P_{50} variability (dependent variable). Several of the anatomical features measured were correlated because many of them were merged to calculate additional traits. To select predictive factors, we screened for multi-collinearity by calculating variance inflation factors in multiple regression analyses (VIF option in PROC REG). This resulted in four predictive characters in our model: proportion of lignified tissues compared to entire stem diameter, proportion of pith compared to entire stem area, proportion of cell wall per fibre, hydraulically weighted (metaxylem) vessel diameter. The VIFs for the predictor variables in our regression model were <2, which indicates that multi-collinearity did not cause a loss of precision. This multiple regression model was applied independently to the 16 grasses and 20 herbaceous species for which we measured anatomical features (Tables S1, S5, S6). Finally, we tested the relationship between P_{50} and intervessel pit membrane thickness between metaxylem vessels in six grass species using a simple linear regression.

TABLES

Table 1. Embolism is not pronounced in grasses. Summary of hydraulic parameters for grasses from the Swiss collections, including mean leaf water potential during three time points in spring time (mean $\text{Psi}_{\text{midday}}$ during spring time), its corresponding native levels of embolism ($\text{PLC}_{\text{midday}}$, %), the minimum leaf water potential measured throughout the growing season (= Psi_{min}), and its corresponding PLC. Values are means ± 1 SE for n=6. More detailed information throughout the growing season is provided in Table S4.

Species	P_{50} (MPa)	Mean $\text{Psi}_{\text{midday}}$ in spring time (MPa)	Mean $\text{PLC}_{\text{midday}}$ in spring time (%)	Psi_{min} (MPa)	PLC at Psi_{min} (%)
Dactylis glomerata	-3.49	-1.47 ± 0.06	14.56 ± 0.67	-2.06 ± 0.14	22.30 ± 2.22
Lolium perenne	-3.21	-1.37 ± 0.03	15.80 ± 0.35	-1.81 ± 0.05	21.75 ± 0.73
Phleum pratense	-3.84	-1.24 ± 0.12	5.51 ± 0.86	-1.90 ± 0.10	10.49 ± 1.05
Poa pratensis	-3.65	species not yet growing	species not yet growing	-2.06 ± 0.15	11.06 ± 2.18
Agrostis capillaris	-4.50	-2.05 ± 0.15	8.98 ± 1.20	-2.31 ± 0.14	11.06 ± 1.20

FIGURE LEGENDS

Figure 1. P_{50} values of species measured. The range in P_{50} among the 26 herbaceous and 4 woody species studied varies from -0.5 up to -7.5MPa. Light green bars indicate grasses (Poaceae), dark green bars represent herbaceous eudicots and the orange ones are woody eudicot shrubs that have evolved from some of the herbaceous relatives studied (*daisy lineage, **gentian lineage). Each bar represents the average value for three specimens of the same species and error bars show SE.

Figure 2. P_{50} versus aridity index in herbs and woody species. Herbaceous as well as woody species that are more resistant to embolism formation (more negative P_{50}) grow in drier environments (lower aridity index; Julve, 1998). P_{50} values were averaged for each plant group every 2MPa (light green diamonds: grasses; dark green triangles: herbaceous eudicots; orange circles: woody angiosperms; brown triangles: woody gymnosperms). Error bars show SE.

Figure 3. Boxplots showing P_{50} range amongst different plant groups. There is a striking similarity in P_{50} between grasses, herbaceous eudicots, and woody angiosperms. On the other hand, woody gymnosperms have a statistically more negative P_{50} than each of the angiosperm groups. Mean values are shown with either a cross (grasses), triangle (herbaceous eudicots), circle (woody angiosperms) or plus sign (woody gymnosperms), 'a' and 'b' indicate statistical differences (Table S3).

Figure 4. Lignification and P_{50}. A-C, Cross sections of hollow stems through the internodes of the grasses *Phalaris arundinacea* (A, P_{50} = -0.5MPa), *Lolium perenne* (B, P_{50} = -4.6MPa), and *Brachypodium pinnatum* (C, P_{50} = -6.2MPa), showing more lignification in the outer zones of the stems (arrows), and thicker-walled fibres (inserts) with increasing P_{50}. D-E, Grasses and herbaceous eudicots that are more resistant to embolism have a higher proportion of lignified tissues in their stems (D) and thicker-walled fibres (E). Error bars show SE (only lower limits are presented for clarity purposes, each point represents the average value for three specimens of the same species). Marked zones apply to the 95% confidence limit of the regression. See Table S6 for multiple regression analysis of P_{50} and anatomical features as predictive variables.

Supplemental Data

The following supplemental data are available.

Supplemental Figure S1. Global P_{50} comparison between herbs and woody species.

Supplemental Figure S2. Differences in anatomy between herbs and related woody species.

Supplemental Table S1. P_{50} dataset of herbaceous species from our study and published papers.

Supplemental Table S2. Entire P_{50} and Julve dataset of woody and herbaceous species from our study and published papers.

Supplemental Table S3. Post-hoc comparisons of P_{50} LS-Means across species groups (see Fig. 3).

Supplemental Table S4. Hydraulic measures throughout the growing season for the five Swiss grass species.

Supplemental Table S5. List of the anatomical measurements carried out for the species in this study (3 replicates per species).

Supplemental Table S6. Multiple regression model of anatomical features as explaining factors of P_{50} variability in herbaceous species and grass species.

Supplemental Text S1. More detailed Material and Method descriptions about sampling strategy, embolism resistance measurements, and anatomical observations.

ACKNOWLEDGMENTS

We thank MSc student Jérémy Rivière for his measurements on 16 grasses from the French sites, and the two reviewers for their valuable feedback. This article is supported by COST Action FP1106 STReESS.

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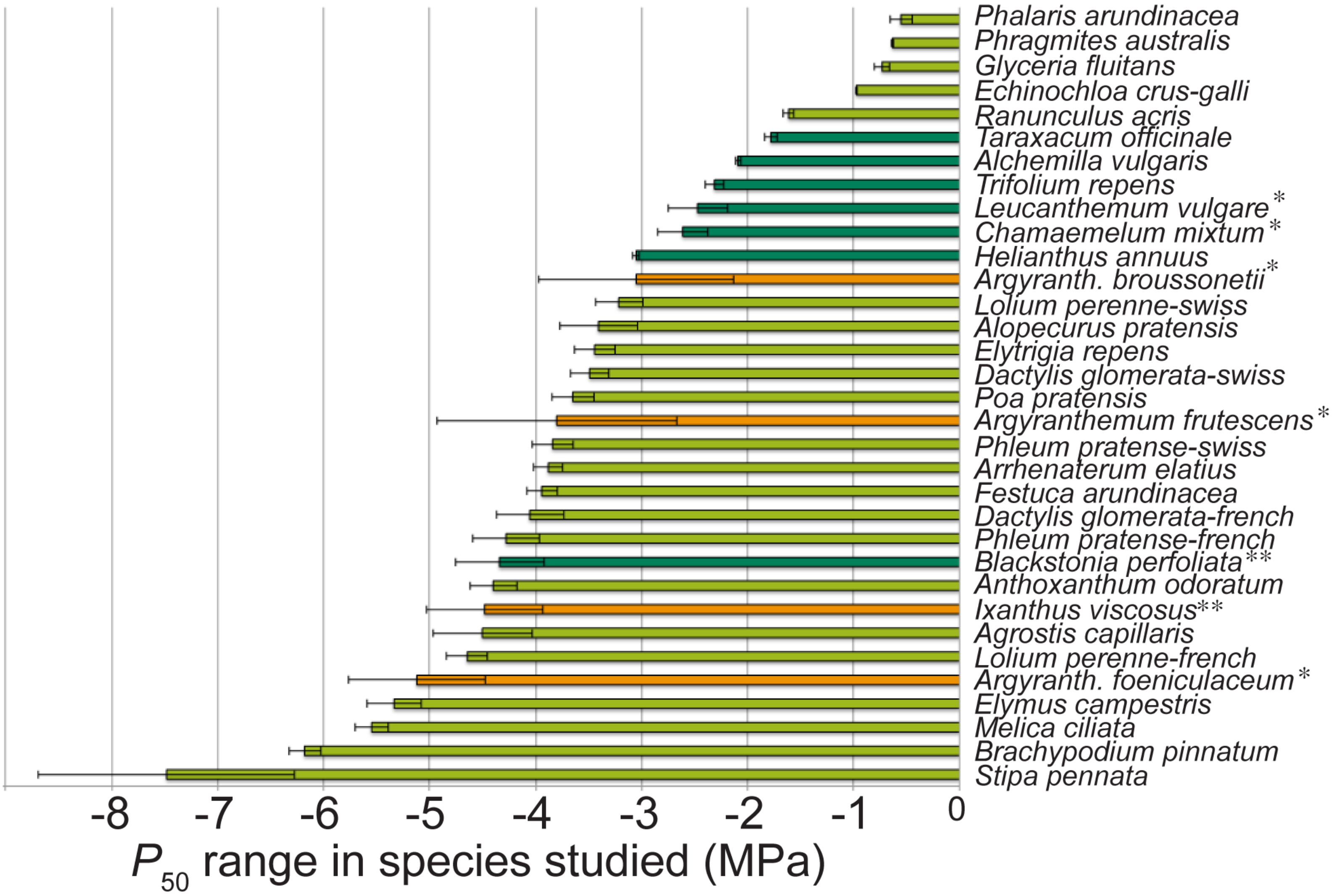

Figure 1. P50 values of species measured. The range in P50 among the 26 herbaceous and 4 woody species studied varies from -0.5 up to -7.5MPa. Light green bars indicate grasses (Poaceae), dark green bars represent herbaceous eudicots and the orange ones are woody eudicot shrubs that have evolved from some of the herbaceous relatives studied (*daisy lineage, **gentian lineage). Each bar represents the average value for three specimens of the same species and error bars show SE.

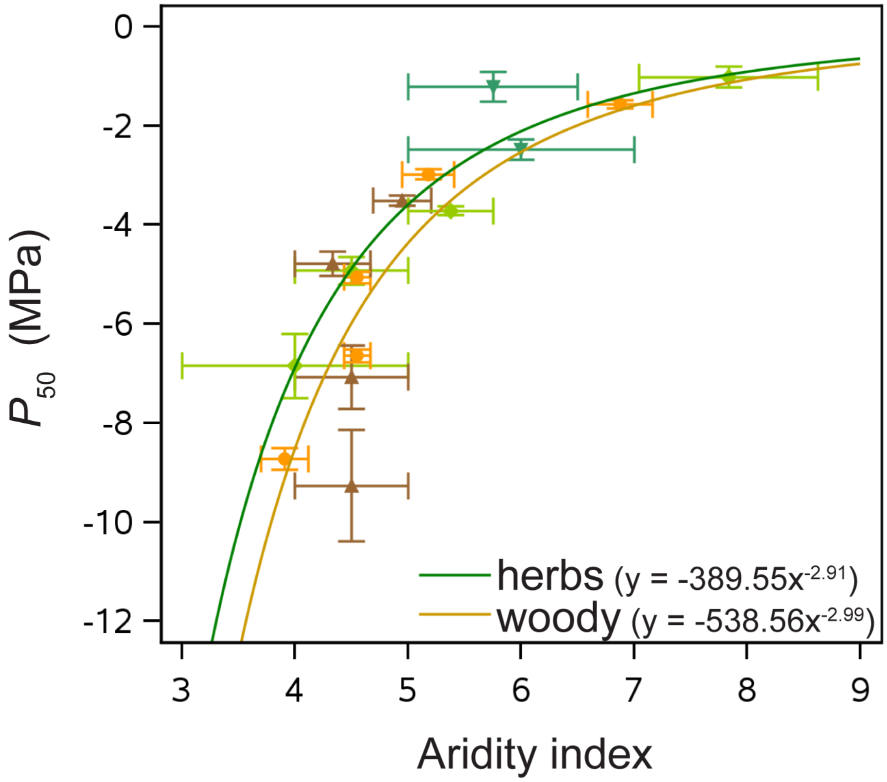

Figure 2. P50 versus aridity index in herbs and woody species. Herbaceous as well as woody species that are more resistant to embolism formation (more negative P50) grow in drier environments (lower aridity index; Julve, 1998). P50 values were averaged for each plant group every 2 MPa (light green diamonds: grasses; dark green triangles: herbaceous eudicots; orange circles: woody angiosperms; brown triangles: woody gymnosperms). Error bars show SE.

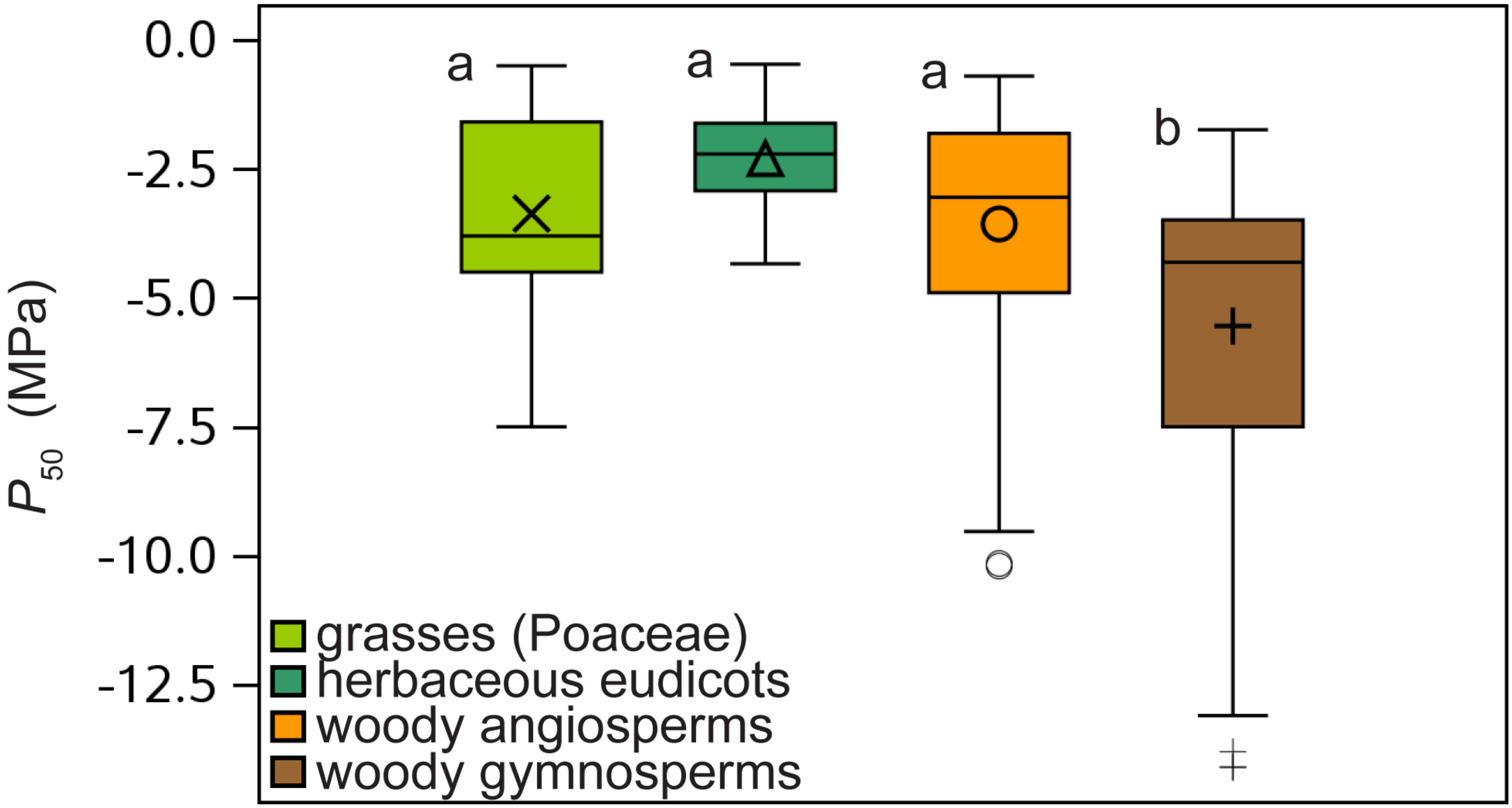

Figure 3. Boxplots showing P50 range amongst different plant groups. There is a striking similarity in P50 between grasses, herbaceous eudicots, and woody angiosperms. On the other hand, woody gymnosperms have a statistically more negative P50 than each of the angiosperm groups. Mean values are shown with either a cross (grasses), triangle (herbaceous eudicots), circle (woody angiosperms) or plus sign (woody gymnosperms), 'a' and 'b' indicate statistical differences (Table S3).

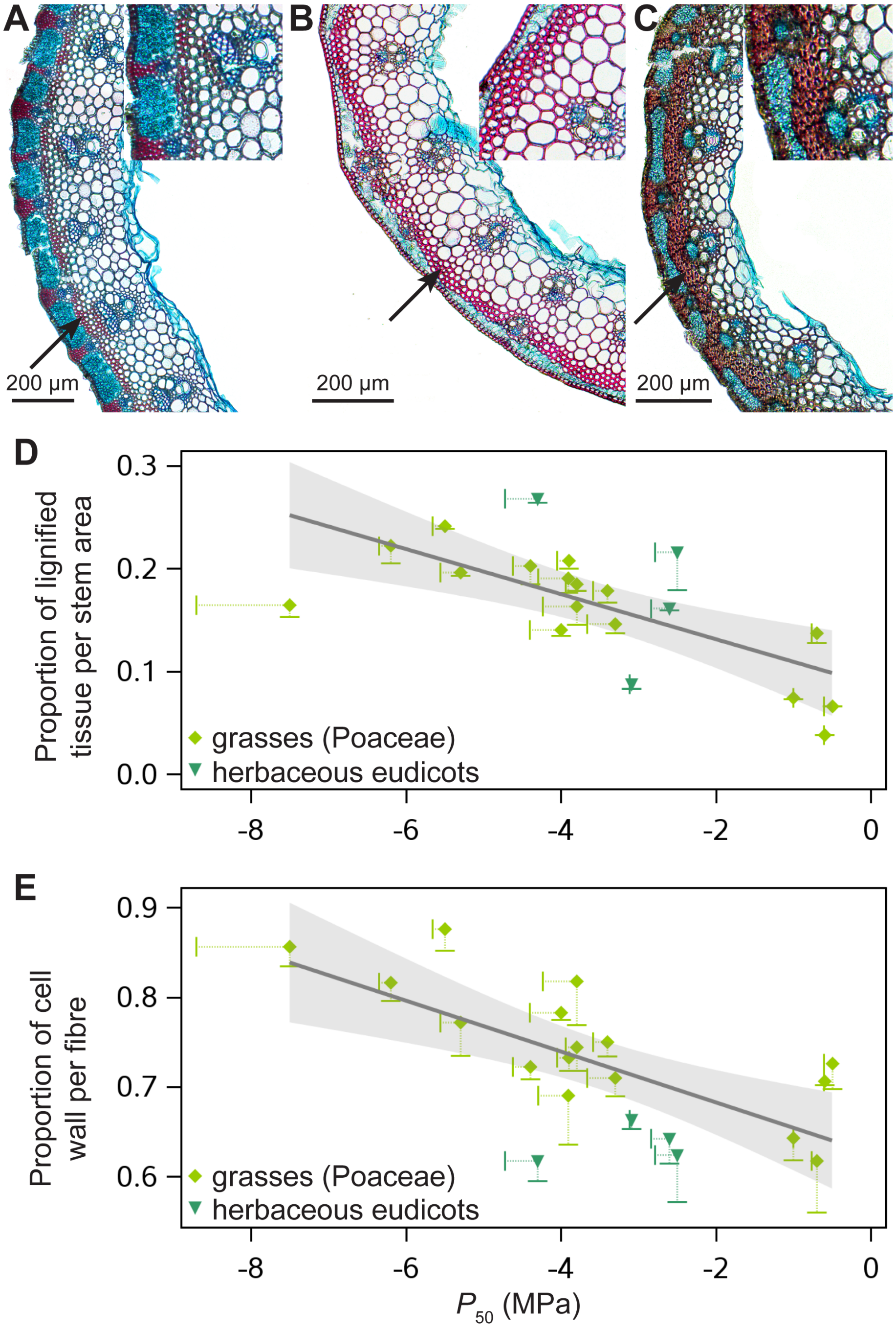

Figure 4. Lignification and P50. A-C, Cross sections of hollow stems through the internodes of the grasses Phalaris arundinacea (A, P50 = -0.5MPa), Lolium perenne (B, P50 = -4.6MPa), and Brachypodium pinnatum (C, P50 = -6.2MPa), showing more lignification in the outer zones of the stems (arrows), and thicker-walled fibres (inserts) with increasing P50. D-E, Grasses and herbaceous eudicots that are more resistant to embolism have a higher proportion of lignified tissues in their stems (D) and thicker-walled fibres (E). Error bars show SE (only lower limits are presented for clarity purposes, each point represents average value for three specimens of the same species). Marked zones apply to the 95% confidence limit of the regression. See Table S5 for multiple regression analysis of P50 and anatomical features as predictive variables.

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Supplemental Data

Herbaceous angiosperms are not more vulnerable to drought-induced embolism than angiosperm trees

Authors

Frederic Lens, Catherine Picon-Cochard, Chloé E. L. Delmas, Constant Signarbieux, Alexandre Buttler, Hervé Cochard, Steven Jansen, Thibaud Chauvin, Larissa Chacon Doria, Marcelino del Arco, Sylvain Delzon

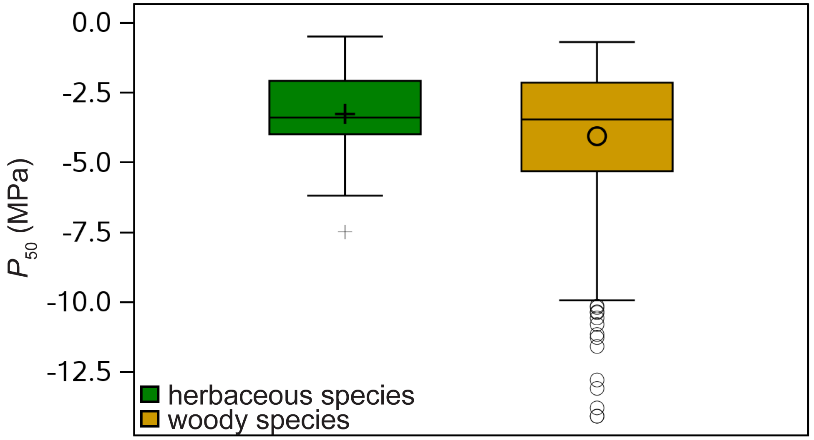

Figure S1. Global P_{50} comparison between herbs and woody species. Based on all available P_{50} data for stems, the herbaceous species (only angiosperms) are significantly more vulnerable to embolism than woody species (angiosperms and gymnosperms).

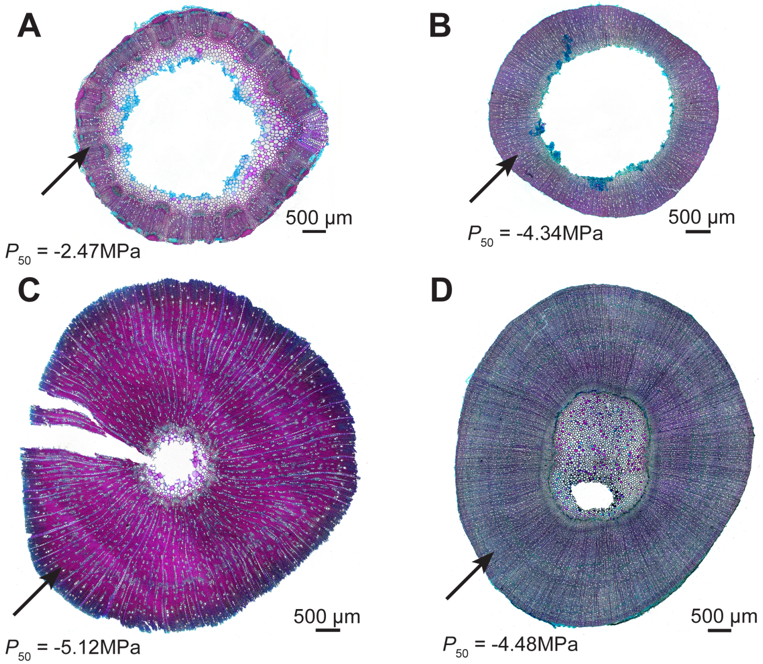

Figure S2. Differences in anatomy between herbs and related woody species. A and C, variation within the daisy lineage (Asteraceae): the herbaceous *Leucanthemum vulgare* (A) and woody *Argyranthemum foeniculaceum* (C). B and D, variation within a sister pair in Gentianaceae: the herbaceous *Blackstonia perfoliata* (B) and woody *Ixanthus viscosus* (D). Pictures are taken at the same magnification. Arrows indicate the wood cylinder.

Supplementary Tables

Table S1. P_{50} dataset of herbaceous species from our study and published papers.

Group	Species	Origin	P_{50} (Mpa)	Shape VC curve	Method used	Anatomical observations	Reference
Monocots: Poaceae	*Agrostis capillaris*	Swiss Jura Mountains, Combe des Amburnex, Switzerland	-4.5	S-shaped	cavitron	no	this study
Monocots: Poaceae	*Alopecurus pratensis*	French Massif Central, St Genès Champanelle, France	-3.3	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Anthoxanthum odoratum*	French Massif Central, St Genès Champanelle, France	-4.4	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Arrhenaterum elatius*	French Massif Central, St Genès Champanelle, France	-3.8	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Brachypodium pinnatum*	French Massif Central, Montrognon, Ceyrat, France	-6.2	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Dactylis glomerata-French accession*	French Massif Central, St Genès Champanelle, France	-4.1	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Dactylis glomerata-Swiss accession*	Swiss Jura Mountains, Saint-George, Switzerland	-3.48	S-shaped	cavitron	no	this study
Monocots: Poaceae	*Echinochloa crus-galli*	Artière river border, Clermont-Ferrand, France	-1.0	S-shaped	cavitron	yes	this study
Monocots: Poaceae	*Elymus campestris*	Campus INRA , Clermont-Ferrand, France	-5.3	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Elytrigia repens*	French Massif Central, St Genès Champanelle, France	-3.4	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Festuca arundinacea*	French Massif Central, St Genès Champanelle, France	-3.9	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Glyceria fluitans*	Artière river border, Clermont-Ferrand, France	-0.7	S-shaped	cavitron	yes	this study
Monocots: Poaceae	*Lolium perenne-French accession*	French Massif Central, St Genès Champanelle, France	-4.6	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Lolium perenne-Swiss accession*	Swiss Jura Mountains, Saint-George, Switzerland	-3.21	S-shaped	cavitron	no	this study
Monocots: Poaceae	*Melica ciliata*	Campus INRA, Clermont-Ferrand, France	-5.5	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Phalaris arundinacea*	Artière river border, Clermont-Ferrand, France	-0.5	S-shaped	cavitron	yes	this study

Monocots: Poaceae	*Phleum pratensis-French accession*	French Massif Central, St Genès Champanelle, France	-4.2	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Phleum pratensis-Swiss accession*	Swiss Jura Plateau, Chéserex, Switzerland	-3.84	S-shaped	cavitron	no	this study
Monocots: Poaceae	*Phragmites australis*	Artière river border, Clermont-Ferrand, France	-0.6	S-shaped	static centrifuge	yes	this study
Monocots: Poaceae	*Poa pratensis*	Swiss Jura Mountains, Saint-George, Switzerland	-3.65	S-shaped	cavitron	no	this study
Monocots: Poaceae	*Stipa pennata*	Larzac Causse in Mediterranean area, Brouzes du larzac, France	-7.5	S-shaped	static centrifuge	yes	this study
Herbaceous eudicots	*Alchemilla vulgaris*	Swiss Jura Mountains, Combe des Amburnex, Switzerland	-2.09	S-shaped	cavitron	no	this study
Herbaceous eudicots	*Blackstonia perfoliata*	Edge of vineyard, Monbadon, France	-4.34	linear	cavitron	yes	this study
Herbaceous eudicots	*Chamaemelum mixtum*	Science Campus at University of Bordeaux, Talence, France	-2.62	S-shaped	cavitron	yes	this study
Herbaceous eudicots	*Helianthus annuus*	Science Campus at University of Bordeaux, Talence, France	-3.10	S-shaped	cavitron	yes	this study
Herbaceous eudicots	*Leucanthemum vulgare*	Science Campus at University of Bordeaux, Talence, France	-2.47	S-shaped	cavitron	yes	this study
Herbaceous eudicots	*Ranunculus acris*	Swiss Jura Mountains, Combe des Amburnex, Switzerland	-1.61	S-shaped	cavitron	no	this study
Herbaceous eudicots	*Trifolium repens*	Swiss Jura Mountains, Saint-George, Switzerland	-2.32	S-shaped	cavitron	no	this study
Herbaceous eudicots	*Taraxacum officinale*	Swiss Jura Mountains, Saint-George, Switzerland	-1.78	S-shaped	cavitron	no	this study
Woody eudicots	*Argyranthemum broussonetii*	Near Casa Forestal, Anaga, Tenerife, Spain	-3.05	S-shaped	cavitron	yes	this study
Woody eudicots	*Argyranthemum foeniculaceum*	Near Arguayo, Santiago del Teide, Tenerife, Spain	-5.12	S-shaped	cavitron	yes	this study
Woody eudicots	*Argyranthemum frutescens*	Near Araya de Candelaria, Tenerife, Spain	-3.80	S-shaped	cavitron	yes	this study
Woody eudicots	*Ixanthus viscosus*	Mirador del Escobon, near El Batan, Tenerife, Spain	-4.48	linear	cavitron	yes	this study
Monocots: Poaceae	*Chusquea ramosissima*	Iguazu National Park, Misiones Province, Argentina	-0.69	S-shaped	bench dehydration	no	Saha et al., 2009
Monocots: Poaceae	*Merostachys claussenii*	Iguazu National Park, Misiones Province, Argentina	-2.98	S-shaped	bench dehydration	no	Saha et al., 2009

Monocots: Poaceae	*Rhipidocladum racemiflorum*	Barro Colorado National Monument, central Panama	-4.5	S-shaped	bench dehydration	no	Cochard et al., 1994
Monocots: Poaceae	*Oryza sativa*	Los Banos, Laguna, Philippines	-1.59	S-shaped	static centrifuge	no	Stiller and Sperry, 2002
Monocots: Poaceae	*Zea mays* ("Pride 5")	Unknown	-1.56	S-shaped	static centrifuge	yes	Li et al., 2009
Monocots: Poaceae	*Zea mays* ("Pioneer 3902")	Unknown	-1.78	S-shaped	static centrifuge	yes	Li et al., 2009
Monocots: Poaceae	*Zea mays*	Northern Colorado Research Demonstration Center near Greeley, Colorado, USA	ca. -1.8	/	acoustic emission	no	Tyree et al., 1986
Herbaceous eudicots	*Boerhavia coccinea*	coastal strands along the Timor Sea about 80 km north of Darwin, Northern Territories, Australia	-3.2	linear	bench dehydration	yes	Kocacinar and Sage, 2003
Herbaceous eudicots	*Chenopodium album*	disturbed habitats in Toronto, Ontario, USA	-1	R-shaped	bench dehydration	yes	Kocacinar and Sage, 2003
Herbaceous eudicots	*Epilobium angustifolium* (diploid)	three mixed ploidy populations in the Canadian Rocky Mountains: Rampart Creek, Coleman and Continental Divide, Canada	-1.59	S-shaped	air injection	yes	Maherali et al., 2009
Herbaceous eudicots	*Epilobium angustifolium* (tetraploid)	three mixed ploidy populations in the Canadian Rocky Mountains: Rampart Creek, Coleman and Continental Divide, Canada	-1.66	S-shaped	air injection	yes	Maherali et al., 2009
Herbaceous eudicots	*Helianthus anomalus*	Little Sahara Recreation Area, Juab County, Utah, USA	-2.1	S-shaped	static centrifuge	no	Rosenthal et al., 2010
Herbaceous eudicots	*Helianthus annuus*	Unknown	-3	S-shaped	static centrifuge	no	Stiller and Sperry, 2002
Herbaceous eudicots	*Helianthus deserticola*	Little Sahara Recreation Area, Juab County, Utah, USA	-2.8	S-shaped	static centrifuge	no	Rosenthal et al., 2010
Herbaceous eudicots	*Ipomoea pes-caprae*	coastal strands along the Timor Sea about 80 km north of Darwin, Northern Territories, Australia	-1.6	linear	bench dehydration	yes	Kocacinar and Sage, 2003
Herbaceous eudicots	*Kochia scoparia*	disturbed habitats in Toronto, Ontario, USA	-3.75	S-shaped	bench dehydration	yes	Kocacinar and Sage, 2003
Herbaceous eudicots	*Phaseolus vulgaris*	Unknown	-0.47	S-shaped	whole shoot vacuum pressure	no	Mencuccini and Comstock, 1999

Table S2. Entire P_{50} and Julve dataset of woody and herbaceous species from our study and published papers.

Plant group	P_{50}	Species	Julve index	Habit	Reference
woody angiosperms	-5.74	*Acer campestre*	5	tree	Brendel and Cochard, 2011
woody angiosperms	-2.30	*Acer glabrum*		tree	Choat et al., 2012
woody angiosperms	-3.66	*Acer grandidentatum*		tree	Choat et al., 2012
woody angiosperms	-6.70	*Acer monspessulanum*	4	tree	Brendel and Cochard, 2011
woody angiosperms	-1.34	*Acer negundo*	7	tree	Choat et al., 2012
woody angiosperms	-4.39	*Acer opalus*	4	tree	Brendel and Cochard, 2011
woody angiosperms	-4.18	*Acer platanoides*	5	tree	Brendel and Cochard, 2011
woody angiosperms	-3.13	*Acer pseudoplatanus*	5	tree	Brendel and Cochard, 2011
woody angiosperms	-1.97	*Acer rubrum*		tree	Choat et al., 2012
woody angiosperms	-3.87	*Acer saccharum*		tree	Choat et al., 2012
woody angiosperms	-1.70	*Adansonia za*		tree	Choat et al., 2012
woody angiosperms	-7.98	*Adenostoma fasciculatum*		shrub	Choat et al., 2012
woody angiosperms	-4.89	*Adenostoma sparsifolium*		shrub	Choat et al., 2012
woody angiosperms	-0.71	*Aglaia glabrata*		tree	Choat et al., 2012
woody angiosperms	-2.17	*Aleurites moluccana*		tree	Choat et al., 2012
woody angiosperms	-2.96	*Allocasuarina campestris*		shrub	Choat et al., 2012
woody angiosperms	-1.40	*Alnus cordata*	7	tree	Choat et al., 2012
woody angiosperms	-1.71	*Alnus crispa*		shrub	Choat et al., 2012
woody angiosperms	-2.20	*Alnus glutinosa*	9	tree	Choat et al., 2012
woody angiosperms	-1.70	*Alnus incana*		shrub	Choat et al., 2012
woody angiosperms	-1.25	*Alnus rhombifolia*		tree	Choat et al., 2012
woody angiosperms	-2.54	*Alnus rubra*		tree	Choat et al., 2012
woody angiosperms	-5.56	*Alphitonia excelsa*		tree	Choat et al., 2012
woody angiosperms	-3.00	*Amborella trichopoda*		shrub	Choat et al., 2012

woody angiosperms	-4.37	*Amelanchier alnifolia*		shrub	Choat et al., 2012
woody angiosperms	-6.87	*Amelanchier ovalis*	4	shrub	Choat et al., 2012
woody angiosperms	-6.55	*Amelanchier utahensis*		shrub	Choat et al., 2012
woody angiosperms	-1.56	*Anacardium excelsum*		tree	Choat et al., 2012
woody angiosperms	-3.30	*Annona glabra*		tree	Choat et al., 2012
woody angiosperms	-7.84	*Arbutus unedo*	4	shrub	Brendel and Cochard, 2011
woody angiosperms	-4.41	*Arctostaphylos glandulosa*		shrub	Choat et al., 2012
woody angiosperms	-4.67	*Arctostaphylos glauca*		shrub	Choat et al., 2012
woody angiosperms	-3.05	*Argyranthemum broussonettii*		shrub	this study
woody angiosperms	-5.12	*Argyranthemum foeniculaceum*		shrub	this study
woody angiosperms	-3.80	*Argyranthemum frutescens*		shrub	this study
woody angiosperms	-4.90	*Artemisia tridentata*		shrub	Choat et al., 2012
woody angiosperms	-1.87	*Ascarina lucida*		tree	Choat et al., 2012
woody angiosperms	-4.12	*Aspalathus pachyloba*		shrub	Choat et al., 2012
woody angiosperms	-5.12	*Austromyrtus bidwillii*		shrub	Choat et al., 2012
woody angiosperms	-2.68	*Baccharis salicifolia*		shrub	Choat et al., 2012
woody angiosperms	-4.47	*Baccharis sarothroides*		shrub	Choat et al., 2012
woody angiosperms	-2.69	*Banksia attenuata*		tree	Choat et al., 2012
woody angiosperms	-2.84	*Banksia ilicifolia*		tree	Choat et al., 2012
woody angiosperms	-1.78	*Banksia littoralis*		tree	Choat et al., 2012
woody angiosperms	-3.24	*Banksia menziesii*		tree	Choat et al., 2012
woody angiosperms	-3.70	*Banksia sphaerocarpa*		shrub	Choat et al., 2012
woody angiosperms	-1.36	*Barringtonia racemosa*		tree	Choat et al., 2012
woody angiosperms	-1.52	*Betula occidentalis*		tree	Choat et al., 2012
woody angiosperms	-2.34	*Betula papyrifera*		tree	Choat et al., 2012
woody angiosperms	-2.40	*Betula pendula*	5	tree	Choat et al., 2012
woody angiosperms	-1.72	*Blepharocalyx salicifolius*		tree	Choat et al., 2012

woody angiosperms	-3.82	*Bourreria cumanensis*		tree	Choat et al., 2012
woody angiosperms	-2.50	*Brabejum stellatifolium*		tree	Choat et al., 2012
woody angiosperms	-3.17	*Brachychiton australis*		tree	Choat et al., 2012
woody angiosperms	-1.00	*Bursera simaruba*		tree	Choat et al., 2012
woody angiosperms	-8.00	*Buxus sempervirens*	4	shrub	Choat et al., 2012
woody angiosperms	-2.11	*Calycanthus floridus*		shrub	Choat et al., 2012
woody angiosperms	-2.87	*Calycophyllum candidissimum*		tree	Choat et al., 2012
woody angiosperms	-1.47	*Canarium caudatum*		tree	Choat et al., 2012
woody angiosperms	-3.75	*Carpinus betulus*	5	tree	Choat et al., 2012
woody angiosperms	-4.35	*Carpinus orientalis*		tree	Choat et al., 2012
woody angiosperms	-2.10	*Carya glabra*		tree	Choat et al., 2012
woody angiosperms	-1.48	*Caryocar brasiliense*		tree	Choat et al., 2012
woody angiosperms	-4.80	*Cassipourea elliptica*		tree	Choat et al., 2012
woody angiosperms	-9.40	*Ceanothus crassifolius*		shrub	Choat et al., 2012
woody angiosperms	-7.96	*Ceanothus cuneatus*		shrub	Choat et al., 2012
woody angiosperms	-6.00	*Ceanothus greggii*		shrub	Choat et al., 2012
woody angiosperms	-3.56	*Ceanothus leucodermis*		shrub	Choat et al., 2012
woody angiosperms	-8.08	*Ceanothus megacarpus*		shrub	Choat et al., 2012
woody angiosperms	-4.13	*Ceanothus oliganthus*		shrub	Choat et al., 2012
woody angiosperms	-4.68	*Ceanothus spinosus*		shrub	Choat et al., 2012
woody angiosperms	-8.12	*Ceratonia siliqua*	4	tree	Choat et al., 2012
woody angiosperms	-2.52	*Cercis canadensis*		tree	Choat et al., 2012
woody angiosperms	-5.19	*Cercis siliquastrum*	4	tree	Brendel and Cochard, 2011
woody angiosperms	-7.46	*Cercocarpus betuloides*		shrub	Choat et al., 2012
woody angiosperms	-4.96	*Cercocarpus ledifolius*		shrub	Choat et al., 2012
woody angiosperms	-5.80	*Cercocarpus montanus*		shrub	Choat et al., 2012
woody angiosperms	-2.10	*Chrysophyllum cainito*		tree	Choat et al., 2012

woody angiosperms	-1.24	*Cinnamomum camphora*		tree	Choat et al., 2012
woody angiosperms	-5.78	*Cistus albidus*	4	shrub	Choat et al., 2012
woody angiosperms	-5.20	*Cistus creticus*	4	shrub	Choat et al., 2012
woody angiosperms	-6.20	*Cistus ladanifer*	4	shrub	Choat et al., 2012
woody angiosperms	-3.65	*Cistus laurifolius*	4	shrub	Choat et al., 2012
woody angiosperms	-10.20	*Cistus monspeliensis*	4	shrub	Torres-Ruiz et al., submitted
woody angiosperms	-8.10	*Cistus populifolius*	4	shrub	Torres-Ruiz et al., submitted
woody angiosperms	-6.60	*Cistus psilosepalus*	4	shrub	Torres-Ruiz et al., submitted
woody angiosperms	-4.29	*Cliffortia ruscifolia*		shrub	Choat et al., 2012
woody angiosperms	-1.30	*Clusia uvitana*		shrub	Choat et al., 2012
woody angiosperms	-1.44	*Cochlospermum gillivraei*		tree	Choat et al., 2012
woody angiosperms	-2.23	*Codiaeum variegatum*		shrub	Choat et al., 2012
woody angiosperms	-5.61	*Comarostaphylis diversifolia*		shrub	Choat et al., 2012
woody angiosperms	-4.00	*Comarostaphylis polifolia*		shrub	Choat et al., 2012
woody angiosperms	-1.78	*Cordia alliodora*		tree	Choat et al., 2012
woody angiosperms	-2.34	*Cordia collococca*		tree	Choat et al., 2012
woody angiosperms	-1.20	*Cordia cymosa*		tree	Choat et al., 2012
woody angiosperms	-3.60	*Cordia dentata*		tree	Choat et al., 2012
woody angiosperms	-2.57	*Cordia lasiocalyx*		tree	Choat et al., 2012
woody angiosperms	-1.58	*Cordia lucidula*		tree	Choat et al., 2012
woody angiosperms	-2.33	*Cordia panamensis*		tree	Choat et al., 2012
woody angiosperms	-5.84	*Cornus florida*		tree	Choat et al., 2012
woody angiosperms	-6.37	*Cornus sanguinea*	5	shrub	Choat et al., 2012
woody angiosperms	-2.22	*Corylus avellana*	5	shrub	Choat et al., 2012
woody angiosperms	-1.50	*Corymbia calophylla*		tree	Choat et al., 2012
woody angiosperms	-8.41	*Crataegus laevigata*	5	shrub	Choat et al., 2012
woody angiosperms	-6.83	*Crataegus monogyna*	5	shrub	Choat et al., 2012

woody angiosperms	-1.48	*Curatella americana*		shrub	Choat et al., 2012
woody angiosperms	-3.62	*Cytisus scoparius*	5	shrub	Choat et al., 2012
woody angiosperms	-3.35	*Daphne gnidium*	4	shrub	Choat et al., 2012
woody angiosperms	-1.64	*Drimys granadensis*		tree	Choat et al., 2012
woody angiosperms	-4.68	*Drimys insipida*		shrub	Choat et al., 2012
woody angiosperms	-2.09	*Drimys purpurascens*		shrub	Choat et al., 2012
woody angiosperms	-3.70	*Drimys stipitata*		shrub	Choat et al., 2012
woody angiosperms	-2.30	*Drimys winteri*		tree	Choat et al., 2012
woody angiosperms	-1.93	*Dryandra sessilis*		shrub	Choat et al., 2012
woody angiosperms	-3.19	*Dryandra vestita*		shrub	Choat et al., 2012
woody angiosperms	-2.32	*Drypetes indica*		tree	Choat et al., 2012
woody angiosperms	-6.13	*Encelia farinosa*		shrub	Choat et al., 2012
woody angiosperms	-2.73	*Enterolobium cyclocarpum*		tree	Choat et al., 2012
woody angiosperms	-2.70	*Erica arborea*	4	shrub	Choat et al., 2012
woody angiosperms	-3.20	*Eucalyptus accedens*		tree	Choat et al., 2012
woody angiosperms	-3.08	*Eucalyptus capillosa*	4	tree	Choat et al., 2012
woody angiosperms	-3.41	*Eucalyptus wandoo*		tree	Choat et al., 2012
woody angiosperms	-5.14	*Euonymus europaeus*	5	shrub	Choat et al., 2012
woody angiosperms	-3.20	*Fagus sylvatica*	5	tree	Choat et al., 2012
woody angiosperms	-1.60	*Ficus citrifolia*		tree	Choat et al., 2012
woody angiosperms	-1.66	*Ficus insipida*		tree	Choat et al., 2012
woody angiosperms	-2.92	*Frangula alnus*	8	shrub	Brendel and Cochard, 2011
woody angiosperms	-1.92	*Fraxinus americana*		tree	Choat et al., 2012
woody angiosperms	-2.80	*Fraxinus excelsior*	7	tree	Choat et al., 2012
woody angiosperms	-2.20	*Fraxinus ornus*	5	tree	Choat et al., 2012
woody angiosperms	-6.50	*Garrya elliptica*		shrub	Choat et al., 2012
woody angiosperms	-6.60	*Garrya ovata*		shrub	Choat et al., 2012

woody angiosperms	-6.02	*Garrya veatchii*		shrub	Choat et al., 2012
woody angiosperms	-1.69	*Heritiera sumatrana*		tree	Choat et al., 2012
woody angiosperms	-1.22	*Hevea brasiliensis*		tree	Choat et al., 2012
woody angiosperms	-3.53	*Holodiscus dumosus*		shrub	Choat et al., 2012
woody angiosperms	-6.30	*Homalium moultonii*		tree	Choat et al., 2012
woody angiosperms	-3.00	*Hymenaea courbaril*		tree	Choat et al., 2012
woody angiosperms	-2.80	*Hymenaea martiana*		tree	Choat et al., 2012
woody angiosperms	-3.17	*Hymenaea stigonocarpa*		tree	Choat et al., 2012
woody angiosperms	-6.60	*Ilex aquifolium*	5	shrub	Choat et al., 2012
woody angiosperms	-3.66	*Illicium anisatum*		shrub	Choat et al., 2012
woody angiosperms	-3.28	*Illicium floridanum*		shrub	Choat et al., 2012
woody angiosperms	-3.75	*Isopogon gardneri*		shrub	Choat et al., 2012
woody angiosperms	-4.48	*Ixanthus viscosus*		shrub	this study
woody angiosperms	-2.30	*Juglans regia*	5	tree	Choat et al., 2012
woody angiosperms	-3.40	*Laguncularia racemosa*		tree	Choat et al., 2012
woody angiosperms	-2.35	*Leucadendron laureolum*		shrub	Choat et al., 2012
woody angiosperms	-3.59	*Leucadendron salignum*		shrub	Choat et al., 2012
woody angiosperms	-9.07	*Ligustrum vulgare*	4	shrub	Brendel and Cochard, 2011
woody angiosperms	-3.12	*Liquidambar styraciflua*	5	tree	Choat et al., 2012
woody angiosperms	-4.97	*Lomatia tinctoria*		shrub	Choat et al., 2012
woody angiosperms	-5.51	*Lonicera etrusca*	5	climber	Choat et al., 2012
woody angiosperms	-1.14	*Macaranga denticulata*		tree	Choat et al., 2012
woody angiosperms	-6.01	*Malus sylvestris*	5	tree	Choat et al., 2012
woody angiosperms	-2.70	*Manilkara bidentata*		tree	Choat et al., 2012
woody angiosperms	-1.07	*Melaleuca preissiana*		shrub	Choat et al., 2012
woody angiosperms	-6.20	*Metalasia densa*		shrub	Choat et al., 2012
woody angiosperms	-3.40	*Miconia cuspidata*		tree	Choat et al., 2012

woody angiosperms	-3.10	*Miconia pohliana*		tree	Choat et al., 2012
woody angiosperms	-2.39	*Morisonia americana*		tree	Choat et al., 2012
woody angiosperms	-1.64	*Myrica cerifera*		shrub	Choat et al., 2012
woody angiosperms	-3.08	*Myrsine ferruginea*		tree	Choat et al., 2012
woody angiosperms	-2.12	*Myrsine guianensis*		shrub	Choat et al., 2012
woody angiosperms	-8.22	*Myrtus communis*	4	shrub	Brendel and Cochard, 2011
woody angiosperms	-1.70	*Nerium oleander*	7	shrub	Choat et al., 2012
woody angiosperms	-1.82	*Nyssa sylvatica*		tree	Choat et al., 2012
woody angiosperms	-1.00	*Ochroma pyramidale*		tree	Choat et al., 2012
woody angiosperms	-5.00	*Olea europaea*	4	tree	Choat et al., 2012
woody angiosperms	-1.48	*Ouratea hexasperma*		tree	Choat et al., 2012
woody angiosperms	-1.80	*Ouratea lucens*		shrub	Choat et al., 2012
woody angiosperms	-4.54	*Oxydendrum arboreum*		tree	Choat et al., 2012
woody angiosperms	-1.01	*Parkinsonia microphylla*		tree	Choat et al., 2012
woody angiosperms	-10.15	*Passerina obtusifolia*		shrub	Choat et al., 2012
woody angiosperms	-2.00	*Pereskia guamacho*		tree	Choat et al., 2012
woody angiosperms	-9.53	*Phillyrea angustifolia*	4	shrub	Choat et al., 2012
woody angiosperms	-6.55	*Phillyrea latifolia*	5	shrub	Choat et al., 2012
woody angiosperms	-6.24	*Photinia arbutifolia*		tree	Choat et al., 2012
woody angiosperms	-1.90	*Physocarpus malvaceus*		shrub	Choat et al., 2012
woody angiosperms	-4.79	*Pistacia lentiscus*	4	shrub	Choat et al., 2012
woody angiosperms	-8.42	*Pistacia terebinthus*	4	tree	Choat et al., 2012
woody angiosperms	-1.53	*Populus alba*	7	tree	Fichot et al., 2015
woody angiosperms	-1.76	*Populus angustifolia*		tree	Fichot et al., 2015
woody angiosperms	-1.75	*Populus balsamifera*	7	tree	Fichot et al., 2015
woody angiosperms	-1.15	*Populus deltoides*	7	tree	Fichot et al., 2015
woody angiosperms	-0.70	*Populus euphratica*		tree	Fichot et al., 2015

woody angiosperms	-1.45	*Populus fremontii*		tree	Fichot et al., 2015
woody angiosperms	-0.75	*Populus nigra*	7	tree	Fichot et al., 2015
woody angiosperms	-1.81	*Populus tremula*	5	tree	Fichot et al., 2015
woody angiosperms	-2.13	*Populus tremuloides*	5	tree	Fichot et al., 2015
woody angiosperms	-1.42	*Populus trichocarpa*	7	tree	Fichot et al., 2015
woody angiosperms	-1.60	*Prioria copaifera*		tree	Choat et al., 2012
woody angiosperms	-3.81	*Protea repens*		shrub	Choat et al., 2012
woody angiosperms	-1.70	*Protium panamense*		tree	Choat et al., 2012
woody angiosperms	-6.13	*Prunus amygdalus*	5	tree	Choat et al., 2012
woody angiosperms	-6.07	*Prunus armeniaca*	5	tree	Choat et al., 2012
woody angiosperms	-4.76	*Prunus avium*	5	tree	Choat et al., 2012
woody angiosperms	-6.27	*Prunus cerasifera*	5	tree	Choat et al., 2012
woody angiosperms	-4.60	*Prunus cerasus*	5	tree	Choat et al., 2012
woody angiosperms	-5.78	*Prunus domestica*	5	tree	Choat et al., 2012
woody angiosperms	-6.13	*Prunus dulcis*	5	tree	Choat et al., 2012
woody angiosperms	-4.39	*Prunus ilicifolia*		shrub	Choat et al., 2012
woody angiosperms	-5.55	*Prunus mahaleb*	4	tree	Choat et al., 2012
woody angiosperms	-3.54	*Prunus padus*	7	tree	Choat et al., 2012
woody angiosperms	-5.18	*Prunus persica*	5	tree	Choat et al., 2012
woody angiosperms	-5.36	*Prunus spinosa*	5	shrub	Choat et al., 2012
woody angiosperms	-3.80	*Prunus virginiana*	5	shrub	Choat et al., 2012
woody angiosperms	-1.00	*Pseudobombax septenatum*		tree	Choat et al., 2012
woody angiosperms	-3.70	*Pseudowintera axillaris*		shrub	Choat et al., 2012
woody angiosperms	-4.30	*Pseudowintera colorata*		shrub	Choat et al., 2012
woody angiosperms	-5.62	*Pseudowintera traversii*		shrub	Choat et al., 2012
woody angiosperms	-4.90	*Psychotria horizontalis*		shrub	Choat et al., 2012
woody angiosperms	-4.30	*Purshia tridentata*		shrub	Choat et al., 2012

woody angiosperms	-3.29	*Pyrus amygdaliformis*		tree	Choat et al., 2012
woody angiosperms	-1.65	*Qualea parviflora*		tree	Choat et al., 2012
woody angiosperms	-2.60	*Quercus berberidifolia*		shrub	Choat et al., 2012
woody angiosperms	-6.96	*Quercus coccifera*	4	shrub	Choat et al., 2012
woody angiosperms	-4.56	*Quercus frainetto*	5	tree	Choat et al., 2012
woody angiosperms	-6.30	*Quercus ilex*	5	tree	Martin-StPaul et al., 2014
woody angiosperms	-3.03	*Quercus oleoides*		tree	Choat et al., 2012
woody angiosperms	-3.50	*Quercus petraea*	5	tree	Choat et al., 2012
woody angiosperms	-3.30	*Quercus pubescens*	4	tree	Choat et al., 2012
woody angiosperms	-2.80	*Quercus robur*	5	tree	Choat et al., 2012
woody angiosperms	-5.50	*Quercus sebifera*		shrub	Choat et al., 2012
woody angiosperms	-5.00	*Quercus suber*	4	tree	Vaz et al., 2012
woody angiosperms	-1.85	*Rapanea melanophloeos*		tree	Choat et al., 2012
woody angiosperms	-2.80	*Rehdera trinervis*		tree	Choat et al., 2012
woody angiosperms	-8.09	*Rhamnus alaternus*	4	shrub	Choat et al., 2012
woody angiosperms	-5.17	*Rhamnus crocea*		shrub	Choat et al., 2012
woody angiosperms	-2.92	*Rhamnus frangula*		shrub	Choat et al., 2012
woody angiosperms	-5.92	*Rhamnus ilicifolia*		shrub	Choat et al., 2012
woody angiosperms	-8.40	*Rhamnus lycioides*	4	shrub	Choat et al., 2012
woody angiosperms	-6.30	*Rhizophora mangle*		tree	Choat et al., 2012
woody angiosperms	-1.75	*Rhododendron catawbiense*		shrub	Choat et al., 2012
woody angiosperms	-3.01	*Rhododendron ferrugineum*	5	shrub	Choat et al., 2012
woody angiosperms	-3.23	*Rhododendron hirsutum*	4	shrub	Choat et al., 2012
woody angiosperms	-2.96	*Rhododendron macrophyllum*		shrub	Choat et al., 2012
woody angiosperms	-2.20	*Rhododendron maximum*		shrub	Choat et al., 2012
woody angiosperms	-2.40	*Rhus laurina*		shrub	Choat et al., 2012
woody angiosperms	-2.70	*Rhus standleyi*		shrub	Choat et al., 2012

woody angiosperms	-2.95	*Rhus trilobata*		shrub	Choat et al., 2012
woody angiosperms	-3.57	*Ribes alpinum*	4	shrub	Choat et al., 2012
woody angiosperms	-1.56	*Rosa nutkana*		shrub	Choat et al., 2012
woody angiosperms	-9.40	*Rosmarinus officinalis*	2	shrub	Choat et al., 2012
woody angiosperms	-1.61	*Rubus leucodermis*		shrub	Choat et al., 2012
woody angiosperms	-1.56	*Rubus parviflorus*		shrub	Choat et al., 2012
woody angiosperms	-1.50	*Salix alba*	8	tree	Choat et al., 2012
woody angiosperms	-0.91	*Salix amygdaloides*		tree	Choat et al., 2012
woody angiosperms	-2.32	*Salix arenaria*	6	shrub	Choat et al., 2012
woody angiosperms	-1.90	*Salix caprea*	5	shrub	Choat et al., 2012
woody angiosperms	-1.99	*Salix cinerea*	9	shrub	Choat et al., 2012
woody angiosperms	-1.31	*Salix exigua*		shrub	Choat et al., 2012
woody angiosperms	-1.39	*Salix fragilis*	8	tree	Choat et al., 2012
woody angiosperms	-1.29	*Salix gooddingii*		tree	Choat et al., 2012
woody angiosperms	-1.97	*Salix purpurea*	8	shrub	Choat et al., 2012
woody angiosperms	-7.30	*Salvia candicans*		shrub	Choat et al., 2012
woody angiosperms	-1.66	*Salvia leucophylla*		shrub	Choat et al., 2012
woody angiosperms	-4.62	*Salvia mellifera*		shrub	Choat et al., 2012
woody angiosperms	-1.43	*Sambucus caerulea*		shrub	Choat et al., 2012
woody angiosperms	-1.52	*Sambucus nigra*	5	shrub	Choat et al., 2012
woody angiosperms	-1.37	*Sapium sebiferum*		tree	Choat et al., 2012
woody angiosperms	-1.72	*Schefflera macrocarpa*		tree	Choat et al., 2012
woody angiosperms	-1.38	*Schefflera morototoni*		tree	Choat et al., 2012
woody angiosperms	-1.68	*Schinus terebinthifolius*		tree	Choat et al., 2012
woody angiosperms	-1.06	*Schisandra glabra*		climber	Choat et al., 2012
woody angiosperms	-3.40	*Sclerolobium paniculatum*		tree	Choat et al., 2012
woody angiosperms	-2.60	*Sideroxylon lanuginosum*		tree	Choat et al., 2012

woody angiosperms	-2.00	*Simarouba glauca*		tree	Choat et al., 2012
woody angiosperms	-0.86	*Sindora leiocarpa*		tree	Choat et al., 2012
woody angiosperms	-2.60	*Sophora japonica*		tree	Choat et al., 2012
woody angiosperms	-5.38	*Sorbus aria*	4	tree	Choat et al., 2012
woody angiosperms	-4.19	*Sorbus aucuparia*	5	tree	Choat et al., 2012
woody angiosperms	-2.77	*Sorbus scopulina*		shrub	Choat et al., 2012
woody angiosperms	-6.20	*Sorbus torminalis*	5	tree	Brendel and Cochard, 2011
woody angiosperms	-3.35	*Styrax ferrugineus*		tree	Choat et al., 2012
woody angiosperms	-2.00	*Styrax pohlii*		tree	Choat et al., 2012
woody angiosperms	-2.90	*Swartzia simplex*		tree	Choat et al., 2012
woody angiosperms	-2.20	*Swietenia macrophylla*		tree	Choat et al., 2012
woody angiosperms	-1.50	*Symplocos lanceolata*		shrub	Choat et al., 2012
woody angiosperms	-1.60	*Symplocos mosenii*		tree	Choat et al., 2012
woody angiosperms	-1.60	*Tachigali versicolor*		tree	Choat et al., 2012
woody angiosperms	-1.80	*Tapirira guianensis*		tree	Choat et al., 2012
woody angiosperms	-1.48	*Tecoma capensis*		shrub	Choat et al., 2012
woody angiosperms	-1.42	*Tetracentron sinense*		tree	Choat et al., 2012
woody angiosperms	-2.58	*Tilia cordata*	5	tree	Choat et al., 2012
woody angiosperms	-3.09	*Tilia platyphyllos*	5	tree	Choat et al., 2012
woody angiosperms	-1.10	*Trattinnickia aspera*		tree	Choat et al., 2012
woody angiosperms	-2.66	*Trichilia dregeana*		tree	Choat et al., 2012
woody angiosperms	-2.35	*Trochodendron aralioides*		tree	Choat et al., 2012
woody angiosperms	-6.58	*Ulex europaeus*	4	shrub	Choat et al., 2012
woody angiosperms	-1.35	*Umbellularia californica*		tree	Choat et al., 2012
woody angiosperms	-7.62	*Viburnum lantana*	4	shrub	Brendel and Cochard, 2011
woody angiosperms	-1.90	*Vitis vinifera*	6	climber	Hochberg et al., 2016
woody angiosperms	-1.00	*Vochysia ferruginea*		tree	Choat et al., 2012

woody angiosperms	-3.00	*Zygogynum bailloni*		tree	Choat et al., 2012
woody angiosperms	-2.30	*Zygogynum bicolor*		tree	Choat et al., 2012
woody angiosperms	-4.54	*Zygogynum crassifolium*		shrub	Choat et al., 2012
woody angiosperms	-5.20	*Zygogynum pancheri*		tree	Choat et al., 2012
woody angiosperms	-3.45	*Zygogynum pomiferum*		tree	Choat et al., 2012
woody angiosperms	-3.60	*Zygogynum queenslandianum*		tree	Choat et al., 2012
woody angiosperms	-3.27	*Zygogynum semecarpoides*		tree	Choat et al., 2012
woody gymnosperms	-3.65	*Abies alba*	5	tree	Choat et al., 2012
woody gymnosperms	-3.87	*Abies balsamea*	5	tree	Choat et al., 2012
woody gymnosperms	-4.00	*Abies bornmuelleriana*	5	tree	Choat et al., 2012
woody gymnosperms	-3.74	*Abies concolor*	5	tree	Choat et al., 2012
woody gymnosperms	-3.65	*Abies grandis*	5	tree	Choat et al., 2012
woody gymnosperms	-3.34	*Abies lasiocarpa*	5	tree	Choat et al., 2012
woody gymnosperms	-4.15	*Abies pinsapo*	4	tree	Choat et al., 2012
woody gymnosperms	-3.06	*Acmopyle pancheri*		tree	Brodribb and Hill, 1999
woody gymnosperms	-14.10	*Actinostrobus acuminatus*		tree	Choat et al., 2012
woody gymnosperms	-10.58	*Actinostrobus arenarius*		tree	Brodribb and Hill, 1999
woody gymnosperms	-2.58	*Agathis australis*		tree	Choat et al., 2012
woody gymnosperms	-1.91	*Agathis borneensis*		tree	Choat et al., 2012
woody gymnosperms	-1.77	*Agathis ovata*		tree	Choat et al., 2012
woody gymnosperms	-3.30	*Araucaria columnaris*		tree	Choat et al., 2012
woody gymnosperms	-4.07	*Araucaria hunsteinii*		tree	Choat et al., 2012
woody gymnosperms	-2.40	*Araucaria laubenfelsii*		tree	Choat et al., 2012
woody gymnosperms	-3.49	*Athrotaxis laxifolia*		tree	Choat et al., 2012
woody gymnosperms	-9.95	*Austrocedrus chilensis*		tree	Choat et al., 2012
woody gymnosperms	-9.20	*Callitris rhomboidea*		tree	Choat et al., 2012
woody gymnosperms	-7.75	*Calocedrus decurrens*		tree	Choat et al., 2012

woody gymnosperms	-4.50	*Cedrus atlantica*	5	tree	Choat et al., 2012
woody gymnosperms	-8.00	*Cedrus brevifolia*		tree	Choat et al., 2012
woody gymnosperms	-4.95	*Cedrus deodara*		tree	Choat et al., 2012
woody gymnosperms	-7.71	*Cedrus libani*	5	tree	Choat et al., 2012
woody gymnosperms	-5.17	*Chamaecyparis lawsoniana*		tree	Choat et al., 2012
woody gymnosperms	-4.55	*Cryptomeria japonica*		tree	Choat et al., 2012
woody gymnosperms	-6.93	*Cunninghamia lanceolata*		tree	Choat et al., 2012
woody gymnosperms	-11.17	*Cupressus forbesii*		tree	Choat et al., 2012
woody gymnosperms	-10.81	*Cupressus glabra*		tree	Choat et al., 2012
woody gymnosperms	-10.39	*Cupressus sempervirens*	4	tree	Choat et al., 2012
woody gymnosperms	-2.27	*Dacrycarpus dacrydoides*		tree	Brodribb and Hill, 1999
woody gymnosperms	-3.57	*Dacrycarpus imbricatus*		tree	Brodribb and Hill, 1999
woody gymnosperms	-3.08	*Dacrydium cupressiformis*		tree	Choat et al., 2012
woody gymnosperms	-7.50	*Fitzroya cupressoides*		tree	Choat et al., 2012
woody gymnosperms	-4.62	*Ginkgo biloba*		tree	Choat et al., 2012
woody gymnosperms	-2.80	*Glyptostrobus pensilis*		tree	Choat et al., 2012
woody gymnosperms	-3.10	*Gnetum costatum*		tree	Choat et al., 2012
woody gymnosperms	-4.62	*Gnetum gnemon*		tree	Choat et al., 2012
woody gymnosperms	-13.80	*Juniperus arizonica*		tree	Choat et al., 2012
woody gymnosperms	-13.10	*Juniperus ashei*		tree	Choat et al., 2012
woody gymnosperms	-12.80	*Juniperus barbadensis*		tree	Choat et al., 2012
woody gymnosperms	-10.36	*Juniperus californica*		tree	Choat et al., 2012
woody gymnosperms	-6.43	*Juniperus communis*	4	shrub	Choat et al., 2012
woody gymnosperms	-8.90	*Juniperus deppeana*		tree	Choat et al., 2012
woody gymnosperms	-7.80	*Juniperus flaccida*		tree	Choat et al., 2012
woody gymnosperms	-8.30	*Juniperus lucayana*		tree	Choat et al., 2012
woody gymnosperms	-7.70	*Juniperus maritima*		tree	Choat et al., 2012

woody gymnosperms	-11.60	*Juniperus monosperma*		shrub	Choat et al., 2012
woody gymnosperms	-9.00	*Juniperus occidentalis*		tree	Choat et al., 2012
woody gymnosperms	-6.92	*Juniperus osteosperma*		tree	Choat et al., 2012
woody gymnosperms	-14.10	*Juniperus pinchotii*		tree	Choat et al., 2012
woody gymnosperms	-9.84	*Juniperus scopulorum*		tree	Cochard, 2006
woody gymnosperms	-6.60	*Juniperus virginiana*		tree	Choat et al., 2012
woody gymnosperms	-3.57	*Lagarostrobos franklinii*		tree	Brodribb and Hill, 1999
woody gymnosperms	-3.66	*Larix decidua*	4	tree	Choat et al., 2012
woody gymnosperms	-3.43	*Larix kaempferi*	5	tree	Choat et al., 2012
woody gymnosperms	-4.31	*Larix occidentalis*		tree	Choat et al., 2012
woody gymnosperms	-4.39	*Libocedrus plumosa*		tree	Choat et al., 2012
woody gymnosperms	-3.76	*Metasequoia glyptostroboides*		tree	Choat et al., 2012
woody gymnosperms	-7.02	*Phyllocladus trichomanoides*		tree	Choat et al., 2012
woody gymnosperms	-3.98	*Picea abies*	5	tree	Choat et al., 2012
woody gymnosperms	-4.91	*Picea engelmannii*		tree	Choat et al., 2012
woody gymnosperms	-4.30	*Picea glauca*		tree	Choat et al., 2012
woody gymnosperms	-5.30	*Picea mariana*		tree	Choat et al., 2012
woody gymnosperms	-3.53	*Picea rubens*		tree	Choat et al., 2012
woody gymnosperms	-3.85	*Picea sitchensis*	5	tree	Choat et al., 2012
woody gymnosperms	-3.59	*Pinus albicaulis*		tree	Choat et al., 2012
woody gymnosperms	-3.27	*Pinus caribaea*		tree	Choat et al., 2012
woody gymnosperms	-3.34	*Pinus cembra*	5	tree	Choat et al., 2012
woody gymnosperms	-3.67	*Pinus contorta*	5	tree	Choat et al., 2012
woody gymnosperms	-5.00	*Pinus corsicana*	4	tree	Choat et al., 2012
woody gymnosperms	-3.21	*Pinus echinata*		tree	Choat et al., 2012
woody gymnosperms	-4.88	*Pinus edulis*		tree	Choat et al., 2012
woody gymnosperms	-3.71	*Pinus flexilis*		tree	Choat et al., 2012

woody gymnosperms	-5.60	*Pinus halepensis*	3	tree	Choat et al., 2012
woody gymnosperms	-5.55	*Pinus monophylla*		tree	Choat et al., 2012
woody gymnosperms	-3.64	*Pinus mugo*	5	tree	Choat et al., 2012
woody gymnosperms	-2.80	*Pinus nigra*	4	tree	Choat et al., 2012
woody gymnosperms	-3.01	*Pinus pinaster*	4	tree	Choat et al., 2012
woody gymnosperms	-3.65	*Pinus pinea*	3	tree	Choat et al., 2012
woody gymnosperms	-2.65	*Pinus ponderosa*		tree	Choat et al., 2012
woody gymnosperms	-3.61	*Pinus sylvestris*	5	tree	Choat et al., 2012
woody gymnosperms	-3.13	*Pinus taeda*		tree	Choat et al., 2012
woody gymnosperms	-4.18	*Pinus uncinata*	5	tree	Choat et al., 2012
woody gymnosperms	-6.61	*Podocarpus cunninghamii*		tree	Choat et al., 2012
woody gymnosperms	-1.74	*Podocarpus latifolius*		tree	Choat et al., 2012
woody gymnosperms	-3.68	*Pseudotsuga menziesii*	5	tree	Cochard, 2006
woody gymnosperms	-5.58	*Prumnopitys ferruginea*		tree	Choat et al., 2012
woody gymnosperms	-2.17	*Retrophyllum minor*		tree	Choat et al., 2012
woody gymnosperms	-2.43	*Sciadopitys verticillata*		tree	Choat et al., 2012
woody gymnosperms	-4.38	*Sequoia sempervirens*		tree	Choat et al., 2012
woody gymnosperms	-3.79	*Sequoiadendron giganteum*		tree	Choat et al., 2012
woody gymnosperms	-5.35	*Taiwania cryptomerioides*		tree	Choat et al., 2012
woody gymnosperms	-2.14	*Taxodium distichum*	9	tree	Choat et al., 2012
woody gymnosperms	-2.88	*Taxodium mucronatum*		tree	Choat et al., 2012
woody gymnosperms	-8.14	*Taxus baccata*	5	tree	Choat et al., 2012
woody gymnosperms	-6.44	*Taxus brevifolia*		tree	Choat et al., 2012
woody gymnosperms	-8.55	*Tetraclinis articulata*		shrub	Choat et al., 2012
woody gymnosperms	-3.57	*Thuja occidentalis*		tree	Choat et al., 2012
woody gymnosperms	-5.27	*Thuja plicata*	5	tree	Choat et al., 2012
woody gymnosperms	-6.03	*Thujopsis dolabrata*		tree	Choat et al., 2012

woody gymnosperms	-3.07	*Tsuga canadensis*		tree	Choat et al., 2012
woody gymnosperms	-11.28	*Widdringtonia cedarbergensis*		tree	Choat et al., 2012
grasses	-4.50	*Agrostis capillaris*	5	herb	this study
grasses	-3.3	*Alopecurus pratensis*	7	herb	this study
grasses	-4.4	*Anthoxanthum odoratum*	5	herb	this study
grasses	-3.8	*Arrhenaterum elatius*	4	herb	this study
grasses	-6.2	*Brachypodium pinnatum*	5	herb	this study
grasses	-0.69	*Chusquea ramosissima*		herb	Saha et al., 2009
grasses	-3.8	*Dactylis glomerata*	5	herb	this study
grasses	-1	*Echinochloa crus-galli*	6	herb	this study
grasses	-5.3	*Elymus campestris*	3	herb	this study
grasses	-3.4	*Elytrigia repens*	5	herb	this study
grasses	-3.9	*Festuca arundinacea*	7	herb	this study
grasses	-0.7	*Glyceria fluitans*	9	herb	this study
grasses	-3.91	*Lolium perenne*	5	herb	this study
grasses	-5.5	*Melica ciliata*	5	herb	this study
grasses	-2.98	*Merostachys claussenii*		herb	Saha et al., 2009
grasses	-1.59	*Oryza sativa*	10	herb	Stiller et al., 2003
grasses	-0.5	*Phalaris arundinacea*	8	herb	this study
grasses	-4	*Phleum pratense*	5	herb	this study
grasses	-0.6	*Phragmites australis*	9	herb	this study
grasses	-3.65	*Poa pratensis*	5	herb	this study
grasses	-4.5	*Rhipidocladum racemiflorum*		herb	Cochard et al., 1994
grasses	-7.5	*Stipa pennata*	3	herb	this study
grasses	-1.71	*Zea mays*	5	herb	Li et al., 2009
herbaceous eudicots	-2.09	*Alchemilla vulgaris*	9	herb	this study
herbaceous eudicots	-4.34	*Blackstonia perfoliata*		herb	this study

herbaceous eudicots	-3.2	*Boerhavia coccinea*		herb	Kocacinar and Sage, 2003
herbaceous eudicots	-2.62	*Chamaemelum mixtum*		herb	this study
herbaceous eudicots	-1	*Chenopodium album*	5	herb	Kocacinar and Sage, 2003
herbaceous eudicots	-1.62	*Epilobium angustifolium*		herb	Maherali et al., 2009
herbaceous eudicots	-2.1	*Helianthus anomalus*		herb	Rosenthal et al., 2010
herbaceous eudicots	-3.05	*Helianthus annuus*	5	herb	this study
herbaceous eudicots	-2.8	*Helianthus deserticola*		herb	Rosenthal et al., 2010
herbaceous eudicots	-1.6	*Ipomoea pes-caprae*		herb	Kocacinar and Sage, 2003
herbaceous eudicots	-3.75	*Kochia scoparia*		herb	Kocacinar and Sage, 2003
herbaceous eudicots	-2.47	*Leucanthemum vulgare*	5	herb	this study
herbaceous eudicots	-0.47	*Phaseolus vulgaris*	5	herb	Mencuccini and Comstock, 1999
herbaceous eudicots	-1.61	*Ranunculus acris*	5	herb	this study
herbaceous eudicots	-1.78	*Taraxacum officinale*	8	herb	this study
herbaceous eudicots	-2.32	*Trifolium repens*	5	herb	this study

Table S3. Post-hoc comparisons of P_{50} LS-Means across species groups (see Fig. 3). Overall model: $F_{3,439} = 22.13$; $P < 0.0001$. P-values are presented for each pairwise comparison ($P < 0.05$ are indicated in bold).

	Herbaceous eudicots	Woody angiosperms	Woody gymnosperms
Grasses	0.4935	0.9785	**0.0003**
Herbaceous eudicots		0.1465	**<0.0001**
Woody angiosperms			**<0.0001**

Table S4. Overview of leaf water potential measures at predawn ($\Psi_{predawn}$) and midday (Ψ_{midday}) and the derived Percentage Loss of Conductivity (PLC) throughout the entire growing season for the five grass species from the Swiss field sites. Soil water content is added to estimate drought. Values are means ± 1 SE for n=6.

Dactylis glomerata

P_{50} = -3.49 MPa	22.04.15	12.05.15	18.05.15	18.06.15	07.07.15	15.07.15	05.08.15	12.08.15	31.08.15	24.09.15
$\Psi_{predawn}$ (MPa)	-0.26 ± 0.04	-0.19 ± 0.03	-0.16 ± 0.02	-0.35 ± 0.04	-0.30 ± 0.05	-0.51 ± 0.11	-0.24 ± 0.04	-0.24 ± 0.05	-0.34 ± 0.05	-0.18 ± 0.01
Ψ_{midday} (MPa)	-1.48 ± 0.11	-1.57 ± 0.14	-1.37 ± 0.08	-1.44 ± 0.14	-2.06 ± 0.14	-1.94 ± 0.11	-1.70 ± 0.11	-2.04 ± 0.13	-1.44 ± 0.03	-1.13 ± 0.08
$PLC_{predawn}$ (MPa)	5.39 ± 0.17	5.10 ± 0.13	4.97 ± 0.07	5.81 ± 0.21	5.60 ± 0.22	6.79 ± 0.66	5.29 ± 0.16	5.31 ± 0.21	5.77 ± 0.23	5.03 ± 0.06
PLC_{midday} (MPa)	14.63 ± 1.26	15.69 ± 1.73	13.37 ± 0.82	14.28 ± 1.55	22.30 ± 2.22	20.41 ± 1.58	17.17 ± 1.32	21.90 ± 1.85	13.98 ± 0.34	11.05 ± 0.76
Soil WC (%)	42.12 ± 1.59	44.80 ± 2.41	49.33 ± 2.92	46.63 ± 2.81	22.05 ± 2.29	26.50 ± 1.21	16.35 ± 1.34	19.40 ± 1.15	17.87 ± 1.51	31.33 ± 1.43

Lolium perenne

P_{50} = -3.21 MPa	22.04.15	12.05.15	18.05.15	18.06.15	07.07.15	15.07.15	05.08.15	12.08.15	31.08.15	24.09.15
$\Psi_{predawn}$ (MPa)	-0.24 ± 0.03	-0.20 ± 0.02	-0.44 ± 0.10	-0.29 ± 0.03	-0.61 ± 0.12	-0.26 ± 0.03	-0.29 ± 0.04	-0.23 ± 0.03	-0.23 ± 0.03	-0.24 ± 0.02
Ψ_{midday} (MPa)	-1.31 ± 0.12	-1.42 ± 0.10	-1.38 ± 0.08	-1.53 ± 0.11	-1.81 ± 0.05	-1.71 ± 0.08	-1.53 ± 0.09	-1.55 ± 0.08	-1.47 ± 0.05	-1.01 ± 0.11
$PLC_{predawn}$ (MPa)	6.49 ± 0.14	6.17 ± 0.13	5.97 ± 0.12	7.42 ± 0.72	6.45 ± 0.19	8.62 ± 0.88	6.29 ± 0.14	6.43 ± 0.25	6.09 ± 0.14	6.09 ± 0.12
PLC_{midday} (MPa)	15.17 ± 1.50	16.37 ± 1.28	15.87 ± 0.99	17.88 ± 1.43	21.75 ± 0.73	20.30 ± 1.31	17.73 ± 1.21	18.05 ± 1.10	16.84 ± 0.68	11.93 ± 1.09
Soil WC (%)	42.12 ± 1.59	44.80 ± 2.41	49.33 ± 2.92	46.63 ± 2.81	22.05 ± 2.29	26.50 ± 1.21	16.35 ± 1.34	19.40 ± 1.15	17.87 ± 1.51	31.33 ± 1.43

Phleum pratense

P_{50} = 3.84 MPa	08.04.15	28.04.15	06.05.15	04.06.15	01.07.15	30.07.15	18.08.15	08.09.15
$\Psi_{predawn}$ (MPa)	-0.35 ± 0.09	-0.21 ± 0.03	-0.17 ± 0.03	-0.22 ± 0.04	-0.23 ± 0.03	-0.23 ± 0.04	-0.15 ± 0.06	-0.17 ± 0.03
Ψ_{midday} (MPa)	-1.48 ± 0.19	-1.11 ± 0.09	-1.13 ± 0.08	-1.82 ± 0.07	-1.90 ± 0.10	-1.69 ± 0.12	-1.61 ± 0.07	-1.48 ± 0.12
$PLC_{predawn}$ (MPa)	2.05 ± 0.20	1.72 ± 0.06	1.64 ± 0.06	1.74 ± 0.07	1.74 ± 0.07	1.75 ± 0.08	1.62 ± 0.11	1.65 ± 0.05
PLC_{midday} (MPa)	7.22 ± 1.15	4.61 ± 0.44	4.70 ± 0.39	9.62 ± 0.63	10.49 ± 1.05	8.56 ± 0.94	7.75 ± 0.56	6.90 ± 0.75
Soil WC (%)	38.27 ± 0.86	37.53 ± 1.94	31.20 ± 1.41	30.05 ± 3.98	17.92 ± 0.58	11.88 ± 0.70	10.00 ± 0.93	17.45 ± 1.08

Poa pratensis

P_{50} = -3.65 MPa	22.04.15	12.05.15	18.05.15	18.06.15	07.07.15	15.07.15	05.08.15	12.08.15	31.08.15	24.09.15
$\Psi_{predawn}$ (MPa)				-0.39 ± 0.08	-0.37 ± 0.10	-0.74 ± 0.13	-0.42 ± 0.11	-0.23 ± 0.03	-0.56 ± 0.09	-0.21 ± 0.04
Ψ_{midday} (MPa)				-1.48 ± 0.13	-2.06 ± 0.15	-1.84 ± 0.11	-1.71 ± 0.15	-1.87 ± 0.13	-1.82 ± 0.07	-1.21 ± 0.13
$PLC_{predawn}$ (MPa)				1.19 ± 0.16	1.18 ± 0.16	2.00 ± 0.38	1.29 ± 0.24	0.93 ± 0.05	1.49 ± 0.16	0.92 ± 0.06
PLC_{midday} (MPa)				5.23 ± 0.92	11.06 ± 2.18	8.15 ± 0.95	7.15 ± 1.29	8.62 ± 1.58	7.75 ± 0.64	3.72 ± 0.68
Soil WC (%)				46.63 ± 2.81	22.05 ± 2.29	26.50 ± 1.21	16.35 ± 1.34	19.40 ± 1.15	17.87 ± 1.51	31.33 ± 1.43

Agrostis capillaris

P_{50} = -4.50 MPa	28.05.15	11.06.15	24.06.15	21.07.15	20.08.15	07.09.15	20.10.2015
$\Psi_{predawm}$ (MPa)	-0.32 ± 0.16	-0.14 ± 0.03	-0.20 ± 0.03	-0.23 ± 0.07	-0.18 ± 0.04		
Ψ_{midday} (MPa)	-2.31 ± 0.14	-1.80 ± 0.07	-2.03 ± 0.19	-1.67 ± 0.08	-1.68 ± 0.12	-1.92 ± 0.08	-1.94 ± 0.05
$PLC_{predawn}$ (MPa)	1.84 ± 0.36	1.44 ± 0.04	1.54 ± 0.04	1.59 ± 0.11	1.51 ± 0.06		
PLC_{midday} (MPa)	11.06 ± 1.20	6.92 ± 0.44	8.95 ± 1.34	6.15 ± 0.41	6.30 ± 0.65	7.66 ± 0.57	7.74 ± 0.35
Soil WC (%)	51.75 ± 1.34	36.45 ± 1.81	34.62 ± 2.45	20.13 ± 1.57	22.23 ± 1.35	19.02 ± 1.90	27.58 ± 2.02

Table S5. List of the anatomical measurements carried out for the species in this study (3 replicates per species). All the measures are in square micrometer, except for the pit membrane data (nanometer).

species	total stem area	area of lignified outer stem tissue	proportion of lignified tissues compared to entire stem diameter	pith area	proportion of pith compared to entire stem	total stem area - pith area (outer stem part)	proportion of lignified tissues compared to outer stem part	fibre cell cross section-al area	fibre lumen cross section-al area	fibre cell wall cross section-al area	proportion cell wall per fibre	total fibre wall area in lignified area	proportion total fibre wall in lignified area over entire stem area	hydraulically weighted (meta-xylem) vessel diameter	pit membrane thickness
Alopecurus pratensis5	2361935.8	343460.3	0.145414733	1252803.2	0.530413742	1109132.6	0.309665649	236.4	81.8	154.6	0.669897558	230083.2	0.097412975	21.0	
Alopecurus pratensis4	2323662.9	305225.0	0.131355103	1273408.3	0.548017671	1050254.6	0.290619996	249.7	69.2	180.5	0.725493323	221438.7	0.09529725	17.9	
Alopecurus pratensis8	2181427.9	354245.5	0.162391562	963011.4	0.441459202	1218416.5	0.290742525	238.3	64.0	174.3	0.734991735	260367.5	0.119356456	24.4	
Anthoxanthum odoratum58	1591369.3	360950.0	0.226817271	525403.4	0.330158057	1065965.9	0.338613121	240.8	74.0	166.7	0.711299948	256743.7	0.161335113	28.7	163.0
Anthoxanthum odoratum8	1559029.2	330018.5	0.211682022	545910.8	0.350160753	1013118.4	0.325745209	330.6	98.4	232.1	0.705833694	232938.1	0.149412303	28.7	163.0
Anthoxanthum odoratum17	1807864.7	305582.9	0.169029763	531305.5	0.293885667	1276559.2	0.239380161	221.8	56.6	165.2	0.750763905	229420.6	0.126901445	28.7	163.0
Arrhenaterum elatius19	2116594.6	380020.0	0.179543114	899569.0	0.425007682	1217025.6	0.312253066	271.8	82.8	189.0	0.693885488	263690.4	0.124582361	30.7	
Arrhenaterum elatius20	1824886.7	361882.5	0.198304066	807675.2	0.442589239	1017211.5	0.355759306	176.7	42.3	134.4	0.7591496	274722.9	0.150542452	29.2	
Arrhenaterum elatius21	2361063.7	418474.9	0.17723999	1200034.9	0.508260307	1161028.7	0.360434581	273.3	61.1	212.2	0.779332588	326131.1	0.1381289	35.0	
Brachypodium pinnatum14	2449848.7	481680.3	0.196616345	1231805.5	0.502808788	1218043.2	0.395454183	256.3	38.4	217.9	0.856886838	412745.5	0.168477958	30.7	248.3
Brachypodium pinnatum22	2820595.4	611309.1	0.216730519	1315502.4	0.466391744	1505093.0	0.406160356	216.7	44.4	172.3	0.798720504	488265.1	0.17310711	22.4	248.3
Brachypodium pinnatum17	2089313.7	528939.2	0.25316408	856734.2	0.410055317	1232579.5	0.429131896	207.2	43.1	164.1	0.793305081	419610.1	0.200836351	23.5	248.3
Dactylis glomerata9	2871991.9	495272.9	0.172449257	987113.9	0.34370359	1884878.0	0.262761238	146.7	40.7	106.1	0.724218322	358685.7	0.124890912	21.7	
Dactylis glomerata6	2839087.2	367397.7	0.129406973	976983.1	0.344118741	1862104.1	0.19730244	81.8	8.7	73.1	0.889483316	326794.1	0.115105343	21.2	
Dactylis glomerata8	2831406.0	534125.4	0.188643167	935963.5	0.330564913	1895442.5	0.281794562	93.6	15.2	78.4	0.839924256	448624.9	0.158445972	23.5	
Echinochloa crus-galli 7	20060273.2	1524451.2	0.075993542	6069224.7	0.302549453	13991048.5	0.10895904	355.0	148.0	207.1	0.599085526	913276.7	0.045526631	46.7	
Echinochloa crus-galli 3	17133683.1	1225548.7	0.071528619	6830996.2	0.398688139	10302686.9	0.118954279	280.3	101.1	179.2	0.645449917	791030.3	0.046168141	45.9	
Echinochloa crus-galli 1	20440638.0	1567588.1	0.076689783	5815117.7	0.284488073	14625520.3	0.107181697	206.7	65.8	140.9	0.685259156	1074204.1	0.052552376	44.7	
Elymus campestris21	3883755.8	764566.7	0.196862717	1251721.8	0.32229672	2632034.1	0.290485118	360.9	110.2	250.7	0.701100261	536037.9	0.138020502	39.7	248.3
Elymus campestris14	3983576.4	760883.6	0.191005159	1295067.4	0.325101698	2688508.9	0.283013246	284.3	51.2	233.1	0.823891544	626885.6	0.157367535	38.1	248.3
Elymus campestris25	3567740.5	719957.1	0.201796386	1102455.9	0.30900674	2465284.7	0.29203814	211.8	43.9	167.9	0.790499065	569125.5	0.159519855	31.3	248.3

Elytrigia repens6	1971580.5	310571.4	0.157524067	768480.8	0.389779056	1203099.7	0.258142675	175.3	48.0	127.3	0.7294902	226558.8	0.114912263	20.1	313.2
Elytrigia repens15	2056311.9	405157.6	0.197031201	640025.5	0.311249229	1416286.4	0.286070389	204.8	56.1	148.7	0.739555082	299636.4	0.145715426	22.8	313.2
Elytrigia repens17	1832652.2	333111.9	0.181764932	714186.1	0.389700858	1118466.1	0.297829244	272.9	61.7	211.2	0.781651483	260377.4	0.142076829	21.9	313.2
Festuca erundinacea5	1641120.9	364013.3	0.221807746	402593.3	0.245316028	1238527.7	0.293908118	241.1	69.7	171.5	0.720044772	262105.9	0.159711508	20.9	
Festuca erundinacea2	1448476.2	284584.6	0.196471696	481451.3	0.332384707	967024.8	0.294288788	203.6	51.4	152.2	0.761552294	216726.0	0.149623471	23.4	
Festuca erundinacea10	1962429.1	401788.9	0.20474057	631945.2	0.322021934	1330483.9	0.301987012	328.0	93.6	234.4	0.715575358	287510.2	0.146507307	26.4	
Glyceria flutans7	2169368.1	341243.5	0.157300892	950534.1	0.438161763	1218833.9	0.279975412	282.7	144.1	138.6	0.50461865	172197.9	0.079376964	20.7	
Glyceria flutans2-0	2501660.3	321263.5	0.128420114	1229222.3	0.491362587	1272438.0	0.252478703	328.0	100.1	227.9	0.696723397	279935.7	0.111899963	24.5	
Glyceria flutans2	2552200.3	325000.5	0.127341299	1279888.3	0.50148426	1272312.0	0.255440879	406.7	158.1	248.7	0.652041553	211913.8	0.083031818	29.2	
Lolium perenne22	1828860.3	324816.5	0.177605971	706086.3	0.386079937	1122774.0	0.289298202	213.8	90.7	123.1	0.581067785	188740.4	0.103201108	20.5	131.7
Lolium perenne11	1463587.8	319458.1	0.218270531	447116.6	0.30549354	1016471.2	0.314281498	217.0	58.4	158.6	0.7446497	237884.4	0.162535085	21.6	131.7
Lolium perenne23	1684526.0	295625.6	0.175494804	536495.4	0.318484511	1148030.5	0.257506699	217.0	58.4	158.6	0.7446497	237884.4	0.141217397	20.7	131.7
Melica cilitata14	1006331.0	243512.7	0.241980675	545492.0	0.542060266	460838.9	0.528411617	175.5	15.8	159.8	0.911283927	267212.4	0.265531314	23.7	
Melica cilitata21	1871649.1	443065.6	0.23672471	970155.0	0.518342361	901494.1	0.491479197	215.3	26.4	189.0	0.886343634	392708.4	0.20981944	29.2	
Melica ciliata23	3572172.5	881136.7	0.246666894	1857386.2	0.519959818	1714786.4	0.513846347	252.7	48.1	204.6	0.830641696	731908.9	0.204891807	32.6	
Phalaris arundinacea sn	18328393.5	1210623.9	0.066051829	12546742.2	0.684552203	5781651.4	0.209390681	254.2	81.3	172.9	0.678390662	821276.0	0.044808944	33.5	244.4
Phalaris arundinacea 2	19028393.5	1270600.9	0.066773946	12600742.2	0.662207356	6427651.4	0.197677323	164.9	37.3	127.6	0.776513864	986639.2	0.051850895	28.2	244.4
Phalaris arundinacea 2-0	18828300.5	1255623.9	0.066688117	12700742.2	0.674555951	6127558.4	0.204914232	257.1	77.0	180.0	0.722619501	1386749.8	0.073652413	26.7	244.4
Phleum pratensis17	2228133.1	288527.2	0.129492799	720485.2	0.323358221	1507647.9	0.191375708	100.3	21.9	78.4	0.776859431	224145.1	0.100597702	16.0	
Phleum pratensis11	2215655.6	319428.3	0.144168771	677651.0	0.305846711	1538004.6	0.207690108	97.1	21.6	75.5	0.773775855	247165.9	0.111554314	16.8	
Phleum pratensis25	2540144.8	377895.6	0.148769309	1000074.7	0.39370776	1540070.1	0.245375579	72.6	15.2	57.4	0.798139343	301613.3	0.118738639	19.5	
Phragmites australis sn	35680777.5	1351664.1	0.037882137	22563682.3	0.632376419	13117095.2	0.103045994	194.3	62.1	132.2	0.698454295	944075.6	0.026458942	35.4	
Phragmites australis sn1	36080777.5	1382700.1	0.038322348	23063683.3	0.639223567	13017094.2	0.106221872	248.5	71.8	176.7	0.709935353	981627.7	0.02720639	38.5	
Phragmites australis sn2	36200777.5	1390000.1	0.038396968	23200683.3	0.640889088	13000094.2	0.106922311	248.5	71.8	176.7	0.709935353	986810.2	0.027259365	37.7	
Stipa pennata 3-01	1002813.0	177557.6	0.177059583	317705.3	0.316814145	685107.6	0.259167519	77.5	8.2	69.4	0.89682165	159237.5	0.158790868	17.4	
Stipa pennata 4	1201179.3	169981.5	0.141512185	477602.3	0.397611139	723577.0	0.234918329	53.3	7.6	45.6	0.852565978	144920.4	0.120648474	17.6	
Stipa pennata 5	1544332.8	271282.0	0.17566292	573463.0	0.371333833	970869.8	0.279421622	61.9	10.9	51.0	0.820653539	222628.5	0.144158397	23.1	

Helianthemum annuum varA 2B3	58645004.2	9355546.9	0.079764228	37513731.6	0.639674805	21131272.6	0.442734667	388.0	122.2	265.8	0.681354969	3187224.2	0.054347753	45.8	
Helianthemum annuum varA 3B4	57845965.3	10349873.4	0.089460633	36660916.4	0.633767907	21185049.0	0.488546116	361.0	121.7	239.3	0.664144266	3436904.5	0.059414767	40.0	
Helianthemum annuum varA 6B2	67405119.5	12656385.6	0.09388297	43936028.3	0.651820346	23469091.2	0.539278896	345.1	122.1	223.0	0.644935983	3868003.7	0.057384421	46.2	
Leucanthemum vulgare basal1	26099174.4	9372827.4	0.17956176	6769161.4	0.259363045	19330013.1	0.242442344	421.4	137.6	283.8	0.677026451	3172826.0	0.121568061	31.8	352.7
Leucanthemum vulgare basal2	14667324.5	7395374.7	0.252103739	3363625.7	0.229327833	11303698.7	0.327121894	351.3	150.0	201.3	0.57178782	2114292.6	0.144149848	25.7	352.7
Chamaemelum mixtum 2-1-1	16059778.0	5056468.0	0.15742646	7105369.0	0.442432579	8954409.0	0.282345155	287.2	118.5	168.7	0.608242187	3075557.2	0.191506829	32.3	291.8
Chamaemelum mixtum 2-1-2	10507905.4	3430038.5	0.163212285	5518153.3	0.525143034	4989752.1	0.343708309	258.7	78.5	180.1	0.696081464	2387586.2	0.227218093	30.7	291.8
Chamaemelum mixtum 2-1-3	16520113.3	5384148.6	0.162957374	7301805.9	0.441994908	9218307.3	0.29203564	258.9	95.0	163.9	0.622137246	3349679.4	0.202763704	32.7	291.8
Blackstonia perfoliata3	17698921.0	9631785.1	0.272100913	5531021.4	0.312506133	12167899.6	0.395786677	319.4	127.8	191.6	0.595105406	2865963.7	0.161928724	27.0	304.8
Blackstonia perfoliata9	7767305.8	4102525.9	0.264089374	2197354.0	0.282897841	5569951.8	0.368273015	302.4	109.1	193.2	0.639372047	2623040.4	0.337702728	23.6	304.8
Ixanthus viscosus1	68945241.8	50110735.2	0.726819341	10079819.8	0.146200369	58865422.0	0.851276242	399.8	173.7	226.1	0.566530821	28389276.0	0.411765558	25.4	312.9
Ixanthus viscosus4	43439786.8	33112923.2	0.762271771	5021483.0	0.1155964	38418303.8	0.861904871	375.6	165.6	210.0	0.560375487	18555670.4	0.427158415	24.9	312.9
Ixanthus viscosus5	39751487.2	26637875.7	0.670110167	8592231.8	0.216148688	31159255.4	0.854894489	272.4	84.8	187.6	0.669281156	17828228.3	0.448492107	26.3	312.9
Argyranthemum broussonnettii7	59997570.9	44756016.0	0.7459638	6930531.8	0.11551354	53067039.1	0.843386342	363.5	144.5	219.0	0.597075346	26722713.7	0.445396594	39.6	370.5
Argyranthemum broussonnettii8	37822467.9	27655878.4	0.731202376	5999350.4	0.158618692	31823117.5	0.86904994	340.1	115.6	224.4	0.655850717	18138127.7	0.479559603	46.4	370.5
Argyranthemum broussonnettii10	61374769.5	50932122.7	0.829854403	3351361.3	0.05460487	58023408.2	0.877785782	344.7	124.6	220.1	0.634249339	32303665.2	0.526334607	41.3	370.5
Argyranthemum foeniculaceum2	48251741.8	39857659.7	0.826035667	1322408.9	0.027406449	46929332.8	0.849312301	347.5	52.4	295.1	0.846802669	33751572.6	0.699489207	35.9	485.5
Argyranthemum foeniculaceum5	21618948.1	15190207.1	0.702633955	2794697.3	0.129270734	18824250.8	0.806948822	311.8	78.2	233.6	0.746869687	11345105.2	0.524776002	37.7	485.5
Argyranthemum foeniculaceum7	18320883.6	12743532.9	0.695574145	2959925.4	0.161560186	15360958.2	0.829605338	264.6	50.3	214.3	0.808679141	10406712.2	0.568024578	30.6	485.5
Argyranthemum frutescens2	59453608.3	50086427.6	0.842445546	2160954.1	0.036346895	57292654.3	0.874220756	276.0	62.0	214.0	0.773686498	38751192.7	0.651788744	33.2	403.3
Argyranthemum frutescens4	49108812.1	39725122.3	0.808920447	803504.0	0.016361707	48305308.1	0.822375921	273.9	56.3	217.6	0.792292587	31473919.9	0.640901674	32.7	403.3
Argyranthemum frutescens6	28366147.3	22162347.2	0.781295638	1710809.5	0.060311661	26655337.9	0.831441241	259.6	37.7	222.0	0.859473657	19047953.6	0.671503019	28.7	403.3

Table S6. Multiple regression model of anatomical features as explaining factors of P_{50} variability in herbaceous species (4 first rows, $N = 20$, overall model $F_{4,15} = 12.78$; $P < 0.0001$) and grass species (4 last rows, $N = 16$, overall model $F_{4,11} = 17.04$; $P<0.0001$). $P < 0.05$ are indicated in bold.

Variable	DF	Parameter estimate	SE	*t*-value	*P*-value	Squared partial correlation coeff (Type II)	VIF
Proportion of lignified tissue per stem	1	-16.24	5.15	-3.15	**0.0066**	0.40	1.84
Proportion of pith area per stem	1	1.69	2.37	0.71	0.4872	0.03	1.69
Proportion of cell wall per fibre	1	-14.50	3.25	-4.46	**0.0005**	0.57	1.23
Vessel diameter	1	-0.02	0.04	-0.63	0.5350	0.03	1.44
Proportion of lignified tissue per stem	1	-12.76	5.67	-2.25	**0.0457**	0.32	1.99
Proportion of pith area per stem	1	4.30	2.33	1.84	0.0922	0.24	1.39
Proportion of cell wall per fibre	1	-16.84	3.99	-4.22	**0.0014**	0.62	1.50
Vessel diameter	1	0.007	0.03	0.20	0.8455	0.004	1.24

Abbreviations: coeff: coefficient; SE: standard error; VIF: Variance Inflation Factor.

Supplemental Text S1

Sampling Strategy

The herbaceous species were collected in France (20 species) and Switzerland (9 species of which three were identical to the French collections), while the four woody species were harvested in Tenerife, Canary Islands (Table S1). The flowering stems of the french grass samples (before anthesis, called thereafter stems) were derived from three sites with a different precipitation regime, and the nine Swiss collections were harvested at the same phenological stage than the french collections in three sites along an altitudinal gradient in the Jura mountains (Table S1). The wood dataset is mainly based on an updated version of the Xylem Functional Traits Database (Choat et al., 2012; Table S2 and references cited therein), and adjusted according to the sampling strategy described in the manuscript. In addition, we added four woody Canary Island species measured in this study (Table S2).

Embolism Resistance Measurements

For the static centrifuge technique (Alder et al., 1997), a negative pressure was applied to separate stem pieces containing internodes in a standard centrifuge with custom-built, 26cm rotor. Each stem segment was only spun once in the centrifuge, after which it was connected to the XYL'EM apparatus (Bronkhorst, Montigny-les-Cormeilles, France) to measure the hydraulic conductance using a solution of 10 mM KCl and 1 mM $CaCl_2$ in deionized ultrapure water. For each pressure point in the vulnerability curve (VC), 2-3 grass stems were used, and one S-shaped curve per species was fitted according to a sigmoid function (Pammenter and Vander Wilgen, 1998).

The cavitron technique (Cochard et al., 2005), housed at the University of Bordeaux (France), is a high-throughput method to generate VCs during spinning. For the herbaceous species, at least 10 S-shaped VCc were constructed using the 26cm rotor, and adjusted with a sigmoid function (Pammenter and Vander Wilgen, 1998; Table S1). Either one herbaceous stem per curve was used when the conductivity was sufficient, or in exceptional cases, several stems grouped in a bunch were spun at the same time to increase the water flow. For the woody stems, always a single stem per VC was used using 26cm or 42cm branches, with in total 10-15 curves per species. Air was injected at one side of the branch using 2 bar to assess the maximum vessel length, ensuring that the stem segments were always longer than the longest vessels.

Anatomical Observations

For the herbaceous species, stems representing three individuals per species were embedded in polyethyleneglycol or LR White (hard grade, London Resin, UK), sectioned with a rotary microtome, and stained with toluidine blue-safranine or carmino-green dye; the woody species were sectioned without embedding according to the standard procedure using a Reichert sledge microtome (Vienna, Austria) and Feather disposable knives (Osaka, Japan); sections were bleached, stained with a mixture of saffranin and alcian blue (35 : 65), dehydrated in an ethanol series (50, 75, 96%) and mounted in Euparal (Agar Scientific, Stansted, UK) or Eukitt. The slides were observed with a Leica DM2500 light microscope equipped with a digital camera. A range of stem anatomical characters, such as total stem area, area of lignified stem tissue, pith area, area of fibre wall and fibre lumen, hydraulically weighted diameter, and traits derived from these measures, such as proportion of lignified tissue per stem area, proportion of pith area per stem area, stem area minus pith area (outer stem part), proportion of lignified tissue per outer stem part, proportion of cell wall per fibre, total fibre wall area per lignified area, and proportion total fibre wall in lignified area over total stem area (Table S5), were measured based on three individuals per species using ImageJ v 1.43 (National Institutes of Health, Bethesda, Maryland, USA). At least 50 observations were performed per feature. For a final selection of the features used in the multiple regression analysis, see section on statistics below.

For transmission electron microscopy observations of intervessel pit membranes, the standard preparation TEM protocol for wood was applied, using 1-2 mm^3 wood samples that were fixed in a formaldehyde-glutaraldehyde fixative (Jansen et al., 2009, Lens et al., 2011; Li et al., in press). Then, samples were washed in a 0.05-0.2 M phosphate buffer and postfixed with 1-2% buffered osmium tetroxide for 2-4 hours at room temperature. The samples were subsequently washed with a buffer solution, dehydrated with a gradual ethanol series, and embedded using Epon resin (Sigma-Aldrich, Steinheim, Germany) at 60°C. 500nm thick cross sections were cut from the resin blocks with a glass knife to observe areas including adjacent vessels, then a diamond knife was used to cut small 60-90 nm cross sections, which were dried on 300 mesh copper grids or Formvar girds (Agar Scientific, Stansted, UK). Several grids were prepared for each resin sample. In general, one grid was left untreated, while the other one was manually counterstained with uranyl acetate and lead citrate. Observations were conducted with a JEOL 1210 and a JEOL 1400 TEM (JEOL, Tokyo, Japan), equipped with a digital camera. At least 25 observations were carried out per species.

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