Oikos

OIK-07338

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Appendix 1–5

Appendix 1: Study species

Table A1. Overview of the study species.

Family	Species	Seed source	Range size in Germany (%)	First record in Germany
Amaranthaceae	*Amaranthus albus* L.	Botanical garden University of Hohenheim	9.37	1880
	Amaranthus blitoides S. WATSON	Botanical garden University of Dresden and Botanical garden University of Halle	3.47	1893
	Amaranthus retroflexus L.	Botanical garden University of Halle	46.81	1815
	Amaranthus tricolor L.	Botanical garden University of Tübingen	0.02[c]	1950
Asteraceae	*Bidens pilosa* L.	Botanical garden University of Braunschweig	0.11[c]	1926
	Cosmos bipinnatus Cav.	Botanical garden University of Bayreuth	1.74[c]	1980
	Iva xanthiifolia NUTT.	Botanical garden University of Dresden	2.90	1860
Brassicaceae	*Berteroa incana* (L.) DC.	Botanical garden University of Frankfurt	39.64	1594
	Diplotaxis muralis (L.) DC.	Botanical garden University of Ulm	14.82	1750
	Hirschfeldia incana (L.) LAGR.-FOSS.	Botanical garden University of Konstanz	1.88	1850
Chenopodiaceae	*Atriplex sagittata* BORKH.	Botanical garden University of Krefeld	26.61	1750
	Bassia scoparia (L.) VOSS	Monoculture of previous experiment[a]	5.61	1750
Fabaceae	*Medicago polymorpha* L.	B & T World Seeds, Paguignan, France	0.98	1820
	Vicia villosa ROTH	Voitsauer Wildblumensamen, Kottes-Purk, Austria	39.68	1808
Poaceae	*Anthoxanthum aristatum* BOISS.	Botanical garden University of Dresden	15.40	1850
	Apera interrupta (L.) P. BEAUV.	Botanical garden University of Konstanz	0.65	1950
	Eragrostis minor HOST	Monoculture of previous experiment[b]	23.69	1782
	Panicum capillare L.	Botanical garden University of Potsdam	4.83	1890
Solanaceae	*Datura stramonium* L.	Botanical garden University of Ulm	26.72	1584
	Nicandra physalodes L. (GAERTN.)	Botanical garden University of Greifswald	6.06	1782

Range size in Germany (% of occupied grid cells at the scale of 6 x 10 arcmin, i.e. 11 x 11 km; database FlorKart (https://doi.org/10.15468/wnkii7) by BfN and NetPhyD Netzwerk Phytodiversität Deutschlands e.V., www.deutschlandflora.de and www.floraweb.de) and year of first record (Jäger 2017; www.floraweb.de) are given.

[a]Originally obtained from Botanical garden University of Gießen
[b]Originally obtained from Botanical garden University of Mainz
[c]Considered as casual neophyte

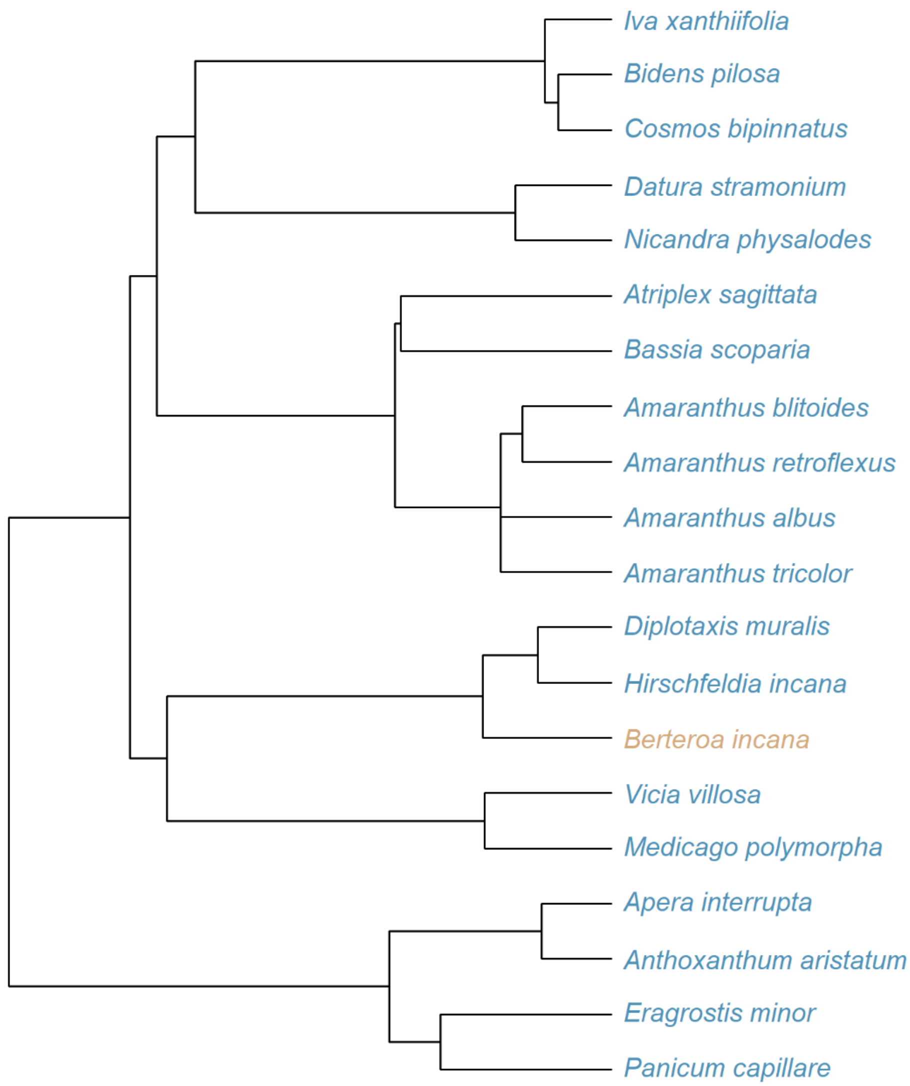

Figure A1. Phylogenetic tree of the study species. Data was acquired from the Daphne database, a phylogeny of European plant species (Durka and Michalski 2012). Species in blue were included in all analyses, *Berteroa incana* (orange) had to be excluded for seed measures as most individuals did not set seeds within the experimental period.

Appendix 2: Trait selection and data collection

To assess variation in plant functional traits, we measured five different traits of each experimental plant: Firstly, specific leaf area (SLA) reflects differences in resource acquisition strategies, high values indicate high photosynthetic rate and an exploitative strategy, whereas low values indicate leaf longevity and a more conservative resource use (Westoby 1998, Pérez-Harguindeguy et al. 2013). For SLA measures, we scanned two randomly chosen leaves per plant during the first week of flowering per species. Fresh leaves were scanned with a resolution of 600 dpi and measured using ImageJ Fiji software (Schindelin et al. 2012) and divided it by the dry mass of the leaf (dried for 72 h at 70 °C) (following Pérez-Harguindeguy et al. 2013). Secondly, plant height reflects competitive ability for light, as higher plants reach better light conditions (Westoby 1998). However, this also comes with the cost of sustaining morphological structures and transporting nutrients and water over longer distances (Westoby 1998). We measured maximum height of each individual plant at harvest. Thirdly, seed mass reflects the chance of successful spread and seedling establishment, whereby seedling growing from heavier seeds have a higher chance of survival, but it is also costlier to produce heavy seeds (Westoby 1998). We measured seed mass before sowing (weighing 6 x 50 seeds with a high-precision balance). Fourth, as flowering phenology is considered an important ecological trait and was suggested to act independent from general resource strategies (Craine et al. 2012) we recorded the opening of the first flower of each individual weekly. Fifth, root:shoot ratio is an important measure of resource allocation in plants. Relatively higher root mass suggests an improved ability of resource uptake (Lloret et al. 1999) which is especially advantageous when competing for nutrients in limiting environments. In nutrient rich environments higher allocation to aboveground biomass is expected in order to compete for light (Tilman 1985). To measure root biomass, we washed and dried (for 72 h at 70 °C) the roots of control individuals at harvest. Additional to these five quantitative traits, we classified the species in plant functional groups (grass, forb, legume). Plant functional groups can be of great use as they cover several traits and can thereby also incorporate traits which are more difficult to measure (Cornelissen et al. 2001).

As niche differences of species might be better represented in multi-dimensional space (Kraft et al. 2015), we calculated multi-trait distance from the species-level average trait values (SLA, height, seed mass, flowering onset and root:shoot ratio) of control individuals. We calculated the Gower distance of the five logarithmized and scaled traits as well as the categorical trait plant functional group using the function daisy in the R package cluster (Maechler et al. 2018). To obtain phylogenetic distances we used Daphne, a phylogeny of European plant species (Durka and Michalski 2012). This phylogeny was reduced to the study species using the R package picante (Kembel et al. 2010, see Fig. A1), and we then derived the cophenetic distance between species pairs with the R package ape (Paradis et al. 2004).

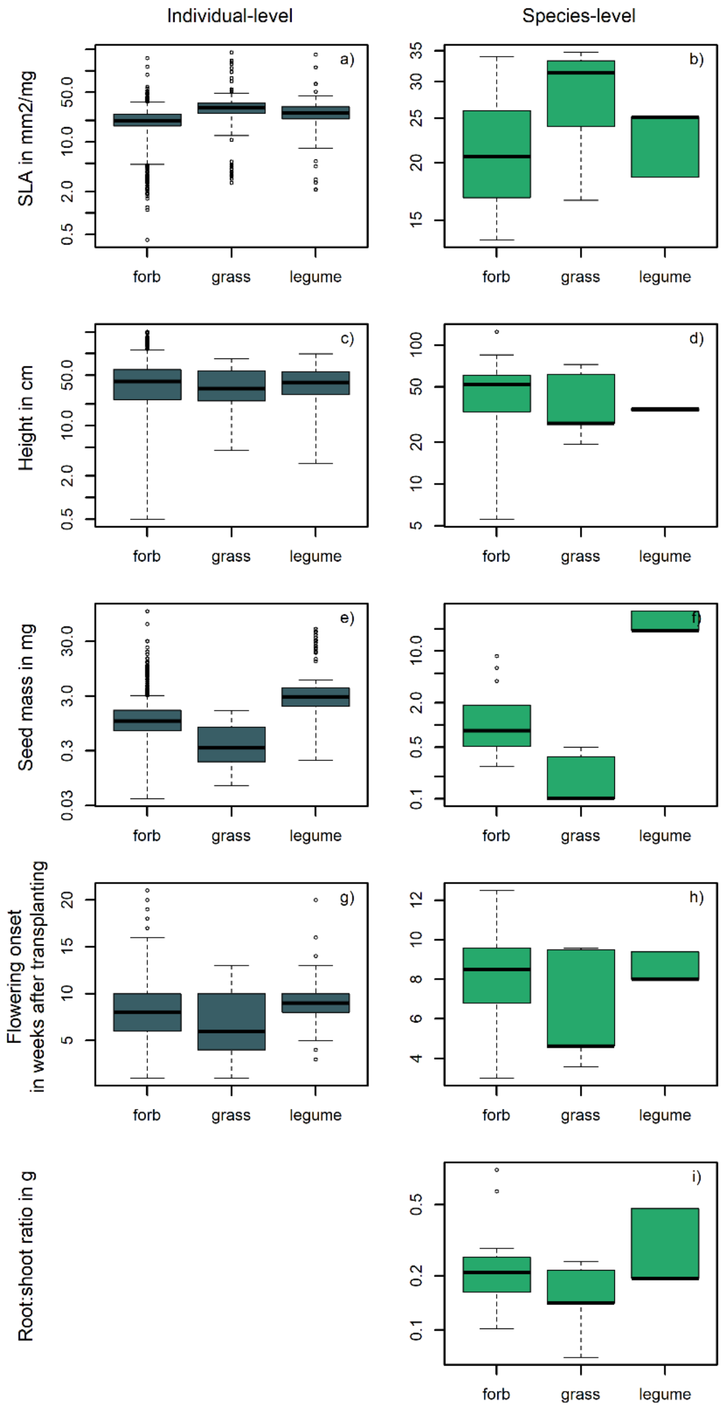

Figure A2. Trait variation across functional groups (including 14 forb, 4 grass, and 2 legume species) of the target plant shown for specific leaf area (SLA) (a,b), maximum height (c,d), seed mass (e,f), flowering onset (g,h) and root:shoot ratio (i). Dark blue boxplots show individual trait values, green boxplots show species-level averages per functional group. All traits except for flowering onset are displayed on logarithmic y-axis.

Appendix 3: Alien species competition versus facilitation

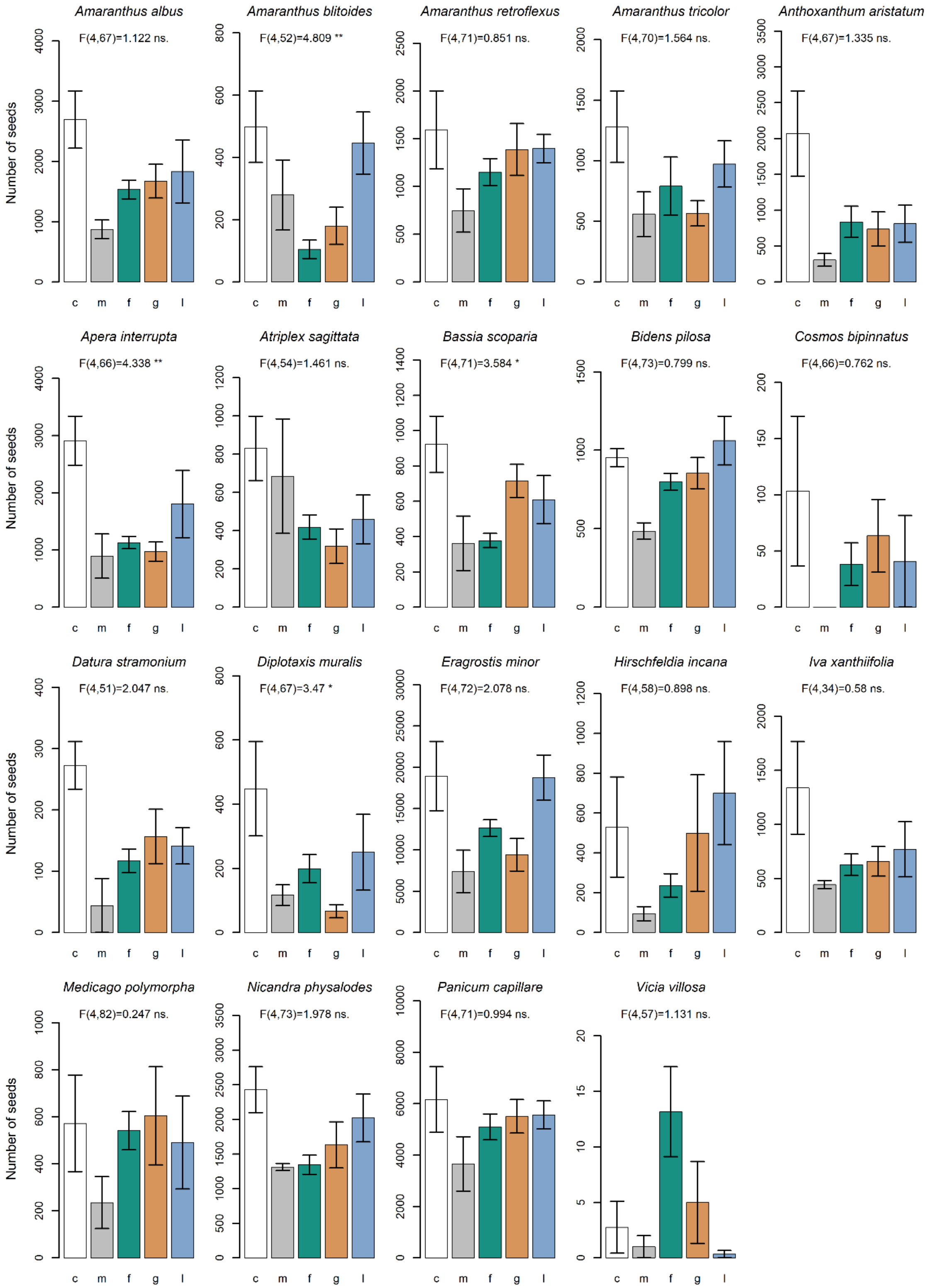

Figure A3. Mean seed number (± 1 standard error) per species depending on competition treatment. White bars represent the control (plants growing alone in the pot, ‘c’); grey bars the monoculture treatment (plants grow with a conspecific individual, ‘m’); coloured bars represent the mixture treatment with the neighbour being a forb (green, ‘f’), a grass (orange, ‘g’) or a legume (blue, ‘l’). Significance of competition treatment effect on log-transformed seed number was tested using ANOVA. F-statistics and significance of p-values (indicated by asterisk; *=p<0.05; **=p<0.01; ns. indicates no significance) are displayed.

Appendix 4: Niche differences (phylogenetic or multivariate) versus functional trait hierarchies

Table A2. Posterior mean values and credible intervals of the four random effects (phylogeny, target species identity, species combination and pot identity, nested in combination). Values for the two most relevant models, using the target trait and trait hierarchy model for both response variables explaining relative performance in interspecific competition compared to growing alone (lnRR_inter/control for biomass and seed number) for species-level trait average models (as reported in Table 1) and individual-level trait models (Table 2) respectively.

Response variable (sample size)	**Model**		**Phylogeny** post.mean (95% credible interval)	**Species ID** post.mean (95% credible interval)	**Combination** post.mean (95% credible interval)	**Combination:Pot ID** post.mean (95% credible interval)
lnRR_inter/control biomass (N=1262)	Target trait	Average traits	0.56 (0.002 - 1.826)	0.29 (0.002 - 0.784)	0.31 (0.192 - 0.435)	0.01 (0.002 - 0.023)
	Trait hierarchy		0.28 (0.002 - 0.777)	0.14 (0.003 - 0.348)	0.08 (0.020 - 0.152)	0.01 (0.001 - 0.023)
lnRR_inter/control seed number (N=1117)	Target trait	Average traits	0.91 (0.002 - 3.797)	0.73 (0.002 - 1.793)	0.25 (0.072 - 0.438)	0.02 (0.002 - 0.057)
	Trait hierarchy		0.27 (0.002 - 1.062)	1.06 (0.382 - 2.001)	0.05 (0.002 - 0.130)	0.02 (0.002 - 0.057)
lnRR_inter/control biomass (N=571)	Target trait	Individual traits	3.93 (0.003 - 14.97)	2.27 (0.003 - 5.199)	0.03 (0.003 - 0.064)	0.02 (0.002 - 0.036)
	Trait hierarchy		0.34 (0.002 - 1.289)	0.39 (0.003 - 0.835)	0.05 (0.002 - 0.122)	0.02 (0.002 - 0.051)
lnRR_inter/control seed number (N=565)	Target trait	Individual traits	0.33 (0.002 - 1.528)	0.65 (0.014 - 1.260)	0.05 (0.004 - 0.105)	0.03 (0.002 - 0.082)
	Trait hierarchy		0.19 (0.002 - 0.597)	0.13 (0.003 - 0.301)	0.04 (0.002 - 0.096)	0.02 (0.002 - 0.046)

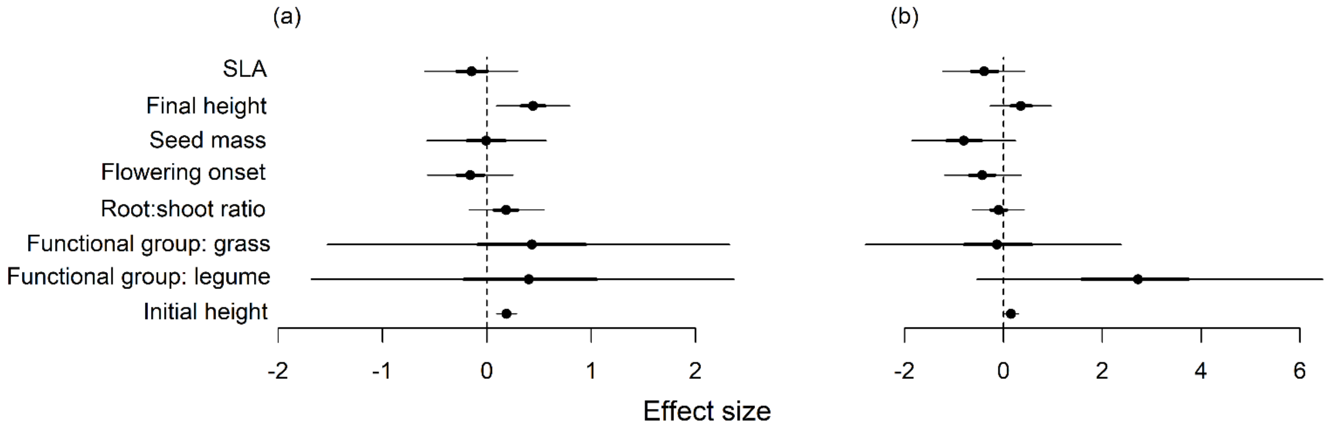

Figure A4. Results of the target trait model to explain relative performance in interspecific competition compared to growing alone (lnRR_inter/control): effects of specific leaf area (SLA), final height, seed mass, flowering onset, root:shoot ratio and the effect of being a grass or a legume (relative to a forb) and initial height on log response ratio biomass (a) and log response ratio seed number (b). All numerical traits are log-transformed and scaled to a mean of 0 and standard deviation of 1 (except for flowering onset which is only scaled). Positive effects indicate that a higher value of the respective trait leads to more biomass (respectively seeds) in interspecific competition (compared to control single individuals). Effects are considered relevant if the 95% credible interval does not overlap zero. Dots show the posterior mean, wide lines indicating one standard deviation (68% credible interval), while narrow lines indicate the 95% credible interval.

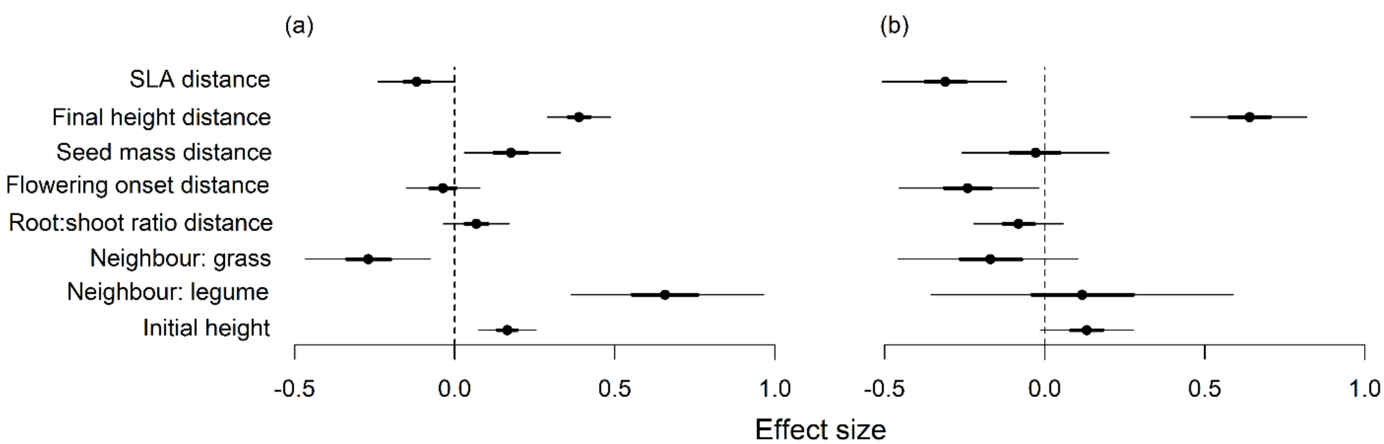

Figure A5. Results of the trait hierarchy model to explain relative performance in interspecific competition compared to intraspecific competition (lnRR_inter/intra): effects of specific leaf area (SLA) distance, final height distance, seed mass distance, flowering onset distance, root:shoot ratio distance and the effect of having a grass or a legume as neighbour (relative to a forb) and initial height of the individual on log response ratio biomass (a) and log response ratio seed number (b). All numerical traits are log-transformed and scaled to a mean of 0 and standard deviation of 1 (except for flowering onset which is only scaled). Positive effects indicate that a higher value of the respective trait leads to more biomass (respectively seeds) in interspecific competition (compared to individuals growing in intraspecific competition). Effects are considered relevant if the 95% credible interval does not overlap zero. Dots show the posterior mean, wide lines indicating one standard deviation (68% credible interval), while narrow lines indicate the 95% credible interval.

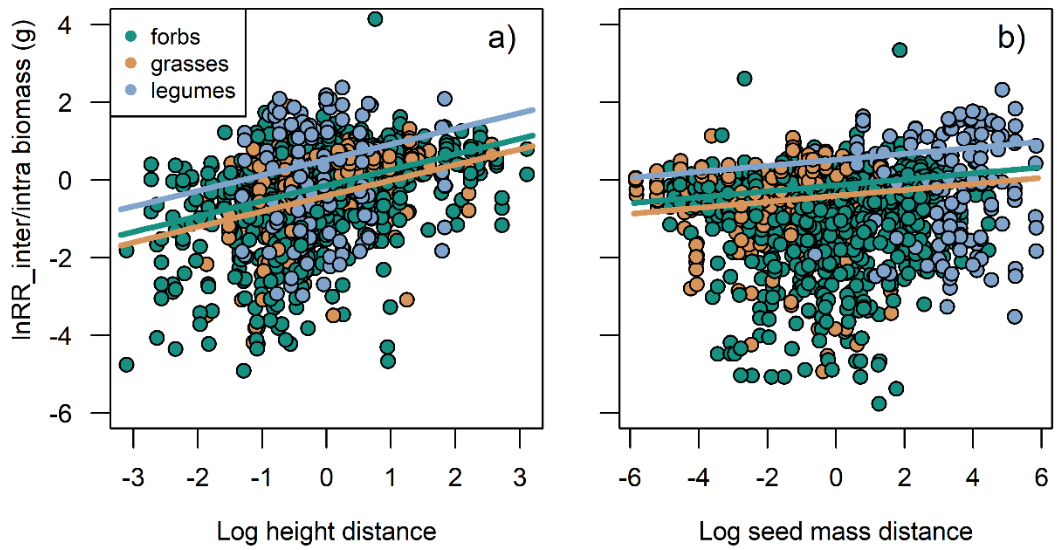

Figure A6. Predictions of trait effects on the log response ratio biomass of alien plants growing in interspecific competition compared to growing in intraspecific competition (lnRR_inter/intra). Displayed are the predicted effects of the two relevant traits from the trait hierarchy model: maximum height distance (a) and seed mass distance (b) (both log-transformed and scaled to a mean of 0 and standard deviation of 1; predictions for each trait effect shown with the other numeric traits fixed at their mean). Different colours depict the different functional groups: forbs (green), grasses (orange) and legumes (blue). Positive effects indicate that a higher value in the respective trait of the target individual compared to its neighbour leads to more biomass production in interspecific competition (compared to growing in intraspecific competition).

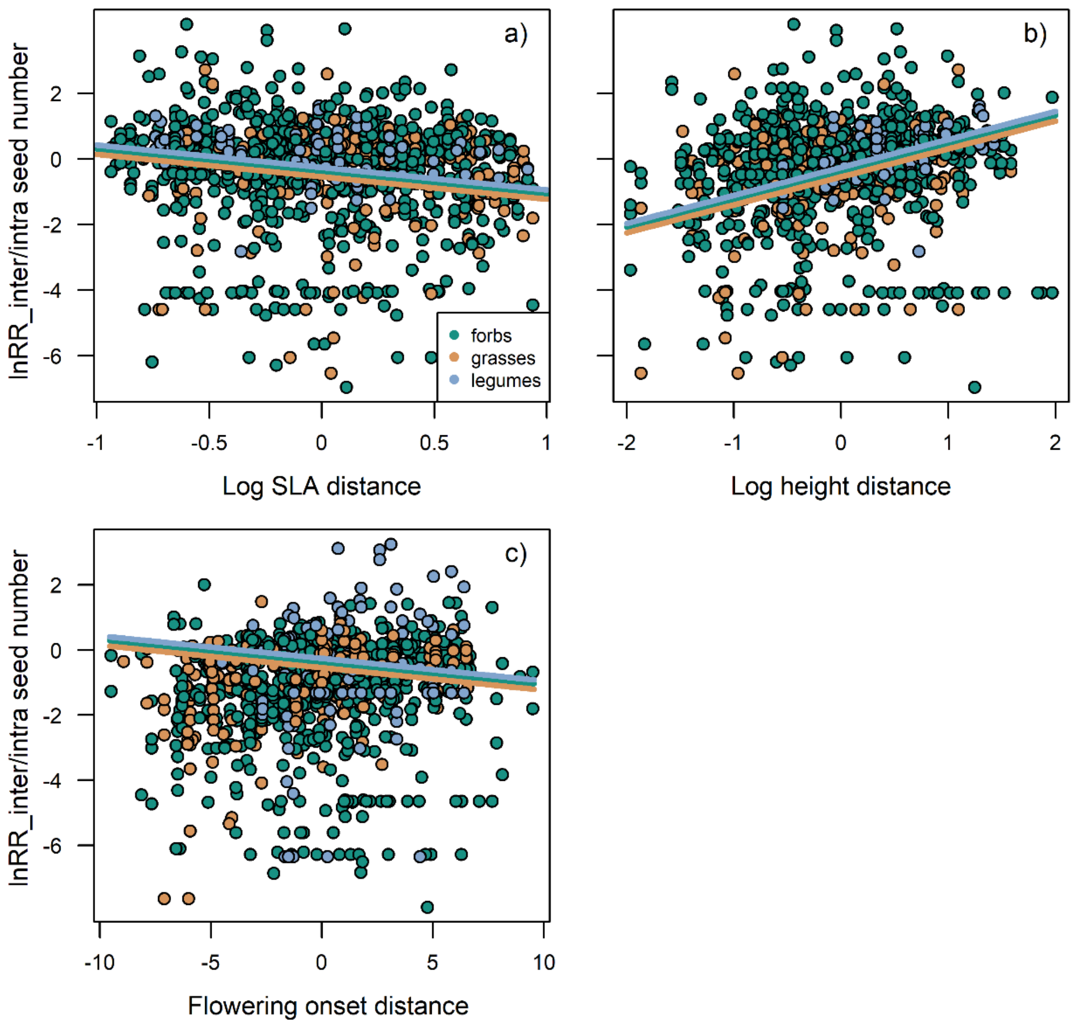

Figure A7. Predictions of trait effects on the log response ratio seed number of alien plants growing in interspecific competition compared to growing in intraspecific competition (lnRR_inter/intra). Displayed are the predicted effects of the three relevant traits from the trait hierarchy model : specific leaf area (SLA) distance (a), maximum height distance (b) and flowering onset distance (c) (log-transformed and scaled to a mean of 0 and standard deviation of 1, except for flowering onset which was only scaled; predictions for each trait effect shown with the other numeric traits fixed at their mean). Different colours depict the different functional groups: forbs (green), grasses (orange) and legumes (blue). Positive effects indicate that a higher value in the respective trait of the target individual compared to its neighbour leads to higher seed production in interspecific competition (compared to growing in intraspecific competition).

Appendix 5: Individual-level traits versus species-level trait averages

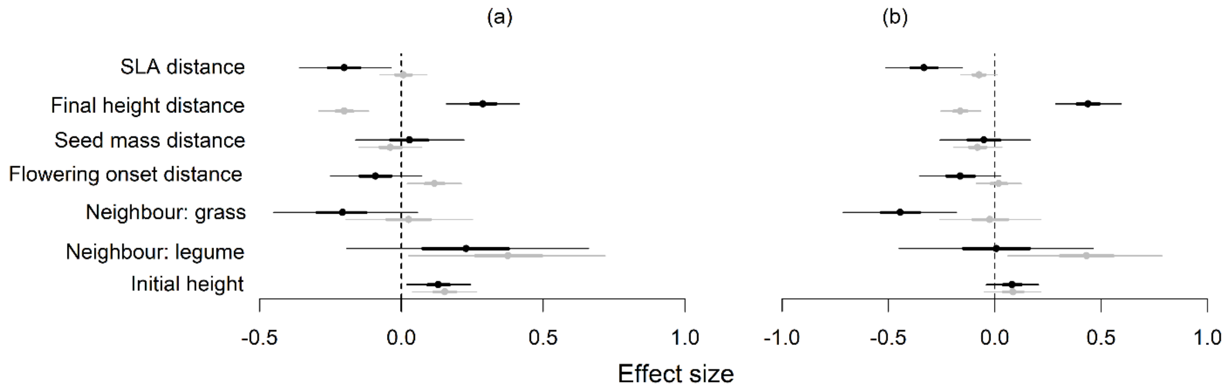

Figure A8. Results of the trait hierarchy model to explain relative performance in interspecific competition compared to growing alone (lnRR_inter/control) based on species-level trait averages (black) compared to individual-level traits (grey): effects of specific leaf area (SLA) distance, final height distance, seed mass distance, flowering onset distance, the effect of having a grass or a legume as neighbour (relative to a forb) and initial height on log response ratio biomass (a) and log response ratio seed number (b). All numerical traits are scaled and log-transformed (except for flowering onset which is only scaled). Positive effects indicate that a higher value of the respective trait leads to more biomass (respectively seeds) in interspecific competition (compared to control single individuals). Effects are considered relevant if the 95% credible interval does not overlap zero. Dots show the posterior mean, wide lines indicating one standard deviation (68% credible interval), while narrow lines indicate the 95% credible interval.

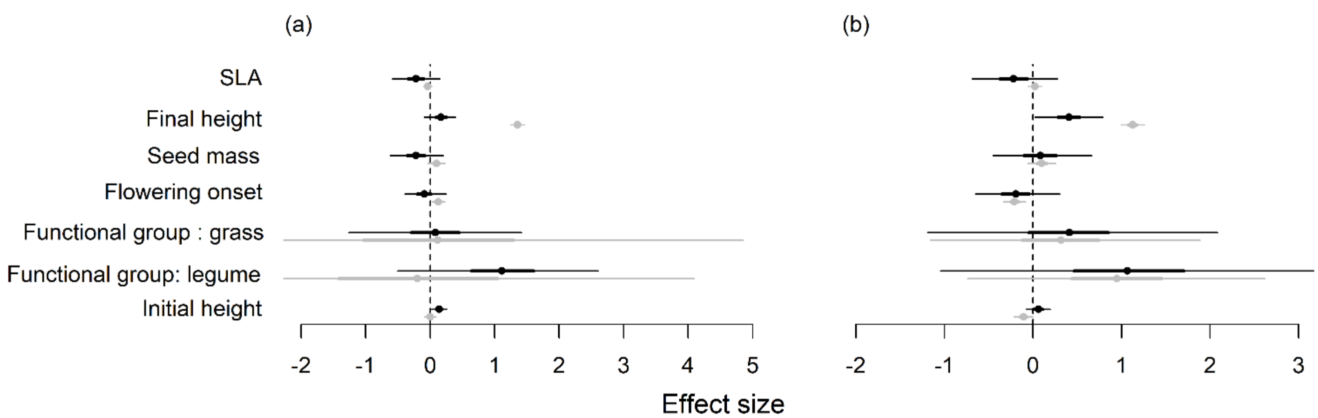

Figure A9. Results of the target trait model to explain relative performance in interspecific competition compared to growing alone (lnRR_inter/control) based on species-level trait averages (black) compared to individual-level traits (grey): effects of specific leaf area (SLA), final height, seed mass, flowering onset, the effect of being a grass or a legume as (relative to a forb) and initial height on log response ratio biomass (a) and log response ratio seed number (b). All numerical traits are scaled and log-transformed (except for flowering onset which is only scaled). Positive effects indicate that a higher value of the respective trait leads to more biomass (respectively seeds) in interspecific competition (compared to control single individuals). Effects are considered relevant if the 95% credible interval does not overlap zero. Dots show the posterior mean, wide lines indicating one standard deviation (68% credible interval), while narrow lines indicate the 95% credible interval.

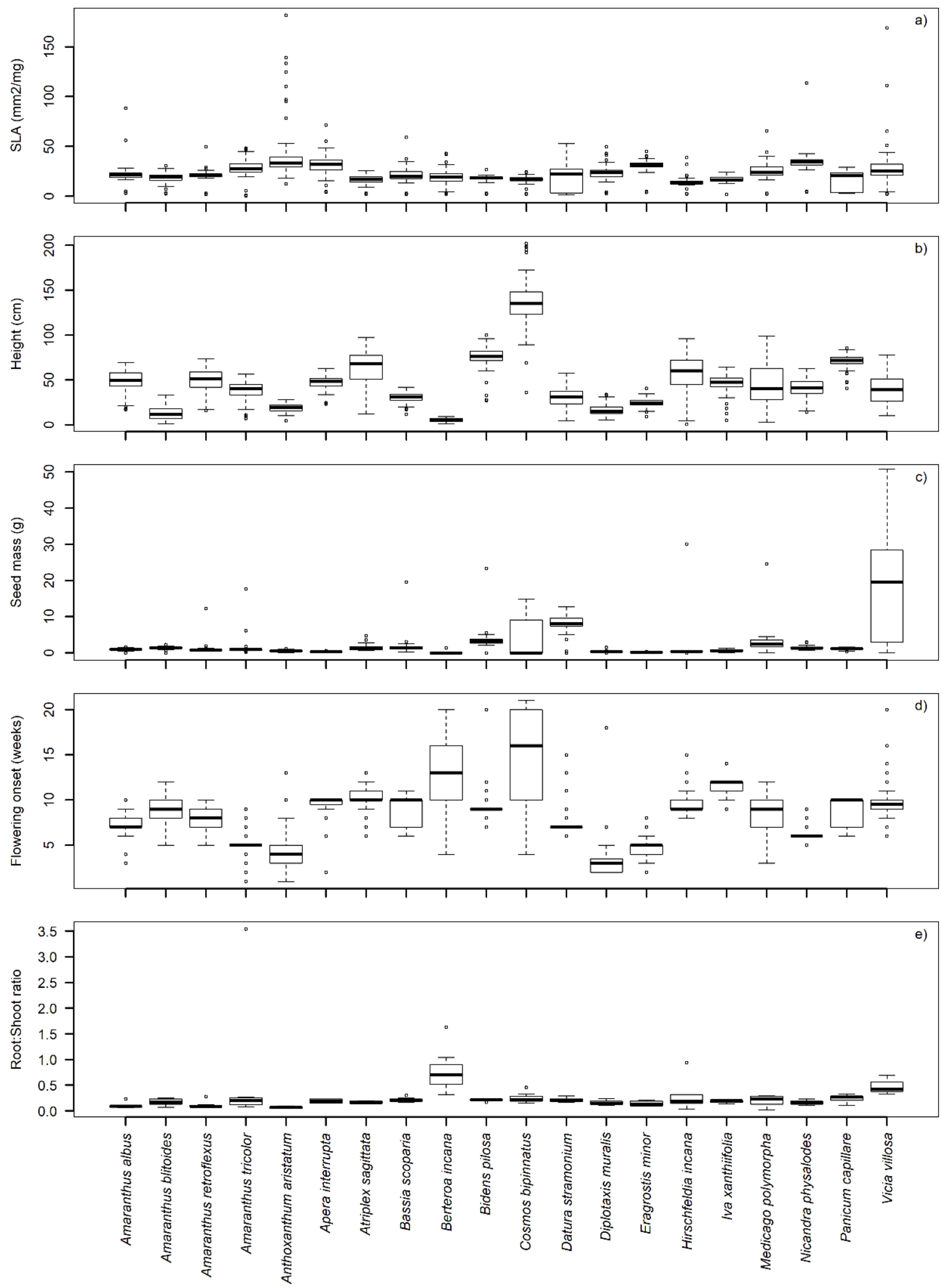

Figure A10. Intraspecific trait variation for the five focal traits across all study species, shown for specific leaf area (SLA) (a), seed mass (b), maximum height (c), root:shoot ratio (d) and flowering onset (e). Note that for root:shoot ratio, measurements were only taken for control plants growing alone, while for the other traits variation is shown across individuals of all competition treatments.

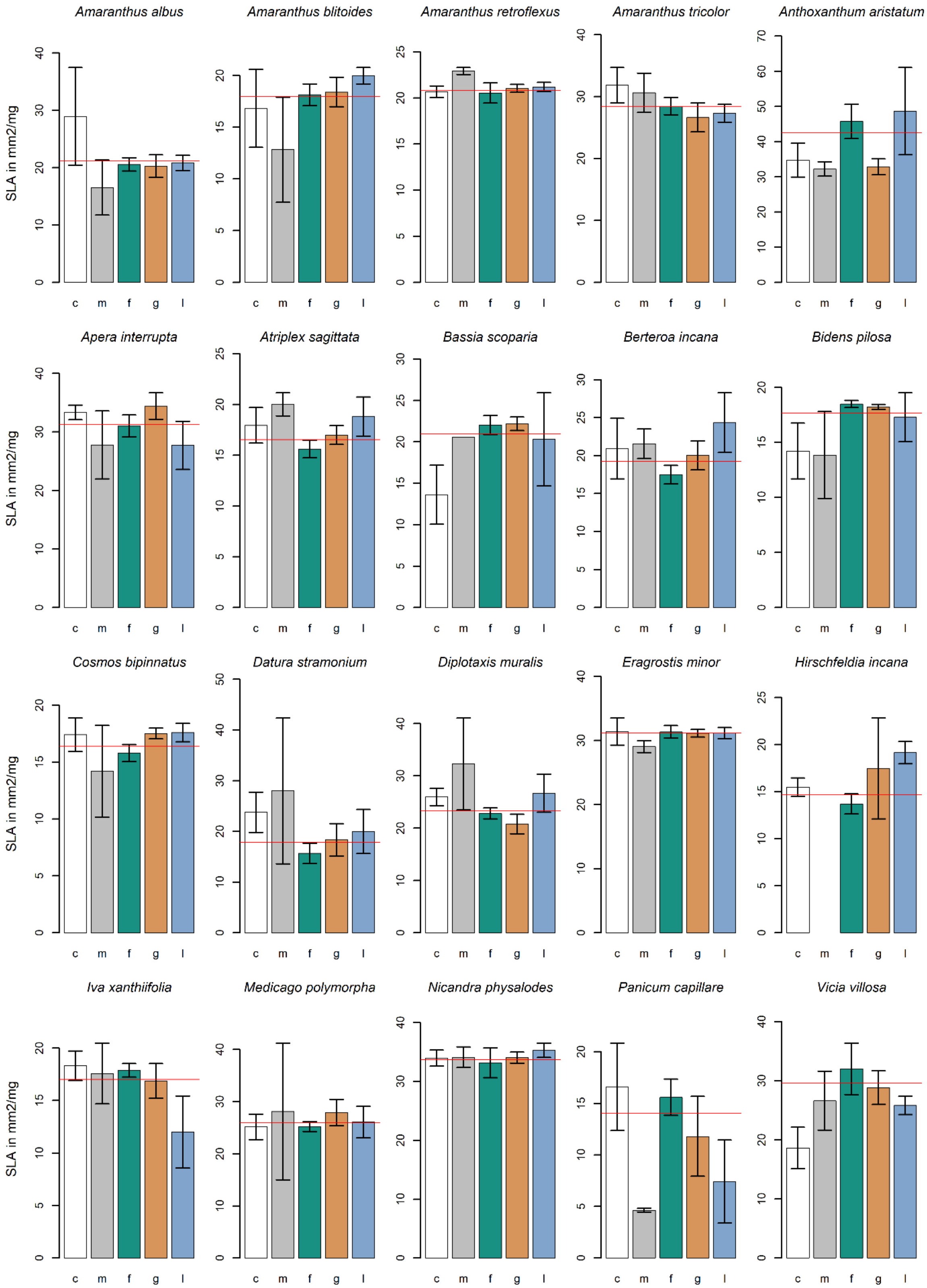

Figure A11. Mean specific leaf area (SLA) in mm2/mg (± 1 standard error) per species depending on competition treatment. White bars represent the control (plants growing alone in the pot, 'c'; note that this value (logarithmized) is used as the species-level trait average in the models); grey bars the monoculture treatment (plants grow with a conspecific individual, 'm'); coloured bars represent the mixture treatment with the neighbour being a forb (green, 'f'), a grass (orange, 'g') or a legume (blue, 'l'); the red line represents the mean trait value across all competition treatments. Values for monoculture treatment of *Hirschfeldia incana* could not be assessed, therefore no bar is displayed.

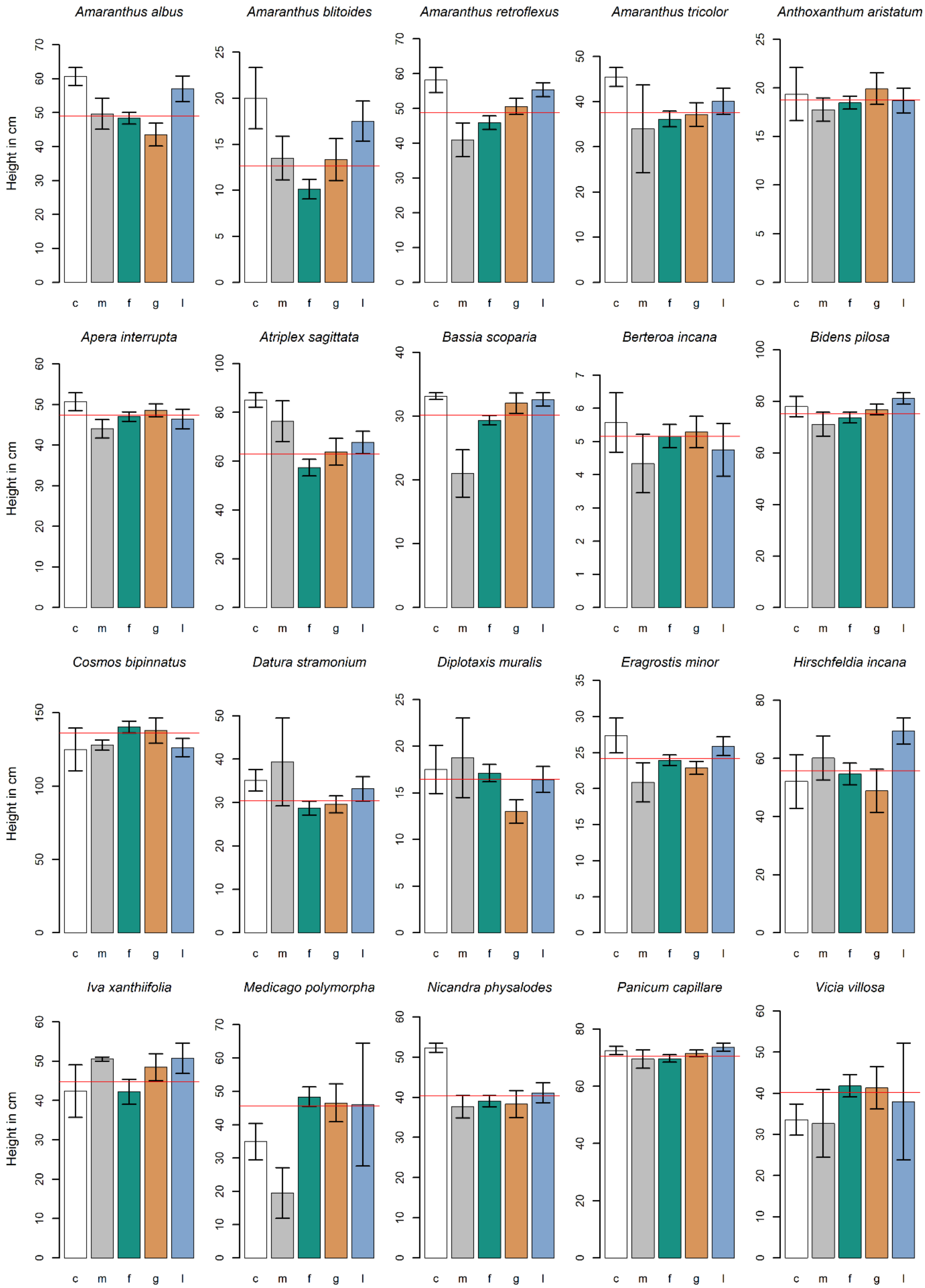

Figure A12. Mean height in cm (± 1 standard error) per species depending on competition treatment. White bars represent the control (plants growing alone in the pot, 'c'; note that this value (logarithmized) is used as the species-level trait average in the models); grey bars the monoculture treatment (plants grow with a conspecific individual, 'm'); coloured bars represent the mixture treatment with the neighbour being a forb (green, 'f'), a grass (orange, 'g') or a legume (blue, 'l'); the red line represents the mean trait value across all competition treatments.

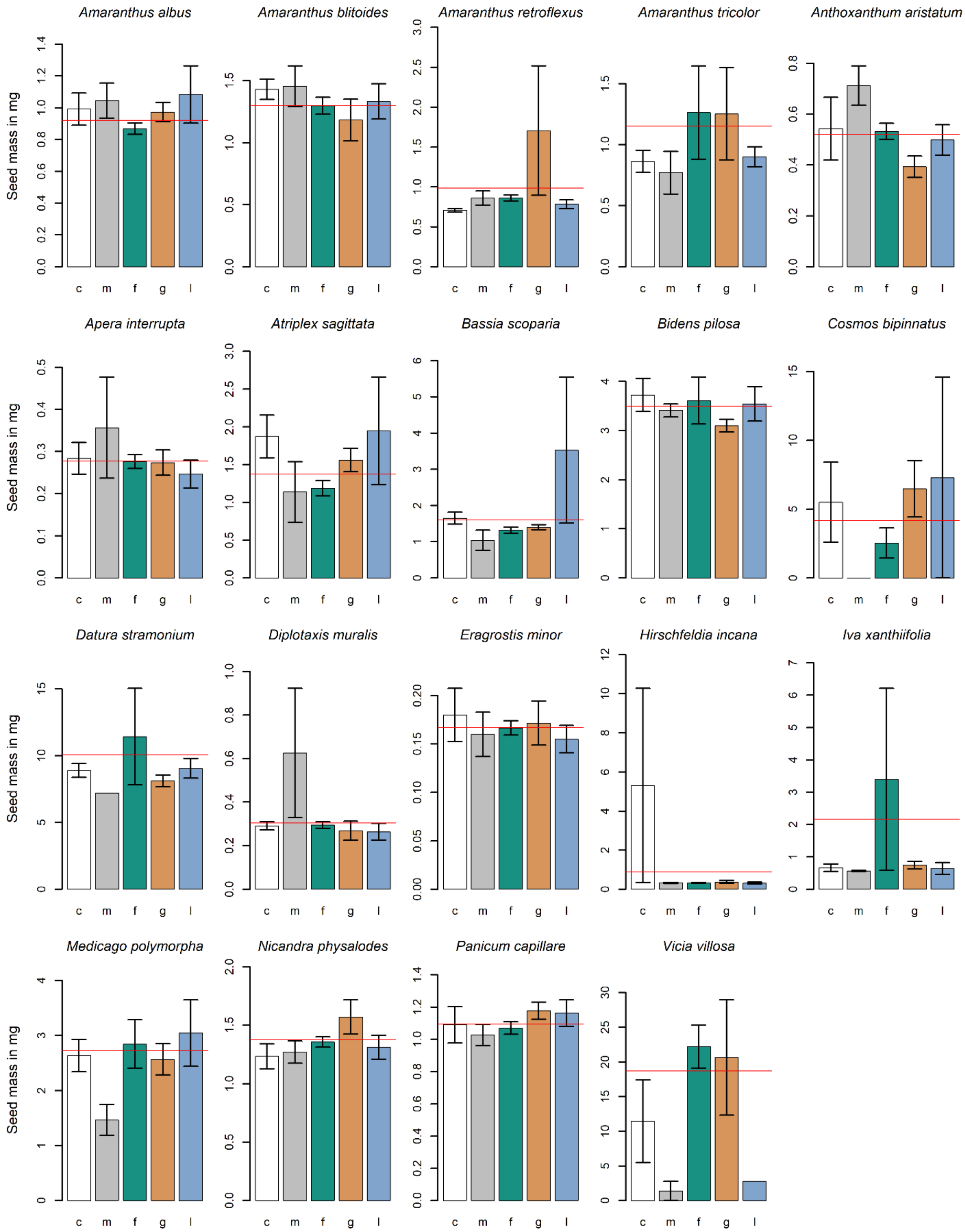

Figure A13. Mean seed mass in mg (± 1 standard error) per species depending on competition treatment. White bars represent the control (plants growing alone in the pot, ‘c’; note that this value (logarithmized) is used as the species-level trait average in the models); grey bars the monoculture treatment (plants grow with a conspecific individual, ‘m’); coloured bars represent the mixture treatment with the neighbour being a forb (green, ‘f’), a grass (orange, ‘g’) or a legume (blue, ‘l’); the red line represents the mean trait value across all competition treatments. Due to missing values, monoculture bar of *Cosmos bipinnatus* could not be displayed. As *Berteroa incana* was excluded from all seed analyses it is not displayed in this figure.

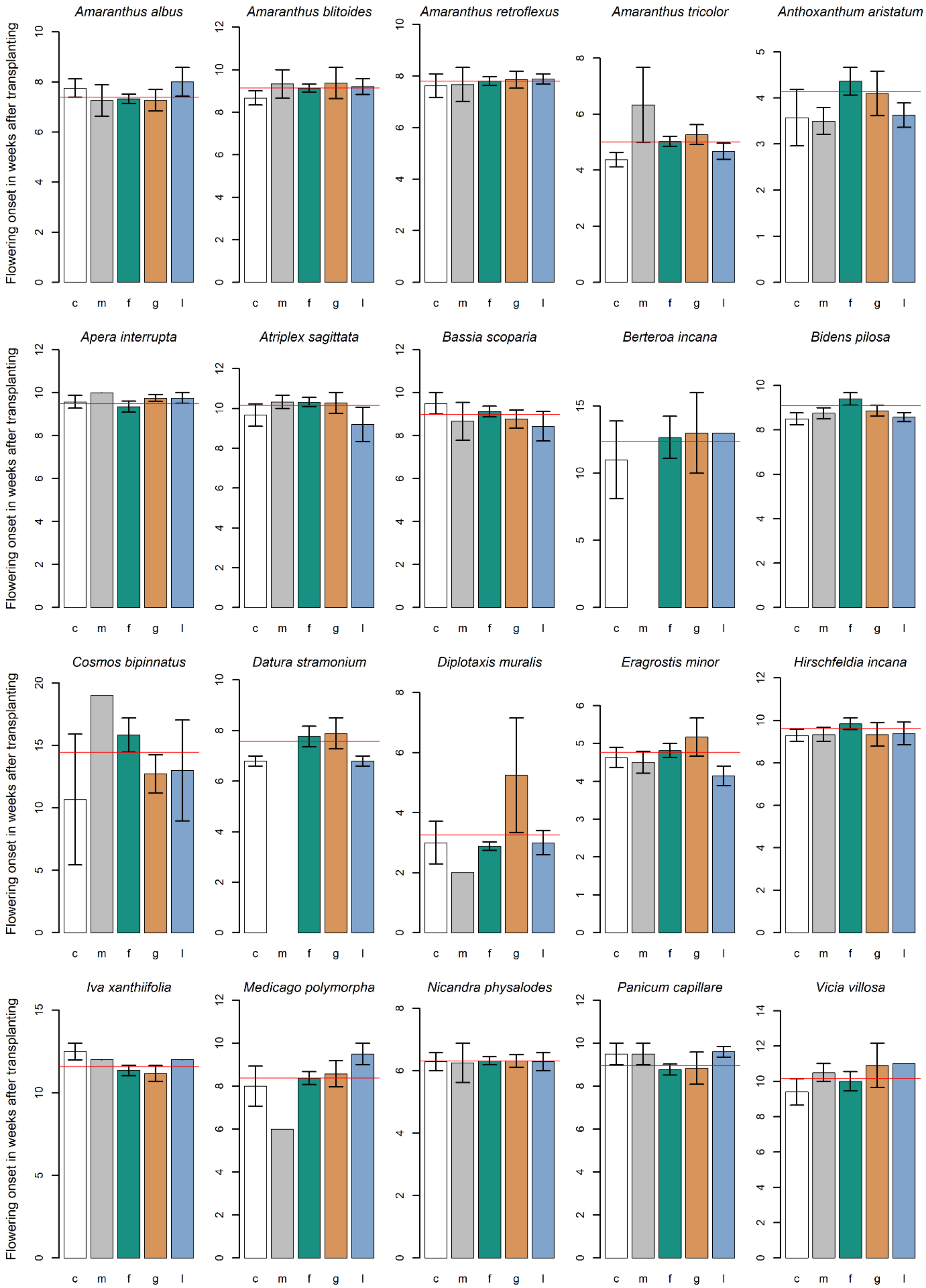

Figure A14. Mean flowering onset in weeks after transplanting (± 1 standard error) per species depending on competition treatment. White bars represent the control (plants growing alone in the pot, 'c'; note that this value is used as the species-level trait average in the models); grey bars the monoculture treatment (plants grow with a conspecific individual, 'm'); coloured bars represent the mixture treatment with the neighbour being a forb (green, 'f'), a grass (orange, 'g') or a legume (blue, 'l'); the red line represents the mean trait value across all competition treatments. Due to missing values, monoculture treatments of *Datura stramonium* and *Berteroa incana* could not be displayed.

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