New Phytologist Supporting Information

Article title: Functional traits influence patterns in vegetative and reproductive plant phenology - a multi-botanical garden study

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Article acceptance date: 23 May 2022

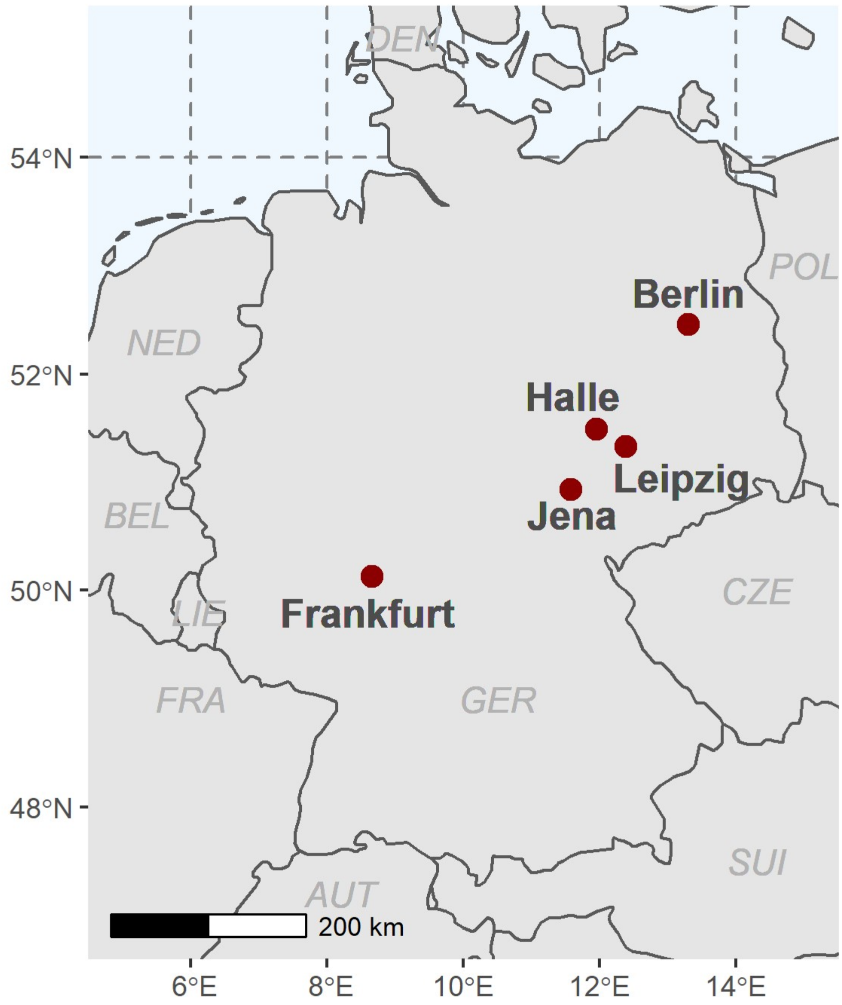

Fig. S1 Geographical location of the five botanical gardens in Germany.

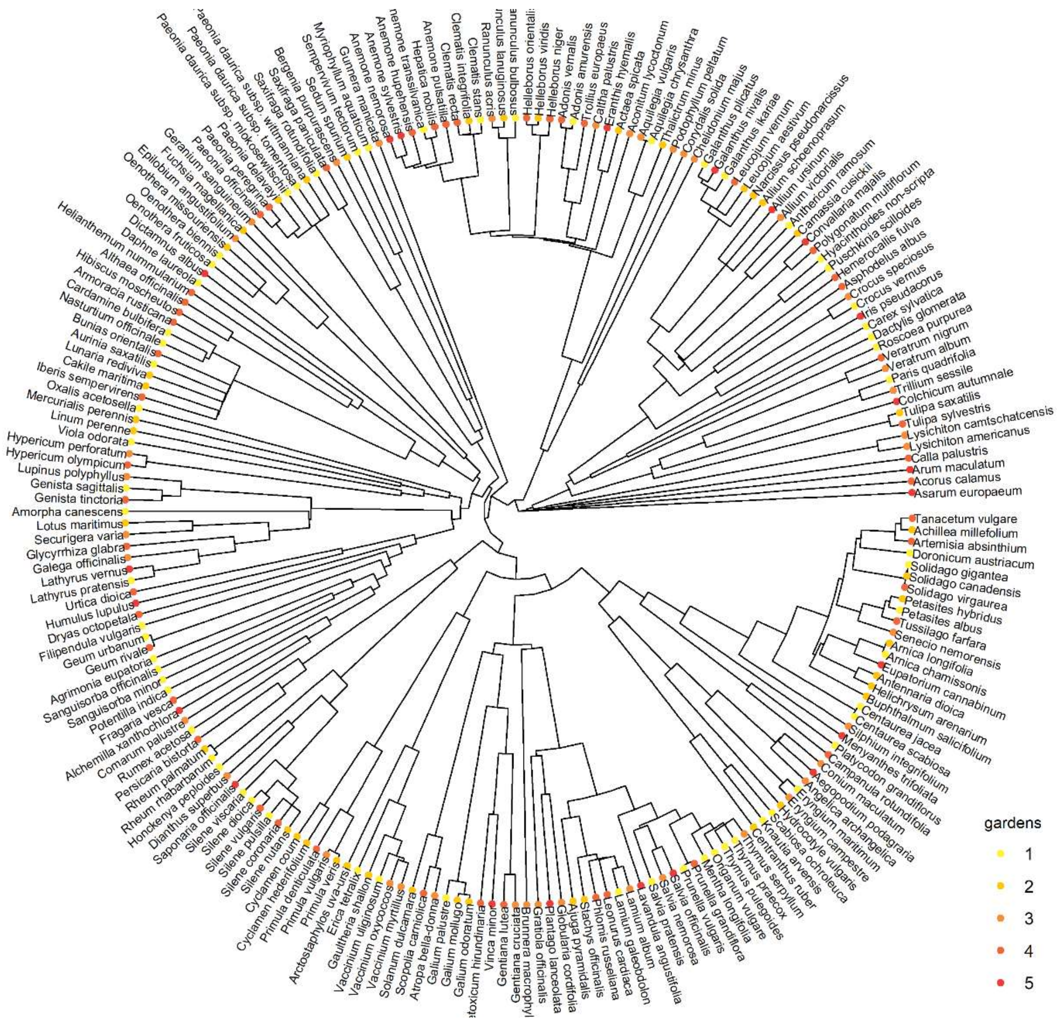

Fig. S2 Phylogenetic tree of the 212 study species, the colour of the tree tips represent the number of gardens a species was monitored in 2020. To create the phylogenetic tree of the studied species the function phylo.maker from the package 'V. PhyloMaker' (Jin & Qian, 2019) was used.

Tab. S2 The five botanical gardens in which phenology was monitored, their location (latitude, longitude), temperature (mean annual, minimum monthly, mean monthly temperature [°C]) and precipitation conditions (annual and monthly precipitation sum [mm]) for the year 2020; data from Deutscher Wetterdienst (DWD) Climate Data Center (CDC) 2021.

		Berlin	Frankfurt (Main)	Halle (Saale)	Jena	Leipzig
Latitude/ Longitude		52.4545/ 13.3050	50.1271/ 8.6585	51.4888/ 11.9611	50.9313/ 11.5852	51.3289/ 12.3912
Mean annual temperature		11.7	12.1	12.0	11.4	11.5
Sum annual precipitation		478	543	401	597	491
Minimum monthly temperature	January	1.1	1.0	1.0	0.7	0.9
	February	3.2	2.4	3.0	3.2	2.9
	March	1.0	1.3	0.9	0.9	0.8
	April	4.0	4.1	3.8	3.2	3.6
	May	6.6	6.4	6.2	6.0	6.1
	June	13.0	12.6	12.7	12.6	12.9
	July	12.4	13.2	13.1	12.9	12.7
	August	15.2	16.2	16.1	15.5	15.9
	September	9.7	10.9	10.1	9.1	9.5
	October	7.7	7.3	7.9	7.9	8.2
	November	4.0	3.1	3.3	2.9	3.5
	December	0.8	1.8	1.1	1.3	1.2
Mean monthly temperature	January	4.2	4.1	4.5	4.2	4.2
	February	6.0	6.5	6.6	6.8	6.3
	March	5.5	7.5	6.1	6.2	5.8
	April	10.7	12.9	11.5	11.1	10.9
	May	12.4	14.2	13.3	12.7	12.6
	June	18.9	18.6	19.4	18.0	18.6
	July	18.2	20.6	19.8	19.6	19.4
	August	21.2	22.0	22.0	21.2	21.4
	September	15.3	17.0	16.5	15.6	16.2
	October	11.0	11.3	11.9	11.3	11.6
	November	7.0	6.6	7.1	6.5	6.7
	December	3.3	4.3	4.2	3.8	3.9
Monthly sum of precipitation	January	32	37	34	23	36
	February	82	79	59	66	88
	March	28	48	30	42	38
	April	15	22	12	13	12
	May	39	31	40	50	42
	June	35	44	26	99	41
	July	40	16	25	35	22
	August	58	76	50	110	50
	September	50	32	67	50	60
	October	61	61	36	78	78
	November	17	16	7	7	11
	December	21	81	15	24	23

Tab. S3 The five botanical gardens in which phenology was monitored, their location (latitude, longitude), and information on bioclimatic variables on long term observations (1979-2013), received from CHELSA database (Karger *et al.*, 2017; Karger *et al.*, 2018).

		Berlin	Frankfurt (Main)	Halle (Saale)	Jena	Leipzig
Latitude/ Longitude		52.4545/ 13.3050	50.1271/ 8.6585	51.4888/ 11.9611	50.9313/ 11.5852	51.3289/ 12.3912
Bio1	Annual Mean Temperature	9.45	10.25	9.75	9.45	9.65
Bio5	Max Temperature of Warmest Month	23.35	24.05	23.65	23.25	23.45
Bio6	Min Temperature of Coldest Month	-1.95	-1.35	-1.65	-2.25	-1.85
Bio8	Mean Temperature of Wettest Quarter	18.75	18.85	18.45	18.15	18.25
Bio9	Mean Temperature of Driest Quarter	7.55	8.55	1.45	0.95	1.15
Bio10	Mean Temperature of Warmest Quarter	18.75	19.45	18.95	18.75	18.85
Bio11	Mean Temperature of Coldest Quarter	0.65	1.65	1.15	0.75	0.95
Bio12	Annual Precipitation	603.7	724.3	531.9	601.4	607.3
Bio13	Precipitation of Wettest Month	62.3	69.1	64.7	74.5	75.2
Bio14	Precipitation of Driest Month	33.6	46.4	28.8	31.5	34.1
Bio16	Precipitation of Wettest Quarter	184.6	204.4	182.2	209.5	208.8
Bio17	Precipitation of Driest Quarter	114.3	150.9	90.4	95.0	108.7
Bio18	Precipitation of Warmest Quarter	184.6	190.7	171.5	206.5	205.2
Bio19	Precipitation of Coldest Quarter	152.4	178.8	108.9	109.2	131.0

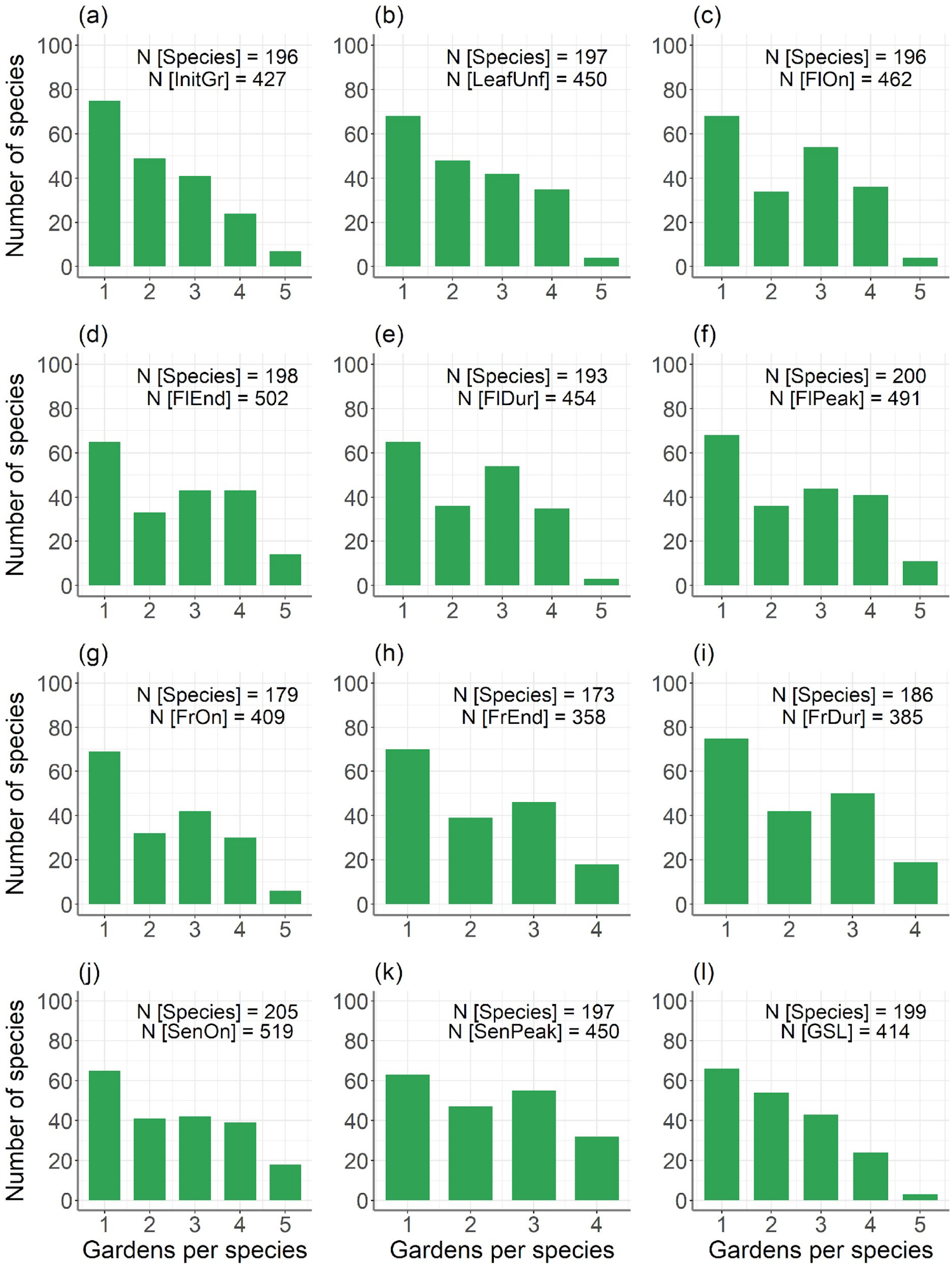

Fig. S3 Histograms showing the variation in the number of species and gardens for each phenological stage: (a) initial growth, (b) onset of leaf unfolding, (c) onset of flowering, (d) end of flowering, (e) flowering duration, (f) peak of flowering, (g) onset of fruiting, (h) end of fruiting, (i) fruiting duration, (j) onset of senescence, (k) peak of senescence, (l) growing season length.

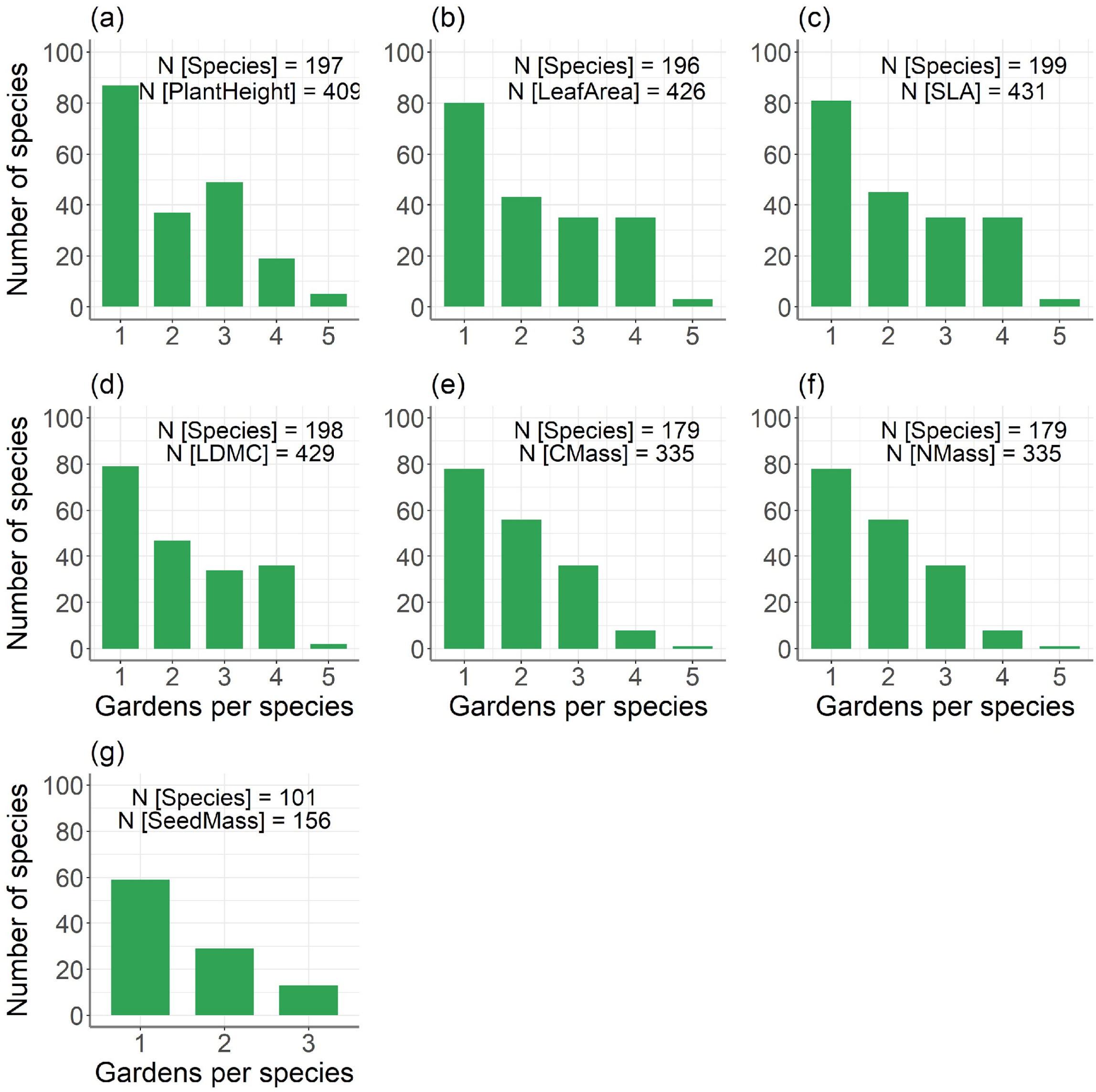

Fig. S4 Histograms showing the variation in the number of species and gardens for each functional trait: (a) Plant Height, (b) Leaf area, (c) Specific leaf area (SLA), (d) Leaf dry matter content (LDMC), (e) Mass-based leaf carbon content (C_{mass}), (f) Mass-based leaf nitrogen content (N_{mass}), (g) Seed mass.

Tab. S5 To quantify the strength of a phylogenetic signal, Pagel's Lambda statistic (Pagel, 1999) was applied, which ranges from 0 for traits being phylogenetically unrelated to 1 for traits following trait evolution according to a Brownian motion (BM) model.

Trait	Pagels Lambda	p-value
Leaf_area	0.671	<0.001
SLA	0.403	0.024
LDMC	0.829	<0.001
Leaf_C	0.633	0.011
Leaf_N	0.547	0.368
Plant_height	0.297	0.017
Seed_mass	0.817	<0.001
Phenological stage		
InitGr	0.024	0.752
LeafUnf	0.229	0.044
FlOn	0.551	<0.001
FlEnd	0.606	<0.001
FlDur	0.214	<0.001
FlPeak	0.441	<0.001
FrOn	0.242	0.008
FrEnd	0.290	0.003
FrDur	0.202	0.001
SenOn	0.506	<0.001
SenPeak	0.462	<0.001
GSL	0.152	0.015

Tab. S9 Contributions (loadings) of onset, end, intensity and duration of phenological stages to the first (Dim.1) to twelfth (Dim.12) PCA axes.

Stage	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8	Dim.9	Dim.10	Dim.11	Dim.12
InitGr	3.01	23.72	1.39	9.94	4.90	18.57	10.09	27.37	0.43	0.55	0.02	0.01
LeafUnf	2.16	28,14	4.38	10.70	1.90	2.62	1.74	22.19	0.96	7.67	11.77	5.72
FlOn	13.01	1.48	0.08	12.33	5.86	3.07	7.22	0.02	0.16	9.71	26.26	20.74
FlEnd	13.68	1.99	4.28	0.98	14.88	0.59	0.44	0.13	0.58	17.41	2.38	42.59
FlDur	2.59	17.86	15.13	9.59	12.25	17.43	7.47	0.35	0.01	3.63	2.56	11.07
FlPeak	13.78	0.71	0.02	10.20	5.36	0.50	6.13	0.65	2.03	45.52	14.85	0.21
FrOn	11.24	1.47	0.76	10.67	9.52	12.18	23.22	4.40	25.46	0.77	0.18	0.08
FrEnd	12.90	0.33	3.28	2.57	22.86	0.44	5.38	0.70	50.37	0.50	0.44	0.17
FrDur	4.53	10.68	19.21	4.90	18.48	15.38	9.21	0.96	16.30	0.12	0.16	0.01
SenOn	10.48	0.02	10.68	15.49	0.05	0.81	2.30	20.61	0.98	6.52	22.04	10.01
SenPeak	8.72	0.01	12.33	11.25	1.41	22.96	18.95	22.21	2.05	0.01	0.02	0.02
GSL	3.85	13.55	28.42	1.33	2.42	5.39	7.79	0.35	0.65	7.57	19.28	9.34

Tab. S10 Trait contributions (loadings) to the first (Dim.1) to seventh (Dim.7) PCA axes.

Trait	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7
LeafArea	28.69	9.22	4.35	0.04	10.13	47.53	0.04
SLA	4.13	38.82	8.98	7.20	0.61	4.81	35.45
LDMC	12.71	27.34	5.06	4.62	31.01	12.85	6.44
LeafC	9.36	4.52	36.96	0.03	47.83	0.01	1.33
LeafN	12.77	0.90	41.49	0.35	7.96	1.15	35.40
PlantHeight	12.71	8.70	0.06	57.76	0.41	20.36	0.01
SeedMass	19.67	10.52	3.10	30.01	2.06	13.29	21.34

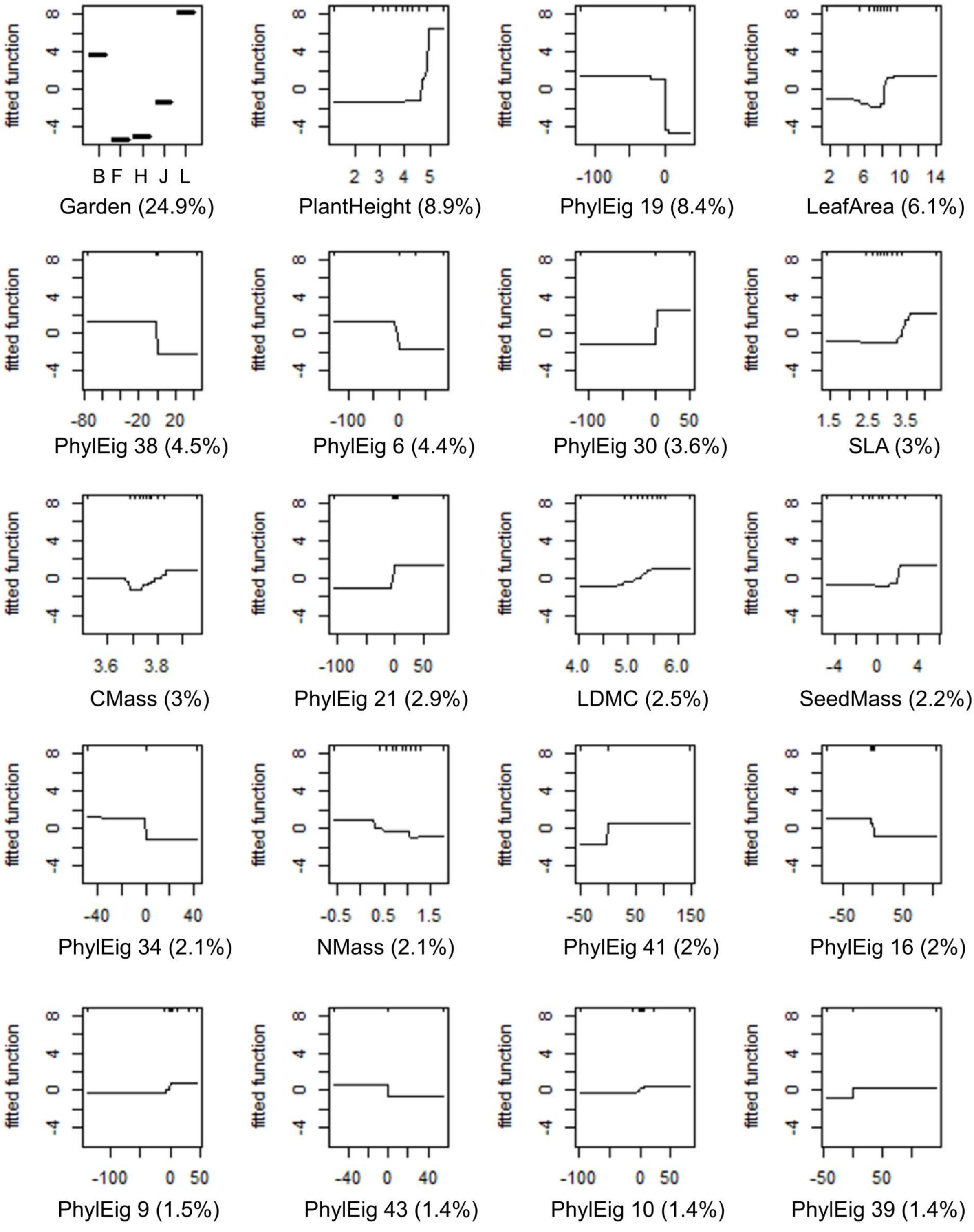

Fig. S5 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Initial growth' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.30. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; Plant height (cm); Leaf area (mm²); SLA: Specific leaf area (cm²/g); CMass: Mass-based leaf carbon content (%); LDMC: Leaf dry matter content (mg/g); Seed mass (mg); NMass: Mass-based leaf nitrogen content (%). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

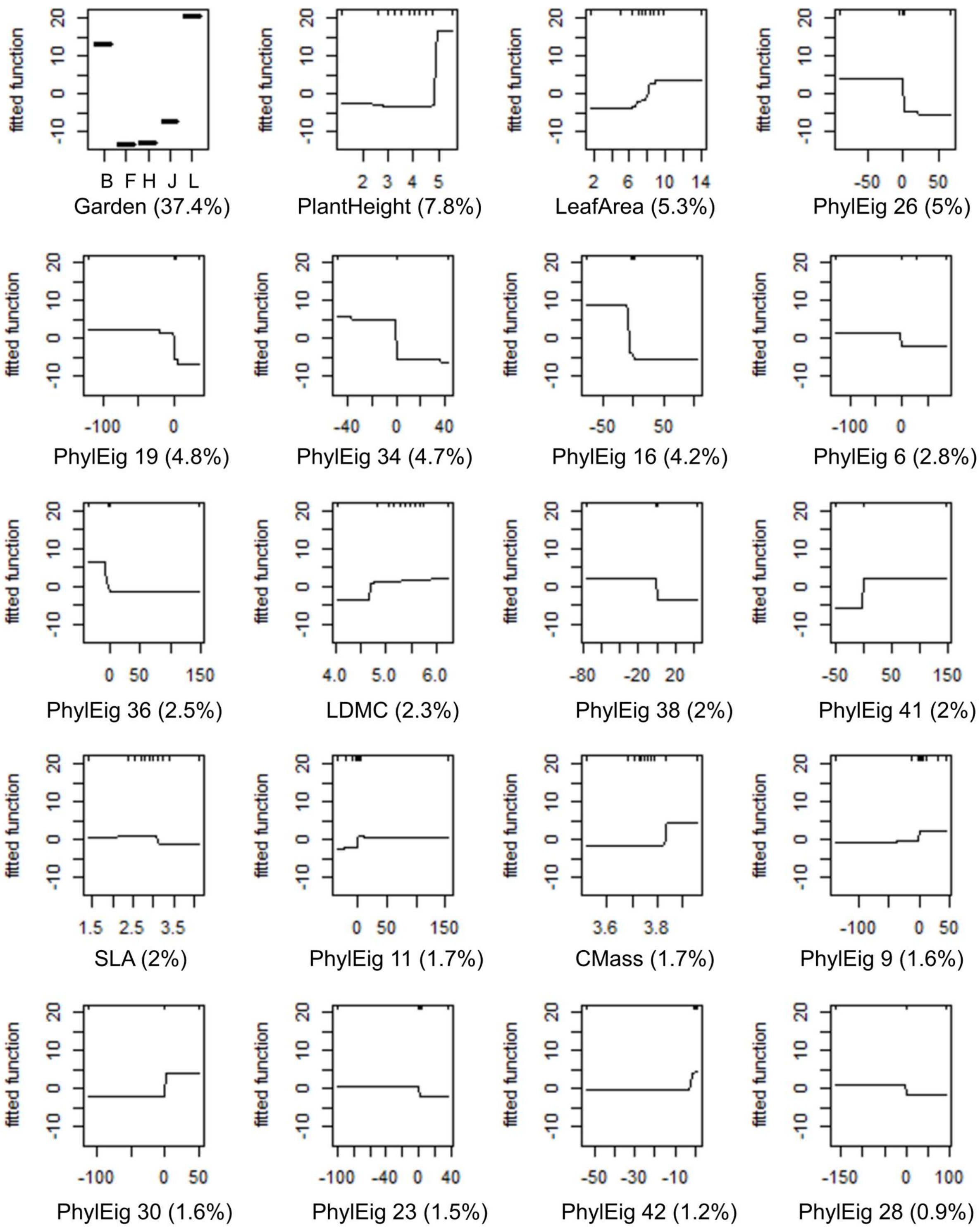

Fig. S6 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Leaf unfolding' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.54. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; Plant height (cm); Leaf area (mm²); LDMC: Leaf dry matter content (mg/g); SLA: Specific leaf area (cm²/g); CMass: Mass-based leaf carbon content (%). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

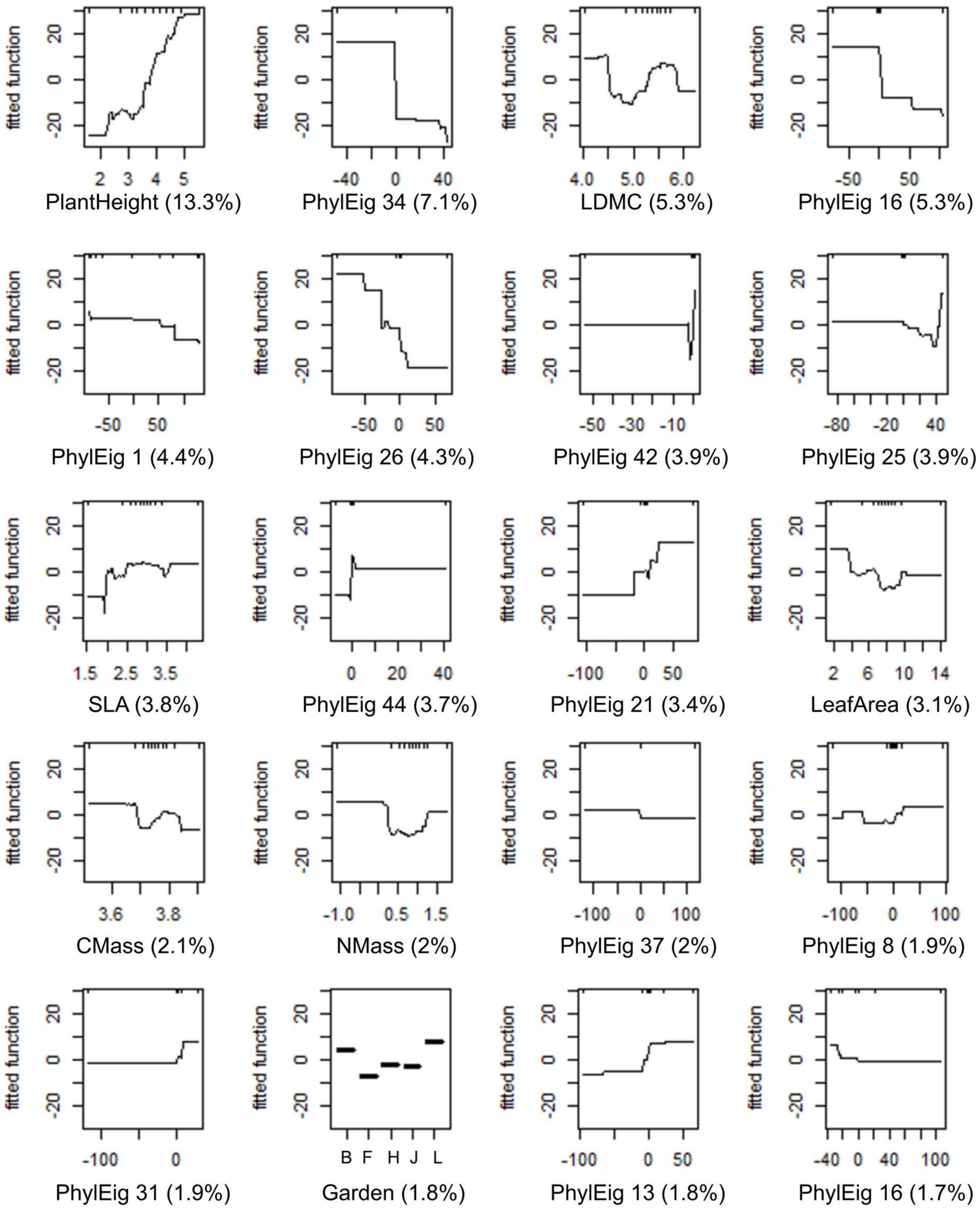

Fig. S7 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Onset of flowering' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.63. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; LDMC: Leaf dry matter content (mg/g); SLA: Specific leaf area (cm²/g); Leaf area (mm²); CMass: Mass-based leaf carbon content (%); NMass: Mass-based leaf nitrogen content (%); Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig. All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

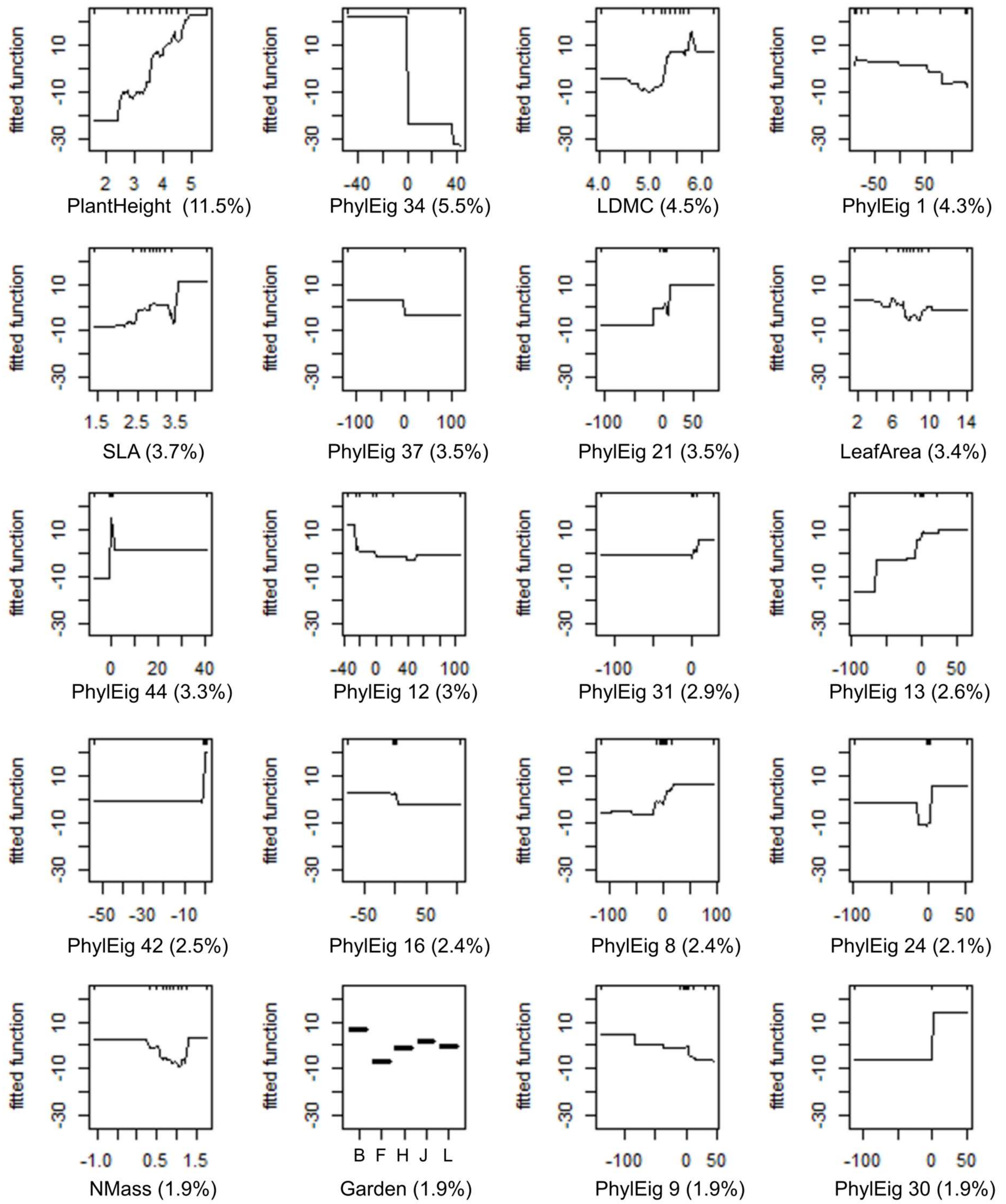

Fig. S8 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Peak of flowering' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.71. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Plant height (cm); LDMC: Leaf dry matter content (mg/g); SLA: Specific leaf area (cm^2/g); Leaf area (mm^2); NMass: Mass-based leaf nitrogen content (%); Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig. All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

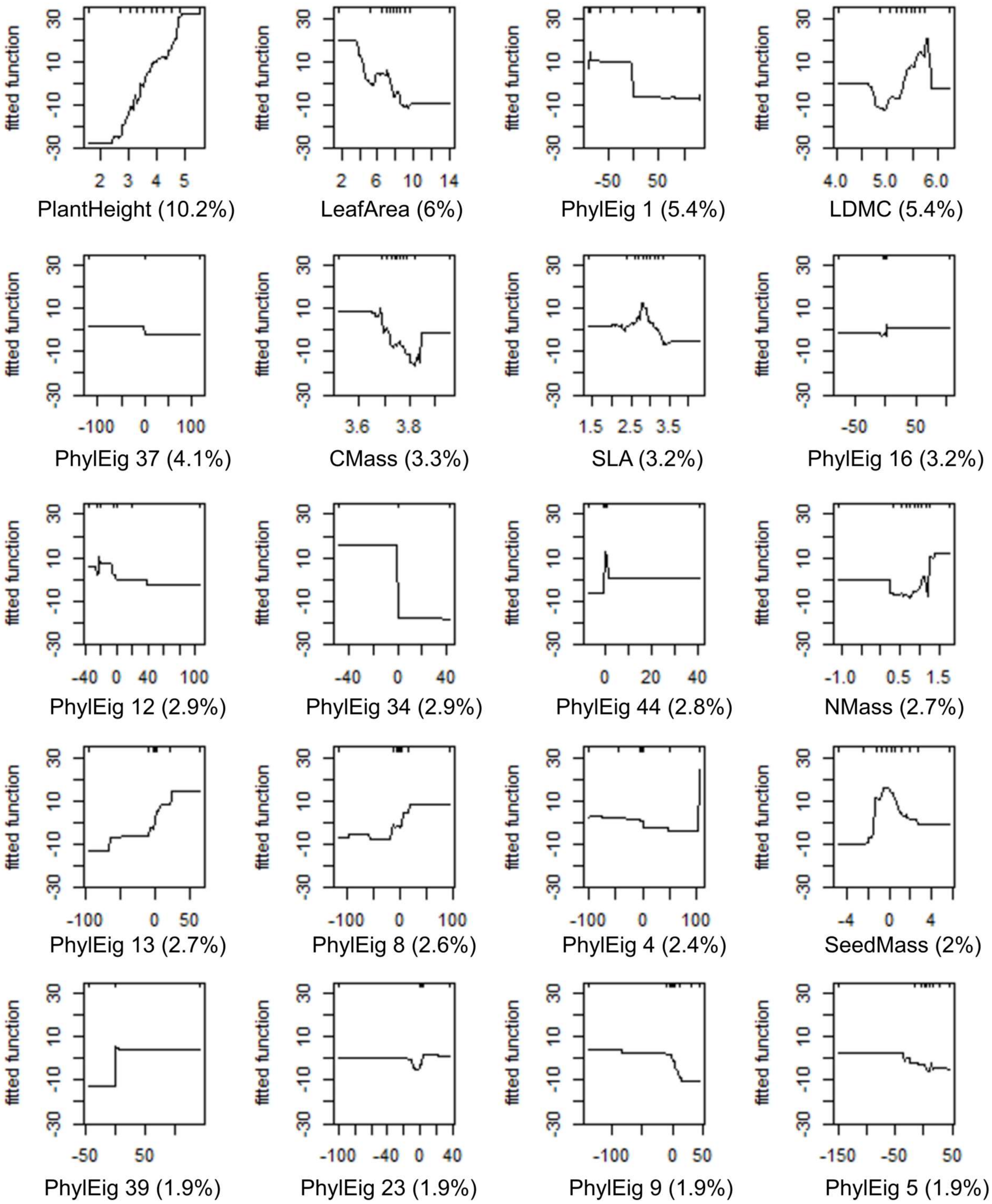

Fig. S9 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'End of flowering' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.68. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Plant height (cm); Leaf area (mm²); LDMC: Leaf dry matter content (mg/g); CMass: Mass-based leaf carbon content (%); SLA: Specific leaf area (cm²/g); NMass: Mass-based leaf nitrogen content (%); Seed mass (mg). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

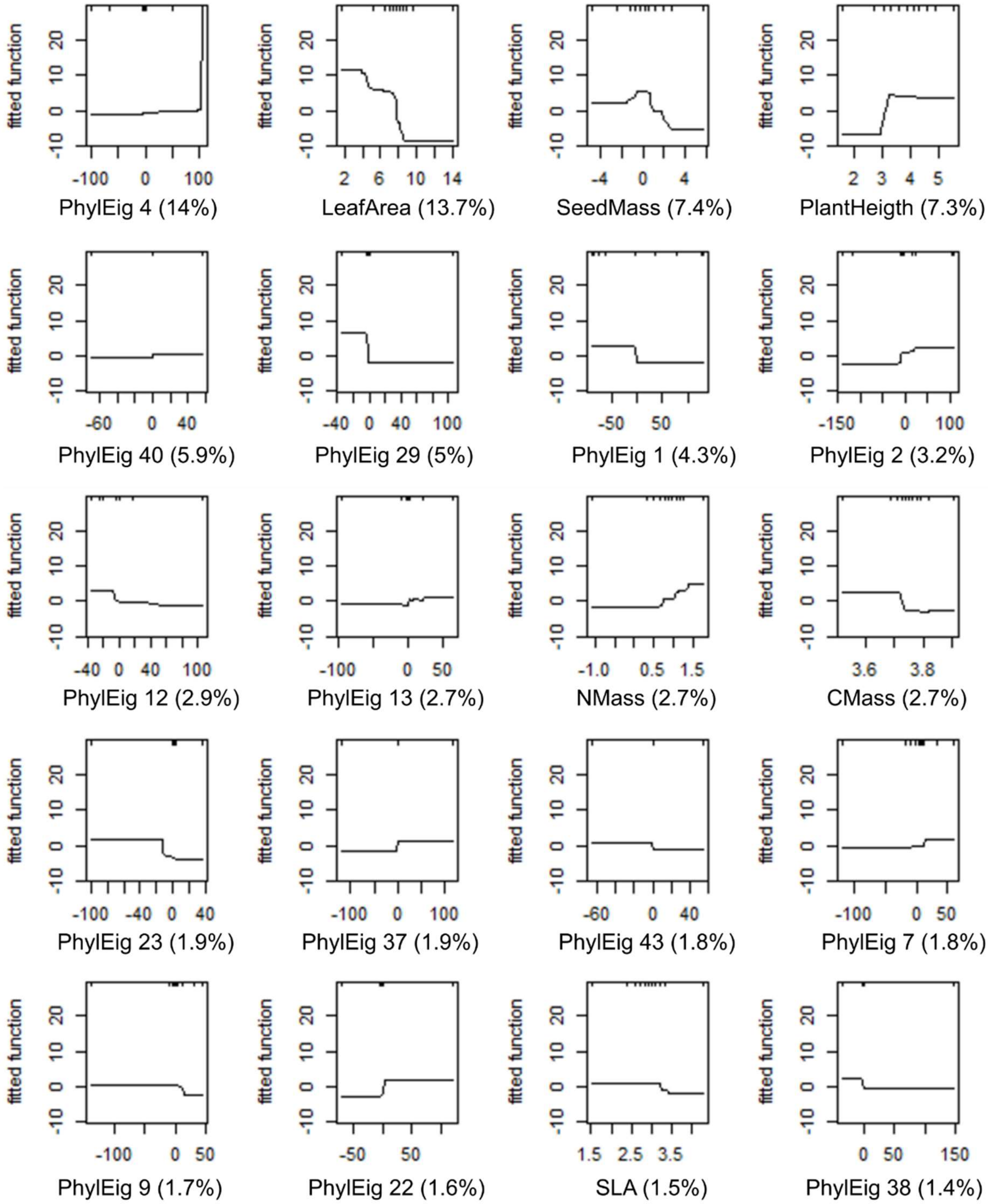

Fig. S10 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Flowering duration' (days) with traits and phylogeny; cross-validation correlation (cv) = 0.49. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Leaf area (mm^2); Seed mass (mg); Plant height (cm); NMass: Mass-based leaf nitrogen content (%); CMass: Mass-based leaf carbon content (%); SLA: Specific leaf area (cm^2/g). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

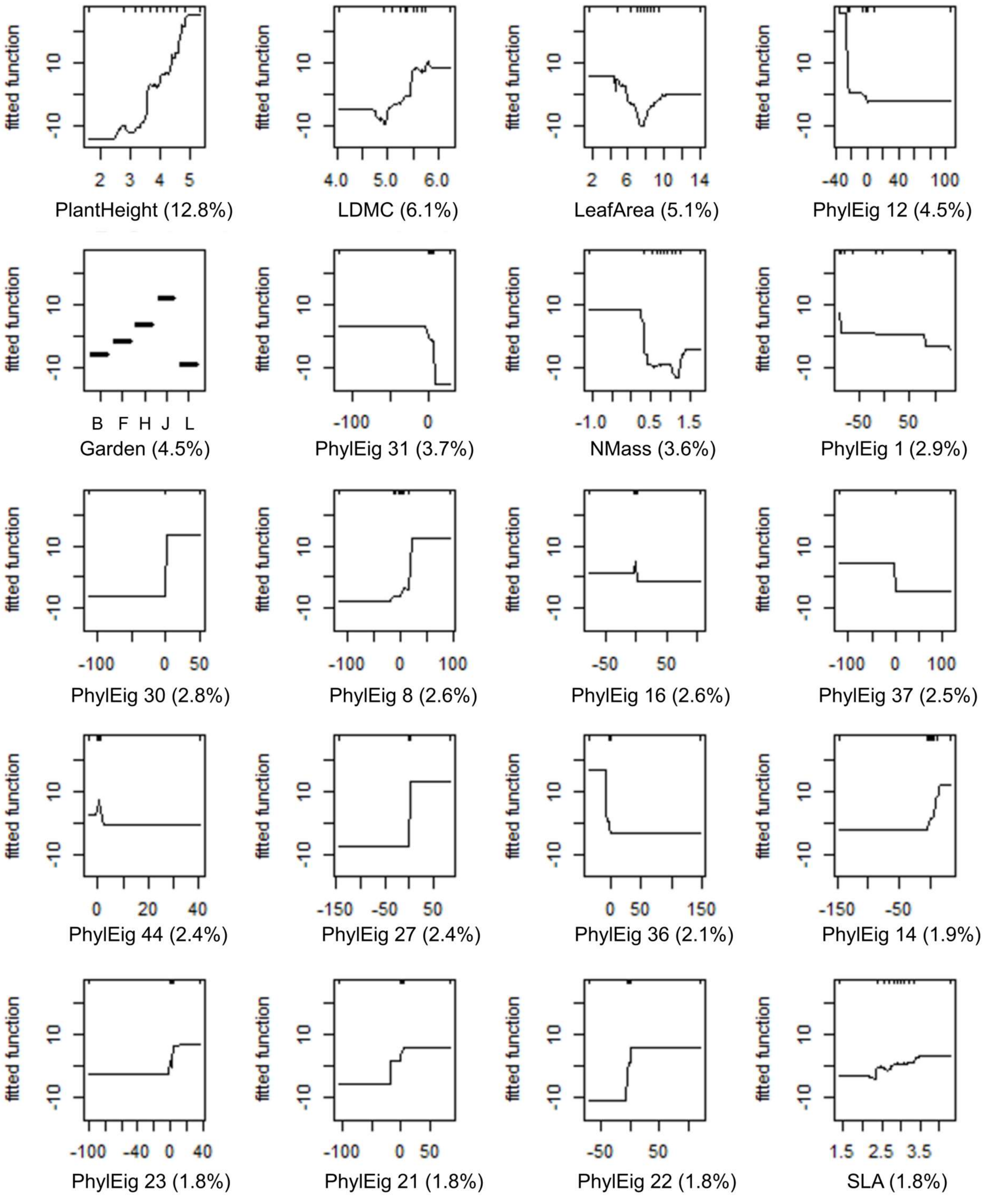

Fig. S11 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Onset of fruiting' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.64. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Plant height (cm); LDMC: Leaf dry matter content (mg/g); Leaf area (mm²); Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; NMass: Mass-based leaf nitrogen content (%); SLA: Specific leaf area (cm²/g). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

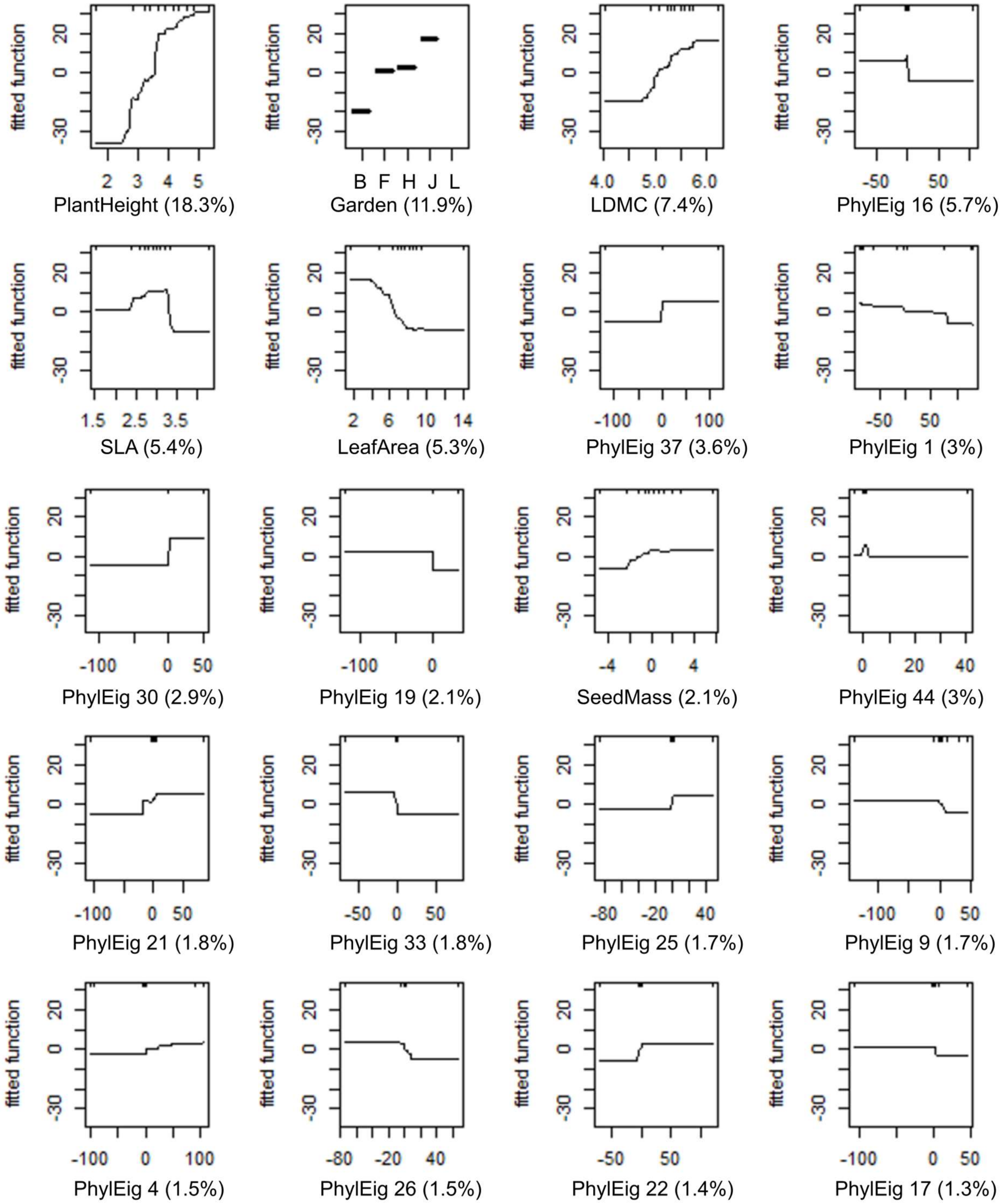

Fig. S12 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'End of fruiting' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.54. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Plant height (cm); Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena L= Leipzig; LDMC: Leaf dry matter content (mg/g); SLA: Specific leaf area (cm²/g); Leaf area (mm²); Seed mass (mg). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

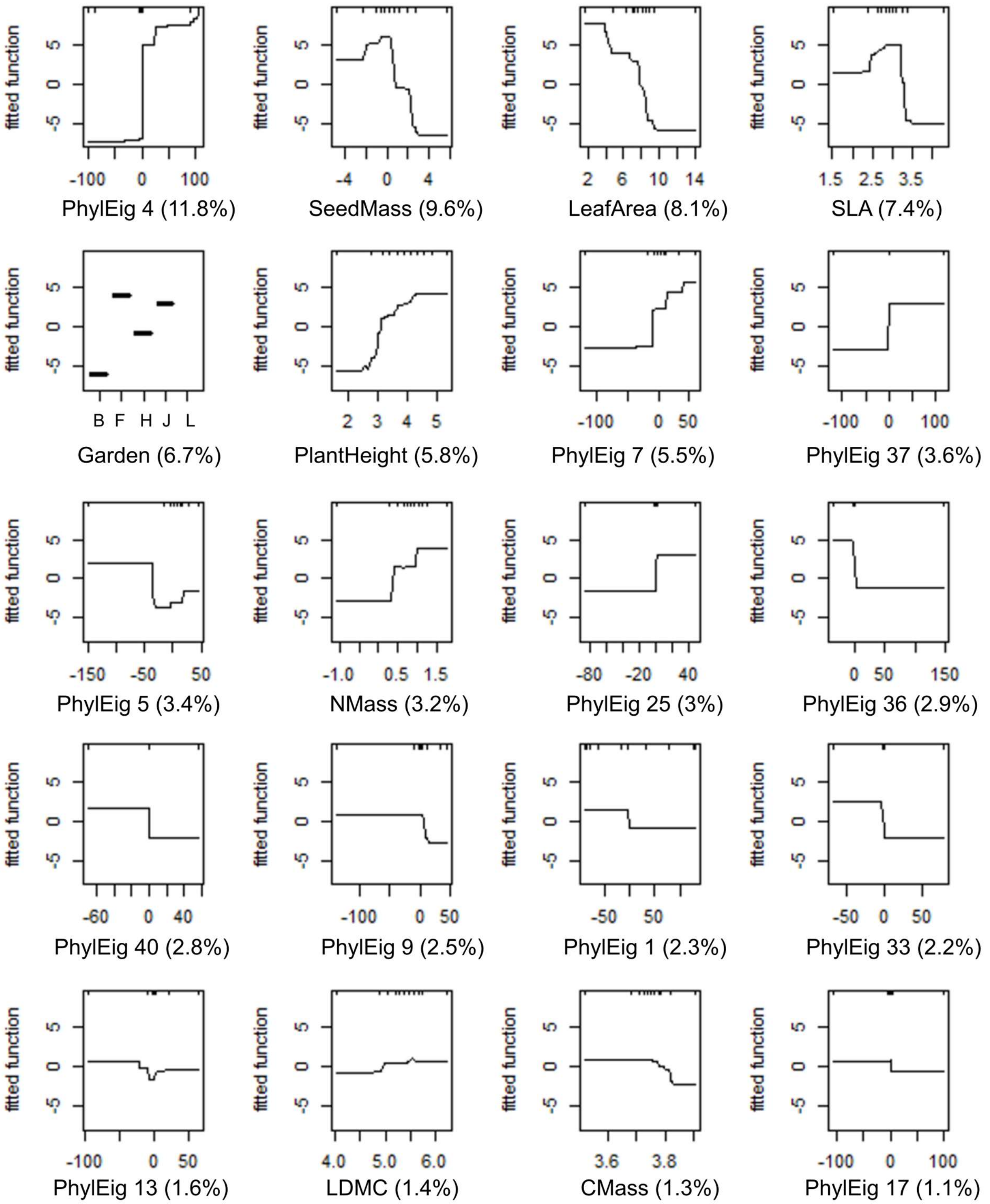

Fig. S13 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Fruiting duration' (days) with traits and phylogeny; cross-validation correlation (cv) = 0.39. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Seed mass (mg); Leaf area (mm²); SLA: Specific leaf area (cm²/g); Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; Plant height (cm); NMass: Mass-based leaf nitrogen content (%); LDMC: Leaf dry matter content (mg/g); CMass: Mass-based leaf carbon content (%). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

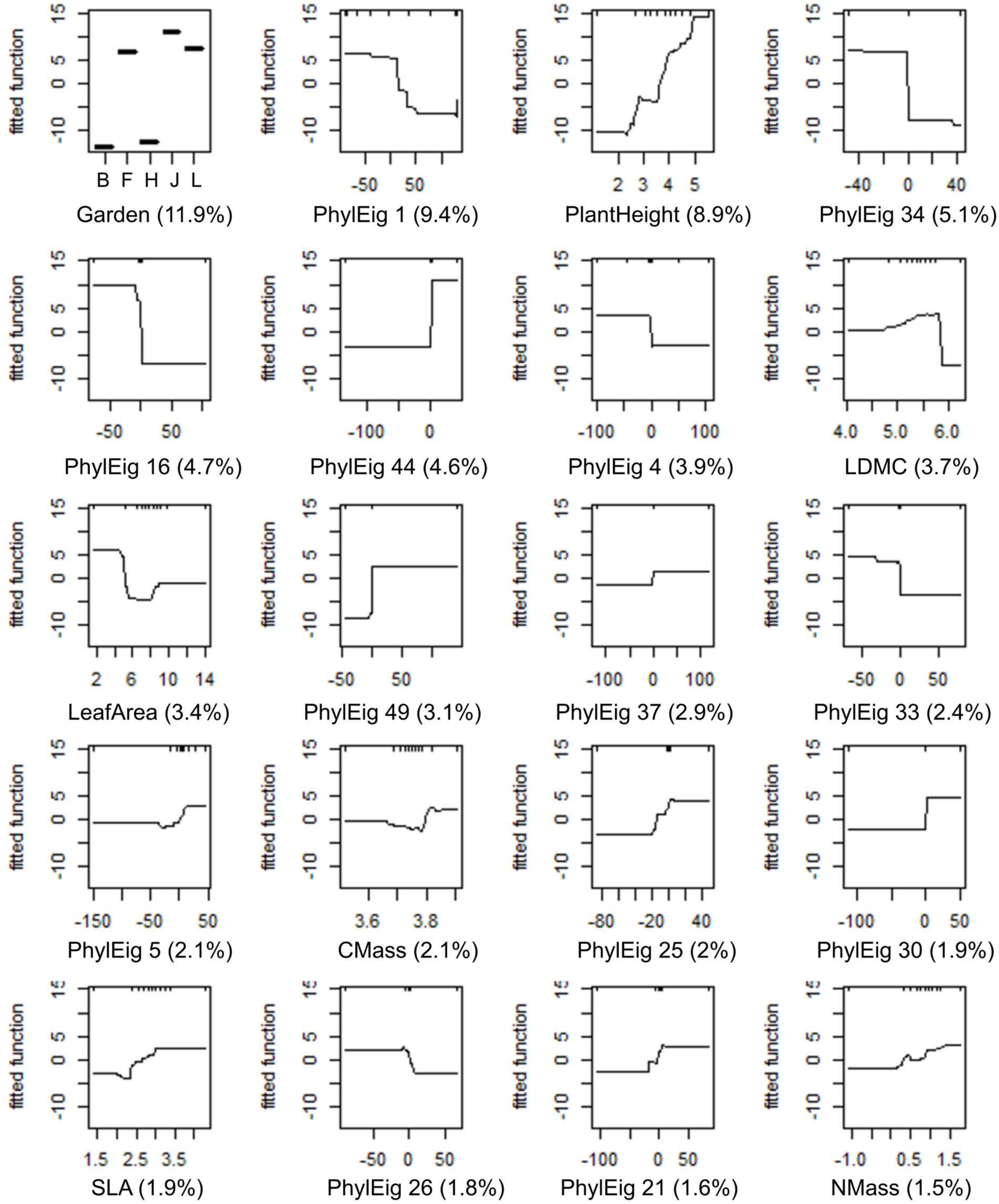

Fig. S14 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Onset of senescence' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.50. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; Plant height (cm); LDMC: Leaf dry matter content (mg/g); Leaf area (mm^2); CMass: Mass-based leaf carbon content (%); NMass: Mass-based leaf nitrogen content (%). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

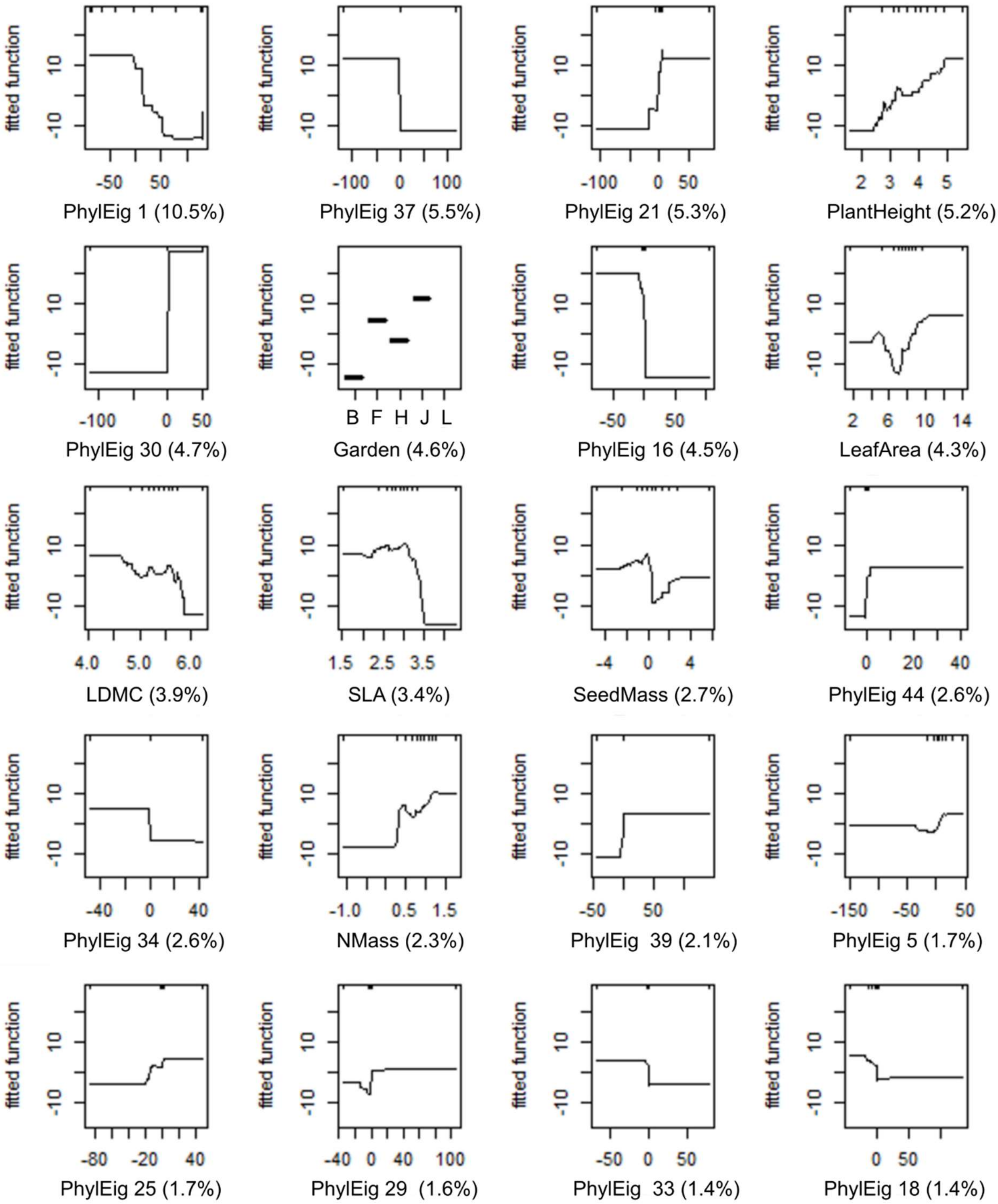

Fig. S15 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Peak of senescence' (doy) with traits and phylogeny; cross-validation correlation (cv) = 0.57. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; Leaf area (mm^2); LDMC: Leaf dry matter content (mg/g); SLA: Specific leaf area (cm^2/g); Seed mass (mg); NMass: Mass-based leaf nitrogen content (%). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

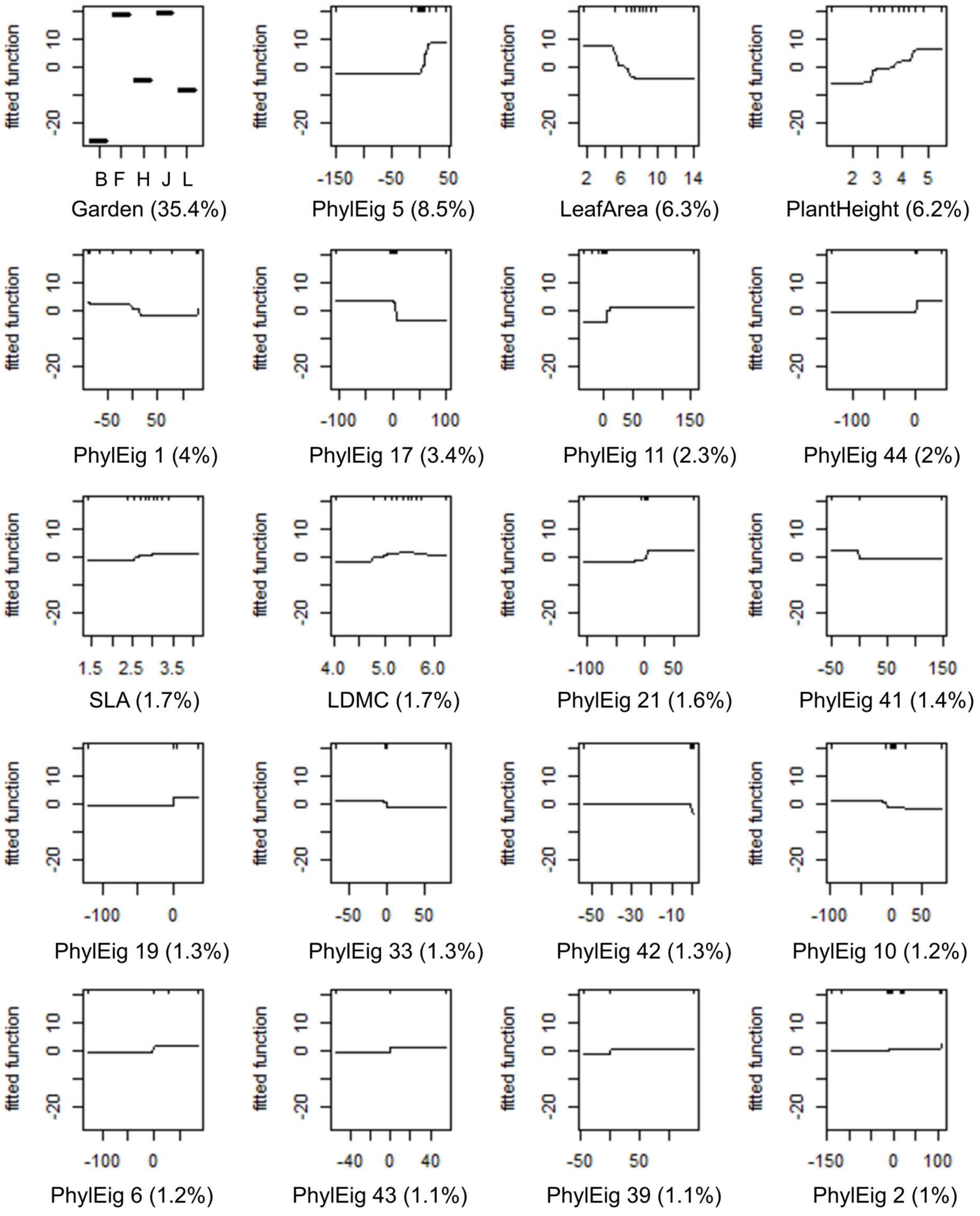

Fig. S16 Partial dependency plots of boosted regression trees (BRTs) of relationship between 'Growing season length (GSL)' (days) with traits and phylogeny; cross-validation correlation (cv) = 0.46. Relative importance (%) for the variables included in the BRT model. PhylEig: phylogenetic Eigenvector; Garden: B= Berlin, F= Frankfurt, H= Halle, J= Jena, L= Leipzig; Leaf area (mm²); Plant height (cm); SLA: Specific leaf area (cm²/g); LDMC: Leaf dry matter content (mg/g). All trait variables were ln-transformed prior to analyses. Only the first 20 variables from BRT model output are depicted.

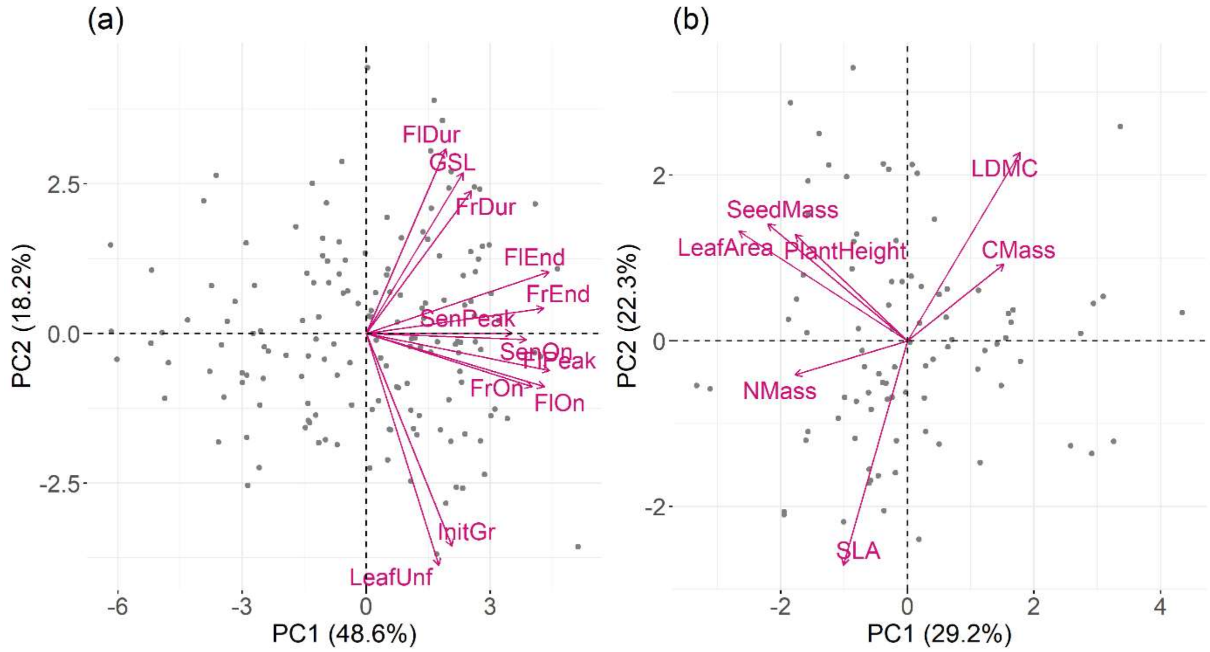

Fig. S17 Principal component analysis of (a) the 12 phenological stages (see Table 2 in the main document) and (b) the seven traits (Table 3) included in this study. Dots represent species for which information on all stages (*n* = 157) or all traits (*n* = 88) were available, respectively. The first and second principal components (PC1 and PC2) accounted for 48.6% and 18.2% of the total variation in the timing of the phenological stages, respectively.

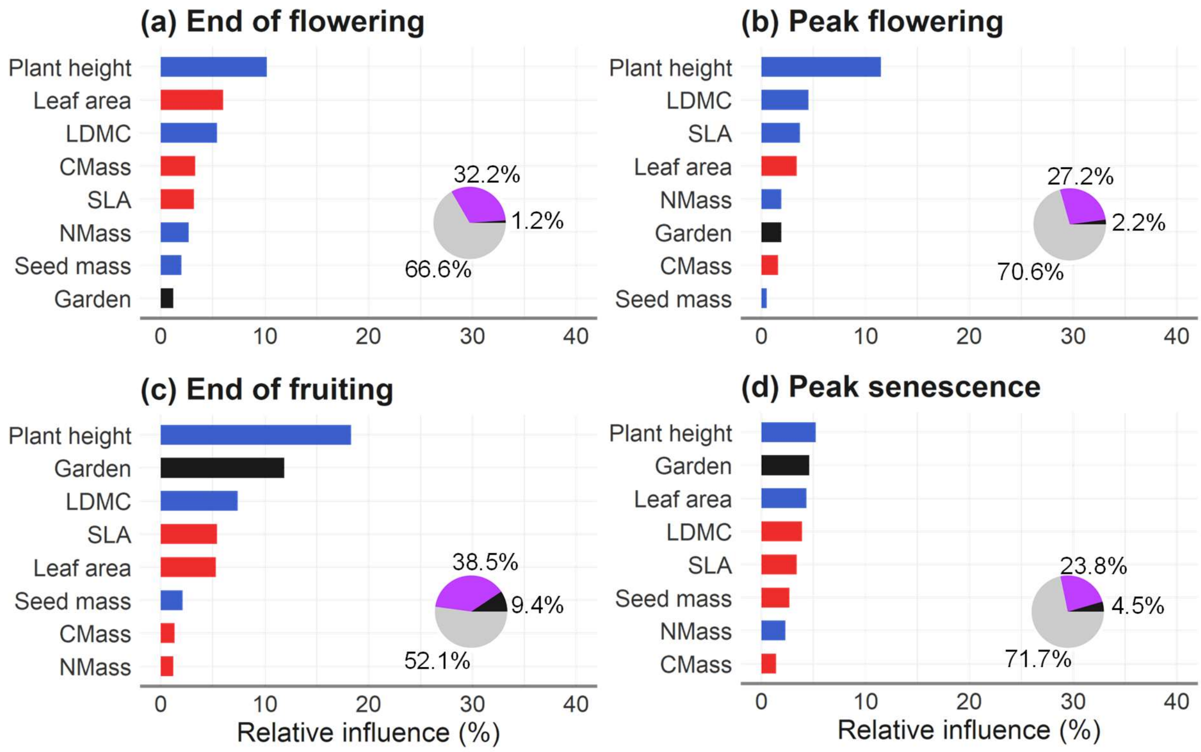

Fig. S18 Relative importance (%) of plant functional traits, measures of phylogenetic relatedness and factor 'garden' on the ending or peak of vegetative or reproductive phenological stages, deduced from boosted regression trees (BRT), in which also 44 phylogenetic eigenvectors were included. Pie charts represent the overall contributions of the variables grouped by 'functional traits' (purple), 'garden' (black) and 'phylogeny' (grey) deduced from the BRT models. Figures S5-S16 give an overview on the relevance of the phylogenetic Eigenvectors compared to functional traits and the factor 'garden'. BRT models were fitted for the stages (a) end of flowering (day of year) [*n* = 502, cross-validation correlation (cv) = 0.68], (b) peak of flowering (day of year) [*n* = 491, cv =0.72], (c) end of fruiting (day of year) [*n* =358, cv = 0.54], and (d) peak of senescence (day of year) [*n* = 450, cv = 0.57]. Colour of bars represents a positive (blue) or negative (red) influence of the predictor variable; black reflects the categorical variable 'garden'. SLA: Specific leaf area (cm^2/g); LDMC: Leaf dry matter content (mg/g); NMass: Mass-based leaf nitrogen content (%); CMass: Mass-based leaf carbon content (%).

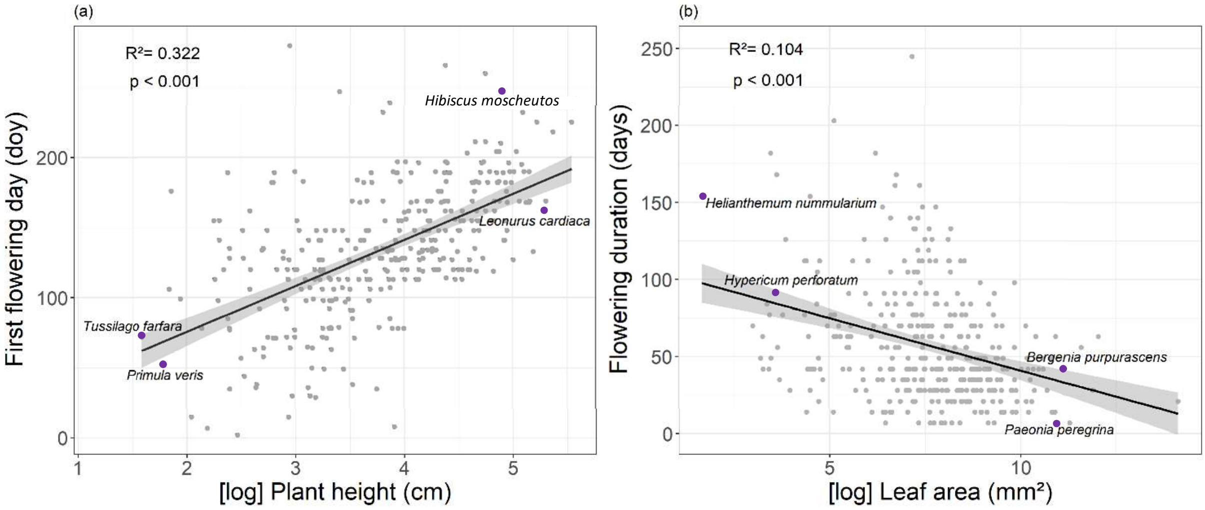

Fig. S19 Scatterplot and regression coefficient (Adjusted R^2) from general linear models between (a) plant height and first flowering day and (b) leaf area and flowering duration. Highlighted species are mentioned in the main text.

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