frontiers

Supplementary Material

Genome-wide association study of wood anatomical and morphological traits in *Populus trichocarpa*

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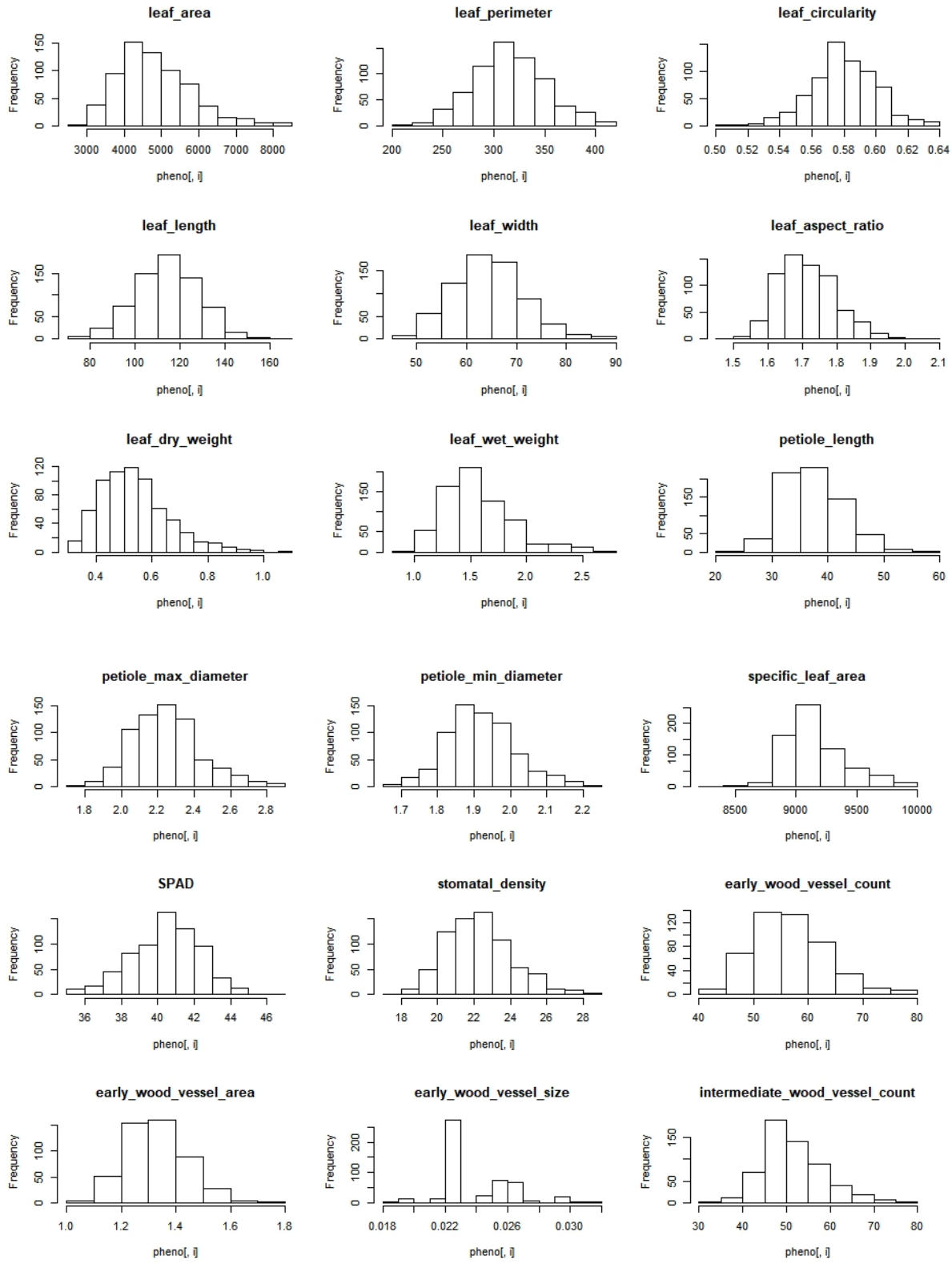
1 Supplementary Figures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leaf_wet_weight
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petiole_max_diameter
petiole_min_diameter
specific_leaf_area
SPAD
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intermediate_wood_vessel_count
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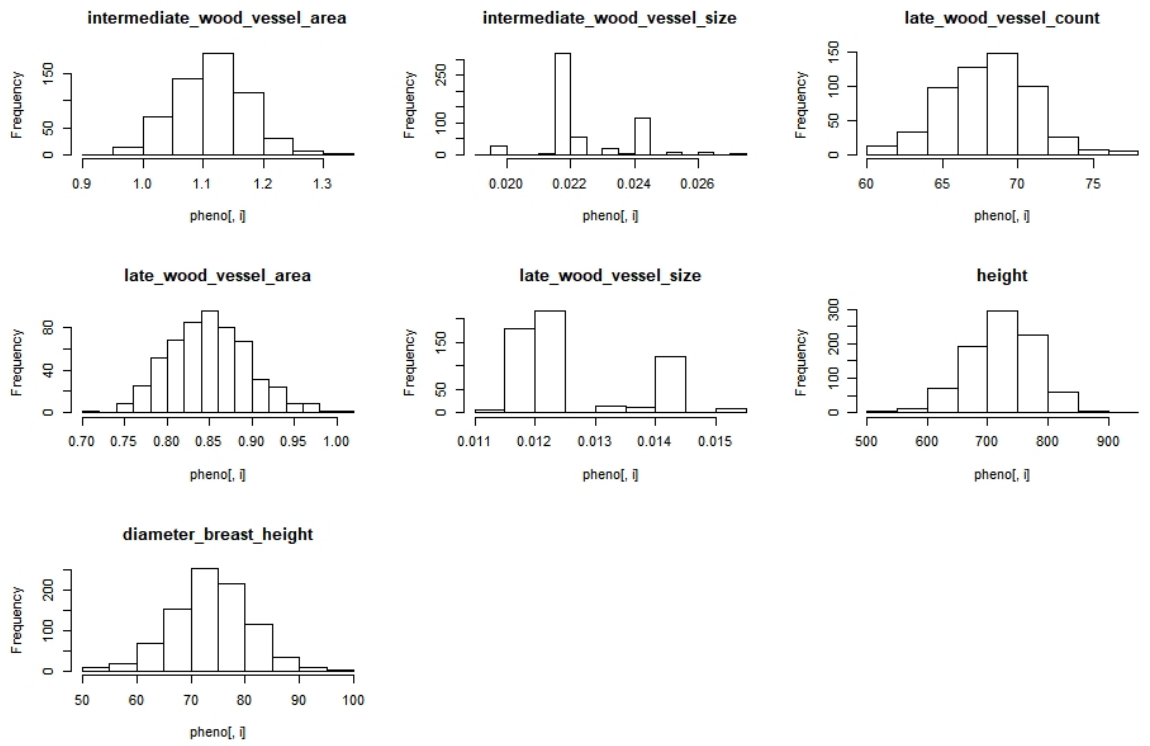

Figure S1. Histograms showing distribution of BLUP adjusted phenotypic values (BLUPs added to the mean phenotypic value) for each of the 25 morphological and anatomical traits used in GWAS study.

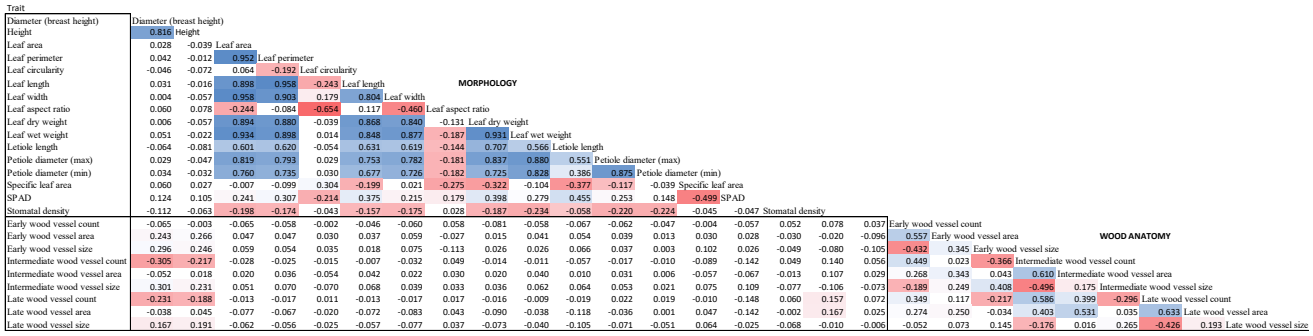

Figure S2. Pairwise correlation (r) of *P. trichocarpa* wood anatomical and morphological traits in Clatskanie, Oregon. Shaded values greater than 0.15 or less than -0.15 are significant based on the Bonferroni correction criteria at 5% significance level.

		CORVALLIS																
	Traits	Water potential	Stomatal density	SPAD	Petiole length	Petiole diameter (max)	Specific leaf area	Leaf area	Leaf perimeter	Leaf length	Leaf width	Leaf feret	Leaf aspect ratio	Leaf dry weight	Carbon isotope	Bud flush	Bud set	Height
CLATSKANIE	Diameter (breast height)	0.09	-0.09	-0.07	0.21	0.17	0.15	0.26	0.28	0.26	0.24	0.25	-0.09	0.18	-0.01	0.23	-0.42	0.38
	Height	0.13	-0.06	-0.05	0.23	0.15	0.14	0.25	0.25	0.22	0.26	0.22	-0.15	0.17	0.00	0.25	-0.45	0.44
	Leaf area	-0.01	-0.12	0.04	0.05	0.09	-0.17	0.10	0.08	0.10	0.07	0.09	0.02	0.14	0.03	-0.15	0.26	-0.15
	Leaf perimeter	-0.01	-0.12	0.07	0.08	0.11	-0.18	0.12	0.11	0.14	0.08	0.13	0.05	0.16	0.05	-0.12	0.26	-0.13
	Leaf circularity	0.01	0.04	-0.06	-0.10	-0.08	0.04	-0.05	-0.09	-0.10	-0.02	-0.10	-0.05	-0.05	-0.04	-0.13	0.03	-0.09
	Leaf length	-0.03	-0.12	0.07	0.07	0.11	-0.18	0.11	0.11	0.15	0.06	0.14	0.07	0.15	0.05	-0.12	0.26	-0.12
	Leaf width	0.00	-0.08	0.04	0.01	0.06	-0.15	0.06	0.04	0.05	0.05	0.04	0.00	0.11	0.02	-0.18	0.29	-0.19
	Leaf aspect ratio	-0.02	-0.07	0.06	0.08	0.09	-0.01	0.09	0.13	0.17	0.03	0.17	0.11	0.06	0.05	0.15	-0.12	0.16
	Leaf dry weight	-0.05	-0.10	0.05	0.02	0.10	-0.23	0.10	0.08	0.10	0.07	0.08	0.01	0.15	0.03	-0.14	0.30	-0.15
	Leaf wet weight	-0.02	-0.14	0.05	0.07	0.15	-0.20	0.17	0.15	0.16	0.13	0.15	-0.02	0.20	0.04	-0.10	0.23	-0.12
	Letiole length	-0.03	-0.02	0.10	0.02	0.01	-0.20	-0.05	-0.05	-0.03	-0.06	-0.04	0.07	0.01	0.01	-0.19	0.40	-0.26
	Petiole diameter (max)	-0.02	-0.12	0.03	0.02	0.13	-0.19	0.12	0.10	0.11	0.11	0.10	-0.03	0.15	0.05	-0.08	0.26	-0.12
	Petiole diameter (min)	-0.01	-0.13	0.04	0.03	0.15	-0.17	0.14	0.13	0.13	0.12	0.12	-0.02	0.16	0.05	-0.05	0.20	-0.10
	Specific leaf area	0.00	-0.03	-0.09	0.02	-0.04	0.09	0.01	0.01	0.02	-0.01	0.02	0.03	-0.02	0.02	-0.02	-0.10	-0.01
	SPAD	-0.05	-0.08	0.20	-0.03	0.01	-0.15	-0.05	-0.05	-0.04	-0.04	-0.04	0.02	-0.01	0.08	0.00	0.20	-0.05
	Stomatal density	-0.02	0.35	-0.09	-0.09	-0.10	0.17	-0.16	-0.16	-0.18	-0.11	-0.18	-0.03	-0.18	-0.09	0.06	-0.01	-0.04
	Early wood vessel count	0.07	-0.03	-0.03	0.03	0.04	0.06	0.04	0.03	0.01	0.05	0.02	-0.03	0.05	-0.01	0.09	-0.13	0.12
	Early wood vessel area	0.08	-0.09	-0.08	0.09	0.09	0.09	0.13	0.13	0.11	0.13	0.11	-0.06	0.13	-0.09	0.07	-0.16	0.15
	Early wood vessel size	-0.02	-0.06	-0.06	0.05	0.04	0.04	0.05	0.07	0.07	0.05	0.06	-0.01	0.05	-0.01	-0.04	-0.03	0.03
	Intermediate wood vessel count	0.06	0.07	0.02	-0.01	-0.01	0.00	0.02	0.00	-0.02	0.01	-0.01	-0.03	0.03	0.01	0.07	-0.05	0.06
	Intermediate wood vessel area	0.06	-0.03	0.01	0.02	0.03	-0.02	0.09	0.09	0.06	0.09	0.07	-0.05	0.09	-0.02	0.10	-0.10	0.12
	Intermediate wood vessel size	-0.06	-0.10	-0.02	0.03	0.06	-0.01	0.09	0.10	0.10	0.09	0.10	-0.01	0.05	-0.02	0.03	-0.11	0.05
	Late wood vessel count	0.05	-0.03	-0.07	0.03	-0.01	0.04	0.02	0.01	0.00	0.02	0.01	-0.01	0.04	0.01	0.06	0.01	0.05
	Late wood vessel area	0.05	-0.05	0.00	0.14	0.10	-0.01	0.13	0.13	0.11	0.13	0.11	-0.06	0.14	-0.05	0.15	-0.16	0.19
	Late wood vessel size	-0.05	-0.02	0.06	0.06	0.04	-0.03	0.06	0.09	0.07	0.06	0.06	-0.04	0.04	-0.02	0.09	-0.16	0.11

Figure S3. Pearson correlation (r) of *P. trichocarpa* wood anatomical and morphological traits in Clatskanie, Oregon with morphological and physiological traits in Corvallis, OR. Shaded values greater than 0.15 or less than -0.15 are significant based on the Bonferroni correction criteria at 5% significance level.

	Trait/Geoclimate	Longitude	Latitude	Elevation	MAT	MWMT	MCMT	TD	MAP	MSP	AHM	SHM	DD_0	DD5	DD_18	DD18	NFFD	bFFP	eFFP	FFP	PAS	EMT	EXT	Eref	CMD	MAR	RH	PC1	PC2	PC3	PC4
MORPHOLOGY	Height	0.346	-0.342	-0.161	0.325	0.119	0.372	-0.386	-0.157	-0.113	0.200	0.057	-0.363	0.266	-0.333	0.135	0.340	-0.261	0.323	0.296	-0.346	0.349	0.153	0.282	0.100	0.116	-0.057	0.320	-0.105	-0.208	-0.153
	Diameter (breast height)	0.288	-0.288	-0.128	0.271	0.110	0.316	-0.325	-0.096	-0.073	0.145	0.029	-0.310	0.220	-0.279	0.107	0.287	-0.224	0.272	0.250	-0.294	0.302	0.128	0.233	0.071	0.103	-0.029	0.265	-0.111	-0.161	-0.143
	Leaf area	-0.049	0.280	0.148	-0.210	-0.126	-0.198	0.176	0.277	0.345	-0.301	-0.307	0.162	-0.212	0.208	-0.165	-0.175	0.124	-0.151	-0.140	0.201	-0.170	-0.232	-0.284	-0.340	-0.074	0.243	-0.244	-0.220	0.160	0.002
	Leaf perimeter	-0.012	0.268	0.119	-0.184	-0.107	-0.180	0.164	0.225	0.306	-0.258	-0.283	0.148	-0.183	0.182	-0.145	-0.154	0.105	-0.133	-0.121	0.164	-0.157	-0.207	-0.255	-0.308	-0.072	0.211	-0.214	-0.195	0.152	0.011
	Leaf circularity	-0.123	0.081	0.120	-0.127	-0.082	-0.118	0.104	0.120	0.081	-0.121	-0.058	0.102	-0.129	0.129	-0.089	-0.127	0.117	-0.119	-0.121	0.138	-0.113	-0.086	-0.113	-0.079	-0.013	0.061	-0.133	-0.011	0.027	-0.012
	Leaf length	-0.004	0.268	0.110	-0.176	-0.114	-0.167	0.145	0.222	0.313	-0.258	-0.294	0.133	-0.179	0.173	-0.145	-0.141	0.095	-0.121	-0.110	0.152	-0.143	-0.216	-0.256	-0.319	-0.065	0.222	-0.208	-0.213	0.139	0.016
	Leaf width	-0.099	0.297	0.166	-0.237	-0.128	-0.232	0.217	0.281	0.331	-0.307	-0.287	0.197	-0.232	0.237	-0.170	-0.210	0.156	-0.185	-0.173	0.233	-0.206	-0.228	-0.296	-0.324	-0.083	0.229	-0.269	-0.184	0.176	0.014
	Leaf aspect ratio	0.158	-0.107	-0.114	0.142	0.037	0.154	-0.168	-0.130	-0.082	0.129	0.037	-0.144	0.124	-0.146	0.060	0.150	-0.124	0.140	0.134	-0.167	0.144	0.054	0.117	0.062	0.049	-0.046	0.145	-0.022	-0.106	-0.005
	Leaf dry weight	-0.024	0.302	0.178	-0.230	-0.130	-0.219	0.200	0.310	0.392	-0.329	-0.347	0.181	-0.228	0.228	-0.168	-0.196	0.137	-0.170	-0.155	0.224	-0.188	-0.243	-0.305	-0.381	-0.051	0.259	-0.268	-0.245	0.199	-0.030
	Leaf wet weight	0.033	0.233	0.130	-0.161	-0.086	-0.149	0.138	0.290	0.371	-0.297	-0.321	0.115	-0.164	0.159	-0.121	-0.128	0.085	-0.102	-0.095	0.164	-0.122	-0.191	-0.236	-0.347	-0.051	0.235	-0.200	-0.256	0.190	-0.062
	Letiole length	-0.200	0.395	0.163	-0.305	-0.186	-0.312	0.286	0.239	0.326	-0.288	-0.295	0.278	-0.288	0.305	-0.219	-0.280	0.206	-0.267	-0.240	0.278	-0.288	-0.272	-0.354	-0.330	-0.108	0.205	-0.331	-0.138	0.170	0.104
	Petiole diameter (max)	0.032	0.240	0.152	-0.178	-0.076	-0.175	0.174	0.302	0.370	-0.306	-0.312	0.140	-0.172	0.178	-0.108	-0.155	0.099	-0.129	-0.115	0.191	-0.150	-0.178	-0.240	-0.340	-0.033	0.215	-0.215	-0.231	0.225	-0.081
	Petiole diameter (min)	0.045	0.182	0.108	-0.123	-0.054	-0.118	0.115	0.241	0.305	-0.246	-0.257	0.095	-0.120	0.123	-0.070	-0.101	0.055	-0.077	-0.067	0.136	-0.098	-0.141	-0.184	-0.280	-0.048	0.178	-0.155	-0.205	0.178	-0.067
	Specific leaf area	-0.029	-0.057	-0.015	0.032	0.009	0.037	-0.040	0.011	-0.035	0.017	0.054	-0.038	0.021	-0.032	-0.004	0.025	0.006	0.023	0.007	-0.018	0.028	0.034	0.051	0.055	-0.009	-0.039	0.029	0.022	-0.040	-0.029
	SPAD	-0.060	0.152	-0.004	-0.084	-0.035	-0.100	0.101	0.016	0.107	-0.052	-0.106	0.082	-0.072	0.083	-0.053	-0.073	0.020	-0.077	-0.048	0.041	-0.090	-0.088	-0.117	-0.112	-0.077	0.073	-0.088	-0.047	0.072	0.105
	Stomatal density	-0.107	-0.157	-0.016	0.048	0.041	0.035	-0.024	-0.107	-0.182	0.138	0.182	0.000	0.069	-0.044	0.079	0.011	0.024	0.002	-0.011	-0.016	0.020	0.139	0.154	0.216	0.030	-0.223	0.073	0.201	-0.072	-0.043
WOOD ANATOMY	Early wood vessel count	0.020	-0.131	-0.042	0.103	0.059	0.103	-0.100	0.025	-0.011	0.012	0.011	-0.099	0.098	-0.104	0.080	0.090	-0.056	0.103	0.080	-0.057	0.093	0.089	0.121	0.045	0.015	-0.059	0.091	-0.025	-0.005	-0.090
	Early wood vessel area	0.148	-0.102	-0.015	0.103	0.052	0.115	-0.120	0.024	0.046	0.011	-0.068	-0.132	0.079	-0.106	0.044	0.111	-0.087	0.121	0.104	-0.093	0.114	0.035	0.073	-0.040	0.086	0.041	0.087	-0.110	-0.014	-0.090
	Early wood vessel size	0.059	0.031	0.017	-0.007	-0.002	0.002	-0.005	-0.008	0.042	0.006	-0.055	-0.027	-0.025	0.004	-0.043	0.010	-0.021	0.002	0.013	-0.031	0.011	-0.048	-0.045	-0.061	0.039	0.092	-0.009	-0.061	-0.012	0.030
	Intermediate wood vessel count	0.043	-0.116	-0.050	0.102	0.109	0.079	-0.045	-0.019	-0.054	0.040	0.079	-0.072	0.114	-0.098	0.129	0.078	-0.048	0.084	0.069	-0.057	0.078	0.136	0.133	0.091	0.026	-0.090	0.099	0.039	0.053	-0.080
	Intermediate wood vessel area	0.111	-0.122	0.010	0.081	0.064	0.077	-0.065	-0.002	-0.016	0.017	0.009	-0.072	0.078	-0.080	0.072	0.067	-0.029	0.076	0.053	-0.053	0.073	0.082	0.107	0.038	0.044	-0.067	0.075	-0.002	0.004	-0.136
	Intermediate wood vessel size	0.033	-0.012	0.032	-0.001	-0.032	0.021	-0.038	0.002	0.012	0.004	-0.042	-0.011	-0.010	-0.003	-0.031	0.013	-0.017	0.019	0.018	-0.004	0.018	-0.047	-0.013	-0.026	0.011	0.027	-0.001	-0.036	-0.055	-0.012
	Late wood vessel count	0.067	-0.061	-0.057	0.080	0.042	0.072	-0.066	0.007	0.000	-0.021	-0.031	-0.071	0.075	-0.077	0.057	0.076	-0.063	0.084	0.074	-0.056	0.071	0.050	0.065	-0.003	-0.031	-0.020	0.066	-0.047	0.016	-0.053
	Late wood vessel area	0.201	-0.219	-0.058	0.183	0.098	0.191	-0.185	-0.050	-0.081	0.088	0.055	-0.185	0.161	-0.184	0.106	0.171	-0.120	0.170	0.146	-0.159	0.175	0.137	0.193	0.094	0.049	-0.096	0.177	-0.014	-0.067	-0.158
	Late wood vessel size	0.108	-0.124	-0.029	0.104	0.059	0.119	-0.117	-0.052	-0.082	0.109	0.088	-0.123	0.086	-0.108	0.048	0.104	-0.075	0.096	0.086	-0.098	0.111	0.069	0.102	0.086	0.073	-0.025	0.110	0.013	-0.073	-0.046

Figure S4. Pearson correlation (r) of *P. trichocarpa* wood anatomical and morphological traits in Clatskanie, Oregon with geo-climate variables of the source location of the trees. Shaded values greater than 0.15 or less than -0.15 are significant based on the Bonferroni correction criteria at 5% significance level.

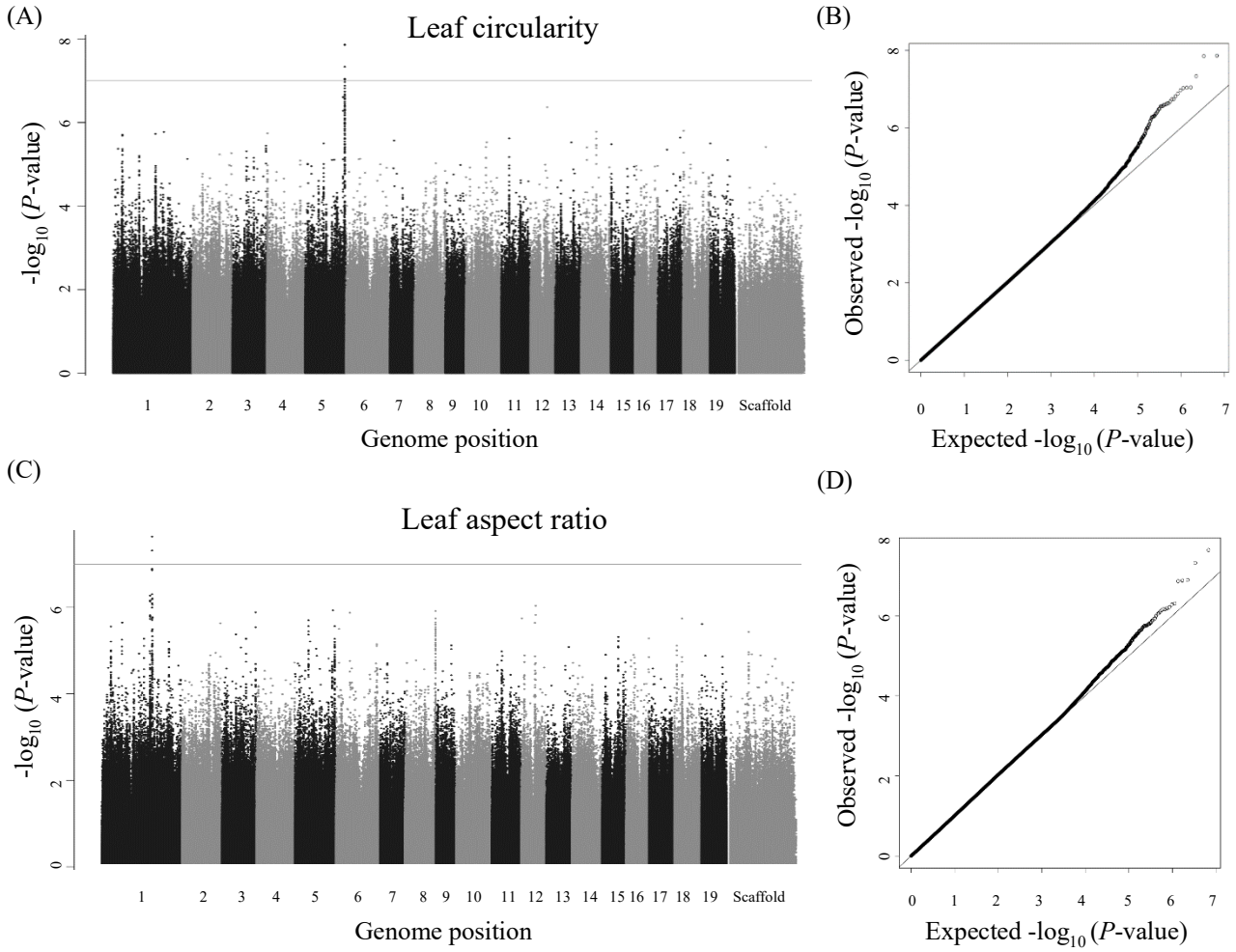

Figure S5. Single trait GWAS – Manhattan (left) and QQ plots (right). Numbers 1 to 19 represent chromosomes; scaffolds are the reads that did not align to any of the 19 chromosomes. (A) and (B) Leaf circularity; (C) and (D) Leaf aspect ratio. SNPs above gray line have $p<1\times10^{-7}$, which is roughly equivalent to FDR≤0.1 and SNPs above black line (the top line) have $p<7.417\times10^{-9}$ (the Bonferroni correction threshold), which is roughly equivalent to FDR≤0.05 in this study.

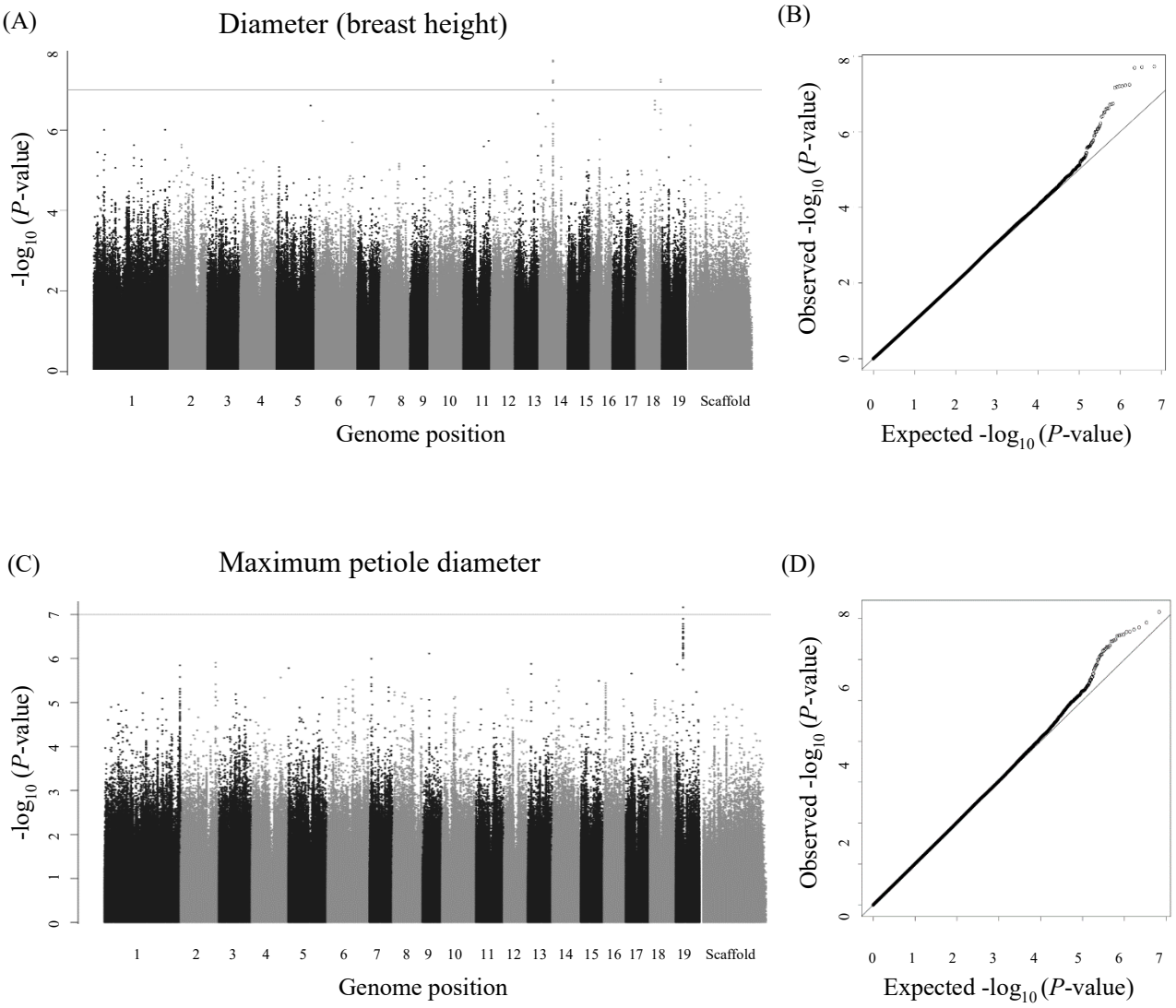

Figure S6. Single trait GWAS – Manhattan (left) and QQ plots (right). Numbers 1 to 19 represent chromosomes; scaffolds are the reads that did not align to any of the 19 chromosomes. (A) and (B) Diameter (breast height); (C) and (D) Maximum petiole diameter. SNPs above gray line have $p<1\times10^{-7}$, which is roughly equivalent to FDR≤0.1 and SNPs above black line (the top line) have $p<7.417\times10^{-9}$ (the Bonferroni correction threshold), which is roughly equivalent to FDR≤0.05 in this study.

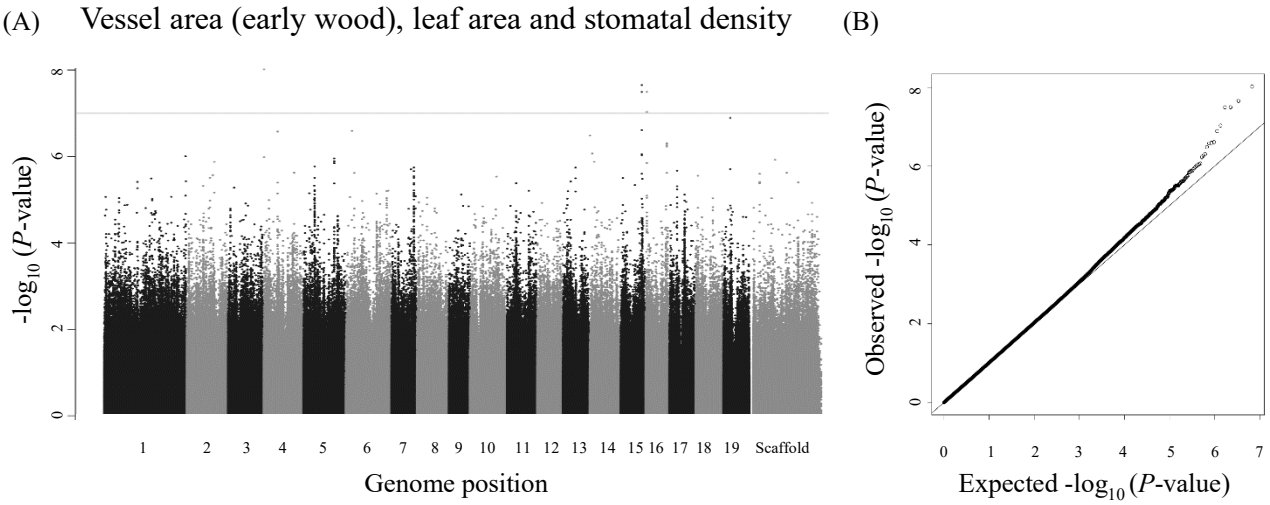

Figure S7. Multitrait GWAS – Manhattan (left) and QQ plots (right). Numbers 1 to 19 represent chromosomes; scaffolds are the reads that did not align to any of the 19 chromosomes. (A) and (B) Vessel area (early wood), leaf area and stomatal density. SNPs above gray line have $p<1\times10^{-7}$, which is roughly equivalent to FDR$\leq$0.1 and SNPs above black line (the top line) have $p<7.417\times10^{-9}$ (the Bonferroni correction threshold), which is roughly equivalent to FDR$\leq$0.05 in this study.

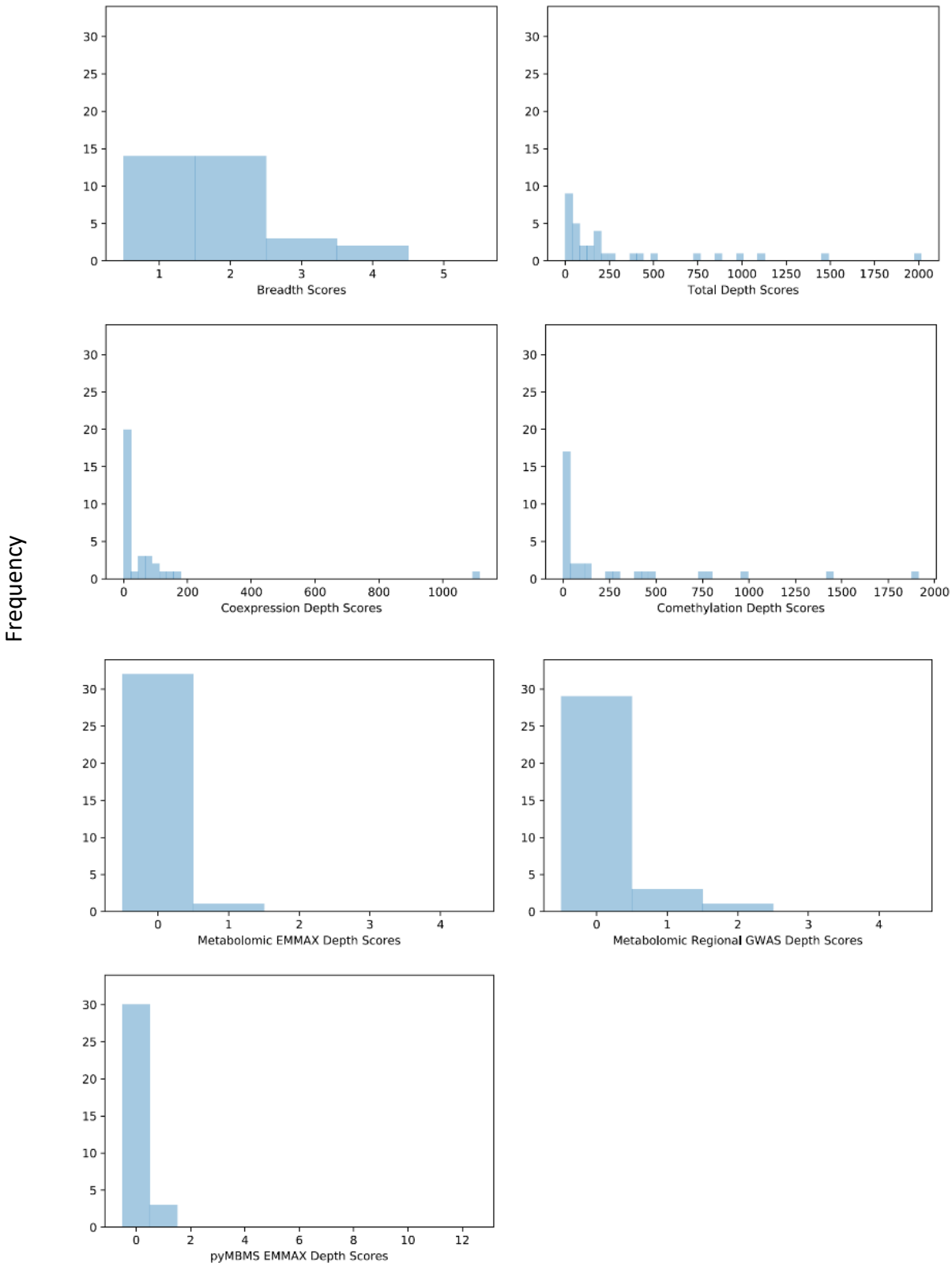

Figure S8. Distributions of LOE scores for all single trait and multitrait anchor (GWAS) genes.

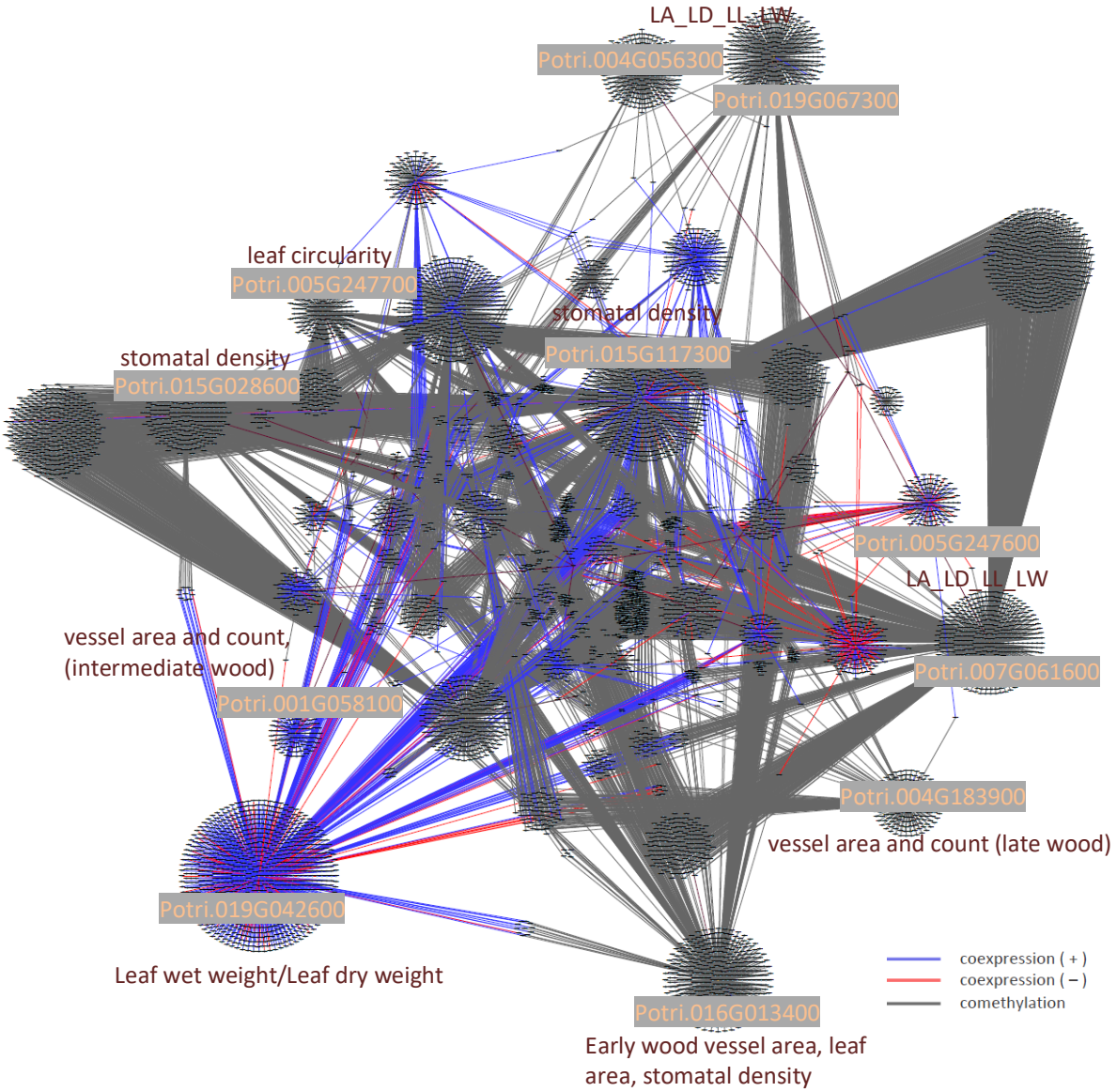

Figure S9. One-hop multi-omic network for all single and multitrati GWAS (anchor) genes with major anchor genes highlighted. LA_LD_LL_LW = leaf area, leaf dry weight, leaf length and leaf width. For GWAS edges, solid maroon indicates "traditional" GWAS and dashed maroon indicates RV metabolite GWAS.

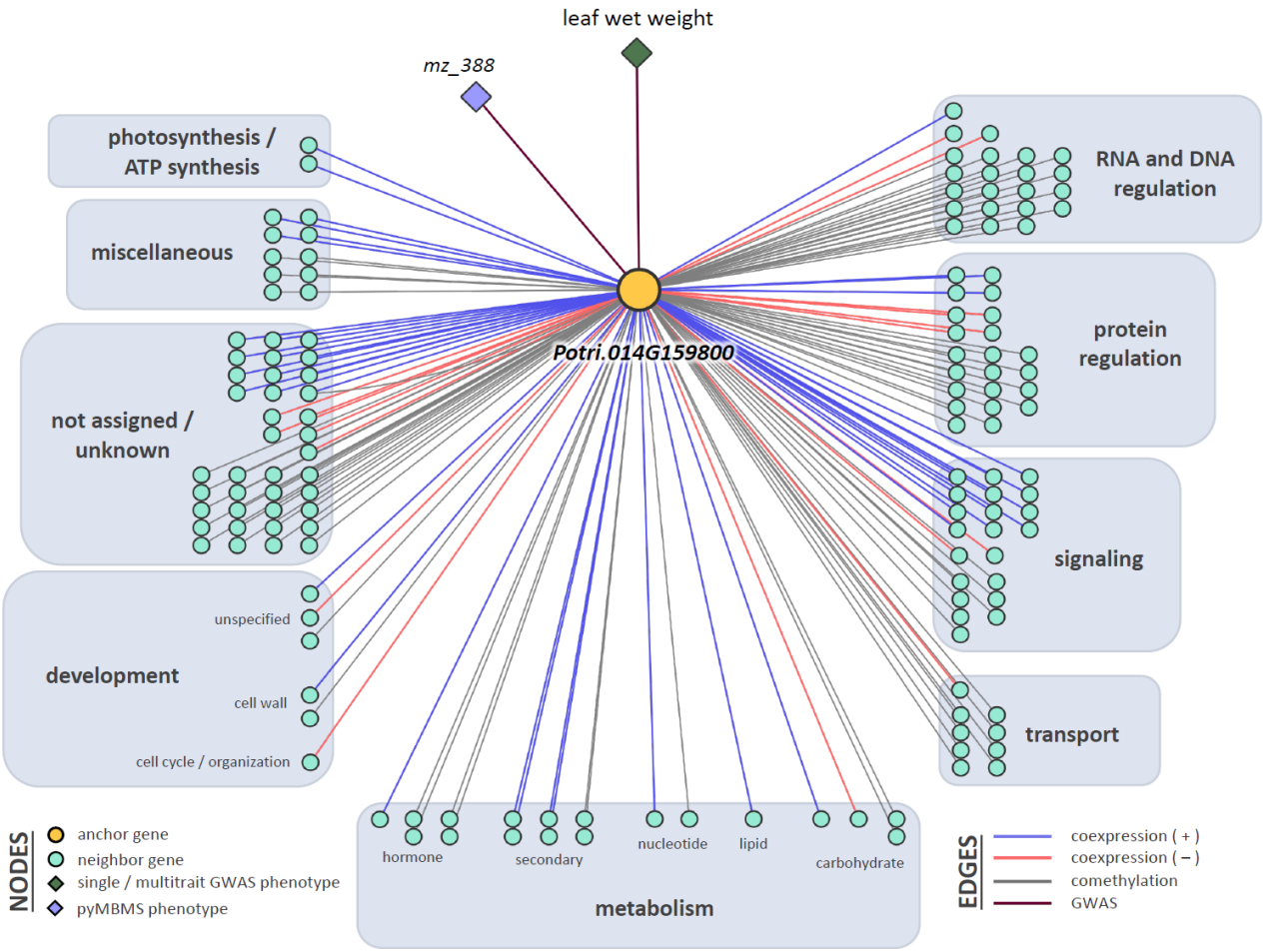

Figure S10. One-hop multi-omic network for the gene Potri.014G159800, which was associated with leaf wet weight.

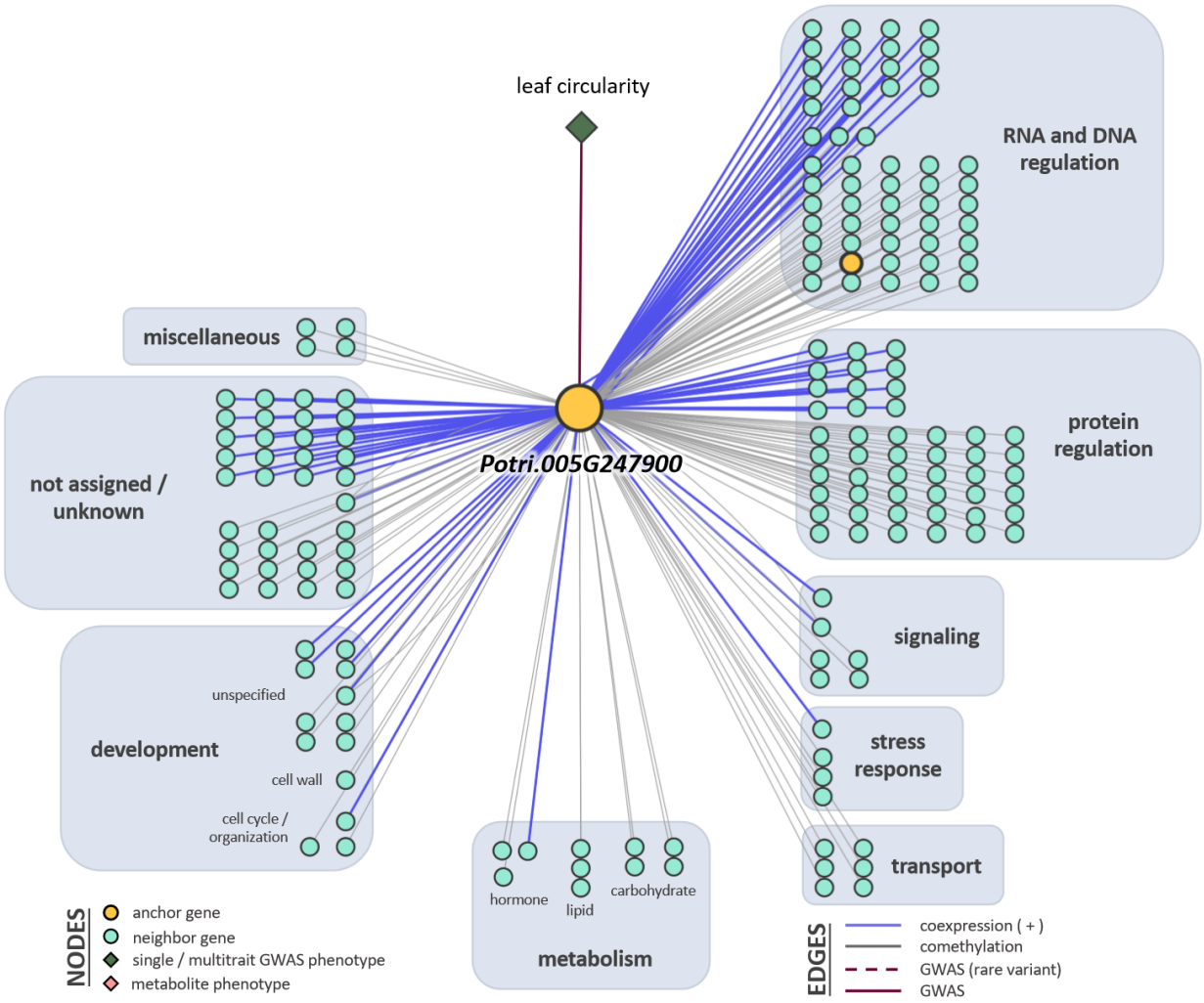

Figure S11. One-hop multi-omic network for the gene Potri.005G247900, which was associated with leaf circularity.

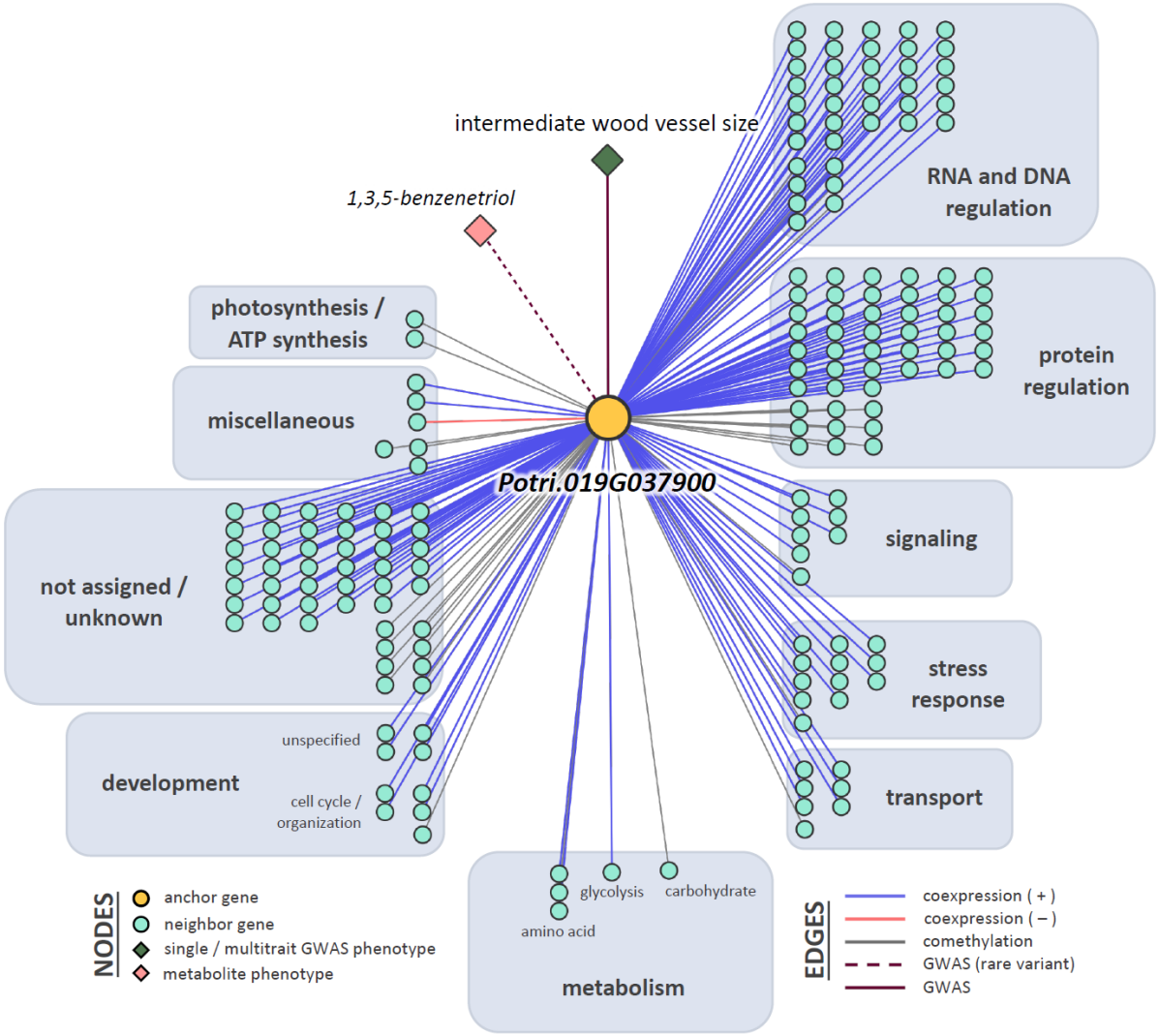

Figure S12. One-hop multi-omic network for the gene Potri.019G037900, which was associated with intermediate wood vessel size.

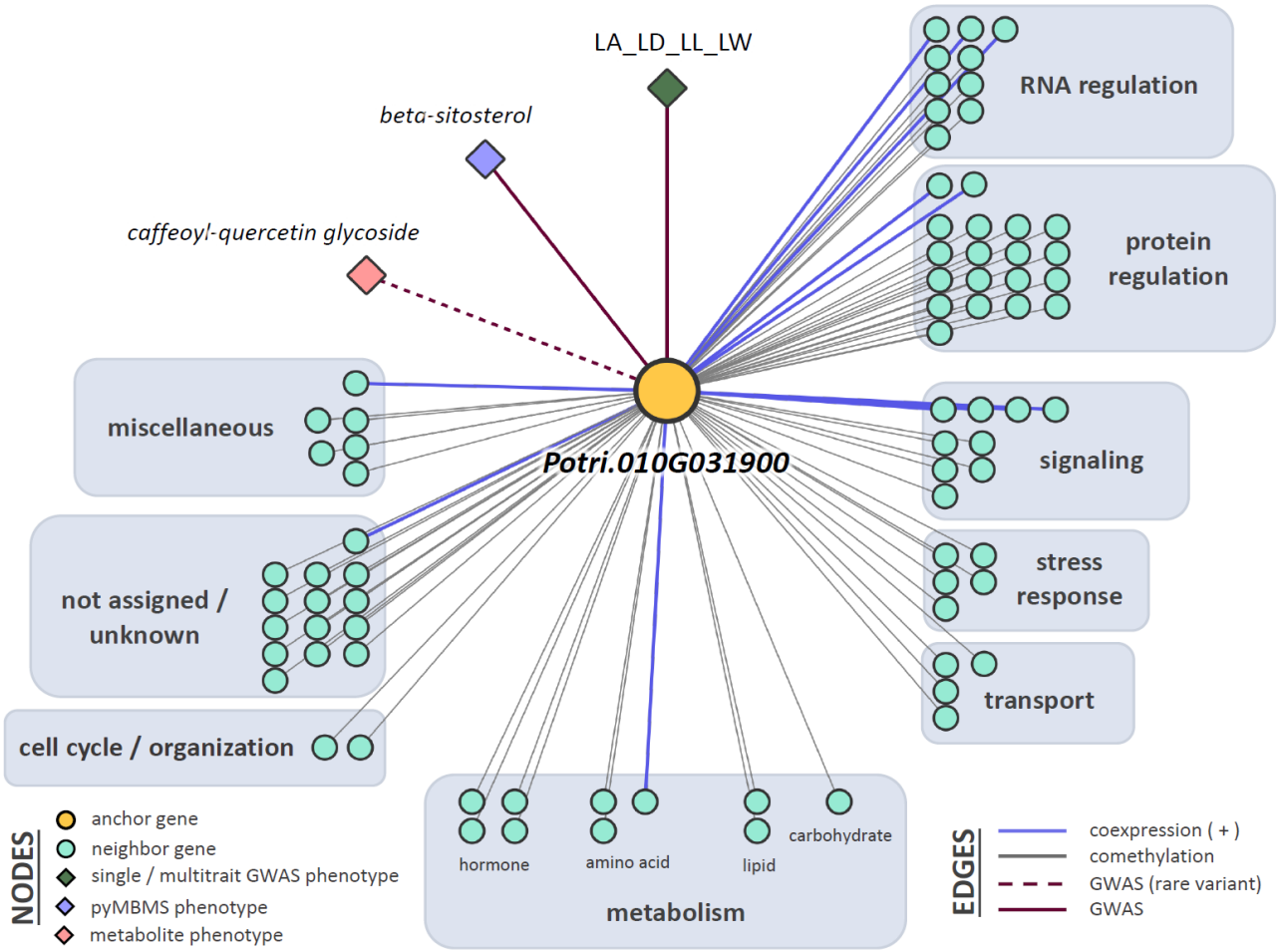

Figure S13. One-hop multi-omic network for the gene Potri.010G031900, which was associated with the multitrait phenotype leaf area, leaf dry weight, leaf length and leaf width.

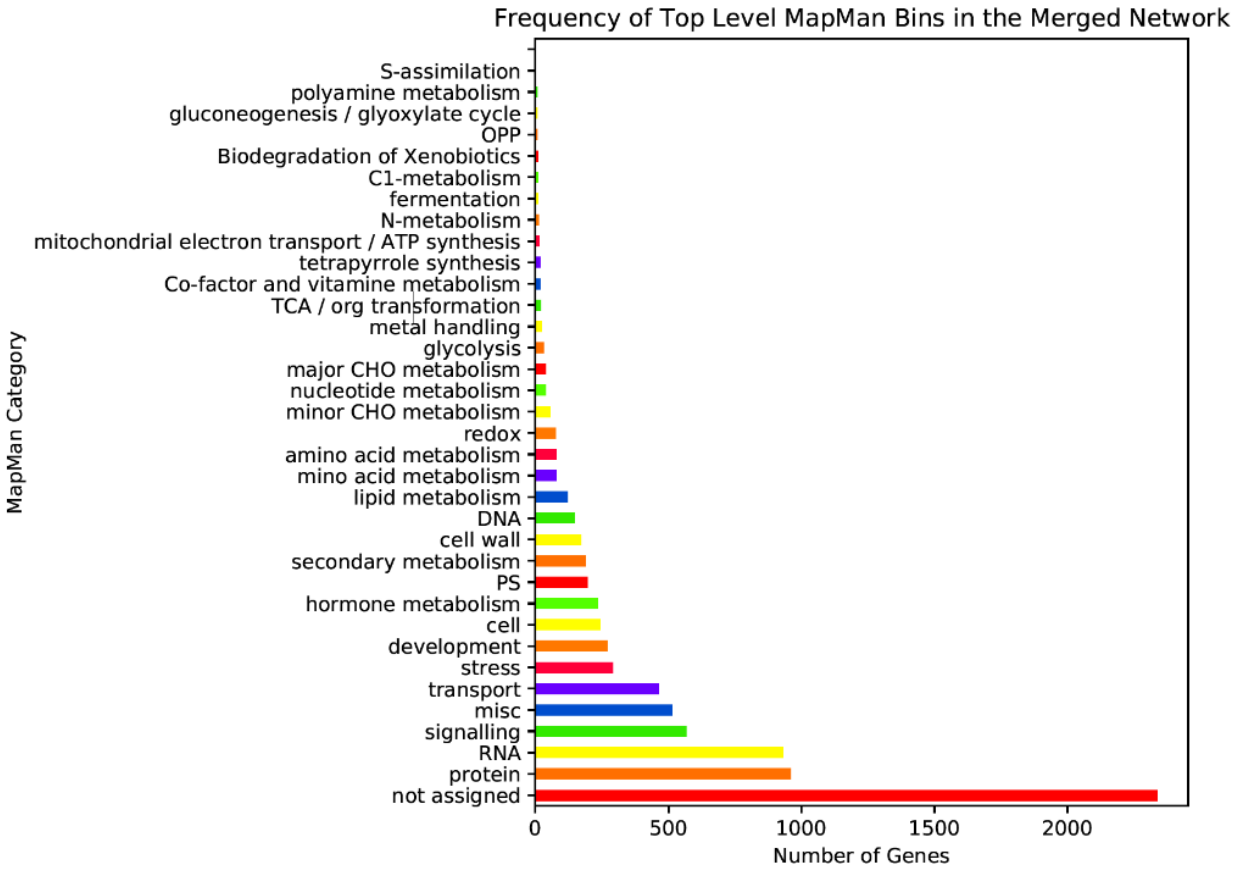

Figure S14. Mapman annotations for all single trait and multitrait GWAS (anchor) genes.

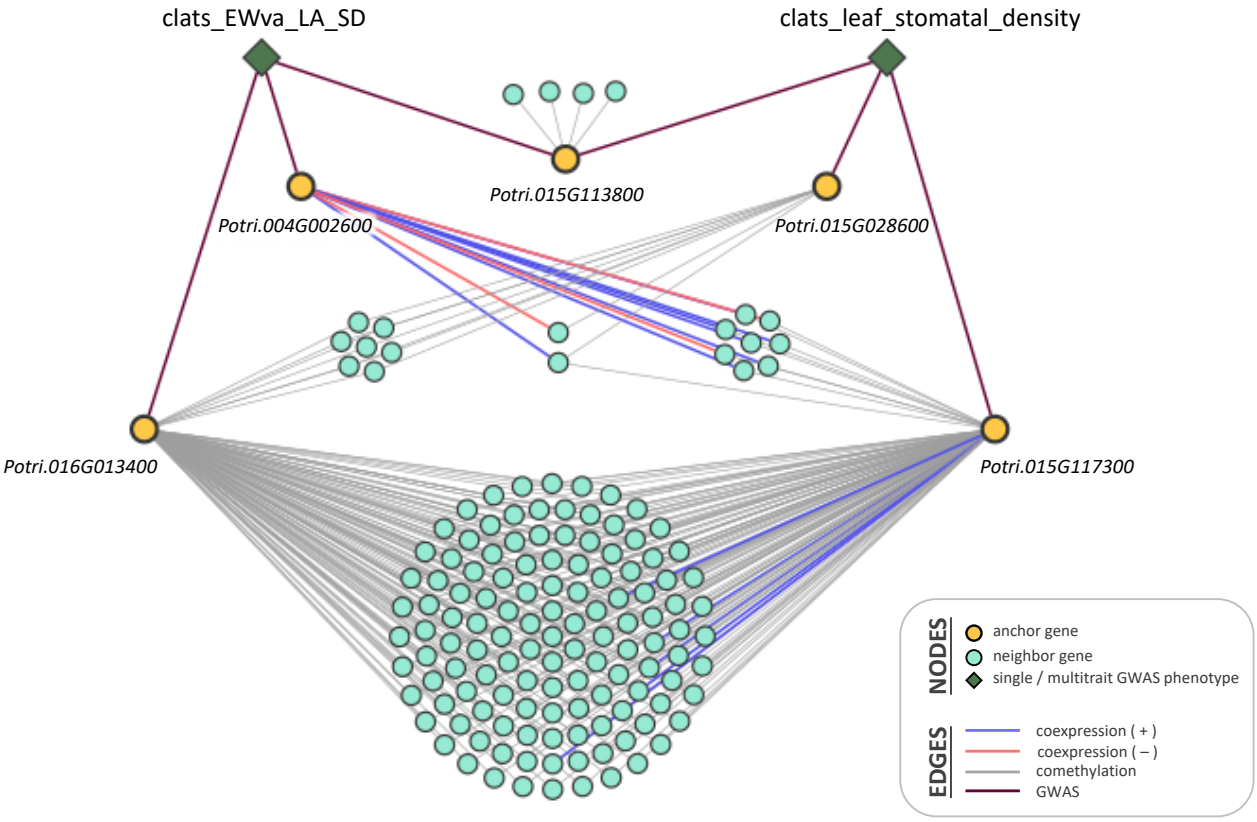

Figure S15. Intersections of subnetworks for single-trait GWAS for Stomatal density and multi-trait GWAS for Early Wood vessel area, Leaf Area, and Stomatal Density.