

Supplementary materials

Table S1. The primers and protocols of PCR amplification.

Target region	Primers	Sequence	PCR protocols
Bacterial V3-V4	338F	5'-ACTCCTACGGGAGGCAGCAG-3'	95 °C for 3 min, 95 °C for 30 s, 55 °C for 30 s, 72 °Cfor 45 s, 27 cycles, 72 °C for 10 min
	806R	5'-GGACTACHVGGGTWTCTAAT-3'	
Fungal ITS	ITS1F	5'-CTTGGTCATTTAGAGGAAGTAA-3'	95 °C for 3 min, 95 °C for 30 s, 55 °C for 30 s, 72 °Cfor 45 s, 35 cycles, 72 °C for 10 min
	ITS2R	5'-GCTGCGTTCTTCATCGATGC-3'	

Table S2. Fresh weight of plants and soil physicochemical properties under phthalic acid.

	Fresh weight (g)	WC (g)	TP (mg/kg)	TK(g/kg)	SOM(g/kg)	NO ₃ ⁻ -N (mg/kg)	NH ₄ ⁺ -N (mg/kg)	TN(mg/kg)	pH
L1-15d	24.22±0.18 ^a	0.24±0.00 ^a	1015.78±6.38 ^a	3.57±0.03 ^a	47.00±0.80 ^a	22.99±0.73 ^{ab}	11.37±0.83 ^c	1821.9±3.37 ^a	5.62±0.11 ^d
L2-15d	18.24±0.10 ^d	0.19±0.00 ^c	841.65±5.56 ^c	3.51±0.02 ^b	39.05±2.48 ^b	22.63±0.47 ^{ab}	6.86±0.08 ^c	1477.59±14.92 ^c	4.74±0.13 ^c
L3-15d	15.72±0.25 ^f	0.16±0.00 ^g	641.19±5.12 ^f	3.46±0.02 ^c	35.15±3.55 ^c	21.53±0.58 ^{bc}	6.18±0.17 ^c	1142.93±32.91 ^c	4.33±0.10 ^f
L1-30d	21.11±0.12 ^b	0.21±0.00 ^d	1004.47±5.59 ^a	3.41±0.04 ^c	38.66±1.28 ^c	21.54±1.54 ^{bc}	14.01±0.52 ^a	1191.40±11.00 ^d	5.84±0.13 ^c
L2-30d	17.68±0.10 ^c	0.18±0.00 ^f	696.87±11.72 ^d	3.19±0.02 ^d	26.65±1.32 ^c	23.24±1.17 ^a	12.97±0.81 ^b	924.40±9.64 ^g	5.72±0.09 ^{cd}
L3-30d	15.37±0.35 ^f	0.14±0.00 ^h	656.4±4.53 ^c	3.43±0.03 ^c	24.79±1.28 ^c	20.25±0.64 ^c	8.49±0.45 ^d	654.00±4.703 ^h	6.09±0.07 ^a
CK-15d	19.55±0.15 ^c	0.22±0.00 ^b	920.04±6.52 ^b	3.45±0.02 ^a	37.08±0.95 ^c	22.47±0.586 ^{ab}	14.88±0.41 ^a	1651.23±13.67 ^b	5.88±0.12 ^{bc}
CK-30d	19.49±0.69 ^c	0.22±0.00 ^c	914.6±7.75 ^b	3.34±0.03 ^b	32.78±0.46 ^d	20.15±0.13 ^c	12.89±0.47 ^b	1041.40±6.92 ^f	6.06±0.04 ^{ab}

Note: Different superscript lowercase letters indicate the data within each concentration treatment are significant different at P <0.05.

Table S3. Fresh weight of plants and soil physicochemical properties under palmitic acid.

	Fresh weight	WC	TP	TK	SOM	NO₃⁻-N	NH₄⁺-N	TN	pH
	(g)	(g)	(mg/kg)	(g/kg)	(g/kg)	(mg/kg)	(mg/kg)	(mg/kg)	
P1-15d	24.37±0.08 ^a	0.25±0.00 ^a	975.35±12.31 ^a	3.45±0.02 ^b	45.37±2.67 ^a	23.13±0.74 ^b	10.74±0.98 ^c	1577.43±15.15 ^c	5.28±0.08 ^c
P2-15d	18.87±0.50 ^d	0.22±0.01 ^c	891.43±5.57 ^c	3.58±0.02 ^a	41.06±4.67 ^b	20.15±0.11 ^d	6.50±0.89 ^d	1194.58±40.039 ^d	5.12±0.10 ^c
P3-15d	16.34±0.12 ^f	0.19±0.00 ^c	664.68±30.18 ^c	3.55±0.03 ^a	42.19±0.77 ^{ab}	24.46±0.51 ^a	6.34±0.803 ^d	1702.76±9.40 ^a	4.71±0.11 ^d
P1-30d	21.00±0.38 ^b	0.24±0.00 ^b	982.87±4.46 ^a	3.37±0.02 ^c	29.31±1.24 ^{dc}	21.50±0.84 ^c	14.95±0.26 ^a	1059.93±3.06 ^c	5.84±0.74 ^b
P2-30d	18.03±0.20 ^c	0.21±0.01 ^d	833.33±14.01 ^d	3.27±0.03 ^d	26.66±1.46 ^c	23.35±0.26 ^b	10.71±0.27 ^c	800.33±23.14 ^f	5.84±0.12 ^b
P3-30d	15.48±0.34 ^e	0.17±0.00 ^f	642.33±2.04 ^c	3.30±0.01 ^d	30.52±1.00 ^d	24.60±0.28 ^a	7.25±0.33 ^d	686.67±13.42 ^e	5.86±0.10 ^b
CK-15d	19.55±0.15 ^c	0.22±0.00 ^c	920.04±6.52 ^b	3.46±0.02 ^b	37.08±0.95 ^c	22.47±0.59 ^b	14.88±0.41 ^a	1651.23±13.67 ^b	5.88±0.12 ^b
CK-30d	19.49±0.69 ^{cd}	0.22±0.00 ^{cd}	914.60±7.75 ^b	3.35±0.03 ^c	32.78±0.46 ^d	20.15±0.13 ^d	12.89±0.47 ^b	1041.40±6.92 ^c	6.06±0.04 ^a

Note: Different superscript lowercase letters indicate the data within each concentration treatment are significant different at P < 0.05.

Table S4. Fresh weight of plants and soil physicochemical properties under mixed organic acid.

	Fresh weight (g)	WC (g)	TP (mg/kg)	TK(g/kg)	SOM(g/kg)	NO ₃ ⁻ -N (mg/kg)	NH ₄ ⁺ -N (mg/kg)	TN(mg/kg)	pH
LP1-15d	23.29±0.5619 ^a	0.23±0.00 ^a	905.62±3.94 ^d	3.45±0.03 ^a	38.77±1.77 ^{ab}	21.49±1.16 ^{bc}	10.03±1.24 ^c	1256.25±42.02 ^c	5.66±0.03 ^c
LP2-15d	17.92±0.76 ^c	0.22±0.00 ^{bc}	691.67±5.01 ^g	3.47±0.06 ^a	35.30±0.14 ^c	20.74±0.97 ^{bc}	10.91±0.95 ^c	1115.92±91.15 ^d	5.09±0.03 ^d
LP3-15d	14.53±0.36 ^e	0.18±0.00 ^e	731.03±10.50 ^f	3.45±0.03 ^a	31.32±0.61 ^d	25.57±1.33 ^a	12.57±0.18 ^b	2032.19±15.13 ^a	5.07±0.05 ^d
LP1-30d	19.01±0.27 ^b	0.19±0.00 ^d	971.00±1.40 ^b	3.24±0.01 ^d	28.347±1.48 ^e	20.90±0.71 ^{bc}	13.37±0.58 ^b	997.47±4.30 ^e	4.83±0.09 ^e
LP2-30d	16.63±0.54 ^d	0.18±0.00 ^e	759.80±4.386 ^e	3.33±0.04 ^{bc}	21.45±2.04 ^f	20.40±0.46 ^{bc}	7.36±0.57 ^d	598.13±9.75 ^f	4.74±0.08 ^e
LP3-30d	13.55±0.33 ^f	0.23±0.00 ^a	1012.73±8.30 ^a	3.28±0.03 ^{cd}	40.57±1.90 ^a	26.26±2.36 ^a	12.91±0.53 ^b	1035.80±16.89 ^e	5.85±0.11 ^b
CK-15d	19.55±0.15 ^b	0.22±0.00 ^{ab}	920.04±6.52 ^c	3.46±0.02 ^a	37.08±0.95 ^{bc}	22.47±0.59 ^b	14.88±0.41 ^a	1651.23±13.67 ^d	5.88±0.12 ^b
CK1-30d	19.49±0.69 ^b	0.22±0.00 ^c	914.60±7.75 ^{cd}	3.35±0.03 ^b	32.78±0.46 ^d	20.15±0.13 ^c	12.89±0.47 ^b	1041.40±6.92 ^e	6.06±0.04 ^a

Note: Different superscript lowercase letters indicate the data within each concentration treatment are significant different at P < 0.05.

Table S5. Correlation between microbial (Bacterial, fungal) community and edaphic factors (R value) (*p < 0.05, **p < 0.01, ***p < 0.001)

	Bacteria				Fungus			
	RDA1	RDA2	r ²	p_values	RDA1	RDA2	r ²	p_values
Bacteria								
pH	-0.9652	-0.2616	0.1154	0.034*	-0.998	0.0628	0.2877	0.001***
SOM	-0.9349	-0.355	0.1487	0.009**	0.4181	-0.9084	0.0005	0.985
TN	-0.7873	-0.6166	0.2121	0.002**	0.8743	0.4854	0.0748	0.116
TP	-0.9976	-0.0689	0.091	0.077	-0.9986	-0.0527	0.1464	0.01*
NO ₃ ⁻ -N	-0.9651	-0.2617	0.0516	0.235	0.1918	-0.9814	0.0727	0.104
NH ₄ ⁺ -N	-0.9932	-0.1163	0.0393	0.325	-0.9686	0.2485	0.2198	0.003**
TK	-0.7375	-0.6753	0.1583	0.011*	0.8275	0.5614	0.15	0.014*
WC	-0.986	-0.1667	0.1776	0.006**	-0.9339	0.3575	0.0904	0.068

Table S6. Different coefficients of bacterial network complexity.

	Node number	Edge number	Average degree	Graph diameter	Graph density	Clustering coefficient	Average Path length
CK-15d	100	671	13.42	8	0.136	0.076	3.573
LL-15d	100	695	13.9	5	0.14	0.147	2.791
LH-15d	99	316	6.384	13	0.065	0.569	4.755
CK-30d	100	993	19.86	5	0.201	0.136	1.781
LL-30d	92	387	8.413	6	0.092	0.07	2.812
LH-30d	95	292	6.17	13	0.065	0.547	4.565
LPL-15d	100	856	17.2	6	0.173	0.152	2.812
LPH-15d	83	522	12.578	8	0.153	0.557	2.946
LPL-30d	100	791	15.82	3	0.16	0.403	1.768
LPH-30d	83	448	10.795	12	0.132	0.554	3.483
PL-15d	99	900	18.182	8	1.186	0	3.368
PH-15d	80	426	10.65	12	0.135	0.579	3.951
PL-30d	79	630	15.949	6	0.204	0.266	2.877
PH-30d	84	379	9.024	12	0.109	0.518	3.978

Table S7. Different coefficients of fungal network complexity.

	Node number	Edge number	Average degree	Graph diameter	Graph density	Clustering coefficient	Average Path length
CK-15d	85	796	18.729	3	0.223	0.215	1.622
LL-15d	75	552	14.72	3	0.199	0.131	1.711
LH-15d	94	662	14.085	10	0.151	0.698	3.531
CK-30d	100	897	17.94	5	0.181	0.062	1.983
LL-30d	73	770	21.096	2	0.293	0.104	1.479
LH-30d	93	556	11.957	11	0.13	0.613	3.791
LPL-15d	100	629	12.58	8	0.127	0.12	3.427
LPH-15d	90	505	11.22	11	0.126	0.572	3.593
LPL-30d	86	767	17.837	6	0.21	0.205	2.808
LPH-30d	91	375	8.242	13	0.092	0.481	3.926
PL-15d	90	556	12.356	3	0.139	0.122	1.91
PH-15d	93	471	10.129	9	0.11	0.495	3.513
PL-30d	83	692	16.675	3	0.203	0.059	1.774
PH-30d	99	570	11.515	2	0.118	0.708	1.882

Note: LL: phthalic acid <250mg/kg; LH: phthalic acid >250mg/kg; PL: palmitic acid <250mg/kg; PH: phthalic acid >250mg/kg; LPL: mixed organic acids <250mg/kg; LPH: mixed organic acids >250mg/kg.

Table S8. Metabolic pathway description of differential metabolites under different organic acids.

Organic acid species	Different Pathway Description	Same Pathway Description
Phthalic acid (<250mg/kg)	Synthesis and degradation of ketone bodies Fructose and mannose metabolism	Steroid hormone biosynthesis Flavonoid biosynthesis
Phthalic acid (>250mg/kg)	—	Steroid hormone biosynthesis Flavonoid biosynthesis
Palmic acid (<250mg/kg)	Biosynthesis of alkaloids derived from shikimate pathway Synthesis and degradation of ketone bodies Biosynthesis of plant secondary metabolites Fructose and mannose metabolism Biosynthesis of plant hormones Biosynthesis of phenylpropanoids Galactose metabolism	Steroid hormone biosynthesis
Palmic acid (>250mg/kg)	Ubiquinone and other terpenoid-quinone biosynthesis Flavonoid biosynthesis	Steroid hormone biosynthesis
Mixed organic acid (<250mg/kg)	alpha-Linolenic acid metabolism Butanoate metabolism	Steroid hormone biosynthesis Linoleic acid metabolism Primary bile acid biosynthesis
Mixed organic acid (>250mg/kg)	Amino sugar and nucleotide sugar metabolism Biosynthesis of plant hormones	Steroid hormone biosynthesis Linoleic acid metabolism Primary bile acid biosynthesis

Table S9. The path analysis data for CK (**p <0.01, ***p <0.001).

X	→	Y	Unstandardized Coefficients	Standardized Coefficients	S.E.	C.R.	P
Plant	→	Metabolites	-0.361	-0.247	0.817	-0.442	0.658
Plant	→	Edaphic factors	1.089	0.746	0.132	8.254	0.000***
Metabolites	→	Edaphic factors	0.859	0.859	0.090	9.511	0.000***
Plant	→	Bacterial α-shannon	-0.156	-0.753	0.079	-1.963	0.050**
Metabolites	→	Bacterial α-shannon	0.044	0.312	0.062	0.709	0.478
Edaphic factors	→	Bacterial α-shannon	-0.042	-0.297	0.071	-0.591	0.555
Plant	→	Fungal α-shannon	0.114	0.233	0.040	2.855	0.004***
Metabolites	→	Fungal α-shannon	-0.304	-0.907	0.027	-11.121	0.000***

Table S10. The path analysis data for phthalic acid conditions.

X	→ Y	Unstandardized Coefficients	Standardized Coefficients	S.E.	C.R.	P
Plant	→ Metabolites	-0.550	-0.708	0.224	-2.458	0.014**
Plant	→ Edaphic factors	0.229	0.793	0.066	3.483	0.000***
Metabolites	→ Edaphic factors	-0.062	-0.167	0.085	-0.734	0.463
Plant	→ Bacterial α -shannon	0.041	0.590	0.063	0.650	0.516
Metabolites	→ Bacterial α -shannon	0.021	0.240	0.048	0.441	0.659
Edaphic factors	→ Bacterial α -shannon	-0.167	-0.698	0.224	-0.745	0.456
Plant	→ Fungal α -shannon	0.158	0.661	0.020	8.086	0.000***
Metabolites	→ Fungal α -shannon	0.125	0.406	0.015	8.265	0.000***
Edaphic factors	→ Fungal α -shannon	0.517	0.624	0.070	7.396	0.000***

Note: **p < 0.01, ***p < 0.001.

Table S11. The path analysis data for palmitic acid conditions (*p < 0.05, **p < 0.01, ***p < 0.001).

X	→ Y	Unstandardized Coefficients	Standardized Coefficients	S.E.	C.R.	P
Plant	→ Edaphic factors	-0.059	-0.674	0.026	-2.235	0.025**
Plant	→ Metabolites	-0.692	-0.982	0.055	-12.565	0.000***
Plant	→ Bacterial α -shannon	-0.007	-0.170	0.016	-0.408	0.683
Edaphic factors	→ Bacterial α -shannon	-0.340	-0.759	0.187	-1.821	0.069*
Edaphic factors	→ Fungal α -shannon	-1.328	-0.568	1.114	-1.191	0.234
Plant	→ Fungal α -shannon	-0.021	-0.102	0.097	-0.214	0.830

Table S12. The path analysis data for mixed organic acid conditions (*p < 0.05, ***p < 0.001).

X	→ Y	Unstandardized Coefficients	Standardized Coefficients	S.E.	C.R.	P
Plant	→ Metabolites	-0.555	-0.962	0.064	-8.660	0.000***
Metabolites	→ Edaphic factors	1.169	0.679	0.321	3.639	0.000***
Plant	→ Edaphic factors	-0.320	-0.322	0.185	-1.725	0.084*
Plant	→ Bacterial α -shannon	0.010	0.124	0.046	0.220	0.826
Metabolites	→ Bacterial α -shannon	-0.115	-0.807	0.081	-1.430	0.153
Edaphic factors	→ Fungal α -shannon	-0.139	-0.886	0.030	-4.692	0.000***

Table S13. Correlation between fresh weight and physicochemical properties of plants under different organic acid conditions (*p <0.05, **p <0.01).

	pH	TN mg/kg	TP mg/kg	NH ₄ ⁺ -N mg/kg	NO ₃ ⁻ -N mg/kg	TK g/kg	SOM g/kg	WC %
Plant fresh weight (L)	0.27	0.80**	0.94**	0.57*	-0.43	0.39	0.80**	0.99* *
Plant fresh weight (P)	0.00	0.39	0.89**	0.60**	-0.40	0.54*	0.36	0.11
Plant fresh weight (LP)	0.03	-0.16	0.10	-0.27	-0.61**	0.33	0.10	0.25
Plant fresh weight (CK)	0.08	0.06	-0.59	0.20	0.09	0.43	0.13	0.10

Table S14. Correlation between microbial (bacterial, fungal) diversity index (Shannon) and soil physicochemical properties (*p <0.05, **p <0.01).

	pH	TN mg/kg	TP mg/kg	NH ₄ ⁺ -N mg/kg	NO ₃ ⁻ -N mg/kg	TK g/kg	SOC g/kg	WC %
Bacterial shannon (L)	-0.51*	-0.46	-0.66**	-0.61**	-0.43	-0.26	-0.47*	-0.72**
Fungal shannon (L)	0.22	0.13	0.33	0.44	0.41	-0.29	0.08	0.36
Bacterial shannon (P)	-0.58	0.40	-0.18	-0.36	-0.11	0.54*	0.27	-0.10
Fungal shannon (P)	-0.42	0.52*	0.25	0.04	-0.36	0.55*	0.30	0.34
Bacterial shannon (LP)	-0.03	-0.47	-0.52*	-0.69**	-0.61**	0.33	-0.25	0.08
Fungal shannon (LP)	-0.13	-0.29	-0.44	-0.61**	-0.58*	0.57*	0.07	0.37
Bacterial shannon (CK)	-0.66	0.44	0.49	0.29	0.37	0.43	0.27	-0.22
Fungal shannon (CK)	-0.76	0.94**	0.22	0.87*	0.90*	0.84*	0.95**	0.29

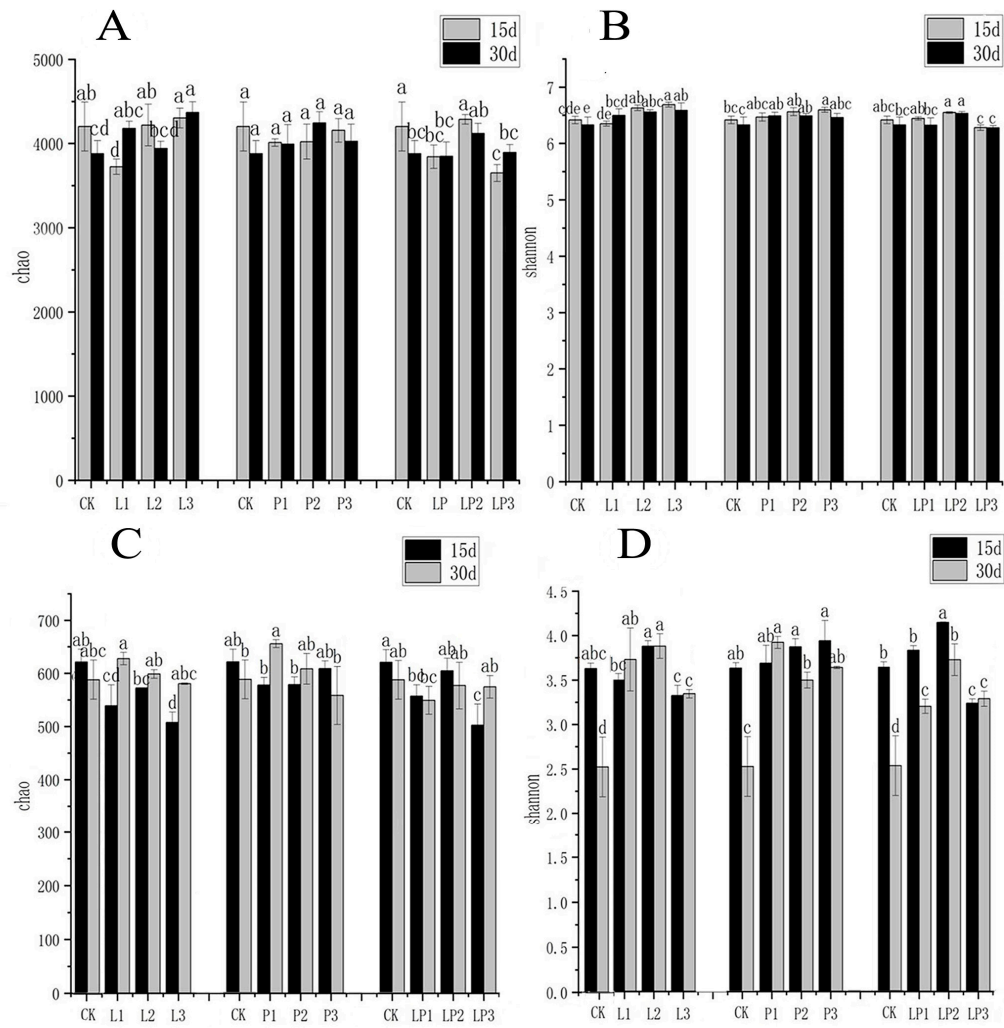


Figure S2. Shannon index and chao index of bacteria and fungi. (A) bacterial chao index, (B) bacterial shannon index, (C) fungal chao index, and (D) fungal shannon index.

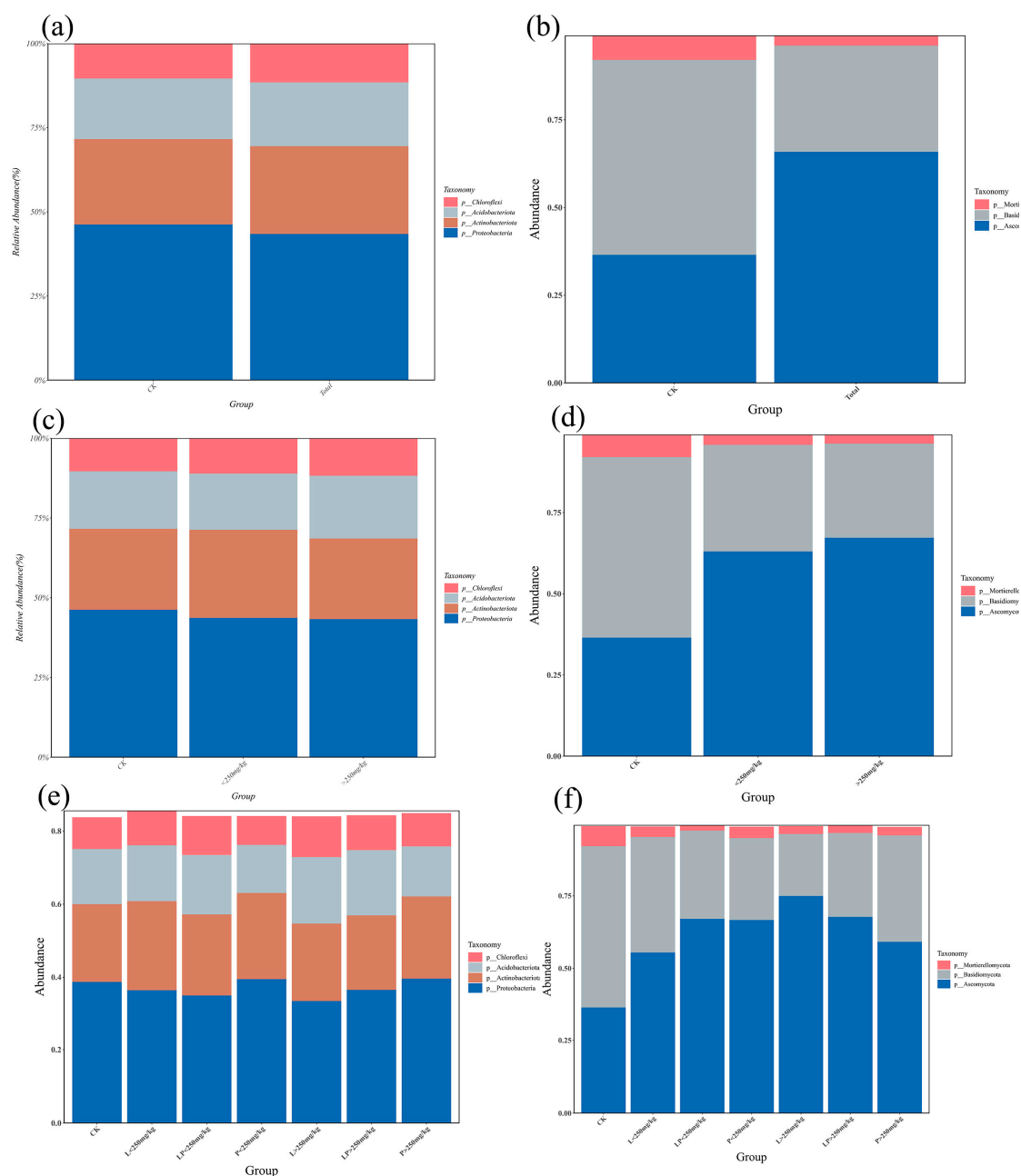


Figure S3. The relative abundance of the bacterial (a, c, e) and fungal (b, d, f) communities at the phylum level.

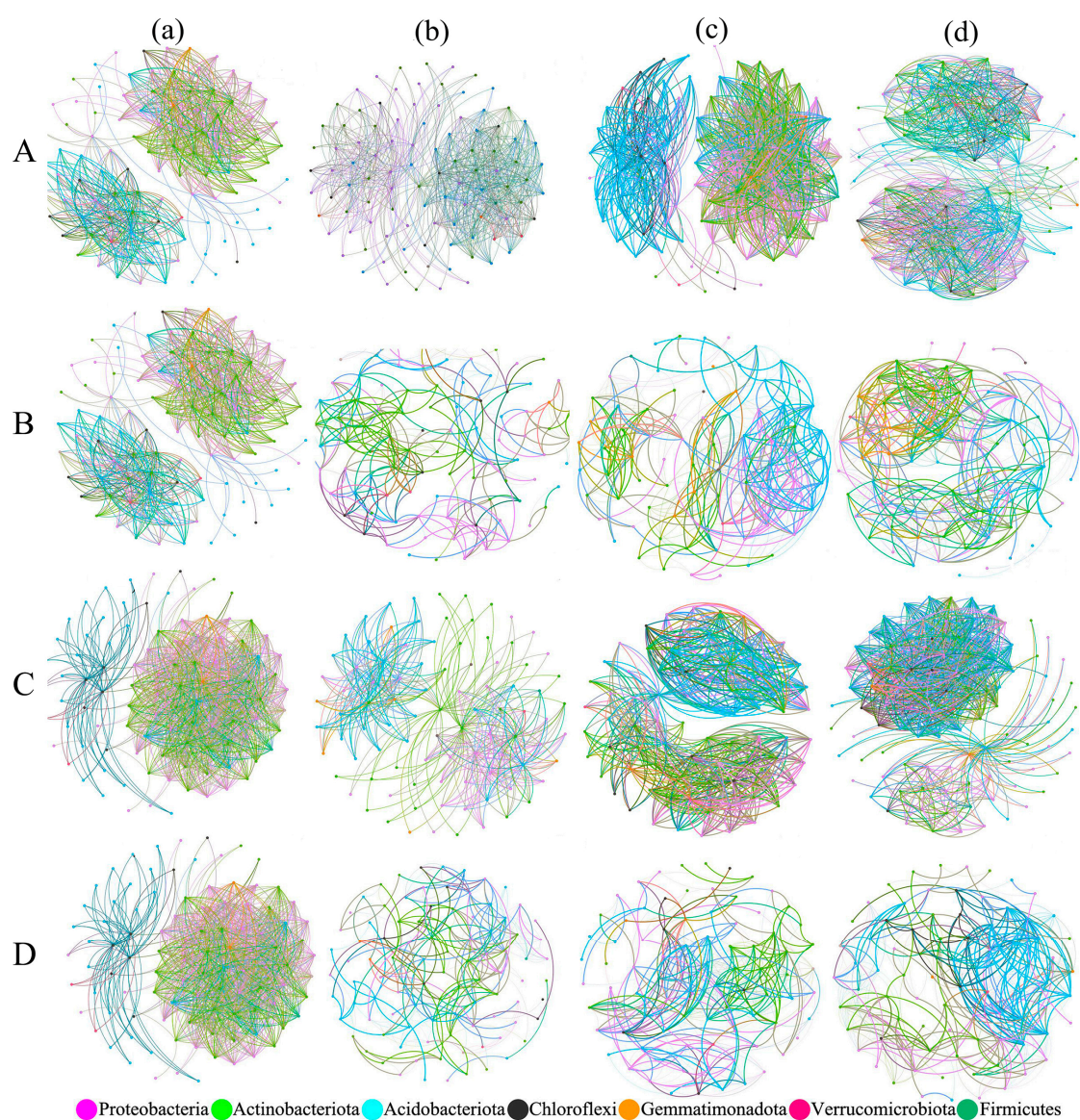


Figure S5. Changes in the complexity of bacterial networks under different organic acids. (A, C) organic acids concentrations < 250mg/kg, respectively. (B, D) organic acids concentrations > 250mg/kg, respectively. (a, b, c, and d) CK, phthalic, palmitic, and mixed organic acids treatment.

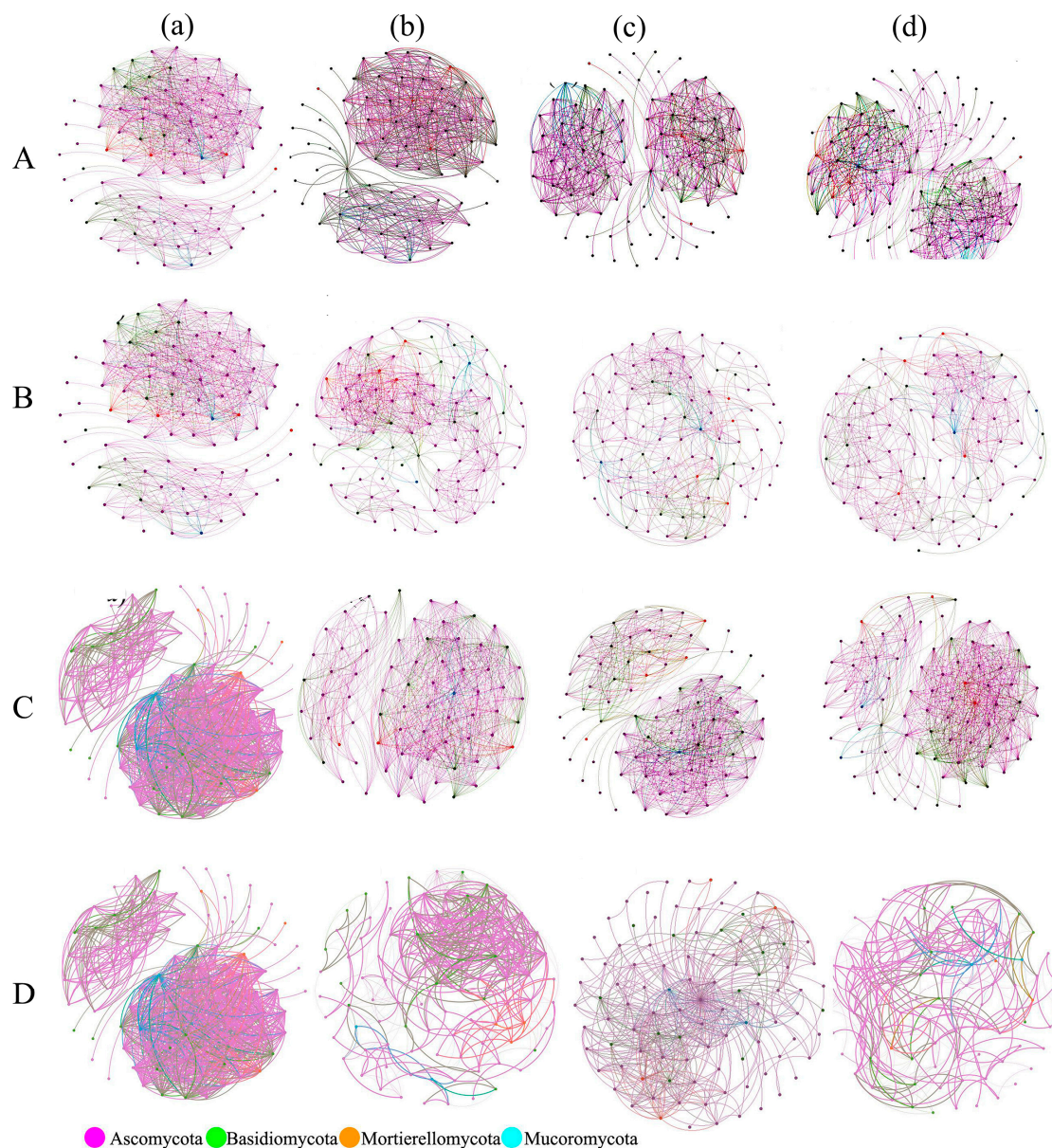


Figure S6. Changes in the complexity of fungal networks under different species organic acids. (A, C) organic acids concentrations < 250mg/kg, respectively. (B, D) organic acids concentrations > 250mg/kg, respectively. (a, b, c, and d) CK, phthalic, palmitic, and mixed organic acids treatment.

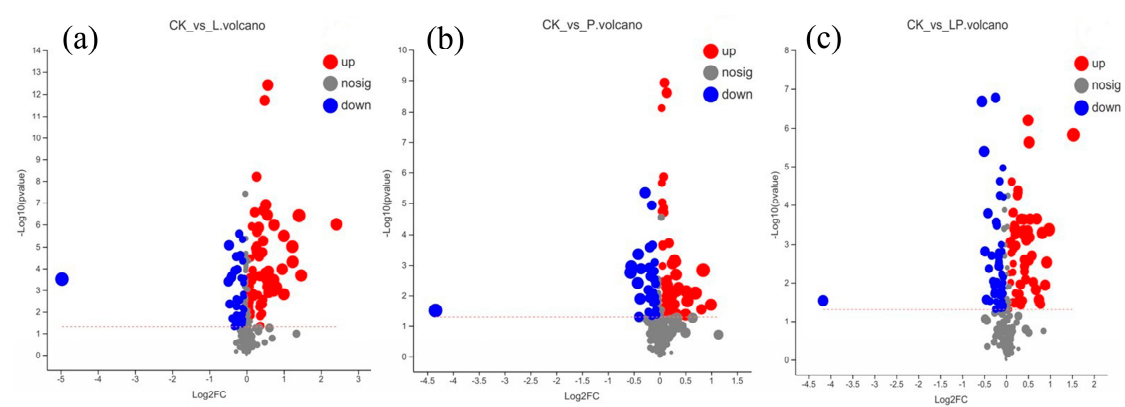


Figure S7. Volcano plot showing the different metabolites with different organic acid treatments ($P < 0.05$, $\text{VIP} > 1$). (a), phthalic acid treatment; (b), palmitic acid treatment; (c), mixed organic acid treatment.

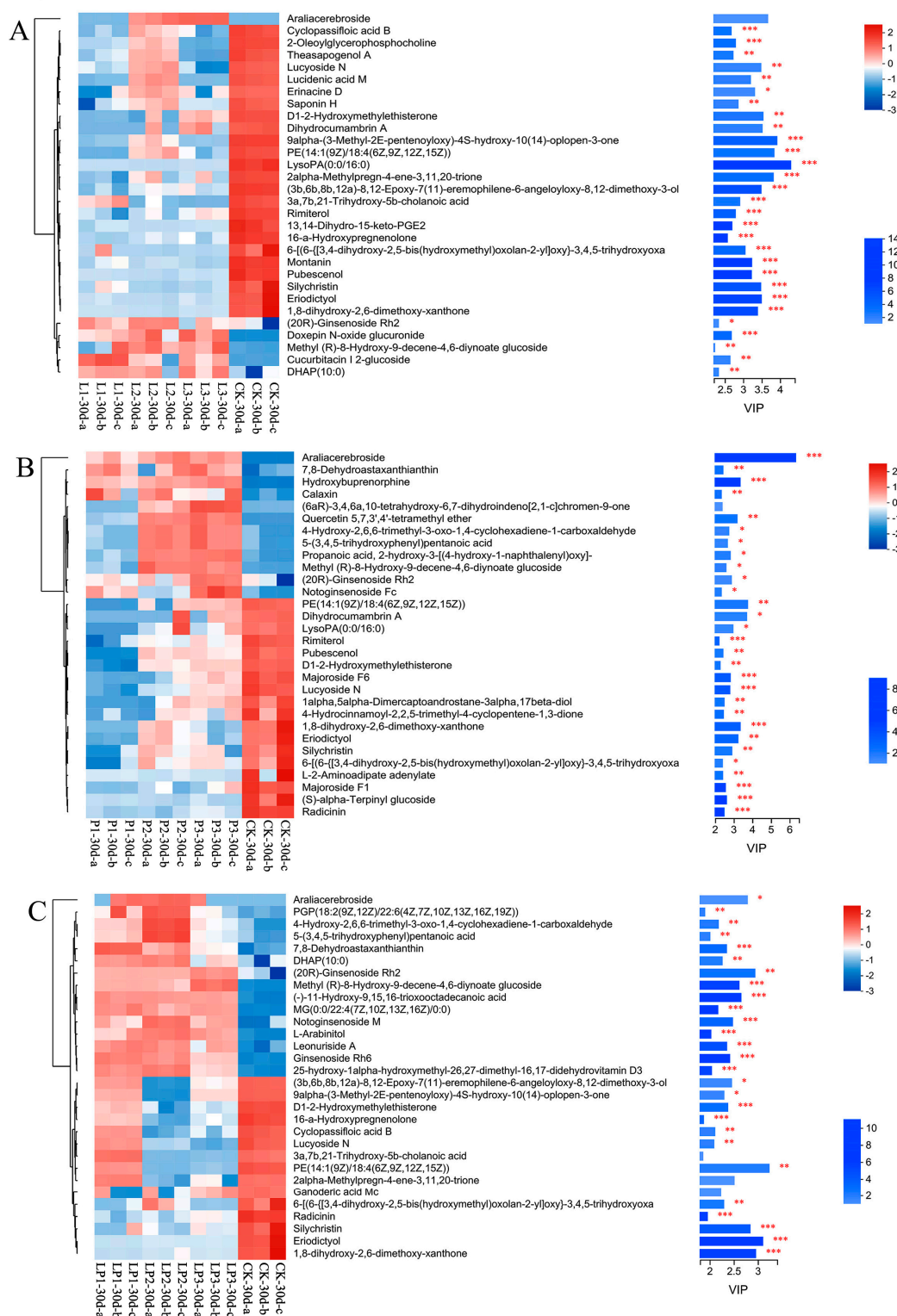


Figure S8. VIP values in the OPLS-DA model (VIP values >1.0) showing DMs under the three organic acid treatments. ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$. (A), phthalic acid treatment (30 days); (B), palmitic acid treatment (30 days); (C), mixed organic acid treatment (30 days).

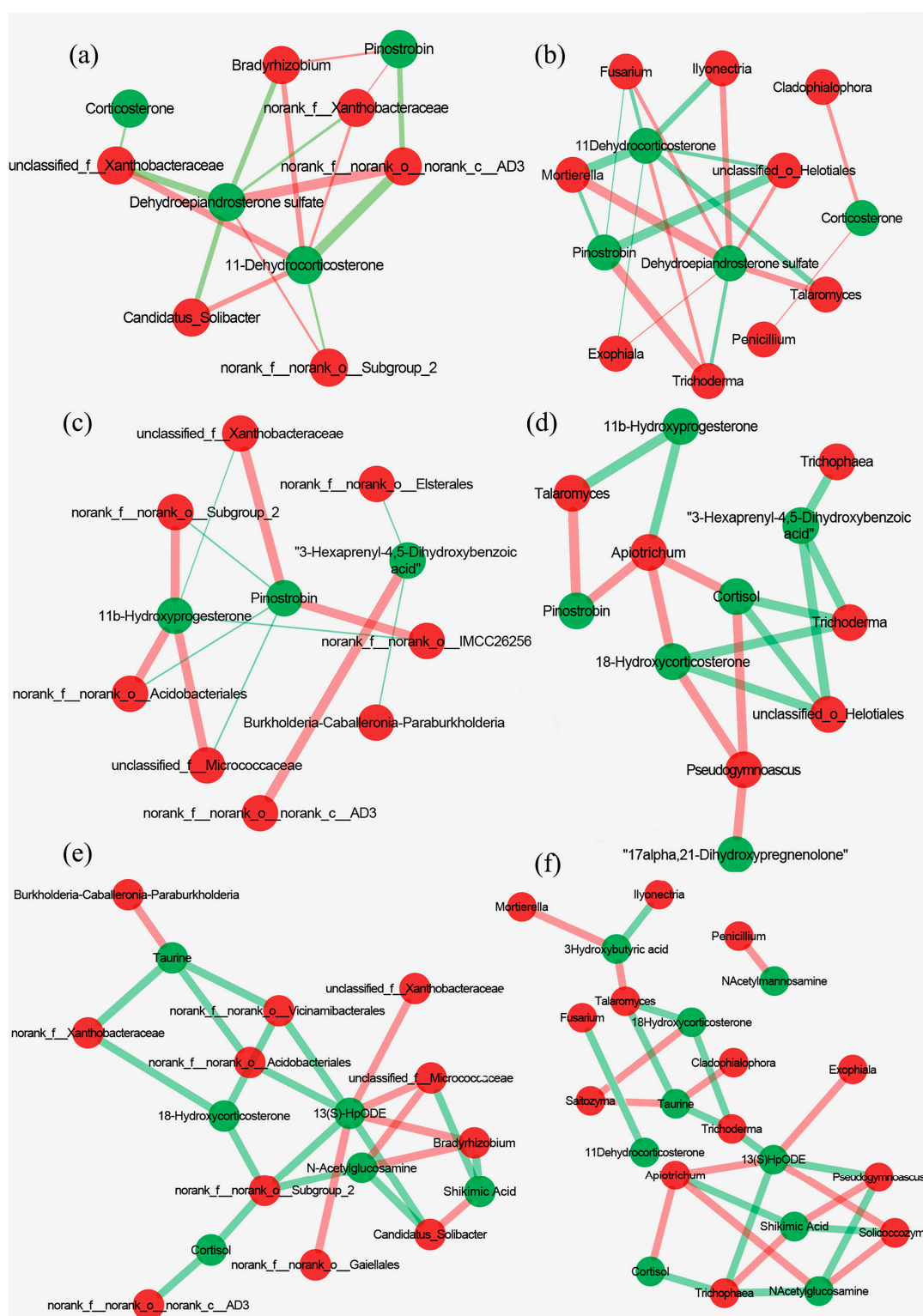


Figure S9. Network analysis of the top 15 bacteria, fungi and DMs. Red and green indicate positive and negative correlation, respectively ($P < 0.05$). The red circle represent bacteria and fungi, the green circle represent metabolites. (a) and (b) phthalic acid conditions. (c) and (d) palmitic acid conditions. (e) and (f) mixed organic acid conditions.