

Online Resource 1: Supplementary Information

Calcium silicate effects on wheat phosphorus nutrition depend on phosphorus-source chemistry

Karwa S, Halpern M. Supplementary Information for submission to *Silicon*.

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Table S1. Run 1 short cross-check: Day-30 biomass (ambient CO₂)

Trait	P source	NoSi mean	Si mean	Si effect (%)	Welch p
Shoot dry weight (g plant ⁻¹)	HA	0.245	0.269	+10.0	0.41
Shoot dry weight (g plant ⁻¹)	FePO ₄	0.345	0.325	-5.7	0.61
Shoot dry weight (g plant ⁻¹)	KH ₂ PO ₄	0.287	0.384	+33.8	0.012
Root dry weight (g plant ⁻¹)	HA	0.179	0.221	+23.8	0.57
Root dry weight (g plant ⁻¹)	FePO ₄	0.362	0.362	+0.0	1.00
Root dry weight (g plant ⁻¹)	KH ₂ PO ₄	0.349	0.690	+97.8	0.022

Run 1 (three P sources crossed with CaSiO₃, ambient CO₂) is a shorter preliminary run retained as a cross-check, with biomass recorded per plant (n = 8 per cell). The principal CaSiO₃-by-P-source directions reproduced, because CaSiO₃ increased shoot and root biomass under KH₂PO₄ and shifted HA in the same direction, whereas FePO₄ was unchanged. Full per-plant Run 1 data are in the reproducibility package.

Table S2. Statistical hierarchy: endpoints, transforms, models and tests

Endpoint	Transform	Model	Within-source test	n per cell	Multiplicity / post-hoc
Shoot biomass (g pot ⁻¹)	original	two-way ANOVA (P source × CaSiO ₃)	Welch, NoSi vs Si	6–7	Tukey HSD (8 cells)
Root biomass (g pot ⁻¹)	original	two-way ANOVA	Welch	4	Tukey HSD
Shoot P concentration (mg kg ⁻¹)	log10	two-way ANOVA	Welch	4	Tukey HSD; FDR in S5
Shoot Fe, Mn concentration (mg kg ⁻¹)	original	two-way ANOVA	Welch	4	Tukey HSD; FDR in S5
Shoot P, Fe, Mn content (μg plant ⁻¹)	log10 (whole-plant basis)	two-way ANOVA	Welch	4	Tukey HSD
Full shoot ionome (11 elements)	original	two-way ANOVA	Welch	4	Benjamini-Hochberg FDR (Table S5)
Root architecture (length, area, diameter, volume)	original	two-way ANOVA	Welch	3–4	Benjamini-Hochberg FDR (Table S6)
Abiotic soluble PO ₄ -P (mg L ⁻¹)	log10	two-way ANOVA (mineral × dose), per time point	Welch vs no-Si	3	Tukey HSD

Content endpoints use the whole-plant basis (concentration × treatment-cell mean shoot dry mass per plant). All tests two-sided; analyses in Python (pandas, scipy, statsmodels).

Table S3. Dosing and chemistry of the P-source and calcium-silicate treatments

Treatment / amendment	Role	Compound	Rate applied	Co-supplied element(s)	Note
KH ₂ PO ₄	soluble-P positive control	KH ₂ PO ₄	0.3 g kg ⁻¹ sand	K	Readily soluble orthophosphate; rate set per kg sand
Hydroxyapatite (HA)	sparingly soluble Ca phosphate	Ca ₅ (PO ₄) ₃ OH	0.21 g kg ⁻¹ sand	Ca	Model Ca-bound P source
FePO ₄	sparingly soluble Fe phosphate	FePO ₄ ·2H ₂ O	0.24 g kg ⁻¹ sand	Fe	Model Fe-bound P source
No added P (NoP)	negative control	–	0	–	No P added
CaSiO ₃ (Si treatment)	silicon amendment	CaSiO ₃	1.24 g kg ⁻¹ sand (10.68 mmol Si kg ⁻¹)	Ca, Si	Mixed into sand before assembly
CaCl ₂ (NoSi treatments)	calcium balance for no-Si cells	CaCl ₂	Ca-matched to CaSiO ₃	Ca, Cl	Balances Ca supplied by CaSiO ₃ ; does not balance pH/alkalinity

HA and FePO₄·2H₂O were dosed to give near-equivalent mineral-P additions: approximately 38.9 and 39.8 mg P kg⁻¹ sand, respectively. KH₂PO₄ supplies approximately 68.3 mg P kg⁻¹ sand at 0.3 g kg⁻¹ sand, about 1.7-fold the mineral-P rate, and is therefore treated as a soluble-P positive control rather than as a strictly equal elemental-P comparison.

Background plant-available nutrients in the quartz sand (ICP-OES, n = 4): CaCl₂-extractable (soluble) P was below detection (< 0.01 mg L⁻¹) and CaCl₂-extractable Si averaged 1.5 mg L⁻¹; acetic-acid-extractable P and Si averaged 2.5 and 1.2 mg L⁻¹, respectively. The sand therefore supplied negligible soluble P and little available Si.

Table S4. Day-30 root-scan audit and sensitivity (Si-vs-NoSi % change by exclusion scenario)

P source	Trait	All scans (corrected key)	Drop scan-name-doubt rows	Drop pot-82 only
FePO ₄	Avg Diameter (mm)	-3.3	-2.5	-2.5
FePO ₄	Total Length (cm)	22.3	28.6	28.6
HA	Avg Diameter (mm)	15.0	15.0	15.0
HA	Total Length (cm)	15.4	15.4	15.4
KH ₂ PO ₄	Avg Diameter (mm)	-6.1	-1.1	-6.1
KH ₂ PO ₄	Total Length (cm)	55.9	32.9	55.9
NoP	Avg Diameter (mm)	4.4	4.4	4.4
NoP	Total Length (cm)	9.6	9.6	9.6

Scenarios: all_corrected_key, drop_pot82_only, drop_all_scan_name_doubts_32_61_67_82. The hydroxyapatite diameter and total-length responses are stable across exclusion scenarios; the KH₂PO₄ total-length effect attenuates under the strictest exclusion

of all flagged scan records (small remaining n). Pot 82 (FePO₄ NoSi) was excluded because its scan identity conflicted with the pot key.

Table S5. Full shoot-ionome CaSiO₃ effect by P source (concentration, with Benjamini-Hochberg q)

Element	P source	NoSi mean (mg kg ⁻¹)	Si mean (mg kg ⁻¹)	Change (%)	Welch p	BH q
P	KH ₂ PO ₄	778.9	1296.4	66.4	0.29	0.35
P	HA	611.6	691.0	13.0	0.0034	0.012
P	FePO ₄	1185.4	1278.0	7.8	0.082	0.13
P	NoP	390.3	459.3	17.7	0.0072	0.019
Fe	KH ₂ PO ₄	53.0	62.3	17.4	0.0037	0.012
Fe	HA	55.7	78.2	40.2	0.0014	0.0057
Fe	FePO ₄	59.8	88.9	48.6	8e-05	0.00088
Fe	NoP	54.8	59.0	7.8	0.21	0.28
Mn	KH ₂ PO ₄	15.6	35.7	128.2	0.26	0.32
Mn	HA	24.2	37.3	53.9	0.00052	0.0029
Mn	FePO ₄	12.2	26.8	119.4	0.0014	0.0057
Mn	NoP	56.8	66.7	17.3	0.00044	0.0029
Zn	KH ₂ PO ₄	17.2	14.2	-17.6	0.04	0.076
Zn	HA	11.7	15.3	30.9	0.0034	0.012
Zn	FePO ₄	6.4	6.7	4.1	0.34	0.4
Zn	NoP	9.8	14.0	43.2	0.00071	0.0035
Ca	KH ₂ PO ₄	4062.8	5660.9	39.3	0.48	0.53
Ca	HA	3736.9	4271.8	14.3	0.018	0.038
Ca	FePO ₄	4414.6	4138.8	-6.2	0.15	0.22
Ca	NoP	4346.2	4853.8	11.7	0.0041	0.012
K	KH ₂ PO ₄	15368.0	14063.4	-8.5	0.65	0.67
K	HA	12965.7	19157.3	47.8	6.5e-07	2.8e-05
K	FePO ₄	11955.7	12969.0	8.5	0.35	0.4
K	NoP	17668.6	19014.4	7.6	0.0091	0.022
Mg	KH ₂ PO ₄	680.6	924.2	35.8	0.57	0.59
Mg	HA	1172.0	1257.0	7.3	0.042	0.077
Mg	FePO ₄	1366.0	1142.3	-16.4	0.0055	0.015
Mg	NoP	1299.8	1359.2	4.6	0.015	0.033
Na	KH ₂ PO ₄	1120.0	1402.4	25.2	0.49	0.53
Na	HA	1810.0	3099.5	71.2	3e-05	0.00045
Na	FePO ₄	1224.4	1221.8	-0.2	0.96	0.96
Na	NoP	2687.1	2585.3	-3.8	0.052	0.088
S	KH ₂ PO ₄	470.7	906.0	92.5	0.26	0.32

Element	P source	NoSi mean (mg kg ⁻¹)	Si mean (mg kg ⁻¹)	Change (%)	Welch p	BH q
S	HA	825.4	1049.8	27.2	0.0001	0.00088
S	FePO ₄	770.3	726.5	-5.7	0.23	0.3
S	NoP	660.2	797.8	20.9	9.7e-06	0.00021
Al	KH ₂ PO ₄	18.2	33.4	83.2	0.4	0.45
Al	HA	20.0	14.7	-26.8	0.033	0.066
Al	FePO ₄	21.3	15.8	-25.4	0.15	0.22
Al	NoP	16.5	25.7	55.8	0.11	0.18
Si	KH ₂ PO ₄	279.4	418.4	49.7	0.046	0.08
Si	HA	169.1	129.5	-23.4	0.013	0.031
Si	FePO ₄	160.6	190.3	18.5	0.2	0.28
Si	NoP	58.8	121.9	107.2	0.00053	0.0029

Si values are operational acid-recovered Si from the same nitric-acid digestion used for the multi-element ionome screen, not complete total plant Si.

Table S6. Day-30 root-architecture within-source contrasts (with Benjamini-Hochberg q)

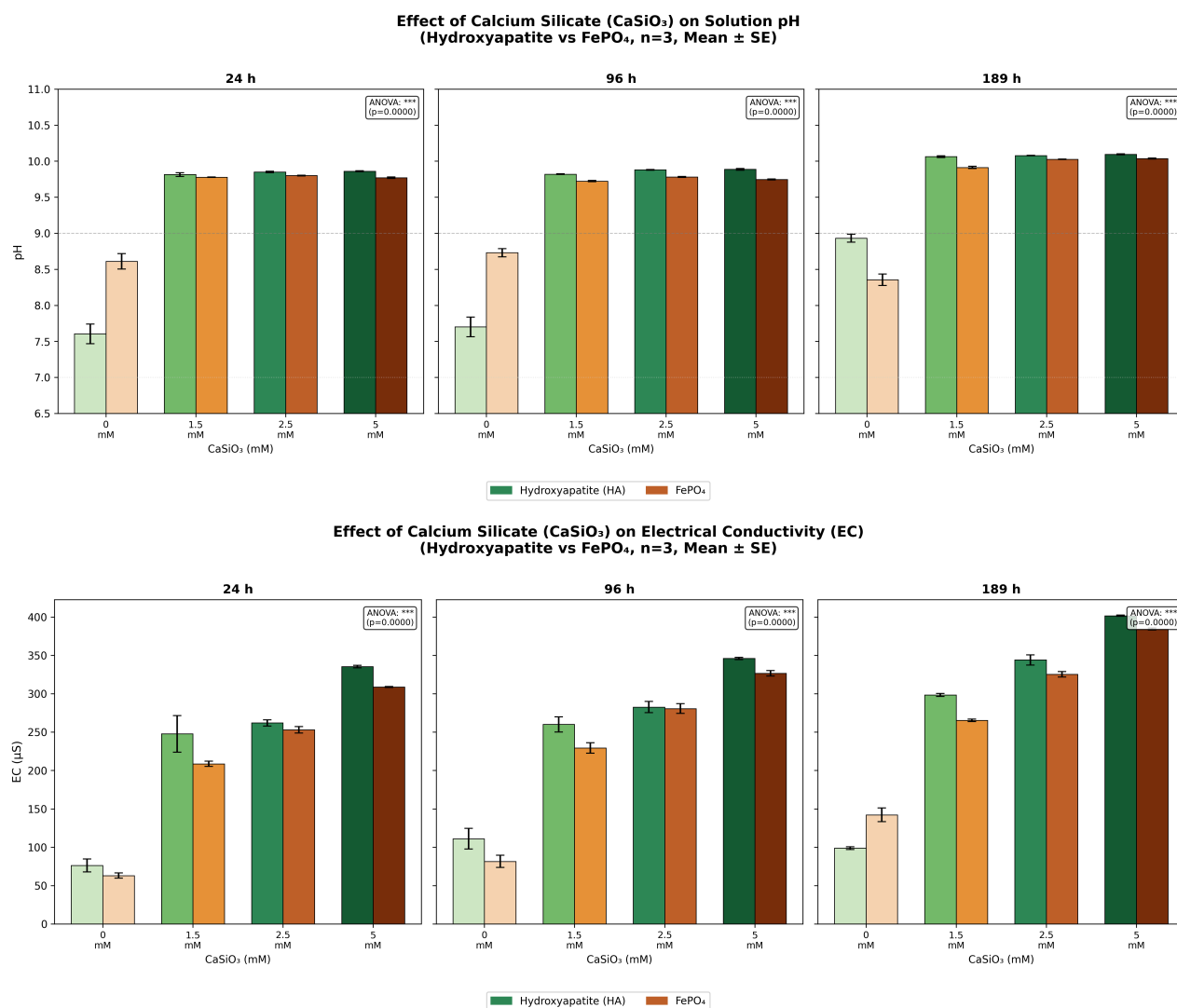
Trait	P source	NoSi mean	Si mean	Change (%)	Welch p	BH q
Total length (cm)	KH ₂ PO ₄	2997.7	4673.2	55.9	0.031	0.086
Total length (cm)	HA	2788.6	3219.2	15.4	0.21	0.35
Total length (cm)	FePO ₄	3034.7	3903.2	28.6	0.086	0.2
Total length (cm)	NoP	2408.9	2641.3	9.6	0.43	0.49
Surface area (cm ²)	KH ₂ PO ₄	412.5	605.5	46.8	0.024	0.086
Surface area (cm ²)	HA	324.6	430.7	32.7	0.032	0.086
Surface area (cm ²)	FePO ₄	426.0	525.9	23.4	0.26	0.37
Surface area (cm ²)	NoP	291.9	335.7	15.0	0.33	0.41
Avg diameter (mm)	KH ₂ PO ₄	0.442	0.415	-6.1	0.2	0.35
Avg diameter (mm)	HA	0.371	0.426	15.0	0.0005	0.008
Avg diameter (mm)	FePO ₄	0.442	0.431	-2.5	0.74	0.74
Avg diameter (mm)	NoP	0.386	0.403	4.4	0.22	0.35
Root volume (cm ³)	KH ₂ PO ₄	4.534	6.257	38.0	0.024	0.086
Root volume (cm ³)	HA	3.010	4.588	52.5	0.0075	0.06
Root volume (cm ³)	FePO ₄	4.782	5.687	18.9	0.47	0.5
Root volume (cm ³)	NoP	2.819	3.400	20.6	0.29	0.38

Table S7. Plant-establishment sensitivity analysis

P source	Plants pot ⁻¹ (NoSi)	Plants pot ⁻¹ (Si)	Unadjusted CaSiO ₃ effect (g pot ⁻¹)	Adjusted CaSiO ₃ coefficient (g pot ⁻¹)	Adjusted P
KH ₂ PO ₄	4.1	4.8	+1.40	+1.29	0.014
Hydroxyapatite	3.8	4.7	+1.14	+1.13	<0.001
FePO ₄	4.3	4.8	+0.56	+0.74	0.042
No added P	5.0	5.0	+0.13	— (uniform density)	—

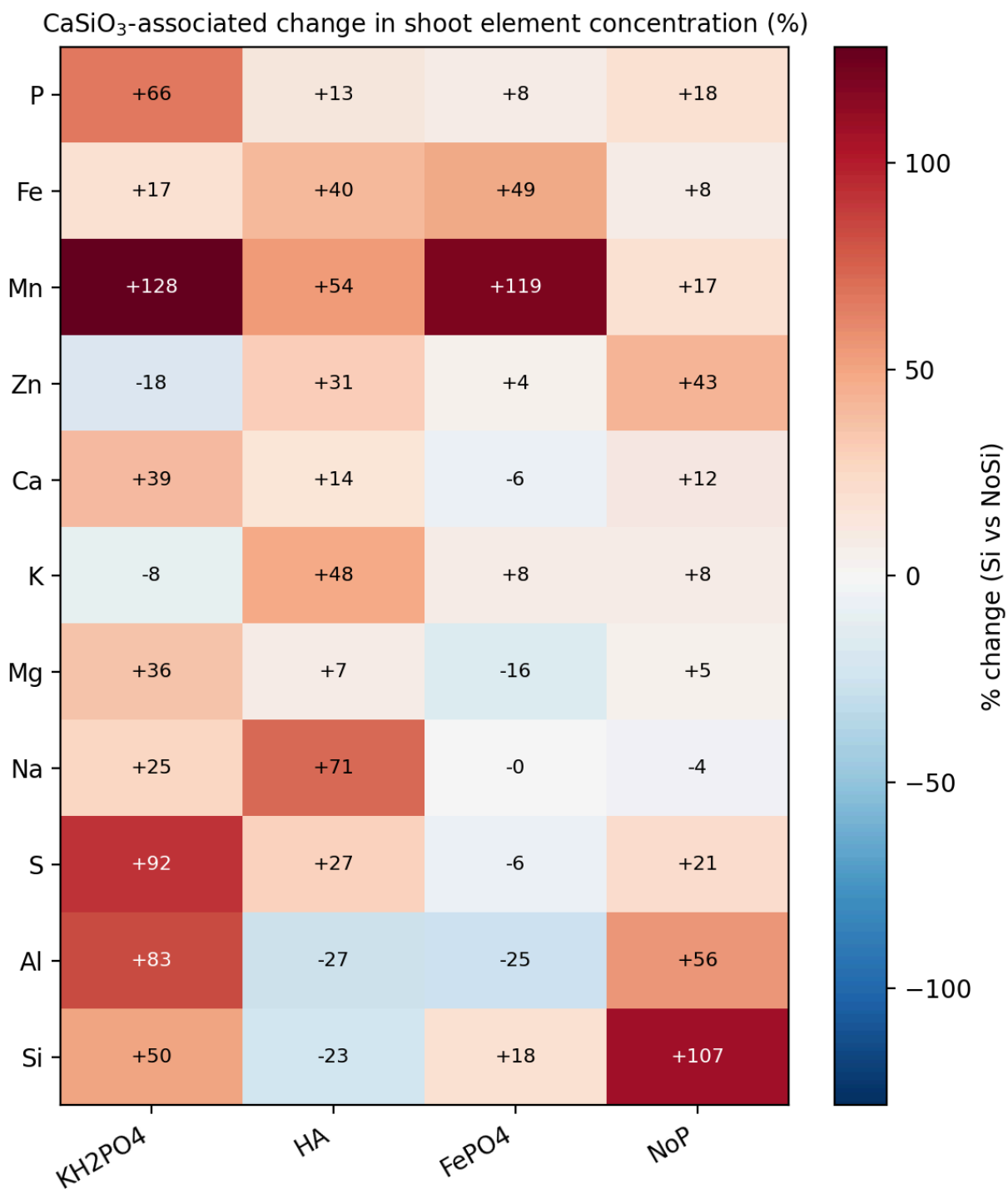
Calcium-silicate (CaSiO₃) effect on shoot biomass (g pot⁻¹) within each phosphorus source, before and after adding plants per pot as a covariate. The adjusted coefficient is the CaSiO₃ term from an analysis of covariance of pot shoot biomass on CaSiO₃ treatment and plants per pot, fitted within each source. Across the phosphorus-supplied sources, CaSiO₃ pots established more plants per pot than no-Si pots (4.8 versus 4.1; P = 0.010). No-added-P pots carried a uniform five plants per pot, so no adjustment applies. Within hydroxyapatite, pot biomass was unrelated to plant number (P = 0.88), and adjusting for plants per pot left every CaSiO₃ biomass effect essentially unchanged.

Fig. S1 Abiotic pH and EC responses



Abiotic pH (top) and electrical conductivity (bottom) versus CaSiO_3 dose and incubation time for HA and FePO_4 (means $\pm$ SE, $n = 3$ per cell).

Fig. S2 Shoot-ionome percent-change heatmap



CaSiO₃-associated percent change in shoot element concentration across P sources (n = 4 per cell).