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Grain zinc, iron and protein concentrations of contemporary wheat cultivars fall short of targets for human health

In the format provided by the authors and unedited

Supplementary Figures

Figure S1

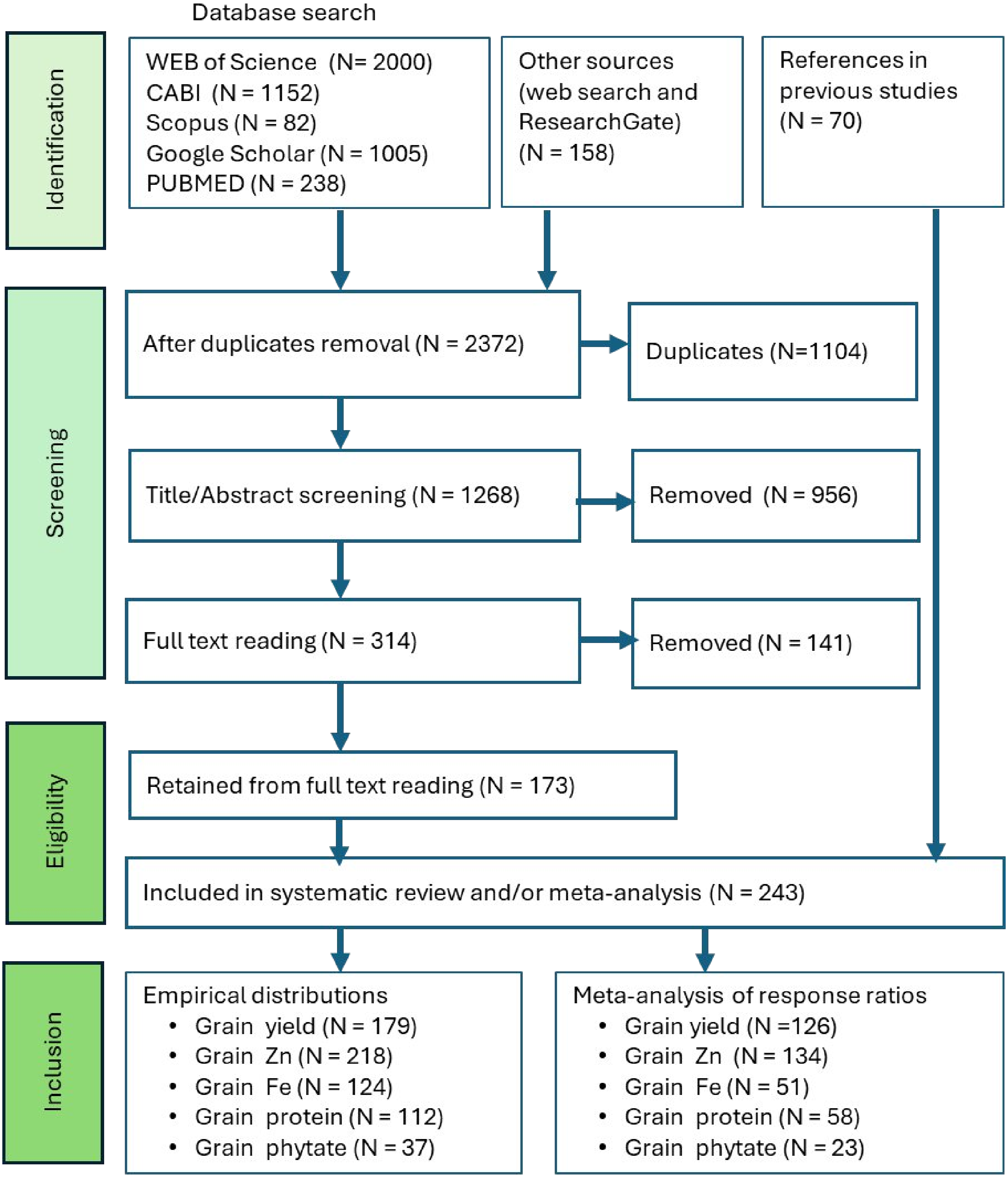


Figure S1. Flow diagram of the literature search, the number of studies (N) found during the search, number of studies excluded at each stage and those retained for review and meta-analysis.

Figure S2

Figure S2. Maps of the studies included in this meta-analysis. This map was created by the authors in R (version 4.4.0, 2024-04-24) using the following packages: ggplot2 (v3.5.2) for visualization, maps (v3.4.1) for geographic boundaries, and dplyr (v1.1.4) for data merging. Country polygons from the world dataset were joined with biofortification crop data via country name matching. The map projection was truncated at 60°S to exclude Antarctica, preserving all major agricultural zones.

Figure S3

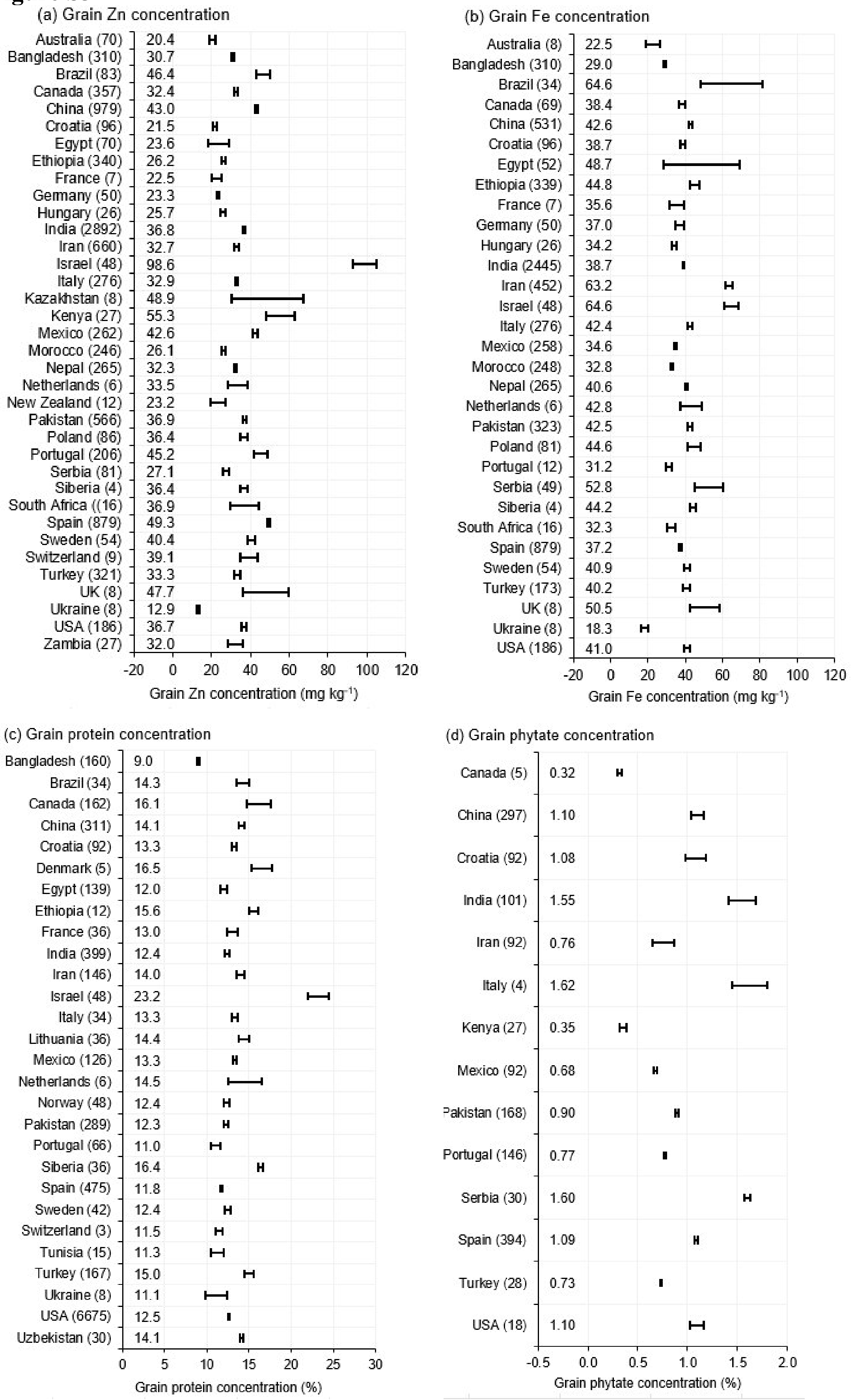
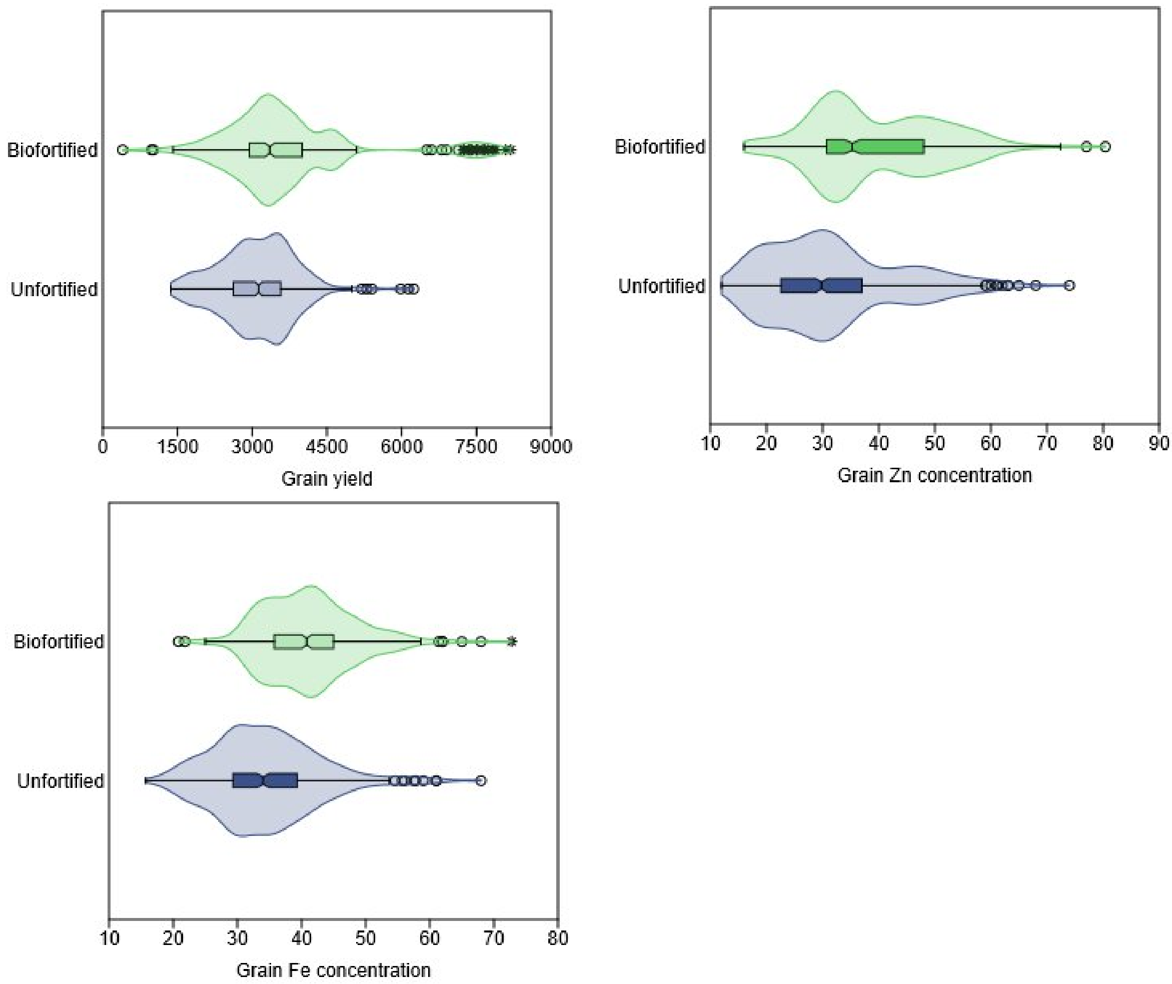


Figure S3. The country-wise distribution of grain Zn, Fe, protein and phytate concentrations across wheat cultivars. Figures in parentheses after country names represent the total sample size available for each country. Values of Zn, Fe and protein were larger than in all other countries because they were entirely from durum and emmer wheat.

Figure S4



	Mann-Whitney test of equality of medians	Kolmogorov-Smirnov test for equality of distributions	Anderson-Darling test for equality of distributions
Grain yield (kg ha^{-1})	P< 0.0001	P< 0.001	P< 0.001
Gran Zn (mg kg^{-1})	P< 0.0001	P< 0.001	P< 0.001
Grain Fe (mg kg^{-1})	P< 0.0001	P< 0.001	P< 0.001

P values were generated using Monte Carlo permutation

Figure S4. Comparison of unfortified and genetically fortified bread wheat cultivars in terms of median values and the distribution of grain yield, grain Zn and Fe concentrations (mg kg^{-1})

Figure S5

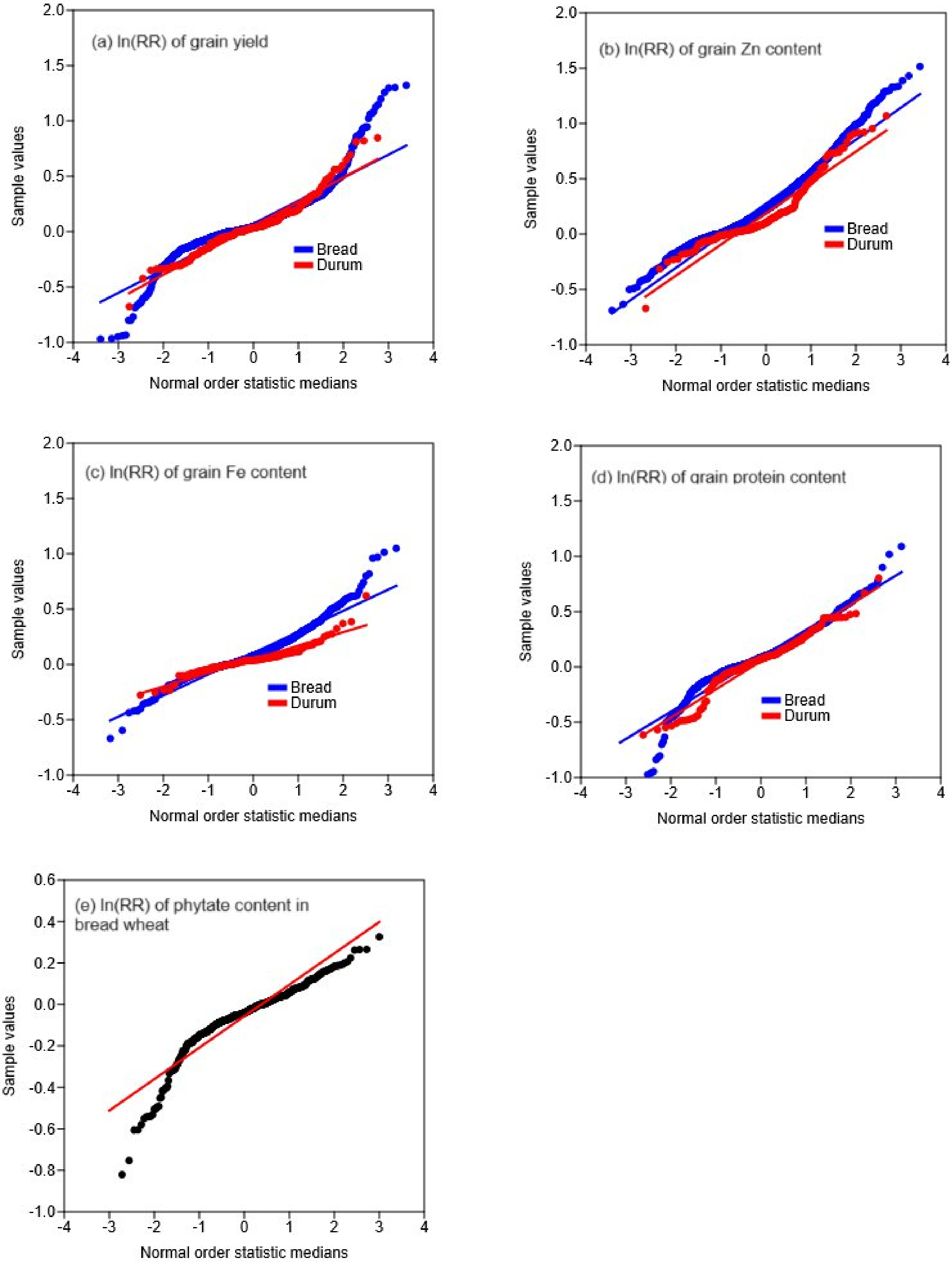


Figure S5. Normal Q-Q plots of ln(RR) of response ratios of grain yield (a), grain Zn (b), grain Fe (c), protein (d) and phytate concentrations in studies chosen for meta-analysis.

Figure S6

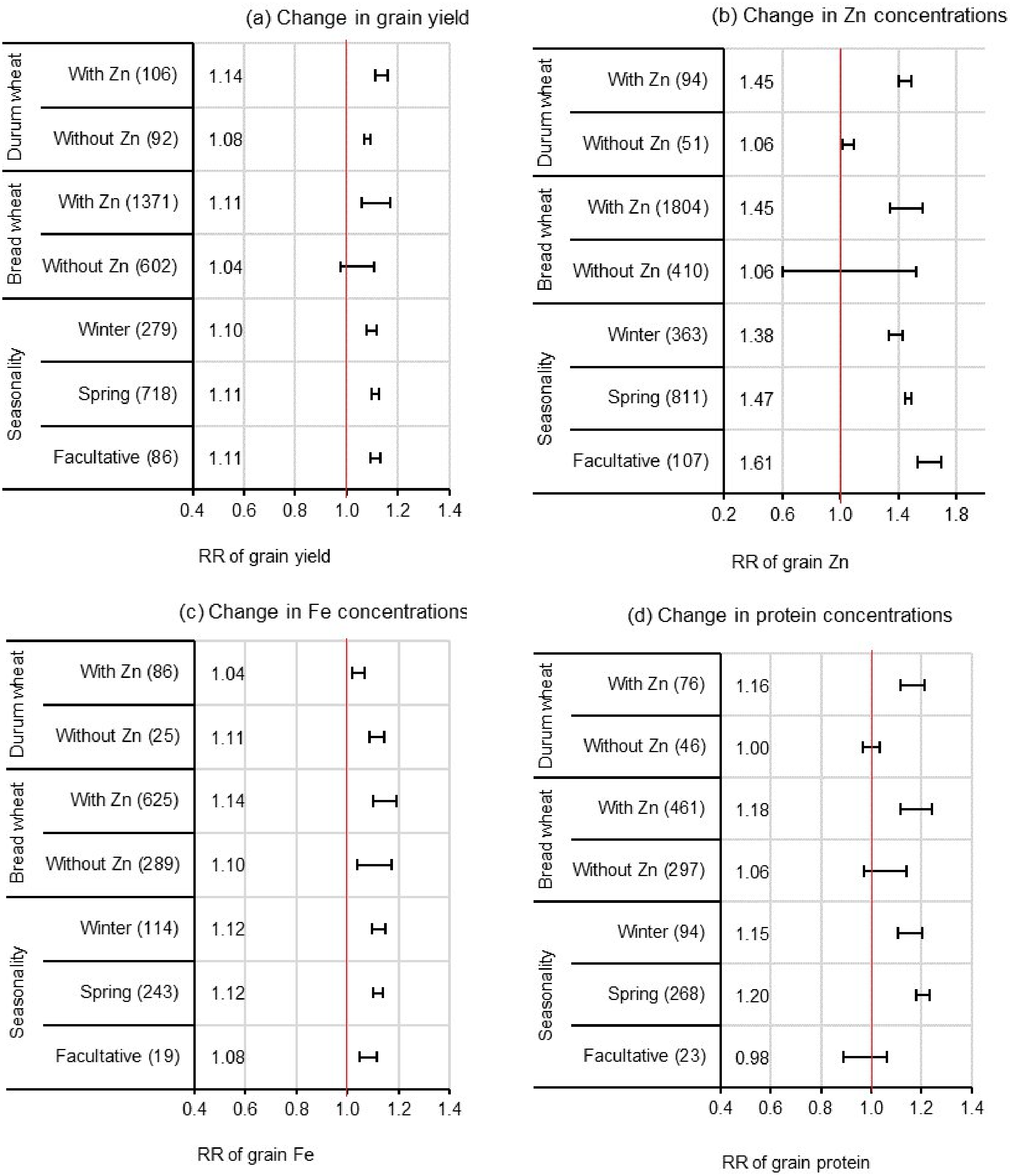


Figure S6. Variations in response ratios of grain yield, grain Zn, Fe and protein concentrations of durum and bread wheat with (With Z) and without (Without) Zn application and with seasonality in bread wheat cultivars. When the CIs encompasses RR = 1, the Zn (+/-Fe) treatment is not significantly different from the NPK control. Figures in in parentheses in front of treatments represent the total sample sizes, while those on the left sides of the horizontal bars represent the marginal means.

Figure S7

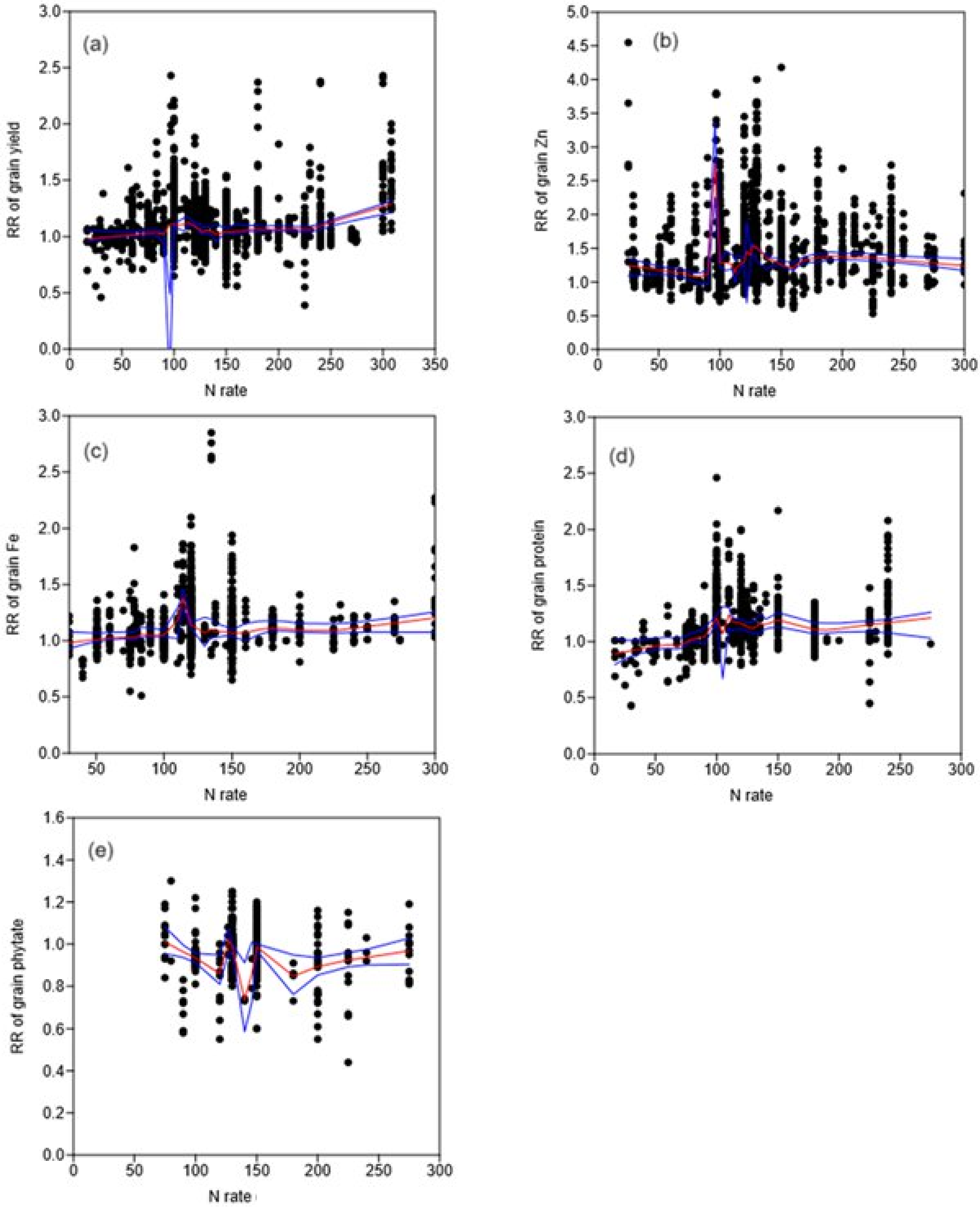


Figure S7. LOESS regression showing trends in response ratios of grain yield (a), grain Zn (b), grain Fe (c), protein (d) and phytate (e) concentrations of bread wheat with increasing rates (kg ha^{-1}) of soil applied N. The blue lines represent the 95% confidence limits of trend lines.

Figure S8

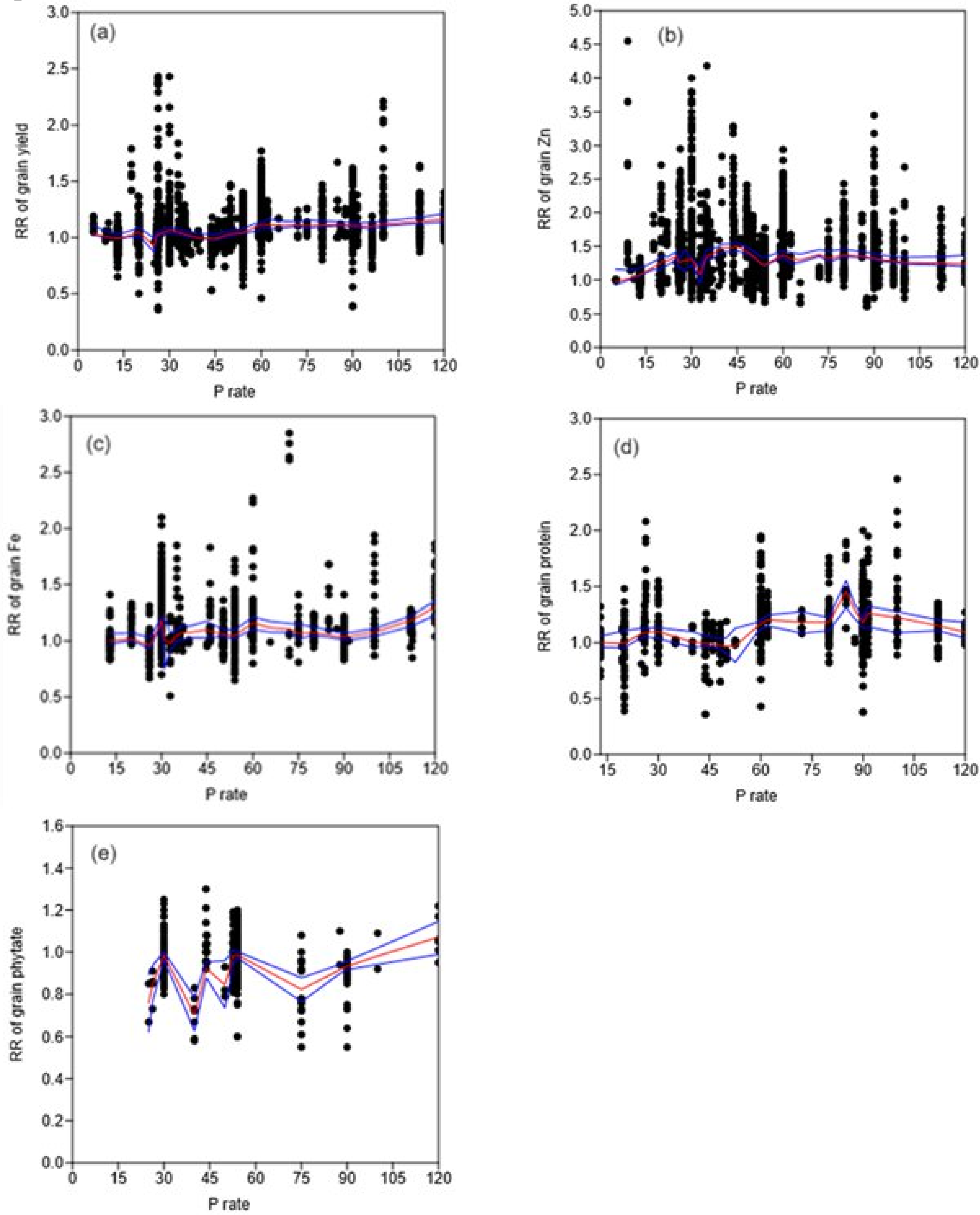


Figure S8. LOESS regression showing trends in response ratios of grain yield (a), grain Zn (b), grain Fe (c), protein (d) and phytate (e) concentrations of bread wheat with increasing rates (kg ha^{-1}) of soil applied P. The blue lines represent the 95% confidence limits of trend lines.

Figure S9

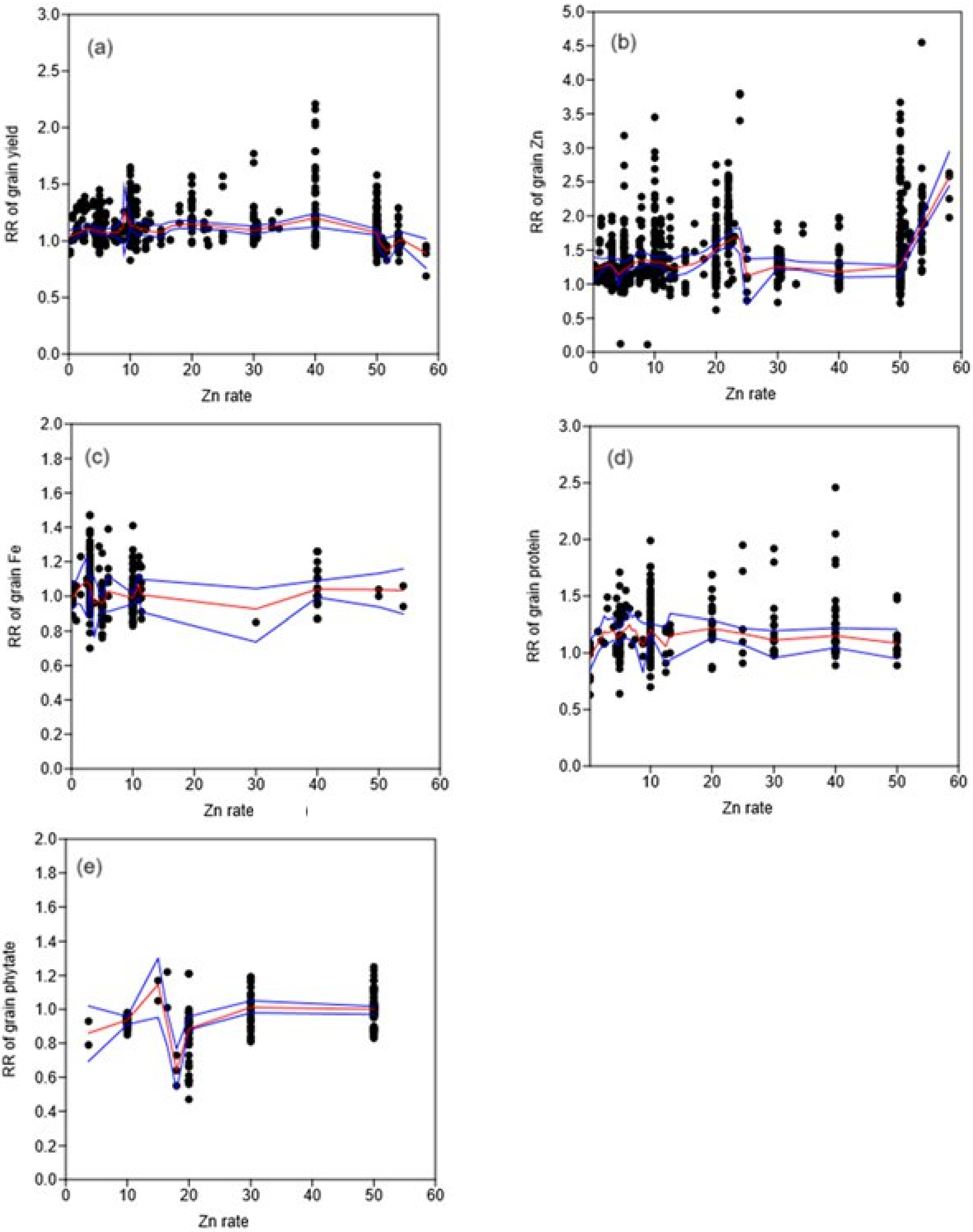


Figure S9. LOESS plots showing trends in response ratios of grain yield (a), grain Zn (b), grain Fe (c), protein (d) and phytate (e) concentrations of bread wheat with increasing rates (kg ha^{-1}) of soil applied zinc. The blue lines represent the 95% confidence limits of trend lines.

Figure S10

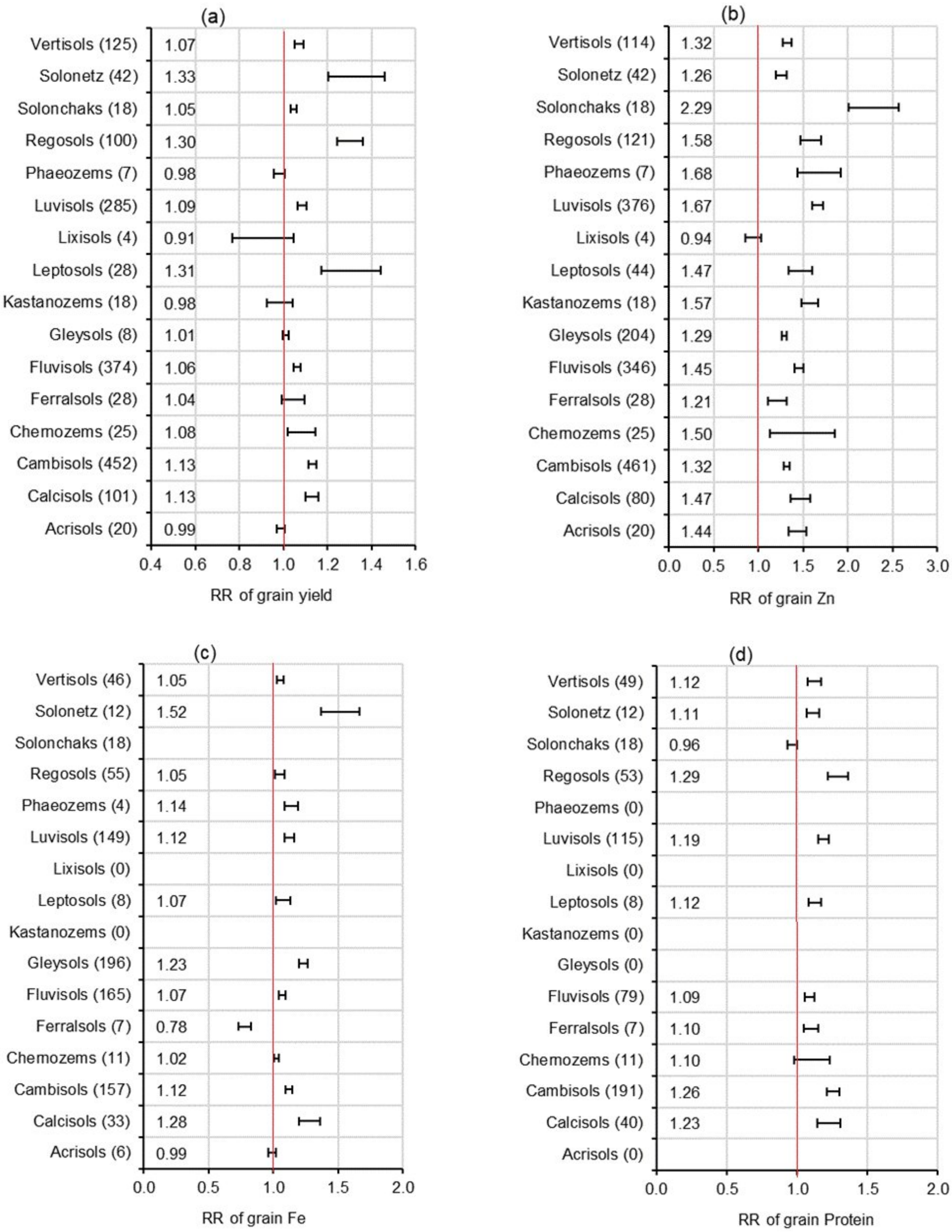


Figure S10. Variations in response ratios of grain yield, grain Zn, Fe and protein concentrations of bread wheat with soil type in treatments involving application of Zn (+/-Fe). The horizontal bars represent the 95% confidence intervals (CIs). When the CIs encompasses RR = 1, the Zn (+/-Fe) treatment is not significantly different from the NPK control. Figures in in parentheses in front of the soil type represent the total sample sizes, while those on the left sides of the horizontal bars represent the marginal means.

Figure S11

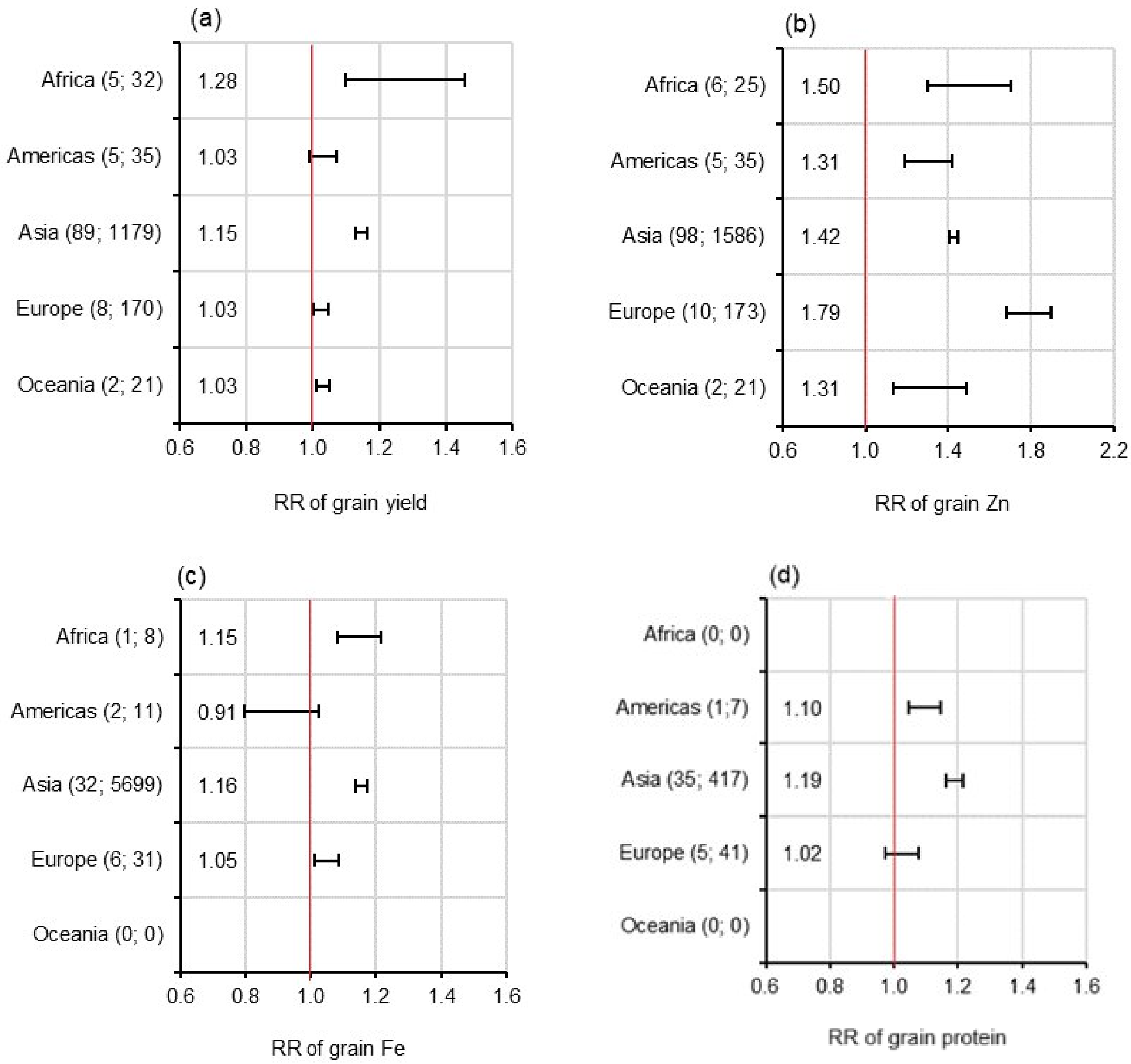


Figure S11. Variations in response ratios of grain yield, grain Zn, Fe and protein concentrations across continents with Zn (+/-Fe) fertilization of bread wheat cultivars. When the CIs encompasses RR = 1, the Zn (+/-Fe) treatment is not significantly different from the NPK control. Figures in in parentheses in front of continents represent the number of studies followed by the total sample sizes, while those on the left sides of the horizontal bars represent the marginal means.

Figure S12

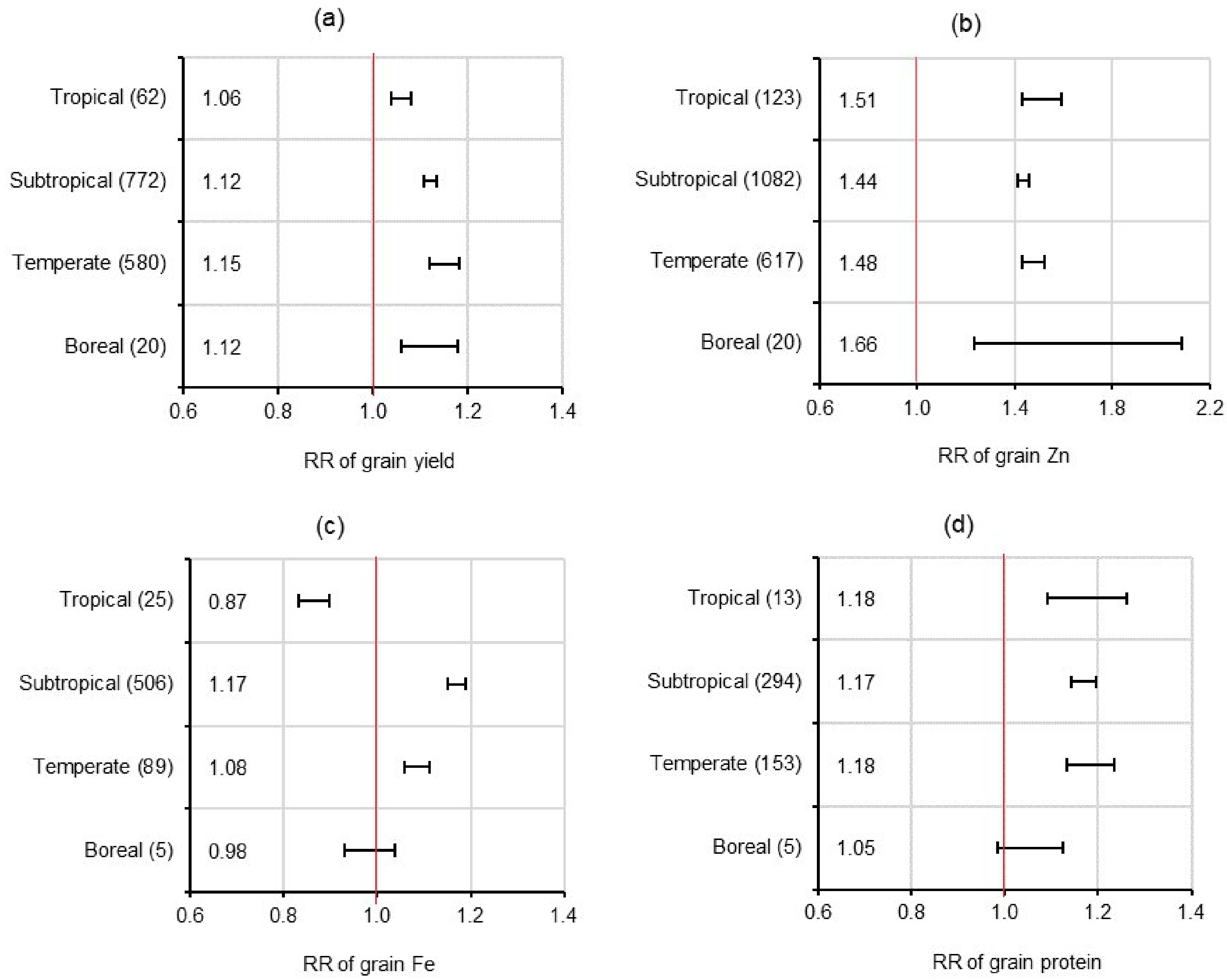


Figure S12. Variations in response ratios of grain yield (a), grain Zn (b), Fe (c) and protein (d) concentrations across climate zones with Zn (+/-Fe) fertilization of bread wheat cultivars. The horizontal bars represent the 95% confidence limits of means. When the 95% CL encompasses the red line (RR = 1), the treatment is not significantly different from the NPK control. Figures in in parentheses in front of treatments represent the total sample sizes, while those on the left sides of the horizontal bars represent the marginal means.

Figure S13

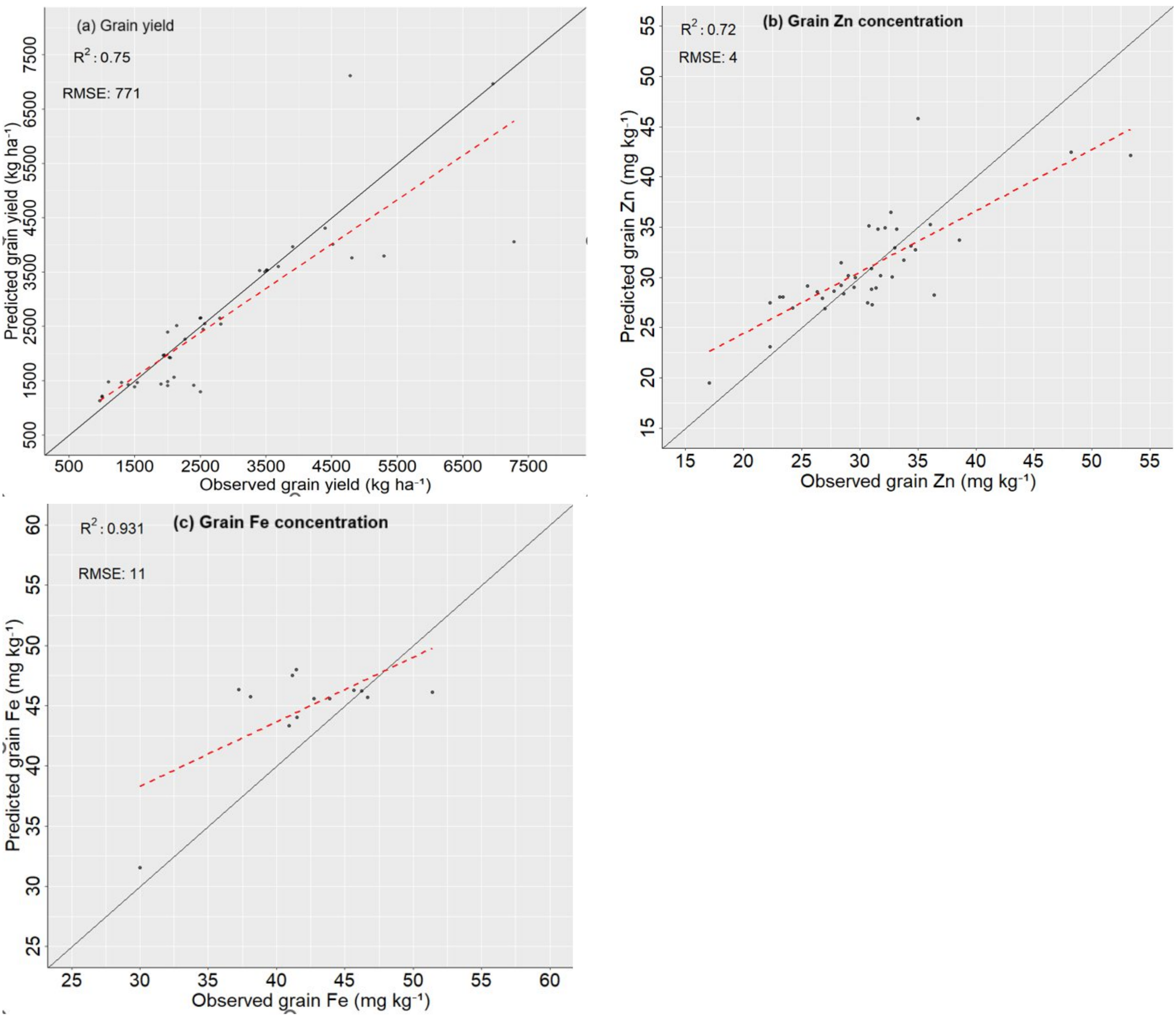


Figure S13. The relationship between the model prediction and observed values for grain yield (a), grain zinc (b) and grain iron concentration (c) from the random forest models. Black dots represent the observed data, red dotted lines represent the fitted lines for the regression of the predicted values on the observed values. Black solid line represents the 1:1 line. The coefficient of determination (R^2) and root mean square of error (RMSE) measure the agreement between the predicted and observed values.

Supplementary Tables

Table S1. List of studies

Table S1. Studies included in the review and meta-analysis

Study #	Complete citation
1	Abbas et. al.(2021) Zn Ferti-fortification of Wheat (Triticum Aestivum L.) Using Zinc Enriched Compost and Biochar in Rainfed Area. Communications in Soil Science and Plant Analysis 52(18). https://doi.org/10.1080/00103624.2021.1921189
2	Abdi et al. (2013) Residual and cumulative effect of fertilizer zinc applied in wheat-cotton production system in an irrigated aridisol. Plant Soil Environ 59
3	Abdoli et. al. (2014) Effects of foliar application of zinc sulfate at different phenological stages on yield formation and grain zinc content of bread wheat (cv. Kohdasht). Azarian Journal of Agriculture 1: 11-17
4	Ahsin et al. 2023 Genetic and agronomic zinc biofortification modify processing and nutritional quality of common wheat. Cereal Chemistry 100 (1). https://doi.org/10.1002/cche.10604
5	Akbar et al. (2023) Mycorrhizal inoculation enhanced tillering in field grown wheat, nutritional enrichment and soil properties. PeerJ http://doi.org/10.7717/peerj.15686
6	Akca & Taban (2024) Optimizing Grain Zinc Biofortification in Bread Wheat: Innovative Fertilization Strategies for Field Conditions. Journal of Soil Science and Plant Nutrition ??? https://doi.org/10.1007/s42729-024-01865-z
7	Akram et. al.(2017) Synergistic use of nitrogen and zinc to bio-fortify zinc in wheat grains. Eurosian Journal of Soil Science 6 (4) 319 – 326. Doi: 10.18393/ejss.306698
8	Ali et al. (2023) Foliar Spraying of Nano- Silicate and Nano-Zinc on Wheat (*Triticum aestivum* L.) Under Salt Stress Conditions Enhances Productivity and Reduces the Optimal Nitrogen Fertilizer Rate. Communications In Soil Science And Plant Analysis 54. https://doi.org/10.1080/00103624.2023.2240817
9	Ali et al. (2024) Enhancing Wheat Yield and Zinc Biofortification through Synergistic Action of Potent Zinc-Solubilizing Bacteria and Zinc Sulfate in Calcareous Soil. Agric Res ??? https://doi.org/10.1007/s40003-024-00750-6
10	Ali et. al.(2018) Micronutrient seed priming improves stand establishment, grain yield and biofortification of bread wheat Crop & Pasture Science, 69, 479–487. doi.org/10.1071/CP18042
11	Amir et al (2018) Estimating genetic variation and genetic parameters for grain iron, zinc and protein concentrations in bread wheat genotypes grown in Iran. Journal of Cereal Science 140: 16e23. https://doi.org/10.1016/j.jcs.2018.01.069
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13	Anwar et al. (2021) Mitigation of Drought Stress and Yield Improvement in Wheat by Zinc Foliar Spray Relates to Enhanced Water Use Efficiency and Zinc Contents. International Journal of Plant Production. https://doi.org/10.1007/s42106-021-00136-6
14	Ayadi et al. (2022) Variation of Grain Yield, Grain Protein Content and Nitrogen Use Efficiency Components under Different Nitrogen Rates in Mediterranean Durum Wheat Genotypes. Agriculture 12(7). https://doi.org/10.3390/agriculture12070916
15	Barut et.al.(2017) The Effect of Different Zinc Application Methods on Yield and Grain Zinc Concentration of Bread Wheat Varieties. Turkish Journal of Agriculture - Food Science and Technology 5(8): 898-907. doi.org/10.24925/turjaf.v5i8.898-907.122
16	Basshi & Nahapetian (1977) Differences in Concentrations and Interrelationships of Phytate, Phosphorus, Magnesium, Calcium, Zinc, and Iron in Wheat Varieties Grown under Dryland and Irrigated Conditions. Journal of Agricultural and Food Chemistry. https://doi.org/10.1021/jf60213a054
17	Bedoussac & Justes (2008) The Efficiency Of Durum Wheat And Winter Pea Intercropping To Increase Wheat Grain Protein Content Depends On Nitrogen Availability And Wheat Cultivar 10th Congress of European Society for Agronomy, 15-19th September 2008, Bologna, Italy. https://oatao.univ-toulouse.fr/4073/

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Table S2. Summary table of grain Zn, Fe, protein and phytate concentrations

Table S2. The number of studies and total number of observations (n) used for estimating grain zinc (Zn), iron (Fe), protein and phytate concentrations and the probability (ϕ in %) of exceeding the target concentrations of Zn (38 mg kg^{-1}), Fe (59 mg/kg) and protein (12%) in different species of cultivated wheat.

A. Analysis by wheat species

	Variable	Studies (n) †	Median (95% CI)‡	Q1	Q3	CV (%)	ϕ > target
Zinc (mg kg^{-1})	Bread	197 (7753)	34.4 (34.2, 34.8)	27.0	43.4	40.0	38.9
	Durum	33 (997)	35.7 (35.1, 36.6)	30.5	53.1	35.3	42.7
	Spelt	17 (443)	41.8 (41.0, 42.7)	37.6	46.5	18.3	80.3
	Emmer	5 (61)	92.0 (88.0, 101.0)	53.9	108.5	51.5	72.0
Iron (mg kg^{-1})	Bread	103 (5678)	37.9 (37.7, 38.2)	32.7	43.1	37.6	7.7
	Durum	26 (863)	36.9 (36.0, 37.4)	33.0	43.0	32.1	6.6
	Spelt	17 (443)	45.3 (44.6, 45.9)	41.4	50.0	19.2	59.0
	Emmer	5 (61)	62.0 (60.0, 68.0)	47.8	72.0	44.7	4.7
Protein (%)	Bread	95 (8782)	12.5 (12.5, 12.6)	11.4	13.6	14.6	63.8
	Durum	24 (672)	13.3 (13.2, 13.5)	12.3	14.9	21.1	58.6
	Spelt	12 (91)	15.7 (15.2, 16.6)	13.4	19.1	21.8	97.8
	Emmer	1 (47)	23.1 (21.4, 24.7)	20.4	25.8	19.2	94.5
Phytate (%)	Bread	33 (972)	0.86 (0.85, 0.88)	0.74	1.05	51.1	NA
	Durum	7 (150)	0.75 (0.73, 0.83)	0.63	1.09	47.7	NA
	Spelt	1 (359)	1.13 (1.12, 1.15)	1.05	1.20	10.1	NA
	Emmer	0	NA	NA	NA	NA	NA

B. Analysis by Zn fertilization treatment of bread wheat

	Zn fertilizer	Studies (n) †	Median (95% CI)‡	Q1	Q3	CV (%)	ϕ > target
Zinc (mg kg^{-1})	Without Zn	185 (5899)	33.2 (32.9, 33.6)	26.0	41.2	38.3	33.5
	With Zn	117 (2024)	40.0 (39.5, 41.0)	31.5	50.7	38.6	56.4
Iron (mg kg^{-1})	Without Zn	101 (5096)	38.2 (38.0, 38.6)	32.9	43.5	47.5	7.1
	With Zn	38 (765)	36.7 (36.1, 37.5)	32.2	42.8	38.2	7.7
Protein (%)	Without Zn	94 (8244)	12.6 (12.6, 12.6)	11.5	13.6	12.3	NA
	With Zn	43 (611)	12.3 (12.2, 12.5)	10.2	13.8	19.7	NA
Phytate (%)	Without Zn	32 (464)	0.89 (0.87, 0.92)	0.74	1.08	49.6	NA
	With Zn	25 (508)	0.84 (0.83, 0.86)	0.73	1.01	52.4	NA

C. Analysis by Zn fertilization and genotypes of bread wheat

Genotype	Zn fertilizer	Number of genotypes	Median (95% CI)‡	Q1	Q3	CV (%)	Proportion with Zn >38 mg kg^{-1}
Landraces	Without Zn	39	47.3 (43.1, 52.9)	39.2	53.4	17.8	82.1
	With Zn	28	58.5 (53.8, 62.8)	50.5	65.5	15.6	100.0
Varieties	Without Zn	673	31.7 (30.7, 32.6)	24.9	39.3	34.7	28.5
	With Zn	283	44.0 (42.5, 45.8)	35.7	52.2	29.8	66.4
Landraces	All	67	51.8 (49.5, 54.5)	45.5	58.5	20.4	89.6
Varieties	All	956	34.8 (33.8, 35.9)	26.9	43.4	36.8	39.7

† Figures in parentheses represent the total number of observations (n) available for analysis

‡ Figures in parentheses are 95% confidence intervals (CIs) of median values. Two medians are deemed significantly different if their 95% CIs do not overlap.

Table S3. G×E interactions

Table S3. The proportion of variation explained (in %) by genotype, environment and the genotype by environment interactions (G×E) in grain yield, gran Zn, Fe and protein concentrations in bread wheat cultivars

Variable	Region/country [G, E]†	Genotype	Environment	GxE	Reference
Grain yield	Ethiopia [11; 4]	8.7*	82.0*	9.3*	Alemayehu et al. (2025)
	Ethiopia [15; 12]	11.3*	52.3*	22.9*	Alemu et al. (2021)
	Ethiopia [180; 2]	27.5*	55.2*	17.4	Atsbeha et al. (2023)
	Ethiopia [30; 7]	2.6*	46.6*	25.4*	Bacha (2015)
	Ethiopia [12; 9]	5.0*	76.5*	18.5*	Bayissa et al. (2023)
	Ethiopia [19; 7]	7.1*	78.3*	14.7*	Mehari et al. (2015)
	Ethiopia [22; 6]	9.0*	52.0*	20.7*	Temesgen et al. (2015)
	Ethiopia [15; 6]	33.5*	35.3*	31.5*	Wardofa et al. (2019)
	India-normal [20; 6]	21.8*	15.4*	30.2*	Khare et al. (2024)
	India-heat stress [20: 6]	19.5*	9.7*	39.8*	Khare et al. (2024)
	India [20; 14]	11.7*	45.1*	28.2*	Joshi et al. (2010)
	India [100; 8]	26.4*	70.2*	3.4*	Gupta et al. (2022)
	India, Pakistan, Mexico [39, 9]	6.1*	85.1*	8.8*	Velu et al. (2012)
	Iran [24; 9]	1.0	83.5	6.5	Roostaei et al. (2022)
	Nepal [20; 3]	5.6*	72.7*	21.8*	Bhandari and Poudel (2023)
	USA [18, 3]	NA*	NA*	NA*	Murphy et al. (2011)
	Uzbekistan [30; 7]	9.5*	63.1*	15.0*	Khazratkulova et al. (2015)
	Global [50, 233]	NA*	NA*	NA*	Velu et al. (2022)
Grain Zn	France [51; 3]	32.4*	44.3*	23.2*	Oury et al. (2006)
	India [309; 3]	16.9ns	57.7*	23.2*	Gopalareddy et al. (2015)
	India [20; 10]	0.50	85.5*	5.8	Joshi et al. (2010)
	India, Mexico [330, 5]	6.0*	67.4*	12.8*	Velu et al. (2016)
	India, Pakistan, Mexico [39, 9]	10.7*	50.9*	20.4*	Velu et al. (2012)
	Kazakhstan-SW [25; 5]	8.7	83.9	7.4	Morgounov et al. (2006)
	Kazakhstan-WWa [5; 2]	8.6	42.7	48.8	Morgounov et al. (2006)
	Kazakhstan-WWb [5; 2]	4.7	61.7	33.6	Morgounov et al. (2006)
	Kyrgyzstan-WW [10; 3]	32.6	42.2	25.2	Morgounov et al. (2006)
	Tajikistan-WW [22; 3]	35.1	31.8	33.1	Morgounov et al. (2006)
	USA [18, 3]	NA*	NA*	NA*	Murphy et al. (2011)
Grain Fe	France [51; 3]	30.7	24.9	44.4*	Oury et al. (2006)
	France [11; 3]	39.3	24.2	36.5*	Oury et al. (2006)
	India [309; 3]	27.1*	37.4*	29.5*	Gopalareddy et al. (2015)
	India [20; 10]	3.3	37.2*	32.6	Joshi et al. (2010)
	India [140; 4]	40.3*	13.4*	20.6*	Tiwari et al. (2016)
	India, Mexico [330; 5]	0.2	99.3*	0.2	Velu et al. (2016)
	India, Pakistan, Mexico [39, 9]	20.9*	41.5*	22.1*	Velu et al. (2012)
	Kazakhstan-SW [25; 4]	50.5	31.6	17.9	Morgounov et al. (2006)
	Kazakhstan-WWa [5; 2]	51.3	9.9	38.8	Morgounov et al. (2006)
	Kazakhstan-WWb [5; 2]	22.8	28.5	48.6	Morgounov et al. (2006)
	Kyrgyzstan-WW [10; 3]	22.2	50.6	27.2	Morgounov et al. (2006)
	Tajikistan-WW [22; 3]	22.7	42.1	35.2	Morgounov et al. (2006)
	USA [18, 3]	NA*	NA*	NA*	Murphy et al. (2011)
Protein	France [51; 3]	20.1	70.1	NA	Oury et al. (2006)
	India [140; 4]	25.3*	43.6*	16.3*	Tiwari et al. (2016)
	Uzbekistan [30; 7]	9.0*	45.0*	33.7*	Khazratkulova et al. (2015)

† C and E represent the number of cultivars and environments in the study; * represents significant effect ($P < 0.05$) of genotype, environment or the GxE interaction

NA = estimate and significance level not available; NA* = significance level reported without estimate

Table S4. Heritability of traits

Table S4. Broad-sense heritability of grain yield, gran Zn, Fe and protein concentrations of bread wheat cultivars reported by various authors

Variable	Region/country [G, E][†]	Wheat	Heritability	Reference
Grain yield	Ethiopia [180; 2]	Diverse	0.29	Atsbeha et al. (2023)
	Ethiopia [30; 2]	Diverse	0.52	Bayisa et al. (2020)
	Iran [80, 2]	Diverse	0.57-0.66	Amiri et al. (2018)
	Nepal [50; 20]	Diverse	0.20-0.57	Thapa et al. (2022)
	Nepal [50; 1]	Biofortified	0.92	Pant et al. (2020)
	Siberia [135; 1]	Diverse	0.82	Shepelev et al. (2022)
	Global [50, 233]	Diverse	0.62-0.83	Velu et al. (2022)
Grain Zn	Kazakhstan and Russia [18; 6]	Spring wheat	0.44	Morgounov et al. (2022)
	China [166; 4]	Diverse	0.71	Tong et al. (2022)
	India [309; 3]	Diverse	0.71	Gopalareddy et al. (2015)
	India [20; 10]	Diverse	0.25	Joshi et al. (2010)
	India, Mexico [330, 5]	Diverse	0.47	Velu et al. (2016)
	India, Pakistan, Mexico [39, 9]	Diverse	0.78	Velu et al. (2012)
	India [140; 4]	Diverse	0.53	Tiwari et al. (2016)
	India [34; 6]	Biofortified	0.41-0.99	Khokhar et al. (2018)
	India [280; 5]	Diverse	0.33-0.85	Krishnappa et al. (2022)
	India [184; 3]	Diverse	0.50–0.88	Rathan et al. (2022)
	Iran [30, 1]	Spring wheat	0.61-0.92	Khodadadi et al. (2014)
	Iran [80, 2]	Diverse	0.31-0.50	Amiri et al. (2018)
	Nepal [50; 20]	Diverse	0.52-0.81	Thapa et al. (2022)
	Nepal [50; 1]	Biofortified	0.58	Pant et al. (2020)
	Siberia [135; 1]	Spring wheat	0.27	Shepelev et al. (2022)
	Global [20, 14]	Diverse	0.74-0.88	Velu et al. (2022)
Grain Fe	Kazakhstan and Russia [18; 6]	Spring wheat	0.38	Morgounov et al. (2022)
	China [166; 4]	Diverse	0.72	Tong et al. (2022)
	India [309; 3]	Diverse	0.81	Gopalareddy et al. (2015)
	India [20; 10]	Diverse	0.37	Joshi et al. (2010)
	India, Mexico [330; 5]	Diverse	0.67	Velu et al. (2016)
	India, Pakistan, Mexico [39, 9]	Diverse	0.88	Velu et al. (2012)
	India [140; 4]	Diverse	0.72	Tiwari et al. (2016)
	India [34; 6]	Biofortified	0.22-0.99	Khokhar et al. (2018)
	India [280; 5]	Diverse	0.45-0.90	Krishnappa et al. (2022)
	India [184; 3]	Diverse	0.40–0.80	Rathan et al. (2022)
	Iran [30, 1]	Spring wheat	0.74-0.85	Khodadadi et al. (2014)
	Iran [80, 2]	Diverse	0.44-0.53	Amiri et al. (2018)
	Nepal [50; 20]	Diverse	0.15-0.79	Thapa et al. (2022)
	Nepal [50; 1]	Biofortified	0.55	Pant et al. (2020)
	Siberia [135; 1]	Spring wheat	0.58	Shepelev et al. (2022)
	Global [20, 14]	Diverse	0.69-0.92	Velu et al. (2022)
Protein	India [140; 4]	Diverse	0.78	Tiwari et al. (2016)
	Iran [80, 2]	Diverse	0.76-0.80	Amiri et al. (2018)
	Siberia [135; 1]	Spring wheat	0.86	Shepelev et al. (2022)
	Germany [369;]	Diverse	0.80	Alomari et al. (2023)
	Germany [255;]	Winter wheat	0.68–0.79	Kartseva et al. (2023)
	France & Germany [372; 8]	Diverse	0.91	Muqaddasi et al. (2020)
	India [184; 3]	Diverse	0.56–0.82	Rathan et al. (2022)
	Kazakhstan and Serbia [42, 9]	Spring wheat	0.59-0.87	Gómez-Becerra et al. (2010)

[†] C and E represent the number of cultivars and environments in the study; * represents significant effect ($P < 0.05$) of genotype, environment or the GxE interaction

NA = estimate and significance level not available; NA* = significance level reported without estimate

SW = spring wheat; WW = winter wheat

Table S5. Correlation between traits

Table S5. Pearson correlation coefficients between wheat grain yield, grain zinc, iron, protein and phytate concentrations (top) and the percentage of studies (bottom) from which significantly positive, negative and non-significant correlation coefficients were found among those focussing on germplasm evaluation and fertilization

Pearson correlation coefficients (top)

		Grain yield	Zinc	Iron	Protein
Bread	Zinc	-0.003			
	Iron	-0.014	0.533***		
	Protein	-0.080***	0.140***	0.298***	
	Phytate	0.150***	-0.124**	-0.226 ***	0.060
Durum	Zinc	0.278***			
	Iron	0.073	0.087*		
	Protein	0.208***	-0.097*	0.248***	
	Phytate	0.320**	-0.237**	-0.602***	0.290**
Spelt	Zinc	-0.431			
	Iron	0.489*	0.098*		
	Protein	0.081	0.800***	0.519***	
	Phytate	NA	0.404***	0.092	NA

Percentage of studies (bottom)

Study type	Correlations	Number of studies	Significantly positive (in %)	Significantly negative (in %)	Non-significant (in %) correlations
Germplasm	Grain vs Zn	19	10.5	31.6	57.9
	Grain vs Fe	13	0.0	30.8	69.2
	Grain vs protein	13	23.1	61.5	15.4
	Zn vs Fe	30	73.3	0.0	26.7
	Zn vs protein	11	72.7	0.0	27.3
	Zn vs phytate	6	50.0	16.7	33.3
	Fe vs protein	11	54.5	0.0	45.5
	Fe vs phytate	5	20.0	0.0	80.0
Fertilization	Grain vs Zn	59	40.7	28.8	30.5
	Grain vs Fe	22	22.7	18.2	59.1
	Grain vs protein	31	38.7	25.8	35.5
	Zn vs Fe	22	50.0	9.1	40.9
	Zn vs protein	26	65.4	3.8	30.8
	Zn vs phytate	12	0.0	25.0	75.0
	Fe vs protein	18	22.2	11.1	66.7

Statistical significance : * $\alpha = 0.05$; ** $\alpha = 0.001$; *** $\alpha = 0.0001$
NA = Not available

Table S6. Number of studies included in meta-analysis

Table S6. The total number of studies (N) and total number of observations (n) for treatments with and without Zn and Fe application and all others inputs. All have NP or NPK as the basic treatment.

Treatment	Study (n)	Treatment	Study (n)
With Zinc (Zn) or iron (Fe)		**Other treatments continued**	
Zn foliar	69 (815)	Mn foliar	1 (3)
Zn soil	66 (647)	Mn soil	1 (2)
Zn seed coating	7 (45)	N alone	5 (44)
Zn soil + foliar	28 (341)	N+ K	1 (2)
Zn + Fe foliar	9 (83)	B	1 (4)
Zn + Fe soil	6 (116)	lime	1 (9)
Zn + Fe soil + foliar	2 (13)	lime +OM	1 (6)
Fe foliar	15 (166)	mycorrhiza	1 (4)
Fe soil	4 (12)	OM	3 (14)
Fe seed coating	1 (8)	Si	1 (10)
Other treatments		NPK high	14 (78)8
No input control	15 (75)	NPK low	12 (53)
Biochar	1 (1)	P alone	2 (26)
B soil	1 (4)	P + K	3 (22)
Compost	1 (1)	Se foliar	2 (6)
Cu foliar	1 (1)	Se soil	1 (4)
I foliar	1 (27)	S soil	1 (5)
Mg soil	1 (3)		

NPK is a shorthand for the recommended nitrogen, phosphorus and potassium fertilizer
In other treatments, B, Cu, I, Mg, Mn, Se and S represent boron, copper, iodine, magnesium, manganese, selenium and sulphur, respectively.

Table S7. Treatment effect on response ratios

Table 7. Variations in the response ratios of grain yield, grain zinc (Zn), iron (Fe), protein, and phytate concentrations across treatments in bread wheat cultivars

	Response ratios				
Treatments	Grain yield	Grain Zn	Grain Fe	Grain protein	Grain phytate
No-input	0.81 (0.76–0.86)	1.02 (0.96–1.07)	1.04 (0.97–1.12)	0.84 (0.76–0.92)	--
NPK+Others[†]	1.03 (1.01–1.06)	1.06 (1.04–1.07)	1.06 (1.01–1.11)	1.01 (0.98–1.04)	0.92 (0.84–1.00)
NPK+Zn foliar	1.09 (1.08–1.11)	1.54 (1.50–1.57)	1.14 (1.10–1.17)	1.10 (1.05–1.15)	0.96 (0.94–0.98)
NPK+Zn soil	1.15 (1.13–1.16)	1.32 (1.29–1.35)	1.05 (1.03–1.07)	1.21 (1.17–1.24)	0.95 (0.93–0.96)
NPK+Zn seed	1.19 (1.11–1.27)	1.26 (1.12–1.41)	NA	NA	NA
NPK+Zn soil+Zn foliar	1.09 (1.07–1.11)	1.65 (1.59–1.71)	0.99 (0.96–1.02)	1.19 (1.14–1.24)	0.95 (0.91–0.98)
NPK+Zn foliar+Fe foliar	1.08 (1.04–1.12)	1.29 (1.22–1.37)	1.17 (1.13–1.21)	1.19 (1.10–1.28)	NA
NPK+Zn soil+Fe soil	1.26 (1.22–1.30)	1.27 (1.23–1.31)	1.41 (1.37–1.45)	1.25 (1.13–1.37)	NA
NPK+Fe foliar	1.07 (1.04–1.10)	1.17 (1.06–1.30)	1.13 (1.09–1.17)	1.18 (1.11–1.26)	0.98 (0.96–1.00)
NPK+Fe soil	1.13 (1.08–1.18)	1.12 (1.08–1.15)	1.48 (1.44–1.52)	1.23 (1.08–1.38)	NA

[†] "Others" represents all treatments other than Zn and Fe inputs (see Supplementary Table S6 for details)

NA indicates that effect sizes could not be estimated due to small sample sizes (see Supplementary Table S6). Data are presented as mean values and 95% confidence intervals (CIs). Figures in parentheses are CIs of means. Effect sizes are deemed significantly larger than those of NPK fertilizers if their CIs fall above 1, but not significantly different from those of NPK control if the CIs encompass 1.

Table S8. Correlation between response ratios

Table 8. Pearson correlation coefficients between response ratios of grain yield, grain Zn, iron, protein and phytate concentrations in bread wheat with application rates of N, P, Zn and Fe and select soil properties

	Response ratios of				
Variable	Grain yield (1941)	Zn (2123)	Fe (906)	Protein (734)	Phytate (463)
Nutrient application rates					
N rate (2361)	0.136***	0.069**	0.207***	0.293***	-0.048
P rate (2278)	0.105***	0.075**	0.097**	0.260**	-0.108*
K rate (1669)	-0.025	-0.101**	-0.120**	0.235***	-0.075
Zn rate (881)	0.020	0.174***	-0.035	0.201***	0.254***
Fe rate (237)	0.368***	-0.507***	0.380***	0.094	NA
Soil variables					
Sand (1960)	0.045	0.140***	-0.093	0.103	0.139**
Clay (1960)	-0.010	0.025	0.049	-0.168**	-0.148**
Soil pH (2024)	0.067*	0.007	-0.042	0.038	0.095
SOC (2004)	-0.073	0.008	0.101*	-0.092	0.143**
Total N (1061)	0.124***	0.133***	0.168***	0.092	-0.136*
Olsen P (2039)	0.099***	0.024	0.057	-0.027	0.045
Available K (836)	-0.074	0.170***	0.251***	-0.208**	0.014
Soil Zn (1640)	-0.040	0.148***	0.059	-0.060	0.463***
Soil Fe (751)	-0.045	-0.066	0.047	0.078	0.502***

Figures in parentheses are the total numbers of observations available for each variable
Statistical significance: * α = 0.05; ** α = 0.001; *** α = 0.0001
NA = Not available

Table S9 Comparison of irrigated with rainfed wheat

Table S9. Variations in response ratios of grain yield, grain Zn, Fe, protein and phytate concentrations with the interactive effect of irrigation with treatments in bread wheat

		Response ratios (95% CI)†				
Treatments	Irrigation	Grain yield	Zinc	Iron	Protein	Phytate
Overall	Irrigated	1.11 (1.10–1.12)	1.33 (1.31–1.35)	1.11 (1.09–1.13)	1.21 (1.18–1.23)	0.96 (0.94–0.97)
	Rainfed	1.06 (1.05–1.07)	1.43 (1.40–1.46)	1.16 (1.13–1.19)	1.06 (1.03–1.08)	0.95 (0.93–0.97)
Zn alone	Irrigated	1.12 (1.11–1.14	1.37 (1.35–1.40)	1.08 (1.06–1.10)	1.21 (1.18–1.24)	0.95 (0.92–0.97)
	Rainfed	1.10 (1.08–1.12)	1.20 (1.19–1.22)	1.07 (1.05–1.09)	1.14 (1.10–1.17)	0.95 (0.94–0.97)
Fe alone	Irrigated	1.09 (1.06–1.12)	1.12 (1.05–1.19)	1.22 (1.18–1.26)	1.30 (1.20–1.39)	0.98 (0.96–1.00)
	Rainfed	1.05 (1.01–1.08)	1.23 (0.99–1.49)	1.28 (1.19–1.36)	1.09 (1.04–1.15)	NA
Zn + Fe	Irrigated	1.11 (1.07–1.15)	1.27 (1.20–1.35)	1.21 (1.16–1.26)	1.20 (1.13–1.28)	NA
	Rainfed	1.08 (1.02–1.16)	1.28 (1.24–1.32)	1.37 (1.33–1.41)	NA	NA
Others	Irrigated	1.08 (1.03–1.12)	1.09 (1.06–1.13)	1.02 (1.00–1.04)	1.16 (1.08–1.24)	0.85 (0.76–0.94)
	Rainfed	1.00 (0.98–1.02)	1.03 (1.02–1.05)	1.07 (1.01–1.14)	0.96 (0.94–0.99)	1.08 (0.98–1.18)

† Figures in parentheses are 95% confidence intervals (CIs) of means. Effect sizes of two or more treatments do not significantly differ if their CIs are overlapping.

NA represents that effect sizes could not be estimated due to small sample sizes or lack of relevant studies.

Supplementary Methods for G×E interactions, heritability and trait correlations

To gain insights into the genetic and environmental control of grain Zn, Fe and protein concentrations in wheat, we reviewed studies that have quantified G×E interactions and heritability of these traits in wheat. From those studies, we compiled estimates of the variance explained by the genotype, environment and the G×E interactions and the broad-sense (H^2) and narrow-sense (h^2) heritability values. The broad-sense heritability is defined as the proportion of phenotypic variance that is attributable to the overall variance for the genotype, thus including additive, dominance, and epistatic variance (Covarrubias-Pazaran, 2019). The narrow-sense heritability is defined as the proportion of phenotypic variance due to additive genetic variation (Evans et al., 2018). To facilitate inferences, heritability was considered low if $H^2 <0.40$, but medium if H^2 is 0.40-0.59 and high if $H^2 > 0.60$ following. However, a low heritability does not necessarily mean that the genetic variance is small. Low heritability can indicate that the error variance is large, which can be caused by high environmental influence (Covarrubias-Pazaran, 2019). The size of H^2 depends on genetic variance in a population, the influence of the environment and on the accuracy of observations such as inaccurate phenotype recording or modelling errors. The genetic variance in one population may be (somewhat) different from that in another population. Heritability within a population can also change over time. The heritability estimate is also specific to the population and environment in which the analysis is performed. The studies used in the review of the G×E interactions and heritability have been listed at the end of the methods.

To gain insights into the potential for simultaneous improvement of grain Fe, Zn and protein with grain yield through either agronomic practices or traditional breeding techniques, we examined the correlations between grain yield, grain Zn, Fe, protein and phytate concentrations. Grain yield and grain protein concentration have been two major targets in wheat breeding programmes as the former determines crop productivity and the latter is a key determinant of the end-use value and baking quality wheat (Bogard et al., 2010). However, grain yield and grain protein concentration have been difficult to improve simultaneously due to the negative genetic relationship between them. It is not yet clear how this negative correlation affects grain Zn and Fe concentrations when all four variables are considered together. Therefore, we performed correlation analyses between grain yield, grain Zn, Fe and protein concentrations using the data compiled for the meta-analysis. We limited the correlation analysis to studies that have reported two target variables concurrently and where the reported number of means was at least 10 to correctly estimate the Pearson correlation coefficient. We performed the correlation analysis separately for studies that evaluated wheat germplasm and those studies that evaluated fertilization treatments. Then we calculated the proportion (in%) of studies that resulted in significantly positive, significantly negative and non-significant correlation coefficients. We judged the significance of the correlation coefficients using both the P values and the 95% confidence limits. A correlation coefficient was deemed significant if $P<0.05$ and the 95% confidence interval does not encompass 0. The type of study, the variables correlated, the data source or the specific study, country (and the total number of observations), the estimated correlation coefficients, the two-tailed *P* value and the statistical significance of each correlation have been presented in a table just before additional references.

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Studies included in the correlation analysis

The type of study, the variables correlated, the data source, country (number of observations), the Pearson correlation coefficient, the t**wo-tailed** P value and statistical significance of each correlation.

Study type	Variables	Data source (study)	Country (N)	Corelation coefficient	P-value	Significance
Germplasm	Fe vs phytate	Petrovi´c et al. (2020)	Croatia (88)	0.308	0.0018	**
Germplasm	Fe vs phytate	Rehman et al. (2018)	Pakistan (112)	0.116	0.2216	ns
Germplasm	Fe vs phytate	Kariithi et al. (2016)	Kenya (27)	-0.109	0.6011	ns
Germplasm	Fe vs phytate	Bilgrami et al. (2017)	Iran (17)	-0.240	0.3461	ns
Germplasm	Fe vs phytate	Huertas-Garcia et al. (2023)	Spain (36)	-0.340	0.0272	*
Germplasm	Fe vs protein	Gómez-Becerra et al. (2010)	Kazakhstan/Serbia [42]	0.640	0.0000	***
Germplasm	Fe vs protein	Feng et al. (2011)	China (32)	0.524	0.0001	**
Germplasm	Fe vs protein	Velu et al. (2019)	Mexico (85)	0.393	0.0000	***
Germplasm	Fe vs protein	Zhang et al. (2010b)	China (38)	0.357	0.0154	*
Germplasm	Fe vs protein	Khan et al. (2023)	Bangladesh (288)	0.353	0.0000	***
Germplasm	Fe vs protein	Chaudhari et al. (2022)	India (110)	0.266	0.0031	**
Germplasm	Fe vs protein	Johansson et al. (2021)	Sweden (33)	0.255	0.1354	ns
Germplasm	Fe vs protein	Rehman et al. (2018)	Pakistan (112)	0.139	0.1392	ns
Germplasm	Fe vs protein	Vazquez et al. (2018)	Spain (203)	0.102	0.1453	ns
Germplasm	Fe vs protein	Petrovi´c et al. (2020)	Croatia (88)	0.059	0.5973	ns
Germplasm	Fe vs protein	Gomez-Coronado et al. (2018)	Portugal (36)	0.010	0.9583	ns
Germplasm	Grain vs protein	Basshi & Nahapetian (1977)	Iran (20)	0.524	0.0030	**
Germplasm	Grain vs protein	Gautam et al. (2020)	India (123)	0.227	0.0087	**
Germplasm	Grain vs protein	Rehman et al. (2018)	Pakistan (112)	0.205	0.0253	*
Germplasm	Grain vs protein	Bloom et al (2021)	USA (6508)	-0.144	0.0000	***
Germplasm	Grain vs protein	Johansson et al. (2021)	Sweden (33)	-0.178	0.3193	ns
Germplasm	Grain vs protein	Feng et al. (2011)	China (32)	-0.236	0.1793	ns
Germplasm	Grain vs protein	Vazquez et al. (2018)	Spain (203)	-0.304	0.0000	***
Germplasm	Grain vs protein	Gómez-Becerra et al. (2010)	Kazakhstan/Serbia [42, 9]	-0.410	0.0021	**
Germplasm	Grain vs protein	Velu et al. (2019)	Mexico (85)	-0.486	0.0000	***
Germplasm	Grain vs protein	Gomez-Coronado et al. (2018)	Portugal (36)	-0.770	0.0000	***
Germplasm	Grain vs protein	Loes et al. (2020)	Norway (48)	-0.838	0.0000	***
Germplasm	Grain vs protein	Morgounov et al. (2013)	Siberia (36)	-0.855	0.0000	***
Germplasm	Grain vs protein	Jablonskytė-Raščė et al. (2013)	Lithuania (18)	-0.928	0.0000	***
Germplasm	Grain vs Fe	Velu et al. (2019)	Mexico (85)	0.095	0.3922	ns
Germplasm	Grain vs Fe	Gomez-Coronado et al. (2018)	Portugal (36)	0.010	0.9583	ns
Germplasm	Grain vs Fe	Feng et al. (2011)	China (32)	-0.011	0.9570	ns
Germplasm	Grain vs Fe	Rehman et al. (2018)	Pakistan (112)	-0.034	0.7354	ns
Germplasm	Grain vs Fe	Joshi et al. (2010)	India (202)	-0.047	0.5168	ns
Germplasm	Grain vs Fe	Tadesse et al. (2023)	Morocco (242)	-0.049	0.4564	ns
Germplasm	Grain vs Fe	Vazquez et al. (2018)	Spain (203)	-0.060	0.4016	ns
Germplasm	Grain vs Fe	Khokhar et al. (2018)	India (628)	-0.092	0.0202	*
Germplasm	Grain vs Fe	Johansson et al. (2021)	Sweden (33)	-0.348	0.0299	*
Germplasm	Grain vs Fe	Basshi & Nahapetian (1977)	Iran (20)	-0.351	0.0986	ns

Germplasm	Grain vs Fe	Pant et. al. (2020)	Nepal (50)	-0.424	0.0004	***
Germplasm	Grain vs Fe	Gómez-Becerra et al. (2010)	Kazakhstan/Serbia [42, 9]	-0.490	0.0001	***
Germplasm	Grain vs Fe	Thapa et al. (2022)	Nepal (215)	-0.607	0.0000	***
Germplasm	Grain vs Zn	EL-Bendary et al. (2013)	Egypt (18)	0.853	0.0000	***
Germplasm	Grain vs Zn	Rawat et al. (2009)	India (12)	0.421	0.1248	ns
Germplasm	Grain vs Zn	Khazratkulova et al. (2015)	Uzbekistan (30)	0.314	0.0699	ns
Germplasm	Grain vs Zn	Joshi et al. (2010)	India (202)	0.192	0.0050	**
Germplasm	Grain vs Zn	Singh et al. (2020)	India (48)	0.108	0.4728	ns
Germplasm	Grain vs Zn	Rehman et al. (2018)	Pakistan (112)	0.102	0.2856	ns
Germplasm	Grain vs Zn	Khokhar et al. (2018)	India (628)	0.063	0.1137	ns
Germplasm	Grain vs Zn	Thapa et al. (2022)	Nepal (215)	0.053	0.4475	ns
Germplasm	Grain vs Zn	Feng et al. (2011)	China (32)	0.049	0.8035	ns
Germplasm	Grain vs Zn	Tadesse et al. (2023)	Morocco (242)	-0.010	0.8862	ns
Germplasm	Grain vs Zn	Ghorttapeh et al. (2018)	Iran (26)	-0.147	0.4806	ns
Germplasm	Grain vs Zn	Velu et al. (2019)	Mexico (85)	-0.221	0.0351	*
Germplasm	Grain vs Zn	Basshi & Nahapetian (1977)	Iran (20)	-0.232	0.3166	ns
Germplasm	Grain vs Zn	Gao et al. (2011)	Canada (60)	-0.385	0.0007	***
Germplasm	Grain vs Zn	Vazquez et al. (2018)	Spain (203)	-0.391	0.0000	***
Germplasm	Grain vs Zn	Johansson et al. (2021)	Sweden (33)	-0.407	0.0076	*
Germplasm	Grain vs Zn	Pant et. al. (2020)	Nepal (50)	-0.421	0.0005	***
Germplasm	Grain vs Zn	Gómez-Becerra et al. (2010)	Kazakhstan/Serbia [42, 9]	-0.620	0.0000	***
Germplasm	Grain vs Zn	Gomez-Coronado et al. (2018)	Portugal (36)	-0.640	0.0000	***
Germplasm	Zn vs Fe	Gómez-Becerra et al. (2010)	Kazakhstan/Serbia [42]	0.780	0.0000	***
Germplasm	Zn vs Fe	Zhao et al. (2009)	Global (26)	0.721	0.0000	***
Germplasm	Zn vs Fe	Velu et al. (2017c)	Mexico (20)	0.706	0.0000	***
Germplasm	Zn vs Fe	Khoshgoftarmanesh et al. (2012)	Iran (120)	0.702	0.0000	***
Germplasm	Zn vs Fe	Murphy et al. (2011)	USA (108)	0.697	0.0000	***
Germplasm	Zn vs Fe	Johansson et al. (2021)	Sweden (33)	0.640	0.0000	***
Germplasm	Zn vs Fe	Feng et al. (2011)	China (32)	0.596	0.0000	**
Germplasm	Zn vs Fe	Garvin et al. (2006)	USA (28)	0.574	0.0000	**
Germplasm	Zn vs Fe	Pant et. al. (2020)	Nepal (50)	0.568	0.0000	***
Germplasm	Zn vs Fe	Neelam et al. (2012)	India (27)	0.495	0.0014	***
Germplasm	Zn vs Fe	Amir et al (2018)	Iran (160)	0.488	0.0000	***
Germplasm	Zn vs Fe	Thapa et al. (2022)	Nepal (215)	0.488	0.0000	***
Germplasm	Zn vs Fe	Petrovi´c et al. (2020)	Croatia (88)	0.472	0.0000	***
Germplasm	Zn vs Fe	Khan et al. (2023)	Bangladesh (288)	0.460	0.0000	***
Germplasm	Zn vs Fe	Tahir et al. (2021)	India (28)	0.451	0.0047	**
Germplasm	Zn vs Fe	Khokhar et al. (2018)	India (628)	0.442	0.0000	***
Germplasm	Zn vs Fe	Krishnappa et al. (2022)	India (1400)	0.280	0.0000	***
Germplasm	Zn vs Fe	Velu et al. (2019)	Mexico (85)	0.279	0.0062	**
Germplasm	Zn vs Fe	Chaudhari et al. (2022)	India (110)	0.277	0.0020	**
Germplasm	Zn vs Fe	Huertas-Garcia et al. (2023)	Spain (36)	0.264	0.1029	ns
Germplasm	Zn vs Fe	Vazquez et al. (2018)	Spain (203)	0.220	0.0011	**
Germplasm	Zn vs Fe	Zhang et al. (2010b)	China (38)	0.215	0.1834	ns
Germplasm	Zn vs Fe	Tadesse et al. (2023)	Morocco (242)	0.212	0.0006	***
Germplasm	Zn vs Fe	Joshi et al. (2010)	India (202)	0.183	0.0076	**
Germplasm	Zn vs Fe	Gashu et al. (2021)	Ethiopia (327)	0.128	0.0190	*
Germplasm	Zn vs Fe	Rodehutscord et al. (2016)	Germany (29)	0.096	0.6340	ns
Germplasm	Zn vs Fe	Bilgrami et al. (2017)	Iran (17)	0.090	0.7472	ns
Germplasm	Zn vs Fe	Rehman et al. (2018)	Pakistan (112)	0.038	0.7043	ns

Germplasm	Zn vs Fe	Gomez-Coronado et al. (2018)	Portugal (36)	0.010	0.9583	ns
Germplasm	Zn vs Fe	Kariithi et al. (2016)	Kenya (27)	-0.114	0.5834	ns
Germplasm	Zn vs phytate	Gomez-Coronado et al. (2018)	Portugal (36)	0.860	0.0000	***
Germplasm	Zn vs phytate	Bilgrami et al. (2017)	Iran (17)	0.635	0.0001	***
Germplasm	Zn vs phytate	Huertas-Garcia et al. (2023)	Spain (36)	0.513	0.0001	***
Germplasm	Zn vs phytate	Petrovi´c et al. (2020)	Croatia (88)	0.195	0.0612	ns
Germplasm	Zn vs phytate	Kariithi et al. (2016)	Kenya (27)	0.191	0.3367	ns
Germplasm	Zn vs phytate	Rehman et al. (2018)	Pakistan (112)	-0.211	0.0210	*
Germplasm	Zn vs protein	Gomez-Coronado et al. (2018)	Portugal (36)	0.860	0.0000	***
Germplasm	Zn vs protein	Johansson et al. (2021)	Sweden (33)	0.689	0.0000	***
Germplasm	Zn vs protein	Gómez-Becerra et al. (2010)	Kazakhstan/Serbia [42, 9]	0.520	0.0000	***
Germplasm	Zn vs protein	Feng et al. (2011)	China (32)	0.509	0.0002	***
Germplasm	Zn vs protein	Rehman et al. (2018)	Pakistan (112)	0.500	0.0000	***
Germplasm	Zn vs protein	Velu et al. (2019)	Mexico (85)	0.448	0.0000	***
Germplasm	Zn vs protein	Vazquez et al. (2018)	Spain (203)	0.420	0.0000	***
Germplasm	Zn vs protein	Khan et al. (2023)	Bangladesh (288)	0.410	0.0000	***
Germplasm	Zn vs protein	Chaudhari et al. (2022)	India (110)	0.151	0.1098	ns
Germplasm	Zn vs protein	Petrovi´c et al. (2020)	Croatia (88)	-0.030	0.7942	ns
Germplasm	Zn vs protein	Zhang et al. (2010b)	China (38)	-0.057	0.7481	ns
Fertilization	Fe vs protein	Montoya et. al. (2020)	Spain (15)	0.846	0.0000	***
Fertilization	Fe vs protein	Xia et al. (2020)	China (12)	0.697	0.0001	***
Fertilization	Fe vs protein	Cakmak et.al.(2010)	Turkey (24)	0.643	0.0000	***
Fertilization	Fe vs protein	Ghasemi et al. (2013)	Iran (20)	0.578	0.0004	***
Fertilization	Fe vs protein	Kiran et. al.(2021)	Pakistan (12)	0.385	0.1760	ns
Fertilization	Fe vs protein	Lu et al. (2024)	China (10)	0.309	0.3724	ns
Fertilization	Fe vs protein	Lu et al. (2024)	China (10)	0.149	0.7000	ns
Fertilization	Fe vs protein	Ghasemi et al. (2013)	Iran (20)	0.107	0.6684	ns
Fertilization	Fe vs protein	Qamari et al. (2023)	Iran (42)	0.063	0.7060	ns
Fertilization	Fe vs protein	Niyigaba et al. (2019)	China (38)	-0.008	0.9657	ns
Fertilization	Fe vs protein	El-Dahshouri et al. (2017)	Egypt (16)	-0.013	0.9661	ns
Fertilization	Fe vs protein	Kandil et al. (2017)	Egypt (36)	-0.123	0.4826	ns
Fertilization	Fe vs protein	Hao et al. (2021)	China (279)	-0.123	0.0377	*
Fertilization	Fe vs protein	Gao et al. (2012)	Canada (156)	-0.370	0.0000	**
Fertilization	Fe vs protein	Ramzan et al. (2020)	Pakistan (14)	-0.442	0.0681	ns
Fertilization	Fe vs protein	Souza et al. (2019)	Brazil (10)	-0.453	0.1317	ns
Fertilization	Fe vs protein	Hafeez et al.(2021)	Pakistan (16)	-0.605	0.0006	***
Fertilization	Fe vs protein	Reznick et al. (2021)	Brazil (12)	-0.610	0.0036	**
Fertilization	Grain vs protein	Singh & Sandhu (2021)	India (13)	0.980	0.0000	***
Fertilization	Grain vs protein	Hussan et al. (2021)	Pakistan (18)	0.955	0.0000	***
Fertilization	Grain vs protein	Akram et. al.(2017)	Pakistan	0.896	0.0000	***
Fertilization	Grain vs protein	Maamoun & El-Shazly (2014)	Egypt (32)	0.854	0.0000	***
Fertilization	Grain vs protein	El-Dahshouri et al. (2017)	Egypt (16)	0.851	0.0000	*
Fertilization	Grain vs protein	Biswas et. al.(2015)	India (20)	0.779	0.0000	***
Fertilization	Grain vs protein	Kandil et al. (2017)	Egypt (36)	0.726	0.0000	***
Fertilization	Grain vs protein	Sadhegi et al. (2021)	Iran (16)	0.663	0.0000	**
Fertilization	Grain vs protein	Montoya et. al. (2020)	Spain (15)	0.523	0.0126	*
Fertilization	Grain vs protein	Kiran et. al.(2021)	Pakistan (12)	0.517	0.0340	*
Fertilization	Grain vs protein	Nadeem et. al. (2023)	Pakistan (16)	0.438	0.0503	ns
Fertilization	Grain vs protein	Ma et al. (2018)	China (48)	0.373	0.0037	**
Fertilization	Grain vs protein	Xia et al. (2020)	China (12)	0.362	0.2131	ns
Fertilization	Grain vs protein	Anwar et al. 2021	Pakistan (20)	0.317	0.1471	ns
Fertilization	Grain vs protein	Gomaa et al. (2018)	Egypt (38)	0.302	0.0489	ns
Fertilization	Grain vs protein	Barut et.al.(2017)	Turkey (72)	0.210	0.0676	ns
Fertilization	Grain vs protein	Mosavian et al. (2021)	Iran (36)	0.201	0.2311	ns
Fertilization	Grain vs protein	Souza et al. (2019)	Brazil (10)	0.132	0.7354	ns
Fertilization	Grain vs protein	Hafeez et al.(2021)	Pakistan (16)	-0.129	0.6491	ns
Fertilization	Grain vs protein	Gomez-Coronado et. al.(2017)	Portugal (30)	-0.133	0.4915	ns
Fertilization	Grain vs protein	Cakmak et.al.(2010)	Turkey (24)	-0.199	0.3479	ns
Fertilization	Grain vs protein	Ramzan et al. (2020)	Pakistan (14)	-0.370	0.1556	ns
Fertilization	Grain vs protein	Gao et al. (2012)	Canada (156)	-0.373	0.0000	***
Fertilization	Grain vs protein	Qamari et al. (2023)	Iran (42)	-0.401	0.0029	**
Fertilization	Grain vs protein	Reznick et al. (2021)	Brazil (12)	-0.472	0.0681	ns

Fertilization	Grain vs protein	Niyigaba et al. (2019)	China (38)	-0.515	0.0000	***
Fertilization	Grain vs protein	Taskin and Gunes (2022)	Turkey (14)	-0.523	0.0168	ns
Fertilization	Grain vs protein	Ghimire et al. (2021)	USA (42)	-0.664	0.0000	***
Fertilization	Grain vs protein	Ning et. al. (2019)	China (18)	-0.693	0.0000	***
Fertilization	Grain vs protein	Lu et al. (2024)	China (10)	-0.789	0.0000	***
Fertilization	Grain vs protein	Zhang et al. (2017)	China (12)	-0.801	0.0000	***
Fertilization	Grain vs Fe	Kiran et. al.(2021)	Pakistan (12)	0.934	0.0000	***
Fertilization	Grain vs Fe	Zia et al. (2020)	Pakistan (48)	0.642	0.0000	***
Fertilization	Grain vs Fe	Reznick et al. (2021)	Brazil (12)	0.630	0.0018	**
Fertilization	Grain vs Fe	Ramzan et al. (2020)	Pakistan (14)	0.580	0.0038	**
Fertilization	Grain vs Fe	Hafeez et al.(2021)	Pakistan (16)	0.450	0.0416	*
Fertilization	Grain vs Fe	Anwar et al. 2021	Pakistan (20)	0.384	0.0629	ns
Fertilization	Grain vs Fe	Gao et al. (2012)	Canada (156)	0.367	0.0000	**
Fertilization	Grain vs Fe	Xia et al. (2020)	China (12)	0.275	0.3786	ns
Fertilization	Grain vs Fe	Montoya et. al. (2020)	Spain (15)	0.208	0.4603	ns
Fertilization	Grain vs Fe	Niyigaba et al. (2019)	China (38)	0.144	0.3912	ns
Fertilization	Grain vs Fe	Qamari et al. (2023)	Iran (42)	0.112	0.4884	ns
Fertilization	Grain vs Fe	El-Dahshouri et al. (2017)	Egypt (16)	-0.022	0.9422	ns
Fertilization	Grain vs Fe	Hao et al. (2021)	China (279)	-0.032	0.6069	ns
Fertilization	Grain vs Fe	Taskin and Gunes (2022)	Turkey (14)	-0.048	0.8825	ns
Fertilization	Grain vs Fe	Sher et al. (2020)	Pakistan (27)	-0.093	0.6588	ns
Fertilization	Grain vs Fe	Zou et al. (2019)	Global (108)	-0.134	0.1627	ns
Fertilization	Grain vs Fe	Souza et al. (2019)	Brazil (10)	-0.267	0.4556	ns
Fertilization	Grain vs Fe	Lu et al. (2024)	China (10)	-0.362	0.2737	ns
Fertilization	Grain vs Fe	Kandil et al. (2017)	Egypt (36)	-0.451	0.0012	**
Fertilization	Grain vs Fe	Milvojevic et al. (2018)	Serbia (30)	-0.465	0.0021	**
Fertilization	Grain vs Fe	Zhang et al. (2010)	China (15)	-0.567	0.0038	**
Fertilization	Grain vs Fe	Cakmak et.al.(2010)	Turkey (24)	-0.677	0.0000	***
Fertilization	Grain vs Zn	Singh & Sandhu (2021)	India (13)	0.973	0.0000	***
Fertilization	Grain vs Zn	Akca & Taban (2024)	Turkey (28)	0.959	0.0000	***
Fertilization	Grain vs Zn	Khalili et al. (2023)	Pakistan (12)	0.950	0.0000	***
Fertilization	Grain vs Zn	Hussan et al. (2021)	Pakistan (18)	0.868	0.0000	***
Fertilization	Grain vs Zn	Abdi et al. (2013)	Pakistan (20)	0.852	0.0000	***
Fertilization	Grain vs Zn	El-Dahshouri et al. (2017)	Egypt (16)	0.847	0.0000	***
Fertilization	Grain vs Zn	Chattha et. al. (2017)	Pakistan (30)	0.841	0.0000	***
Fertilization	Grain vs Zn	Kiran et. al.(2021)	Pakistan (12)	0.841	0.0000	***
Fertilization	Grain vs Zn	Akram et. al.(2017)	Pakistan	0.755	0.0000	***
Fertilization	Grain vs Zn	Ali et al. (2024)	Pakistan (23)	0.741	0.0000	***
Fertilization	Grain vs Zn	Mosavian et al. (2021)	Iran (36)	0.681	0.0000	***
Fertilization	Grain vs Zn	Ramzan et al. (2020)	Pakistan (14)	0.662	0.0001	**
Fertilization	Grain vs Zn	Khoshgoftarmanesh et al. (2005)	Iran (19)	0.628	0.0000	***
Fertilization	Grain vs Zn	Nadeem et. al. (2023)	Pakistan (16)	0.596	0.0009	***
Fertilization	Grain vs Zn	Vaziri et al. (2023)	Iran (36)	0.539	0.0000	***
Fertilization	Grain vs Zn	Liu et. al.(2017)	China (30)	0.530	0.0001	**
Fertilization	Grain vs Zn	Shah et al. (2023)	Pakistan (16)	0.495	0.0180	*
Fertilization	Grain vs Zn	Ivanovic et al. (2021)	Serbia (32)	0.460	0.0017	***
Fertilization	Grain vs Zn	Kandil et al. (2017)	Egypt (36)	0.460	0.0008	***
Fertilization	Grain vs Zn	Rashid et al. (2019)	Global (57)	0.454	0.0000	***
Fertilization	Grain vs Zn	Hafeez et al.(2021)	Pakistan (16)	0.449	0.0422	*
Fertilization	Grain vs Zn	Yilmaz et al. (1997)	Turkey (18)	0.441	0.0337	*
Fertilization	Grain vs Zn	Sher et al. (2020)	Pakistan (27)	0.390	0.0240	*
Fertilization	Grain vs Zn	Shariatipour et al. (2020)	Iran (48)	0.385	0.0025	**
Fertilization	Grain vs Zn	Souza et al. (2019)	Brazil (10)	0.374	0.2527	ns
Fertilization	Grain vs Zn	Xia et al. (2020)	China (12)	0.330	0.2698	ns
Fertilization	Grain vs Zn	Dhaliwal et. al.(2019)	India (15)	0.321	0.2169	***
Fertilization	Grain vs Zn	Sadhegi et al. (2021)	Iran (16)	0.306	0.2256	ns
Fertilization	Grain vs Zn	Biswas et. al.(2015)	India (20)	0.285	0.2024	ns
Fertilization	Grain vs Zn	Montoya et. al. (2020)	Spain (15)	0.281	0.2945	ns
Fertilization	Grain vs Zn	Qamari et al. (2023)	Iran (42)	0.141	0.3753	ns
Fertilization	Grain vs Zn	Ram et. al. (2013)	India (16)	0.089	0.7592	ns
Fertilization	Grain vs Zn	Zou et al. (2019)	Global (108)	0.037	0.7174	ns
Fertilization	Grain vs Zn	Zhang et al. (2010)	China (15)	0.001	0.9972	ns
Fertilization	Grain vs Zn	Barut et.al.(2017)	Turkey (72)	-0.017	0.8962	ns
Fertilization	Grain vs Zn	Anwar et al. 2021	Pakistan (20)	-0.051	0.8440	ns
Fertilization	Grain vs Zn	Dhaliwal et.al. (2023)	India (16)	-0.053	0.8584	ns
Fertilization	Grain vs Zn	Meena et. al.(2021b)	India (23)	-0.074	0.7513	ns
Fertilization	Grain vs Zn	Gomez-Coronado et. al.(2017)	Portugal (30)	-0.088	0.6579	ns
Fertilization	Grain vs Zn	Ram et. al. (2016)	Global (72)	-0.112	0.3518	ns
Fertilization	Grain vs Zn	Luis et al. (2021)	Portugal (36)	-0.121	0.4903	ns

Fertilization	Grain vs Zn	Hao et al. (2021)	China (279)	-0.176	0.0026	**
Fertilization	Grain vs Zn	Zou et al. (2012)	Global (91)	-0.223	0.0275	*
Fertilization	Grain vs Zn	Ma et al. (2018)	China (48)	-0.280	0.0412	*
Fertilization	Grain vs Zn	Ning et. al. (2019)	China (18)	-0.283	0.2358	ns
Fertilization	Grain vs Zn	Niyigaba et al. (2019)	China (38)	-0.295	0.0555	ns
Fertilization	Grain vs Zn	Peck et al. (2008)	Australia (21)	-0.353	0.0868	ns
Fertilization	Grain vs Zn	Cakmak et.al.(2010)	Turkey (24)	-0.357	0.0604	ns
Fertilization	Grain vs Zn	Xu et al. (2022)	China (24)	-0.402	0.0278	*
Fertilization	Grain vs Zn	Gomez-Coronado et. al.(2016)	Portugal (104)	-0.451	0.0000	***
Fertilization	Grain vs Zn	Zia et al. (2020)	Pakistan (48)	-0.580	0.0000	***
Fertilization	Grain vs Zn	Lu et al. (2024)	China (10)	-0.591	0.0162	*
Fertilization	Grain vs Zn	Porter & Paulsen (1983)	USA (90)	-0.623	0.0000	***
Fertilization	Grain vs Zn	Gao et al. (2012)	Canada (156)	-0.640	0.0000	***
Fertilization	Grain vs Zn	Milvojevic et al. (2018)	Serbia (30)	-0.640	0.0000	***
Fertilization	Grain vs Zn	Reznick et al. (2021)	Brazil (12)	-0.641	0.0011	**
Fertilization	Grain vs Zn	Hui et al. (2019)	China (15)	-0.783	0.0000	***
Fertilization	Grain vs Zn	Curtin et. al.(2008)	Ne Zealand (12)	-0.852	0.0000	***
Fertilization	Grain vs Zn	Zhang et al. (2017)	China (12)	-0.911	0.0000	***
Fertilization	Zn vs Fe	Kiran et. al.(2021)	Pakistan (12)	0.857	0.0000	***
Fertilization	Zn vs Fe	Ghasemi et al. (2013)	Iran (20)	0.786	0.0000	***
Fertilization	Zn vs Fe	Lu et al. (2024)	China (10)	0.778	0.0000	***
Fertilization	Zn vs Fe	Xia et al. (2020)	China (12)	0.676	0.0002	***
Fertilization	Zn vs Fe	Cakmak et.al.(2010)	Turkey (24)	0.675	0.0000	***
Fertilization	Zn vs Fe	Montoya et. al. (2020)	Spain (15)	0.654	0.0001	***
Fertilization	Zn vs Fe	Hafeez et al.(2021)	Pakistan (16)	0.566	0.0027	**
Fertilization	Zn vs Fe	Zou et al. (2019)	Global (108)	0.498	0.0000	***
Fertilization	Zn vs Fe	Qamari et al. (2023)	Iran (42)	0.482	0.0001	***
Fertilization	Zn vs Fe	Milvojevic et al. (2018)	Serbia (30)	0.469	0.0018	**
Fertilization	Zn vs Fe	Souza et al. (2019)	Brazil (10)	0.461	0.1214	ns
Fertilization	Zn vs Fe	Hao et al. (2021)	China (279)	0.435	0.0000	***
Fertilization	Zn vs Fe	El-Dahshouri et al. (2017)	Egypt (16)	0.329	0.1845	ns
Fertilization	Zn vs Fe	Kandil et al. (2017)	Egypt (36)	0.298	0.0599	ns
Fertilization	Zn vs Fe	Zhang et al. (2010)	China (15)	0.283	0.2904	ns
Fertilization	Zn vs Fe	Ramzan et al. (2020)	Pakistan (14)	0.240	0.4056	ns
Fertilization	Zn vs Fe	Sadhegi et al. (2021)	Iran (16)	0.225	0.3999	ns
Fertilization	Zn vs Fe	Sher et al. (2020)	Pakistan (27)	-0.055	0.7992	ns
Fertilization	Zn vs Fe	Niyigaba et al. (2019)	China (38)	-0.099	0.5657	ns
Fertilization	Zn vs Fe	Zia et al. (2020)	Pakistan (48)	-0.132	0.3738	ns
Fertilization	Zn vs Fe	Gao et al. (2012)	Canada (156)	-0.218	0.0047	ns
Fertilization	Zn vs Fe	Reznick et al. (2021)	Brazil (12)	-0.501	0.0444	*
Fertilization	Zn vs phytate	Ning et. al. (2019)	China (18)	0.400	0.0647	ns
Fertilization	Zn vs phytate	Lu et al. (2024)	China (10)	0.151	0.6958	ns
Fertilization	Zn vs phytate	Gomez-Coronado et. al.(2016)	Portugal (104)	0.138	0.1580	ns
Fertilization	Zn vs phytate	Ghasemi et al. (2013)	Iran (20)	0.096	0.7027	ns
Fertilization	Zn vs phytate	Akca & Taban (2024)	Turkey (28)	0.074	0.7230	ns
Fertilization	Zn vs phytate	Hao et al. (2021)	China (279)	0.044	0.4732	ns
Fertilization	Zn vs phytate	Xia et al. (2018)	China (36)	0.017	0.9287	ns
Fertilization	Zn vs phytate	Gomez-Coronado et. al.(2017)	Portugal (30)	-0.215	0.2440	ns
Fertilization	Zn vs phytate	Bharti et. al. (2013)	India (60)	-0.523	0.0000	***
Fertilization	Zn vs phytate	Khalili et al. (2023)	Pakistan (12)	-0.718	0.0000	**
Fertilization	Zn vs phytate	Zhang et al. (2017)	China (12)	-0.853	0.0000	***
Fertilization	Zn vs phytate	Chattha et. al. (2017)	Pakistan (30)	-0.945	0.0000	***
Fertilization	Zn vs protein	Singh & Sandhu (2021)	India (13)	0.992	0.0000	***
Fertilization	Zn vs protein	Xia et al. (2020)	China (12)	0.954	0.0000	***
Fertilization	Zn vs protein	Hussan et al. (2021)	Pakistan (18)	0.927	0.0000	***
Fertilization	Zn vs protein	Akram et. al.(2017)	Pakistan (27)	0.904	0.0000	***
Fertilization	Zn vs protein	Reznick et al. (2021)	Brazil (12)	0.895	0.0000	***
Fertilization	Zn vs protein	Zhang et al. (2017)	China (12)	0.892	0.0000	***
Fertilization	Zn vs protein	El-Dahshouri et al. (2017)	Egypt (16)	0.797	0.0000	***
Fertilization	Zn vs protein	Ning et. al. (2019)	China (18)	0.758	0.0000	***
Fertilization	Zn vs protein	Ghasemi et al. (2013)	Iran (20)	0.754	0.0000	***
Fertilization	Zn vs protein	Montoya et. al. (2020)	Spain (15)	0.615	0.0006	***
Fertilization	Zn vs protein	Mosavian et al. (2021)	Iran (36)	0.612	0.0000	***
Fertilization	Zn vs protein	Gao et al. (2012)	Canada (156)	0.587	0.0000	***
Fertilization	Zn vs protein	Biswas et. al.(2015)	India (20)	0.488	0.0083	**
Fertilization	Zn vs protein	Kandil et al. (2017)	Egypt (36)	0.453	0.0011	**
Fertilization	Zn vs protein	Cakmak et.al.(2010)	Turkey (24)	0.441	0.0121	*
Fertilization	Zn vs protein	Nadeem et. al. (2023)	Pakistan (16)	0.417	0.0684	ns
Fertilization	Zn vs protein	Niyigaba et al. (2019)	China (38)	0.402	0.0046	*
Fertilization	Zn vs protein	Gomez-Coronado et. al.(2017)	Portugal (30)	0.378	0.0218	*

Fertilization	Zn vs protein	Kiran et. al.(2021)	Pakistan (12)	0.342	0.2479	ns
Fertilization	Zn vs protein	Lu et al. (2024)	China (10)	0.279	0.4315	ns
Fertilization	Zn vs protein	Ma et al. (2018)	China (48)	0.248	0.0759	ns
Fertilization	Zn vs protein	Souza et al. (2019)	Brazil (10)	0.198	0.5977	ns
Fertilization	Zn vs protein	Ramzan et al. (2020)	Pakistan (14)	0.091	0.7736	ns
Fertilization	Zn vs protein	Qamari et al. (2023)	Iran (42)	0.089	0.5873	ns
Fertilization	Zn vs protein	Barut et.al.(2017)	Turkey (72)	-0.098	0.4188	ns
Fertilization	Zn vs protein	Hafeez et al.(2021)	Pakistan (16)	-0.780	0.0000	***

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Supplementary_Information_Code_used

SAS code for running linear mixed effects models

The following codes were used for the various analyses but models were adjusted based on the goodness of fit statistics, i.e., AIC, BIC generated for any given combination of explanatory variables Xi. The final model was the one that minimized the AIC and BIC.

Proc sort; By variable; */*requests sorting the analysis by the response variables, i.e., lnRR of grain yield, Zn, Fe, protein, phytate*/*
proc mixed data= Wheat method = REML covtest; */*requests a linear mixed effects procedure for the dataset named "Wheat" using a restricted maximum likelihood and display the covariance test results*/*
Class X1 X2 X3 Xn Study; */Specifies X1, X2, X3, X4 and Study as the classification variables*/*
model lnRR = X1, X2, X3, X4/solution ddfm = kr; */*specifies independent variables X1 to X4 as the fixed effects and computation of the denominator degrees of freedom using the Kenward Roger method*/*
Random Study; */*specifies study as the random effect*/*
LSmeans X1/diff adjust = Tukey; */*requests marginal means for lnRR and 95% CI for the different classes of the independent variable X1, for example soil pH and Tukey-Kramer adjusted P value*/*
By variable; */*requests display of analysis for each*

R codes for Random Forest model

```
rm(list=ls(all=TRUE))
setwd("C:\\........\\Data set")
Data <- read.csv("Data.csv", header=T)
Data <- Data[, c(x,x1,x2,……..)]
library(randomForest)
set.seed(1234567)
rownames(Data)<-1:nrow(Data)
rows <- sample(x=1:nrow(Data),size=0.8 *  nrow(Data))
train <- sample(nrow(Data), 0.8*nrow(Data), replace = FALSE)
TrainSet <- Data [train,]
ValidSet <- Data [-train,]
library(randomForest)
set.seed(1234567)
selected<-c(as.character(imp[1:25, 1]),'variable')
model1<-randomForest(variable ~.,data=TrainSet[,,],replace=T,ntree=1000, type=regression,
na.action=na.omit)
model1
par(mfrow=c(1,2))
varImpPlot(model1,main='Variable Importance Plot: Final Model',pch=16,col='blue')
plot(model0, main='Error vs No. of trees plot: Final Model',col='blue')
pred<-predict(object=model1,newdata=ValidSet)
actual<-ValidSet$variable
result<-data.frame(actual=actual,predicted=pred)
paste('Mean Squared error: ',mean(model1$mse))
paste('Root Mean Squared error: ',mean(sqrt(model1$mse)))
write.csv(result, "rf.csv")
mf <- read.csv("rf.csv", header=T)
ls(mf)
RF.rmse<-round(sqrt(mean( (mf$actual-mf$predicted)^2 , na.rm = TRUE )),0)
print(RF.rmse)
RF.r2<-round(summary(lm(actual~predicted, mf))$r.squared,3)
print(RF.r2)
#plotting predicted Vs observed
library(ggplot2)
```

```
plot1<-ggplot(result)+
  geom_point(aes(x=actual,y=predicted),alpha=0.6)+
  ggtitle('Grain yield') +
  scale_x_continuous("Observed grain yield (kg ha⁻¹)",
                     limits=c(500,8000),
                     breaks=seq(x, x1, x2))+
  scale_y_continuous("Predicted grain yield (kg ha⁻¹)",
                     limits=c(500,8000),
                     breaks=seq(500, 8000, 1000)) +
  theme(axis.line = element_line(colour = "black"),
        axis.text.y=element_text(size=14,angle = 90, hjust = 0.5, vjust=1),
        axis.text.x = element_text(size=14)) +
  geom_abline(intercept=0,size = 0.5)+
  geom_smooth(aes(x=actual,y=predicted), method = "lm", se = FALSE, colour="red",linetype = 2,size =
0.75)+
  annotate("text", x=.., y=…, label= paste("RMSE:",RF.rmse), frontface= "italic", colour="black", size=6)+
  annotate("text", x=…, y=…, label= paste("R^2: " ,RF.r2), frontface= "italic", colour="black", size=6, parse=T)
plot1
plot2<-plot1+
  theme(
    axis.title.x = element_text(colour="black", size=..),
    axis.text.x = element_text(colour="black", size=..),
    axis.title.y = element_text(colour="black", size=20, angle = 90),
    axis.text.y = element_text(colour="black", size=20),
    plot.title = element_text(colour="black", size=18, face="bold"))
plot1+theme(
  legend.background = element_rect(fill="grey85", colour="red", size=1),
  legend.title = element_text(colour="blue", face="bold", size=18),
  legend.text = element_text(colour="red", size=…),
  legend.key = element_rect(colour="blue", size=…))
plot2
paste('Function Call: ', model1$call)
```