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Effects of soil pH levels on iron and zinc concentrations of common bean (*Phaseolus vulgaris* L.) genotypes

Kinguye Masamaki Magomere*, Susan Nchimbi-Msolla and George Muhamba Tryphone

Department of Crop Science and Horticulture, Sokoine University of Agriculture, P. O. Box 3000, Chuo Kikuu, Mogorogo, Tanzania.

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Plants grown in acid soils experience a variety of stresses which include aluminium, hydrogen and/or manganese toxicity, as well as nutrient deficiencies of calcium and magnesium. A study was carried out to determine the influence of soil pH levels on iron and zinc concentrations in leaves and seeds of twenty-five common bean genotypes. Plastic cups trial was carried out in the screen house to determine the actual amount of quick lime $Ca(OH)_2$ required to reach a targeted soil pH level. In each pot, 4 kg soil was amended with $Ca(OH)_2$ to obtain the target soil pH levels of 5.3, 5.5, 6.5 and 7.5. The experimental design followed a randomized complete block design in a split plot arrangement with three replications per treatment. The pH levels were treated as main factor and genotypes as sub plot. Data collected include leaf iron concentration, seed iron concentration, leaf zinc concentration, and seed zinc concentration and analysis of variance was performed for all data using GenStat statistical package 15th edition. The result demonstrated that soil pH affects absorption of micronutrients directly or indirectly by affecting the nutrients availability to common bean plants.

Key words: Soil pH, micronutrients, zinc, iron, genotype, lime, common bean.

INTRODUCTION

Soil pH is a measure of hydrogen ions (H^+) in the soil (Miller, 2013). Soil pH is important because it directly affects soil nutrient availability (Fageria, 2002). Plant roots can only absorb nutrients after they have been transformed into certain ionic forms. Lower pH increases the solubility of Al, Mn, and Fe, which are toxic to plants in excess. Extreme pH levels decrease the availability of most nutrients. As pH rises, micronutrients precipitate as insoluble minerals, which cannot be taken up by plants. Plants usually grow well at pH values above 5.5. Soil pH of 6.5 is usually considered optimum for nutrient availability (Taye, 2008). In many areas of the world, soil acidity limits agricultural production.

It has been observed that application of fertilizer has already contributed to the acidification of some soil in Tanzania (Mkonda and He, 2017). Plants grown in acid soils can experience a variety of stresses including aluminium, hydrogen and/or manganese toxicity, as well

*Corresponding author. E-mail: emmanuelimasamaki@gmail.com; Tel: +255754570208.

as nutrient deficiencies of calcium and magnesium (Brady and Weil, 2002). This had led to low average yield of common beans which ranges from 0.72 to 1.10 tonnes/ha, in pH affected soil which is far below potential yields recommended by agricultural research of 1.5 to 3 tonnes/ha using improved varieties (Ronner and Giller, 2013). A build-up of soil acidity is a threat to agriculture productivity, especially if strong acidifying fertilizers are used. Therefore, the objective of this study is to determine the effect of soil pH on common bean genotypes.

MATERIALS AND METHODS

Experimental site

The screen house experiment was carried out at Sokoine University of Agriculture (SUA), Morogoro region, Tanzania.

Plant

Twenty genotypes from CIAT, Uganda and five check materials from Tanzania, Morogoro were used in this study and their Fe and Zn concentrations in both seeds and leaves.

Soil sampling and analysis

Soil samples were collected from the Magadu site at the depth of 0-20 cm using an auger. Ten soil samples were taken from each arm of the shaped pattern. All samples were bulked and composited and a 1 kg composite sample was taken for analysing physical and chemical properties of the soil. The samples were air-dried, disaggregated and sieved through a 2 mm sieve and analysed (Day, 1965). All soil samples were analysed for soil pH, cation exchange capacity (CEC), exchangeable bases (Ca, K, Mg and Na), micronutrients (Fe and Zn), organic carbon (OC) and available phosphorus. Soil textural classes were determined using the USDA textural class triangle (USDA, 1975). Soil pH was determined in water at a soil: water ratio of 1:2.5 suspension using pH meter. Available P was extracted using the Bray 1 method (Bray and Kurtz, 1945) and colour was developed by the ascorbic acid of Murphy and Riley (1962). Exchangeable calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectrophotometry whereas K and Na were extracted using ammonium acetate and analysed by flame spectrophotometry. Cation exchange capacity (CEC) was determined with ammonium acetate saturation method at pH 7.0 (Chapman, 1973). Organic carbon was determined by the Walkley-Black wet combustion method (Tan, 1996) and total N was determined using the Kjeldahl method. The DTPA extractable Fe and Zn were determined by atomic absorption spectrophotometry (Lindsay and Norvell, 1978).

Incubation experiment to obtain the target soil pH

Plastic cups trial was carried out in the screen house to determine the actual amount of quick lime $Ca(OH)_2$ required to reach a targeted soil pH level. A soil incubation experiment was performed before conducting the pot culture experiment to attain the standard. The composite soil sample was air dried, ground and passed with 2 mm sieve and then 0.5 kg soil was placed in 6 plastic cups replicated 3 times and mixed with different treatments in a greenhouse. Six rates of quick lime 0, 2.5, 5, 10, 15 and 20 tons per hectare in terms of $Ca(OH)_2$ equivalents were separately applied to obtain a standard curve. The soils were then moistened with distilled water, with a field capacity of 60%, and placed under a polyethylene cover containing a hole and in each five days the soil was pulverized. After 4 weeks, soil pH was measured. The relationships between soil pH and the amounts of $Ca(OH)_2$ were established in a standard curve and amount of $Ca(OH)_2$ required for pot culture experiment targeted pH of 5.3, 5.5, 6.5, and 7.5 were obtained at 0, 0.2, 0.8, and 2.5 g respectively.

Experimental design

The treatments consisted of 25 genotypes and soil pH with four levels (5.3, 5.5, 6.5 and 7.5). The experimental design followed a randomized complete block design in a split plot arrangement with three replications. Soil pH level was used as main factor and genotypes were treated as sub factor.

Plant sampling

At early flowering (10% flowering of the whole plant), trifoliate leaves were sampled randomly from 10 plants per row in a plot for all soil pH levels. Leaf samples were put into paper bags, clearly labelled and oven dried and then ground to fine powder using a motor and pestle to pass through a 0.5 mm sieve for Fe and Zn analyses. After physiological maturity, seeds were harvested from each pot in all soil pH levels and put into paper bags and then air dried. Then, seeds were ground using a sample mill. The powder obtained was used for determination of Fe and Zn in the seeds.

Plant sample analysis

The plant leaves and seeds analyses were done according to atomic absorption spectroscopy (AOAC, 1995).

Data collection

Laboratory analysis of iron and zinc concentrations in leaf and seed.

Statistical analysis

In assessing the concentrations of zinc and iron in seeds and leaves, the fixed main effects were pH levels subjected to whole plot and bean genotypes subjected to sub plot, whereas replications were treated as random effect during analysis of variance. The factors' effect model is shown in Equation 1. The significant differences in concentrations of zinc and iron in leaves and/or seeds based on the variation in pH and bean genotypes were isolated by a post-hoc Tukey's-HSD test at 5% using GenStat Discovery Edition 15.

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij} \quad (1)$$

Where Y_{ij} is the observed concentration of zinc or iron in the ijth factors; μ is the overall (grand) mean; α_i and β_j are the main effects of the factors pH levels and bean genotypes, respectively; $(\alpha\beta)_{ij}$ is the interaction between the factors; ε_{ij} is the random error.

Table 1. Effects of genotypes on zinc and iron concentrations in leaf and seed.

Genotype	C zinc in leaf	C zinc in seed	C iron in leaf	C iron in seed
NUA 9	47.0^{d-e}	30.8^{a-f}	210.5^{c-i}	76.6^{a-c}
NUA 11	46.6^{d-e}	27.3^{a-d}	220.3^{e-i}	118.28^{d}
NUA 13	46.2^{d-e}	31.3^{a-g}	175.5^{a-e}	78.8^{a-c}
NUA 15	42.0^{b-e}	34.8^{c-h}	223.3^{e-i}	68.2^{a-c}
NUA 16	41.7b^{-e}	35.5^{d-h}	219.8^{d-i}	61.8^{a}
NUA 17	50.6^{e}	40.9^{h}	198.4^{a-g}	71.1^{a-c}
NUA 18	38.8^{a-e}	34.2^{c-h}	247.9^{f-i}	80.6^{a-c}
NUA 19	49.1^{d-e}	33.8^{c-h}	159.9^{a-e}	89.7^{b-c}
NUA 23	48.8^{de}	34.9^{c-h}	155.6^{a-d}	87.7^{a-c}
NUA 30	36.7^{a-e}	35.3^{d-h}	264.8^{g-j}	68.2^{a-c}
NUA 31	33.6^{a-d}	32.4^{a-h}	142.1^{a-b}	73.5^{a-c}
NUA 39	33.8^{a-d}	39.2^{f-h}	134.1a	74.6^{a-c}
NUA 40	34.8^{a-e}	36.8^{e-h}	148.7^{a-c}	92.0^{c-d}
NUA 48	37.6^{a-e}	34.0^{c-h}	244.4^{f-i}	71.9^{a-c}
NUA 57	28.6^{a-c}	34.7^{c-h}	316.9^{j-l}	88.9^{b-c}
NUA 59	44.1^{c-e}	29.9^{a-f}	184.3^{a-f}	84.6^{a-c}
NUA 64	27.3^{a-b}	32.9^{b-h}	226.5^{e-i}	78.7^{a-c}
NUA 66	37.4^{a-e}	38.1^{e-h}	204.9^{b-h}	64.7^{a-b}
NUA 67	38.7^{a-e}	39.4^{g-h}	220.7^{d-i}	84.5^{a-c}
NUA 79	46.8^{d-e}	38.2^{f-h}	247.9^{f-i}	93.9^{c-d}
SUA 90	40.7^{a-e}	24.1^{a}	373.3^{i}	75.7^{abc}
MSHINDI	26.9^{a-b}	24.9^{a-b}	274.9^{i-k}	72.8^{a-c}
PESA	32.8^{a-d}	26.4^{a-c}	340^{k-l}	74.2^{a-c}
ROJO	26.1^{a-b}	32.3^{a-g}	141.7^{a-b}	73.1^{a-c}
ZAWADI	24.7^{a}	27.4^{a-d}	271.7^{h-j}	79.6^{a-c}
G. MEAN	38.5	33.2	221.9	79.3
S.D	7.9	4.6	62.4	11.7
S.E	1.6	0.9	12.5	2.3
CV (%)	20.52	13.86	28.12	14.75
P value	<0.001	<0.001	<0.001	<0.001

Means with the same letters in a column are not significantly different at 5 % level of significance by the Turkey, C= Concentration.

Estimation of simple correlation coefficients

All collected data were utilized for the computation of correlation coefficients between seed iron and zinc concentrations with other traits using the formulae suggested by Snedecor and Cochran (1967).

$$r\ r(xy) = (\mathrm{Cov}\ (xy))/\sqrt{((\mathrm{Var}\ x)\times(\mathrm{Var}\ y))} \quad (2)$$

where r(xy) = correlation between x and y; Cov (xy) = covariance for traits x and y; Var (x) = variance for x; Var (y) = variance for y; r = correlation coefficient; xy = two independent variables.

To test the significance of correlation coefficients, the estimated values were compared with the table values of correlation coefficients (Fisher and Yates, 1967) at 5% levels of significance with (n-2) degrees of freedom, where n is the total number of observations used.

RESULTS

Effects of genotypes for seed and leaf Iron and Zinc concentrations

The results indicated that there was significant variation ($p<0.05$) in iron concentrations in leaves among genotypes (Table 1). The highest concentration of iron in leaves was 373.3 mg/kg observed in SUA 90 and lowest concentration of iron in leaves was 141.7 mg/kg for ROJO (Table 1). Further, the results indicated that there were significant ($p<0.001$) differences among genotypes in concentrations of iron in seeds (Table 1). The highest concentration of iron in seeds was 118.28 mg/kg, observed in NUA11 and lowest concentration of iron in

Table 2. Mean square of pH levels on leaf and seed Iron and zinc concentrations.

pH levels	Concentrations			
	Seed Fe	Leaf Fe	Leaf Zn	Seed Zn
5.3	333.5^{ns}	13380**	211.6**	137.03**
5.5	572.1^{ns}	11559**	221.8*	82.79**
6.5	485.3^{ns}	12801**	278.4^{ns}	105.47**
7.5	650.4**	12515**	172.0*	67.62*

** = high significant (*p<0.01*), * = significant (p<0.001), ns=not significant.

Table 3. Analysis of variance for the different variables evaluated for the common at p<0.05.

Variable	Source	Df	*Ss*	Ms	F value	P value
Concentrations of Zinc in leaf (mg/kg)	Genotype	24	18327.1	763.6	6.32	<0.001
	pH level	3	4829.4	1609.8	13.32	<0.001
	Genotype × pH	72	2900.5	40.3	0.33	0.978
Concentrations of Zinc in seed (mg/kg)	Genotype	24	6173.16	257.22	7.58	<0.001
	pH level	3	2885.01	961.67	28.35	<0.001
	Genotype × pH	72	3257.86	45.25	1.33	0.062
Concentrations of iron in seeds (mg/kg)	Genotype	24	39055.4	1627.3	5.08	<0.001
	pH level	3	15487.3	5162.4	16.13	<0.001
	Genotype × pH	72	10036.5	139.4	0.44	0.996
Concentrations of iron in leaf (mg/kg)	Genotype	24	1122284	46762	22.98	<0.001
	pH level	3	116942	38981	19.15	<0.001
	Genotype × pH	72	85420	1186	0.58	0.986

seeds was 61.8 mg/kg, observed in NUA 16.

Results indicated that there were significant (p<0.001) differences among genotypes in concentration of zinc in leaves (Table 1). The highest concentration of zinc in leaf was 50.6 mg/kg observed in Nua 17 and lowest concentration of zinc in leaf was 24.7 mg/kg observed in ZAWADI. Further, results indicated that there were high significant (p<0.001) differences among genotypes in concentration of zinc in seeds (Table 1). The highest concentration of zinc in seeds was 40.9 mg/kg observed in NUA 17 and lowest concentration of zinc in seeds was 24.1 mg/kg observed SUA 90.

Effects of pH on Zinc and Iron concentration in seeds and leaves

Results indicated that there were significant (p<0.05) differences among pH levels in concentration of zinc in leaves except for pH level of 6.5 (Table 2).

Results indicated that there were significant (p<0.05) differences among pH levels in concentration of zinc in seeds (Table 2). There were significant (p>0.05) differences among pH values in concentration of zinc in leaves except for pH 6.5.

There were high significant (p<0.001) differences among pH levels in concentrations of iron in leaves (Table 2). In the concentration of iron in seeds, the significant effect was observed at pH level of 7.5. There were non-significant (p < 0.05) differences among pH levels of 5.3, 5.5 and 6.5 in concentration of iron in seeds (Table 2).

There was no interaction effect of genotypes × pH levels in the concentrations of iron and zinc at all levels of pH (Table 3).

Correlation analysis among variables under pH levels of 5.5 and 6.5

Concentration of iron in leaves was strongly and positively correlated with concentration of iron in seed (r = 0.563**, 0.274**) under pH levels 6.5 and 5.5, respectively and concentration of zinc in seed (r = 0.259**) under pH level of 6.5 but were significantly and positively correlated with concentration of zinc in seed and leaves (r = 0.114*,

Table 4. pH level 5.5 (Above diagonal) and pH level 6.5 (Below diagonal) correlation coefficients of different character combinations.

Variable	Seed Fe	Leave Fe	Seed Zn	Leave Zn
Seed Fe	1	0.274**	0.799**	0.045*
Leave Fe	0.563**	1	0.114*	0.093*
Seed Zn	0.340**	0.259**	1	0.340**
Leave Zn	0.106*	0.209*	0.262**	1

** = High significant ($p< 0.01$), * = significant ($p<0.001$).

0.093*) under pH level of 5.5 (Table 4). There were significant and positive correlations of concentration of zinc in leaves under soil pH level of 6.5 (r = 0.209*). Concentration of iron in seeds was significantly and positively correlated with concentration of zinc in seed (r = 0.799**, 0.340**) under pH levels of 5.5 and 6.5, respectively and concentration of zinc in leaves (r = 0.340**) under pH level of 5.5. Concentration of zinc in leaves was significantly and positively correlated with concentration of zinc in seed (r =0.262**) under pH level of 6.5 but was significantly and positively correlated with concentration of iron in seed and leaves (r = 0.106*, 0.209*) under pH level of 6.5.

DISCUSSION

Concentration of iron in leaf and seeds

Different concentration of iron in leaves and seeds found in each genotype is due to the soil pH levels. At pH 5.3, concentration of iron in seed and leaves was low because manganese competes with Fe uptake in the soil. This was rendering both nutrients unavailable for plant uptake due to decreased root iron concentration and uptake. Zinc deficiency prevents transfer of iron from root to shoot in zinc deficiency conditions. The results are in agreement with Rengel and Romheld (2000) who reported that zinc deficiency led to iron deficiency, due to prevention of transfer of iron from root to shoot in zinc deficiency conditions. The results are in agreement with Mortvedt (1991) who reported that the antagonistic interaction between iron and manganese was probably due to the reduction of manganese concentration by dilution effect, reduction in root to shoot ratio, reduced manganese uptake, or toxic concentration of iron in plant tissue. Further, the results conform to the findings of Moosavi and Ronaghi (2010) who reported that soil iron application decreased root manganese concentration of dry bean by 17% due to the dilution effect. At pH 5.5 and 6.5 concentration of iron in seeds and leaves was high. At pH levels, solubility of iron increased and the dominant ferric (Fe^{3+}) form was converted to a ferrous (Fe^{2+}) form in the soil, and was then absorbed by plants. The results are in agreement with Rout and Sahoo (2015) who did similar work reported that insoluble ferric (Fe^{3+}) form was reduced and converted to a ferrous form in the soil, and was then absorbed by plants and translocation into plant tissue.

At pH 7.5, concentration of iron in seed and leaves was low indicating that iron predominantly exists as Fe^{+3} chelate forms in the soil, and cannot absorb under this form because there was less available in the soil. The results are in agreement with Rengel (2015) who did similar work reporting that increasing soil pH, especially above 6.5, results in decreased extractability and plant availability of soil zinc and iron.

Genotypes responded differently on concentration of zinc in seeds and leaves. Differences in Fe concentrations found in each genotype in leaves and seeds, suggest that there is a variety of difference in the uptake and partitioning of nutrients in common bean and genetic makeup. The results were similar to the findings of Tryphone and Nchimbi-Msolla (2010) who reported that different iron and zinc concentration found in each genotype for both seeds and leaves was due to their difference in uptake capacity and partitioning of nutrients in the different parts of plant. Some genotypes in this experiment showed tolerance in low pH (5.3), example NUA 11 showed high concentrations of iron in seed in low pH. This demonstrates the superior performance of the genotype when grown on acid, thus it might have genes for acidic condition.

Genotypes × pH levels interaction did not have significant differences in both iron in leaf and seeds. The sum of square of pH of iron in leave contributed more than genotype and interaction. This indicates that concentration of iron in leaves was influenced by soil pH factors than genotype and interaction. The sum of square of genotype of iron in seed contributed more than pH and interaction. This indicates that concentration of iron in seed was influenced by genotype than pH and interaction.

However, micronutrient concentrations in leaves in all soil pH were higher than micronutrient concentrations in seeds; the results indicate that the availability of micronutrients was adequate in the soil and was absorbed by common bean. The results are in agreement with Fernandes et al. (2013) who reported that higher concentration of Fe and Zn in the leaves than in grains in the current study may be attributed to the role of leaves as the source of assimilates which is accumulated in grains as the sink. The higher accumulation of micronutrients in leaves and stem is related to their functions in plant metabolism. Iron acts in the synthesis of chlorophyll, and participates in photosynthesis and respiration (Fernandes et al., 2013).

Concentration of zinc in leaf and seeds (mg/kg)

Soil pH is known to control the uptake of micronutrients from soil so it is a quite important factor to be observed. This showed that soil pH had a strong impact on the common bean growth and absorption of micronutrients. At pH 5.3, concentration of zinc in seed and leaves was low due to high content of free iron, and manganese ions which caused adsorption of zinc to non-exchangeable form on their hydrated oxides surface. The results are in agreement with Phogat et al. (1994) who reported that low zinc contents in most of the soils probably is due to high content of free iron, aluminium and manganese ions which caused adsorption of zinc to non-exchangeable form on their hydrated oxides surface. The results also were similar to the findings of Hafeez et al. (2013) who reported that insoluble zinc compounds formed are likely to be with Mn 90 and Fe hydroxides from the breakdown of oxides and adsorption on carbonates, specifically magnesium carbonate. Under the submerged conditions for rice cultivation, zinc is transformed into amorphous sesquioxide precipitates or franklinite; $ZnFe_2O_4$ (Hafeez et al., 2013). Further, uptake of zinc ion was reduced in acidic soil due to reduction in loading of polyvalent cations in the apoplasm of root cortical cells. The results were similar to the findings of Marschner (1995) who reported that in acid soils, there is a reduction in loading of polyvalent cations in the apoplasm of root cortical cells, not only Ca^{2+} but also Mg^{2+}, Zn^{2+}, and Mn^{2+}.

At pH 5.5 and 6.5, concentration of zinc in leaves was high; examples NUA 16 at pH 5.5 and NUA 23 at pH 6.5 had high concentration of zinc in leaves. At pH 5.5 and 6.5, solubility of zinc increased and the dominant form of Zn^{++} was taken up by genotypes. The results were similar to the findings of McCauley et al. (2017) reported that the nitrogen (N), potassium, calcium, magnesium and sulphur are more available within soil pH 6.5 to 8, while boron (B), copper, iron, manganese, nickel (Ni), and zinc are more available within soil pH 5 to 7. The results are also in agreement with Rengel (2015) who did similar work reporting that increasing soil pH, especially above 6.5 results in decreased extractability and plant availability of soil zinc and iron.

At pH 7.5, concentration of zinc in both leaves and seeds was low because hydroxides and carbonates present in soil lead to adsorption of zinc on their surface or precipitation of zinc as zinc hydroxide or zinc carbonate, which reduce zinc availability to soil which was required to be up taken genotypes. The results were similar to the findings of Hafeez et al. (2013) who reported that the lower availability of zinc under alkaline conditions is attributed to the precipitation of zinc as zinc $(OH)_2$ or $ZnCO_3$.

Genotypes responded differently on concentration of zinc in seeds and leaves. Differences in zinc concentrations found in each genotype in leaves and seeds, suggest that there is a variety difference in the uptake and partitioning of nutrients in common bean. The results were similar to the findings of Tryphone and Nchimbi-Msolla (2010) who reported that the differences in iron and zinc concentration found in each genotype for both seeds and leaves were due to their difference in uptake capacity and partitioning of nutrients in the different parts of plant. Some genotypes in this experiment showed tolerance in low pH (5.3) and high pH (7.5). Examples NUA 17 and NUA 79 at pH levels 5.3 and 7.5, respectively showed high concentrations of zinc in seed both in acidic and alkaline soil. This demonstrates the superior performance of the genotype when grown on both acidic and alkaline soil and thus they might have genes for both kinds of stresses, that is, the acidic and alkaline condition, it is therefore important to exploit by the common bean breeders to develop acid and alkaline tolerant and high yielding genotypes.

Genotypes × pH levels interaction did not have significant differences in both zinc in leaf and seeds. Sum of square of pH in both seeds and leaves contributed more than genotype and interaction. This indicates that concentration of zinc in seeds and leaves was influenced by soil pH factors than genotype and interaction.

However, micronutrient concentrations in leaves in all soil pH were higher than micronutrient concentrations in seeds, the results indicate that the availability of micronutrients was adequate in the soil and was absorbed by common bean. The results are in agreement with Fernandes et al. (2013) who reported that, the amounts of micronutrients accumulated in the vegetative part, that is, in the leaves and stem, were higher than the amounts in the reproductive structures. The higher the accumulation of micronutrients in leaves and stem is related to their functions in plant metabolism. Zinc used in the formation of chlorophyll and some carbohydrates, conversion of starches to sugars and its presence in plant tissue helps the plant to withstand cold temperatures (Fernandes et al., 2013).

Correlation among variables

The positive correlations between concentration of iron in leaves with concentration of iron in seed, the concentration of zinc in seeds and leaves indicated that the improvement for one of the traits could lead to significant parallel increase of concentration of iron and zinc in leaves and seeds. This suggested that it possible to develop cultivars with high zinc and iron concentrations both in leaves and seeds. This result was in agreement with the study by Tryphone and Nchimbi-Msolla (2010) who reported that a significant positive correlation between grain iron and zinc concentration and leaf Fe and zinc concentration suggests that genetic factors for increasing iron and zinc are co-segregating with genetic factors for increasing zinc.

Concentration of zinc in leaves was positively correlated with concentration of iron in leaves and concentration of zinc in seeds was positively concentrated with concentration of iron in seeds. This implies that the amount in leaves can be reflected in seeds. It further shows that these traits may be important for zinc and iron predictors and perhaps it is important for zinc and iron improvement in bio fortified common beans. This result was in agreement with the study by Tryphone and Nchimbi-Msolla (2010) who reported a significant positive correlation between grain iron and zinc concentration and leaf iron and zinc concentration suggests genetic factors for increasing iron and zinc are co-segregating with genetic factors for increasing zinc.

Conclusion

At low soil pH of 5.3, the ability to uptake the zinc and iron concentration in both leaves and seeds was low compared to optimal soil pH of 6.5. However, some genotypes such as NUA 11 and NUA 17 showed high performance in absorption of zinc and iron at pH 5.3. Therefore, selecting and growing common bean genotypes that are tolerant to low pH, such as as NUA 11 and NUA 17 genotypes, could lead to increased production enhancing household and national food security. Also, some genotypes showed high ability in absorption of zinc and iron at pH greater than 6.5 which are optimal conditions for most micronutrients in the soil. NUA 79 at pH 7.5 demonstrates high performance of the genotype when grown in alkaline soil. The study recommends the determination of the morphological and chemical characteristics possessed by the tolerant genotypes in acidic and alkaline condition. Furthermore, screening many common bean genotypes should be done to identify more cultivars that are tolerant to soil acidity and alkalinity with potential and quality grain on such acidic and alkaline soils in the future.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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