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Genetic parameters estimate of iron and zinc nutrients in common bean genotypes

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There is need to know the heritability of different traits for the effective selection of parents for future breeding activities. A study was carried out to determine heritability of iron and zinc in common bean. Crosses were made with each donor and recipient parents to obtain four different types of crosses. Part of the F1 seed from each cross was sown in the screen house to produce F2 seeds and also backcrossed to both parents. Heritability was estimated using backcross method for high broad sense heritability and narrow-sense heritability. Broad sense heritability for progenies of NUA 11 × Zawadi (56%), NUA 11 × Pesa (76%), NUA 17 × Zawadi (57%) and NUA 17 × Pesa (59%) were obtained. Narrow sense heritability estimates for progenies of NUA 11×Zawadi, NUA 11 × Pesa, NUA 17 ×Zawadi and NUA 17 × Pesa were 65%, 71%, 79% and 63%, respectively. Genetic advance (GA) values for NUA 17 × Zawadi, NUA 11 × Pesa, NUA 17 × Pesa and NUA 11 × Zawadi was 35, 12.3, 3.5 and 1%, respectively. This study demonstrates that there is a potential for improvement of concentration of iron and zinc in common bean genotypes. Therefore, selection of a superior genotype on the basis of its phenotypic performance, heritability of traits could be well exploited.

Key words: Common bean, iron, zinc, heritability, genetic advance, GA as percentage of mean (GAM).

INTRODUCTION

Heritability is the most important genetic parameter on which different breeding strategy depends on (Singh and Ceccarelli, 1995). The knowledge of heritability is a prerequisite for the formulation of breeding plans on scientific lines.

There is need to know the heritability of different characters such as Micronutrients which are used for selection of parents for future breeding programme. Common bean (*Phaseolus vulgaris* L.) is the most important legume for human consumption worldwide and it is an important source of microelements, especially iron and zinc. Bean biofortification breeding programs develop new varieties with high levels of Fe and Zn targeted for countries with human micronutrient deficiencies. Biofortification efforts thus far have relied on phenotypic selection of raw seed mineral concentrations in advanced generations.

Micronutrients are essential elements needed in small amounts for adequate human nutrition and include the elements iron and zinc. To develop common bean

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cultivars with iron and zinc concentrations in seeds that meet the specific dietary needs of bean consumers, it is necessary to study the genetic parameters of these minerals.

The expression of a maternal effect of iron and zinc concentrations in common bean seeds depends on the evaluated gene pool and the tested hybrid combination. Similarly, there is a wide range of variation for narrow-sense heritability and predicted gain with selection estimates for iron and zinc concentrations in Middle American and Andean common bean seeds. Genetic parameter estimates are important to identify the nature of the action of genes involved in the control of quantitative traits, and enables the evaluation of the efficiency of different breeding strategies for obtaining genetic gains and maintaining the genetic variability (Cruz and Carneiro, 2006).

In the field of quantitative genetics, the concept of heritability is used to partition observable phenotypic variation between individuals into genetic and environmental components (Falconer and Mackay, 1996).

Estimation of heritability in populations depends on the partitioning of observed variation into components that reflect unobserved genetic and environmental factors. Therefore, the objective of this study was to determine the heritability and other parameters of Fe and Zn nutrient concentration in common bean genotypes.

MATERIALS AND METHODS

Experimental site

The screen house experiment was carried out at Sokoine University of Agriculture (SUA) which is found in the Morogoro region, Tanzania. SUA is located at 6° 45' S latitude and 37° 40' E longitudes at an altitude of 547 masl.

Soil sample collection, preparation 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 one kilogram 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 (Thompson and Banerjee, 1991). 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 (MacLean, 1982). Available P was extracted using the Bray 1 method (Bray and Kurtz, 1945) and quantified by the ascorbic acid calorimetric 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). The soil was mixed thoroughly with basic nutrients (rates in mg/kg soil) nitrogen 40 (as sulphate of ammonia), potassium 10 (as potassium chloride), and zinc 10 (as zinc sulphate).

Experimental material, layout, design and trial management

Plant materials were selected based on screening of common beans genotypes for iron and zinc concentrations.

Therefore, NUA 11 and NUA 17 were selected as donor parents because of high concentration of both iron and zinc respectively, while Zawadi and Pesa were selected as recipient parents because of low concentration of Fe and Zn. Parental lines were planted in the screen house located at Sokoine University of agriculture (SUA). Six pots were used per variety. Three seeds were sown per pot and thinning was done two weeks after planting.

Watering was done once a day throughout the growth of the plants so as to make sure that there are flowers for crossing for longer time. The recipient and donor parents were sequentially planted at an interval of seven days to permit synchronization or nicking of flowering of the crossing parents. Donor lines (NUA 11 and NUA 17) were planted first because of their late flowering at an interval of seven days before planting recipient parents (Zawadi and Pesa). Crosses were made between genotypes with higher Fe and Zn concentration in seeds (NUA 11 and NUA 17) and genotypes with lower concentration of Fe and Zn (Zawadi and Pesa) used as male and female parents, respectively.

Mating design and hybridization procedure

Emasculation and pollination were done either early in the morning or evening as described by Tumwesigye (1988). The procedure of crossing involved emasculation of the female flowers (Zawadi and Pesa) line and transfer of pollen from donor flowers (NUA 11 and NUA 17) to the stigma of emasculated bean plants. Both rubbing and hooking methods were used. Pollination was performed by rubbing the pollinated stigma of the male flower to the female flower. Crosses were as follows: - NAU 11 x Zawadi, NUA 11 x Pesa, NUA 17 x Zawadi, and NUA 17 x Pesa to get F1 populations (Figure 1). Hooking technique was done by removing the pollinated stigma of donor parents by means of forceps and hooking it on the flowers of recipient parents. Forceps were sterilized by dipping in alcohol to avoid contamination with pollen or other pathogenic organisms from one flower to another. The pollinated flowers were covered with small pieces of cello-tape to avoid desiccation of flower. Then a cotton thread and a tag labelled with the pedigree of the cross were tied loosely on the flower stalk. At maturity, the pods were harvested together with their identification tags. These were sun-dried and threshed to give F1 seed. Thereafter, seeds were bulked into four replicates for iron and zinc analysis at SUA laboratory using a completely randomized design (CRD). Part of the F1 seed from each cross was sown in the screen house to produce F2 seeds and also backcrossed to both parents.

Grain micronutrients analysis

At maturity, the pods of F1, F2 and backcross plants were harvested, sun-dried and threshed to give F1, F2 and BC seeds. Thereafter, seeds were put into four replicates for iron and zinc determination at SUA Laboratory. A gram of ground seed was weighed in digestion tubes. The solution was therefore ready for

Figure 1. Hybridization process in screen house.
Source: Author

determination of iron and zinc as per AAS method (AOAC, 1995).

Statistical and genetic analyses

Genstat statistical package was used to compute means, variance, standard deviation and standard error of variation between variables. Mean performance of the crosses and parents were obtained based on the general analysis of variance model in GenStat 15th edition. The genetic parameters were estimated from the variances of the parents' (P1 and P2) and the F1, F2, BC1 and BC2 generations based on seeds generation for each hybrid combination.

Estimation of heritability (broad sense, narrow sense) and genetic advance

The genetic parameters were estimated from the variances of the parents (P1 and P2) and the F1, F2, BC1 and BC2 generations based on concentration of zinc and iron for each population. The broad-sense heritability and the narrow-sense heritability were estimated with the backcross method (Warner, 1952), by the following expressions

Broad-sense heritability

The broad-sense heritability was estimated using the formula suggested by Warner (1952):

$$h_a^2 = \frac{\sigma_G^2}{\sigma_P^2}$$

Narrow-sense heritability

Narrow-sense heritability was estimated by the following expressions suggested by Warner (1952),

$$h_r^2 = \frac{\sigma_A^2}{\sigma_P^2}$$

Where σ^2_G refers to the genotypic variance, estimated by:

$\sigma^2_G = \sigma^2_P - \sigma^2_E$

σ^2_E represents the environmental variance in F_2 estimated by:

$\sigma^2_E = (\sigma 2F1 + \sigma^2_{PI} + \sigma^2_{P2})/3)$, σ^2_P is the phenotypic variance; $\sigma^2_P = \sigma^2_{F2}$

σ^2A is the additive variance, estimated by:

$\sigma^2A = 2\sigma^2F2 - (\sigma^2BC1 + \sigma^2BC2)$

The range of heritability estimates were categorized as follows as suggested by Johnson et al. (1955): Low: 0-30%, Medium: > 30-60%, High: > 60%.

Genetic advance

The extent of genetic advance expected by selecting certain proportion of the superior progeny was calculated by using the following formula suggested by Robinson et al. (1949)

Genetic advance (GA) = $k.\sigma_{p.}h^2$

Where: K = Intensity of selection 5% (k= 2.06), σp = Phenotypic standard deviation, h^2 = Heritability in narrow sense.

Genetic advance as percent of population mean (GAM)

The GAM was estimated for comparison of the extent of predicted genetic gain for the studied traits using the equation given by

Johanson et al (1955): GAM = $\frac{GA}{\bar{X}}$ X 100

Where: GA= Genetic advance
$\bar{X}$ = General mean character

The GAM was categorized as suggested by Johanson et al. (1955) as: 0-10% = Low, 11-20% = Moderate, and >20% High

RESULTS

Pre-cropping soil fertility status and pH curve

Results of pre-sowing soil analysis showed that soils used for experimental sites were sandy clay loam in texture with a pH of 5.1. The soil is strongly acidic with medium contents of organic matter, total nitrogen and available phosphorus, respectively. Exchangeable K, and Mg in the soil were high and Ca was medium; whereas exchangeable Na was low and Cation Exchange Capacity (CEC) in the soil was high. The micronutrients such Mn, Zn and Fe were high. The physical and chemical properties of the experimental soil are shown in Table 1.

Table 1. Physical-chemical properties of the experimental soil.

Soil parameter	Value	Remark (Landon, 1991)
pH in water	5.1	Strongly acid
Cationic Exchange Capacity (CEC)	6.4	Low
Organic Carbon (% C)	3.21	High
Organic matter (% OM)	4.31	High
Nitrogen (%)	0.50	Medium
Phosphorous (mg/kg^{-1})	9.33	Low
Extractable K (Cmol(+) kg^{-1})	0.91	High
Extractable Na (Cmol(+) kg^{-1})	0.19	Low
Extractable Mg (Cmol(+) kg^{-1})	2.33	High
Extractable Ca (Cmol(+) kg^{-1})	2.28	High
DTPA Extractable micronutrients (mg kg^{-1})		
Fe	54.96	High
Zn	4.08	High
Mn	6.31	High
Particle size analysis (PSA)		
%Clay	31.96	
%Silt	8.94	
%Sand	54.5	
Textural class	Sandy clay loam (USDA, 1975)	

Source: Author

Table 2. Genetic parameters and components of variation in four crosses of common bean genotypes.

Genetic parameter	Iron concentration		Zinc concentration	
	NUA 11 x Zawadi	NUA 11 x Pesa	NUA 17 x Zawadi	NUA 17 x Pesa
Additive variance	0.31	0.68	0.53	0.61
Environment variance	0.21	0.23	0.29	0.4
Phenotypic variance	0.48	0.96	0.67	0.97
Genotypic variance	0.37	0.73	0.58	0.67
Broad sense heritability	0.56	0.76	0.57	0.59
Narrow sense heritability	0.65	0.71	0.79	0.63
Genetic advance	1	12.3	35	3.5
GAM	0.93	1.43	13.32	1.28

Source: Author

Heritability and components of variation

The estimates of heritability, genetic advance, components of variance are presented in Table 2. Broad sense heritability observed in NUA 11 x Zawadi was (0.56), NUA 11 x Pesa was (0.76) while NUA 17 x Zawadi was (0.57) and NUA 17 x Pesa was (0.59). Narrow sense heritability observed in NUA 11 x Zawadi was (0.65), NUA 11 x Pesa was (0.71) while NUA 17 x Zawadi was (0.79) and NUA 17 x Pesa was (0.63). Genetic advance as per cent of mean was expressed in NUA 17 x Zawadi was (35%) followed by NUA 11 x Pesa was (12.30%), NUA 17 x Peas was (3.5%) and NUA 11 x Zawadi was (1%). The GAM was categorized as suggested by Johanson et al. (1955) as: 0-10% = Low, 11-20% = Moderate, >20% and above is High as displayed in Table 2.

Concentration of iron in grain

In the population of NUA 11x Zawadi, heritability in broad sense was moderate (0.56) for concentration of iron in grain. Heritability in narrow sense was high (0.65) for concentration of iron in grain. Genetic advance was 0.93 for concentration of iron in grain. Genetic advance as per cent mean was low (1) for concentration of iron in grain as displayed in Table 2.

In the population of NUA11 x Pesa, heritability in broad sense was higher (0.76) for concentration of iron in grain. Heritability in narrow sense was high (0.71) for concentration of iron in grain. Genetic advance was 1.43 for concentration of iron in grain. Genetic advance as percent mean was low (12.30%) for concentration of iron in grain as displayed in Table 2.

Concentration of zinc in grain

In the population of NUA 17 x Zawadi heritability in broad sense was moderate (0.57) for concentration of zinc in grain. Heritability in narrow sense was high (0.79) for concentration of iron in grain. Genetic advance was 13.3 for concentration of zinc in grain. Genetic advance as per cent mean was high (35%) for concentration of zinc in grain as displayed in Table 2.

In the population of NUA 17 x Pesa, heritability in broad sense was low (0.59) for concentration of zinc in grain. Heritability in narrow sense was high (0.63) for concentration of zinc in grain. Genetic advance was 1.28 for concentration of iron in grain. Genetic advance as per cent mean was low (3.5%) for concentration of iron in grain. as displayed in Table 2.

DISCUSSION

Broad sense heritability was moderate while narrow sense heritability was high for the concentration of iron in the crossing of NUA 11 x Zawadi with low genetic advance as percentage. In crossing of NUA 11 x Pesa, both broad sense heritability and narrow sense heritability were high with moderate genetic advance as percentage. These results indicate that the additive gene effect plays an important role for concentration of iron. There is contribution equally to the production of qualitative phenotype. Early generation selection would therefore be successful. Improvement will be achieved through selection because of the environmental effect has less effect on genotypes in early generation selection. It is also indicating the important role of genetic variance; hence, direct selection for these traits could bear desirable results. This result was in agreement with the study by Panse (1957) who stated that high heritability coupled with high genetic advance indicates the additive gene effects while high heritability coupled with low genetic advance indicates the non-additive gene effects for control of the particular character.

High narrow sense heritability and moderate broad sense heritability were observed for crossing of NUA 17 x Zawadi and NUA 17 x Pesa for concentration of Zinc in grain. Genetic advance as percentage of means for the crossing NUA 17 x Zawadi while for NUA 17 x Pesa was low. A high heritability means that most of the variation that is observed in the present population is caused by variation in genotypes. High heritability coupled with high genetic advance in these crosses because of additive gene action. Hence, genetic components of these traits are important and selection based on these traits might be effective. It means that, in the current population, the phenotype of an individual is a good predictor of the genotype. Results indicate that for this trait there is high ability of transferring gene and additive gene effect plays an important role for concentration of zinc. Improvement can be achieved through selection because of the environmental effect has less effect on genotypes. This is in agreement with the findings by Mollasadeghi et al. (2012) who also reported high estimates of heritability for days to heading (84%) and thousand kernel weights (89%). Further, the results are in agreement with the findings by Sarvamangala et al. (2018) who reported that high heritability (>60%) with moderate genetic advance (11-12%) were recorded for number of primary branches at 50 days after sowing (DAS), plant spread (E-W) at 50 DAS, plant spread (N-S) at 25 DAS, pod length, pod flesh thickness, number of seeds per plant, number of clusters per plant, number of pods per cluster, dry matter content of leaves and stem. Hence, the traits are highly heritable; selection based on these traits would improve the characters.

Conclusion

This study demonstrates that the evaluated common bean germplasm has potential for improvement of concentration of zinc and iron in common bean genotypes. Therefore, in order to select a superior genotype on the basis of its phenotypic performance, heritability of traits could be efficiently utilized. Heritability was relatively greater proportion for both broad sense heritability and narrow sense heritability in all crosses. Therefore, direct selection of these genotypes can be fulfilling and the identified suitable parents and crosses should enhance selection of breeding strategies for high genetic gain in the development of high micronutrients varieties in future common bean breeding programmes. Genotypes with high zinc and iron should be used for improvement of preferred bean genotypes with low concentration of these micronutrients.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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