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FULL-LENGTH RESEARCH ARTICLE

Genotypic Variation of Microelements Concentration in Sesame (*Sesamum indicum* L.) Mini Core Collection

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Abstract Evaluation of germplasm for mineral content and selecting varieties with high quantities of essential minerals and incorporating those varieties in breeding program can assist in developing mineral-efficient crops with higher yield which can accumulate minerals from marginal soil. Sesame an oldest oilseed crop is a popular food with medicinal value although its production is often focussed in marginal and sub-marginal lands. In the present study, 60 sesame genotypes of diverse origin collected from Bangladesh, Bulgaria, India and USA were examined in the acid-digested samples by atomic absorption spectrophotometer for Fe, Zn, Cu, Mn, Cr and Co contents. All elements except Cr were found to be highly variable among genotypes. A significant discrimination showed that elements content in the sesame seeds was a seed coat coloured specific character. High-yielding developed varieties of India contain high Zn but low Fe concentration in seed. The concentration of mineral elements in black-seeded genotypes was significantly higher than those in white seeded. The indigenous collections were found to be a good reservoir of mineral elements. Correlation study among trace elements and yield attributes indicated that though Fe and Zn were not correlated significantly with yield and its components, but the two elements were interrelated. Phenotypic and genotypic coefficient of variability and heritability were high for Fe and Zn. The study suggests that observed large genetic variability for element concentrations in the genotypes provides good prospects to breed improved sesame cultivars with elevated levels of micronutrients to mitigate mineral deficiency.

Keywords Correlation · Genetic variability · Micronutrients · Seed colour · Sesame

Introduction

Micronutrient malnutrition is currently of alarming proportions in many developing nations including India and hence becoming a growing concern in the world [24]. The research interest has been centred to micronutrient malnutrition over the last few years because it leads to several diseases and causes large economic costs to society [23]. The World Health Organization (WHO) has estimated that nearly 3.7 billion people were iron-deficient, whereas in India anaemia prevalence among young children remains over 70% in most of the parts [10]. All the studied elements in the present study namely Fe, Zn, Cu and Mn, Cr and Co functions as an essential cofactor present in certain enzymes and are crucial in numerous biochemical pathways [20]. Major reason for the widespread occurrence of micronutrient deficiencies in human beings is the high consumption of foods with very low content of micronutrients. Earlier breeding program were mostly focused on the improvement of physiochemical and morphological characteristics of grain [8]. To mitigate the problem of micronutrient malnutrition, several ways have been adopted such as pharmaceutical supplementation, dietary diversification and industrial fortification, but it has

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not been fully utilized in the developing countries because of poor infrastructure and delivery system [9]. Bio-fortification of crops especially for mineral nutrients is a sustainable and economical approach and provides long-term solution and has great potential for improving the mineral nutritional status and health of poor populations of the developing world [9]. In major cereals, a number of genotypes with enhanced concentrations of elements have been developed to improve the nutritional quality of grain for human consumption, but no such major progress has been reported in oilseed crops especially in sesame [6], and hence, exploitation of large genetic variation for microelement in existing germplasm is, therefore, a high-priority research area to minimize the extent of their deficiencies. Sesame (*Sesamum indicum* L.) is an oldest oilseed with high protein (10–25%) and oil content (34–63%) [16]. Sesame seed is rich in vitamins, minerals and lignans, and it is a popular food with medicinal value [7]. In India, sesame is generally cultivated for oil (65%) and food (35%), and hence, it is one of the major sources of dietary energy and mineral micronutrients. Improvement of cereal-based foods by adding whole oil seeds has received significant consideration [1]. According to a study of Alobo [3], around 40% of millet flour has been replaced by defatted whole sesame seeds for biscuits preparation because of its high nutritious value. In this study, concentration of six essential microelements, Fe, Zn Cu, Mn, Cr, and Co was estimated in the sesame seeds of diverse genotypes including landraces, mutant lines, high-yielding developed varieties, indigenous collections (IC) and exotic collections (EC) from India, Bangladesh, USA and Bulgaria. An understanding of the nature of genetic variability will have a direct effect on developing efficient breeding strategies for micronutrient content.

Materials and Methods

The mini core subset comprising only about 10% of the core collection (611 accessions from USA, Bulgaria, India and Bangladesh) drawn from NBPGR, New Delhi, held at Department of Genetics and Plant Breeding, Calcutta University, was selected for the present study. The present mini core collection still signifies the diversity of the entire core collection, and genotypes for mini core collection were selected based on origin and geographical distribution, agronomical, morphological and quality traits. Core collections (10% of total collection) and mini core collections (either 10% of core collection or 1% of total collection) are of great value due to its drastically reduced size for proper exploitation of genetic resources [21]. Sixty sesame genotypes (Supplementary Table 1) were grown in randomized block design with three replications at agricultural experimental station of Calcutta University at Baruipur (22.35°N, 88.44°E.). The crop was grown following normal cultural practice in *Rabi/summer* season in 2011, 2012 and 2013. Five randomly selected plants from each replication were recorded for morphological trait namely days to 50% flowering (DTF), days to maturity (DTM), capsule length (CL), number of capsules/plant (NCP), number of seeds/capsule (NSC), 1000 seed weight (SW) and seed yield/plant (SY). Mean of three successive seasons was used to construct the table of morphological characters.

Estimation of Trace Elements

Digestion Procedures

For wet digestion, three replicates of 1 g ($\pm$0.0001 g) from crushed and homogenized samples for each year were treated with 10 mL mixture of three acids of 70% HNO_3, 70% $HClO_4$ and 98% H_2SO_4 (10:4:1) at 80°C on the hot plate. The sample was heated electrically to nitrify and decompose the sesame seeds until the solution became clear and dry. After cooling, the residue was diluted with deionized water and then filtered. Then, the volume was made up to 100 mL with distilled water. The blank digestions were also carried out in the same way.

Calibration Curves

The calibration curves were prepared from standards by dissolving appropriate amounts of the metal salts (Sigma-Aldrich, USA) in purified nitric acid, diluting with deionised water and storing as stock solutions in a quartz flask. Fresh working solutions of final concentration of 2, 1 and 0.5 ppm were obtained by serial dilution of stock solutions. The respective standards that were to be analysed in a Beer-Lambert analysis concentrations were entered and the units were assigned (mg/L = ppm). The standard certified reference materials for Fe, Zn Cu, Mn, Cr and Co were all 1000 mgL^{-1} provided from the Export Quality Laboratory, BCKV, West Bengal. The measurements were taken by calibration using aqueous mixed standards prepared in HNO_3 (1 M). All calibration curves were based on five standard stock solutions (1 gL^{-1}) including a blank. For preparation of aqueous standard solutions, appropriate dilutions of a 1 gL^{-1} multi-element solution were applied. The calibration ranges were selected according to the expected concentrations of the elements of interest and depended on the technique applied.

Sample Analysis

The concentrations of elements were determined in an air–acetylene flame by AAS method using deuterium background correction. Varian AA240 atomic absorption spectrometers were used for metal analyses. Measurements were taken using a hollow cathode lamp for Fe, Cu, Zn, Mn, Cr and Co at wavelengths of 248.3, 324.8, 213.9, 279.5, 357.9 and 240.7 nm, respectively. The measurement was replicated five times to minimize the error for each replicate. Sixty genotypes under study were estimated for mineral element content, and the table of mineral element content was developed on the basis of mean data.

Data Analysis

The data analysis was conducted by using a SPSS (version17.0; Chicago, IL, USA) [17]. An initial descriptive statistics, including mean, standard deviation (SD), standard error (SE), critical difference (CD) range and frequencies, was performed. Correlation analysis was used to find the relationship between microelements and yield attributing traits. Analysis of variance was also computed for all the thirteen traits using SPSS. Genetic parameters were estimated for the 13 characters to identify variability among 60 genotypes. Genotypic (σ^2 G), phenotypic (σ^2 P) and error (σ^2 E) variances were calculated for each trait. Phenotypic (PCV) and genotypic coefficients of variation (GCV) were also calculated [5]. Broad-sense heritability was defined as the ratio of the genetic variance [σ^2G] between genotypes to the total phenotypic variance ($\sigma^2 P = \sigma^2 G + \sigma^2 E$) [2]. Genetic advance was calculated as GA (%) $= K \times \sigma_P \times h_{bs} \times 100$, where K (selection differential at 5%) = 2.06 where, σ_P = the phenotypic standard deviation and h_{bs} = broad-sense heritability. Genetic advance over mean as % (GAM) was calculated as per cent of the genetic advance over the mean.

Results and Discussion

Variation of Mineral Concentration and Morphological Traits in 60 Genotypes

The analysis of variance revealed significant variation among genotypes for all traits (Table 1). Fe content varied from 35.20 (Savitri) to 231.50 (EC-90) ppm among the 60 genotypes (Table 2). The genotype EC-107 possessed maximum Zn concentration (80.09 ppm), minimum being

Table 1 Analysis of variance table for thirteen characters of 60 sesame genotypes

Source of Variance	*df*	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Co (ppm)	Cr (ppm)	DTF	DTM	CL (cm)	NCP	NSC	SW (g)	SY (g)
Replication	2	1.896	0.052	0.27	0.166	0.177	0.007	0.272	0.23	0.133	0.067	0.110	0.072	0.15
Treatment	59	6656.0**	216.5**	15.00**	51.53**	338.0**	7.10**	58.03**	16.4**	0.15**	429.91**	118.0**	0.56**	15.1**
Error	118	1.754	0.013	0.033	0.020	0.059	0.006	0.973	1.01	0.009	0.009	0.009	0.006	0.015

** Significant at 1% level of significance; * significant at 5% level of significance; days to 50% flowering (DTF), days to maturity (DTM), capsule length (CL), number of capsules/plant (NCP), number of seeds/capsule (NSC), 1000 seed weight (SW) and seed yield/plant (SY)

Table 2 Mean, critical difference and standard error and genetic parameters of 13 characters of sesame

	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Co (ppm)	Cr (ppm)	DTF	DTM	CL (cm)	NCP	NSC	SW (g)	SY (g)
Mean	105.7	61.79	19.46	22.98	35.92	0.63	32.78	89.69	2.16	56.47	55.5	3.12	10.07
SD	47.29	8.48	2.23	4.13	10.57	1.55	4.49	2.53	0.22	11.97	6.27	0.43	2.24
Max	231.5	80.09	25.2	35.9	53.3	2.1	48	95	2.8	99.89	72.49	4.32	18.01
Min	35.2	43.09	12.2	14.6	9.3	0.1	27	85	1.59	30.14	43.66	2.2	6.57
CD (1%)	2.87	0.24	0.39	0.3	0.52	0.17	2.14	2.19	0.2	0.2	0.2	0.17	0.26
CD (5%)	2.16	0.18	0.29	0.23	0.39	0.12	1.61	1.64	0.15	0.15	0.15	0.13	0.2
SE	0.76	0.06	0.1	0.08	0.14	0.04	0.56	0.58	0.05	0.05	0.05	0.04	0.07
CV	1.25	0.18	0.93	0.61	0.67	1.24	3	1.12	4.42	0.165	0.17	2.54	1.21
Vg	221.8	72.18	4.99	17.17	112.6	5.36	19.01	5.14	0.04	143.3	39.34	0.18	5.03
Vp	221.9	72.19	5.02	17.19	112.7	5.37	19.99	6.15	0.05	143.31	39.35	0.19	5.04
PCV	44.57	13.75	11.51	18.04	29.55	24.56	13.64	2.76	10.99	21.2	11.29	14.03	22.31
GCV	44.55	13.75	11.47	18.03	29.54	24.52	13.3	2.52	10	21.2	11.29	13.8	22.28
H^2	99.9	99.9	99.3	99.9	99.9	99.7	95.1	83.5	83.8	99.9	99.9	96.7	99.7
GAM	28.73	28.28	23.32	36.72	60.21	44.8	26.5	4.72	18.7	43.22	23.01	27.8	45.66

Days to 50% flowering (DTF), days to maturity (DTM), capsule length (CL), number of capsules/plant (NCP), number of seeds/capsule (NSC), 1000 seed weight (SW) and seed yield/plant (SY). Coefficient of variation (CV), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), genetic and phenotypic variances (Vg and Vp), genetic advance over mean (GAM), broad-sense heritability (H^2)

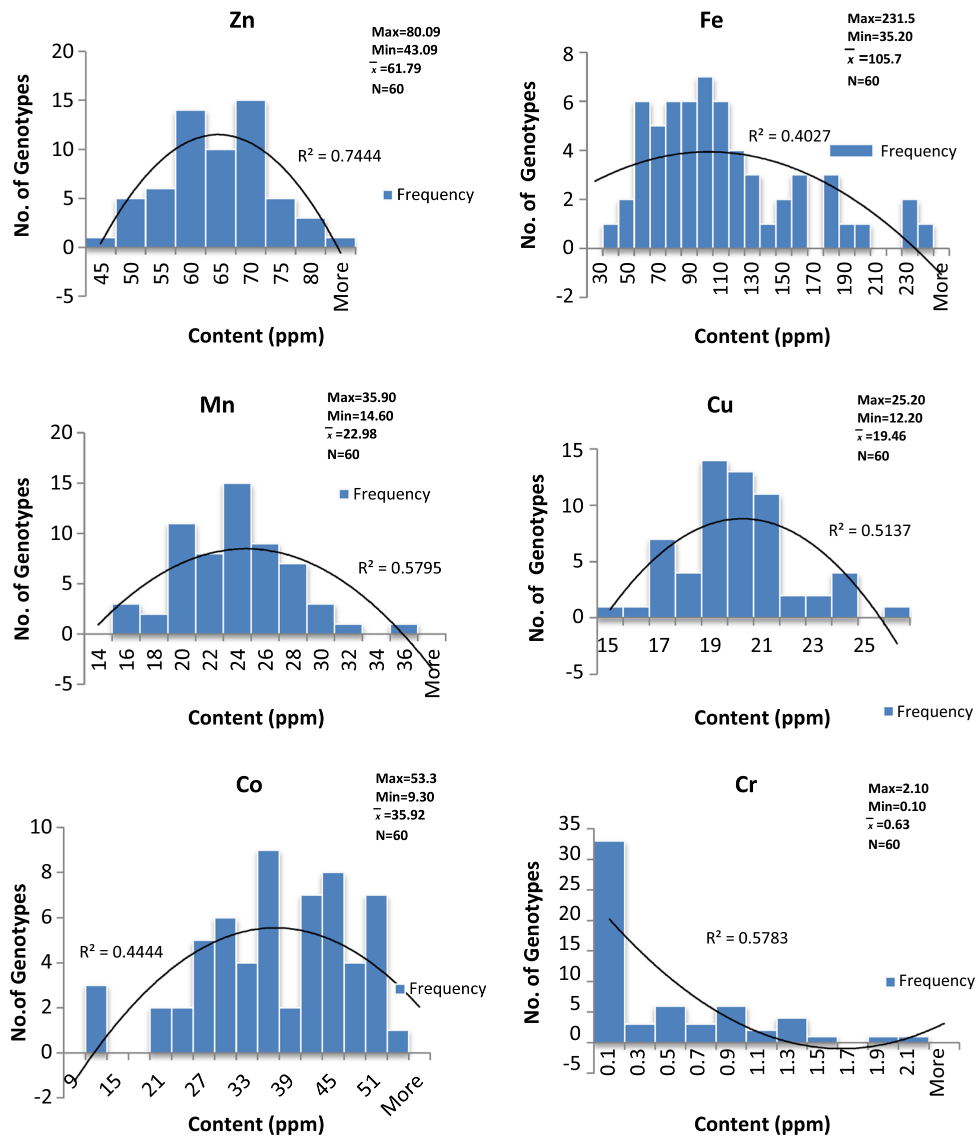

Fig. 1 Distribution and differences for contents of Fe, Zn, Cu, Mn, Co and Cr among 60 sesame genotypes

shown by the indigenous collection IC-60 (43.09). Özcan et al. [14] and Cao et al. [6] have reported the similar range of microelements in sesame collection of Turkey and China, respectively. Quite a high range of variation of Fe and Zn content existed among the genotypes (Fig. 1). High range of variation was also observed for Cu, Mn, Co and Cr content of the genotypes. The mineral content varied from 12.20 (IC-60) to 25.20 (DSS-09) ppm for Cu, 14.6 (EC-79) to 35.9 (EC-90) ppm for Mn, 9.3 (EC-79) to 53.3 (TMV-6) ppm for Co, 0.1 (TKG-22) to 2.10 (EC-107) ppm for Cr (Table 2). A significant range of variation was observed for all the traits (Table 2), and this variation provided chances to select materials with high contents of microelements. Obiajunwa et al. [13] reported sesame seeds as a good reservoir of essential and beneficial micronutrients such as Cr, Mn, Fe, Ni, Cu and Zn. Maximum yield was obtained from IC-63 followed by IC-59 and IC-62. Phenotypic variances and phenotypic coefficients of variation exhibited a bit higher values but maintained a close relation with genotypic variances and genotypic coefficients of variation for all the traits, indicating low G × E interaction. The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were high for Fe content (44.57; 44.55%) followed by Co content (29.55, 29.54%) and Cr content (24.56; 24.52%) of the seeds (Table 2); however, low GCV and PCV were observed for days to maturity (2.52; 2.76%), followed by capsule length (10.06; 10.99%) and number of seeds per capsules (11.29; 11.29%) (Table 2). High estimates for these genetic parameters were also reported by Sarwar et al. [19]. High heritability was recorded for all of the thirteen traits. A moderate genetic advance (GA%) over mean was found among

Table 3 Comparison of mineral content among different collection of sesame genotypes

Collections	Fe	Zn	Cu	Mn	Co	Cr
Developed varieties						
Mean	83.73	61.68	19.6	22.6	45.3	0.4
Standard error	5.99	1.84	0.5	0.85	0.90	0.07
Range	116.3	30.52	9.5	14.4	17.8	1.09
Exotic collection						
Mean	119.76	61.28	19.0	22.8	27.4	0.6
Standard error	9.88	1.31	0.3	0.95	1.68	0.1
Range	174.5	28.89	7.4	21.3	29.8	2
Indigenous collection						
Mean	124.43	62.39	18.0	23.6	32.2	0.1
Standard error	17.67	3.34	0.8	1.03	2.37	0.0
Range	184.5	33.84	10.9	12.6	24	0.3

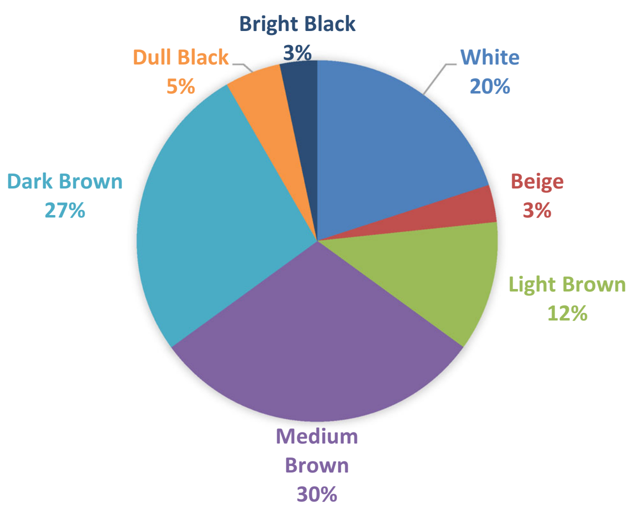

Fig. 2 Percentage of different colour genotypes in mini core collection of sesame

genotypes for Fe, Mn, Zn, Cu, days to 50% flowering, days to maturity, capsule length, number of seeds/capsule and 1000 seed weight, whereas for number of capsules/plant and seed yield/plant, Cr and Co content a high GA% (more than 40%) over mean was estimated (Table 2).

Difference of Mineral Concentration Between Indigenous, Exotic Collection and Developed Varieties

Among different groups of genotypes, high iron content was found in indigenous collections (124.4 ppm); low content was observed in high-yielding varieties (83.73 ppm) of India. Similarly, Zn content was also high in indigenous collection (62.39 ppm) and low in exotic collections (61.28 ppm) (Table 3; Fig. 2). High Fe content with moderate Zn content in the seeds of sesame was earlier reported by Alyemeni et al [4], and they suggested that incorporation of sesame seeds in bakery industry at appropriate levels may fulfil the recommended daily dietary allowances of minerals. High Cu content (19.65 ppm) was found in high-yielding varieties of India, followed by exotic collections (19.42 ppm), while lowest was observed in indigenous collections (18.84 ppm). High Cr content was estimated in exotic collections (0.65 ppm), minimum being in indigenous collections (0.17 ppm). High-yielding varieties of India contained high Co content (45.30 ppm), while in exotic collections low Co content was recorded (27.43 ppm) (Table 3). On the contrary, Mn content was found to be high in indigenous collections (23.62 ppm), low content being in high-yielding varieties (22.71 ppm). Thus, high-yielding varieties of sesame need to be upgraded genetically to become more nutritious. Based on average mean value of different collections belonging to Indian and exotic, the trend line depicted that indigenous collections were found to be good source of microelements (Table 3). This result finds support from the earlier study by Obiajunwa et al [13].

Difference of Mineral Concentration Among Different Seed Coat Coloured Genotypes

Seed coat colour of sesame is commercially an important trait [15]. Morris [12] reported that people generally consume more than twice of white sesame in comparison to black sesame. A comparison of microelements among different seed coat coloured genotypes revealed that high Fe content (134.12 ppm) was observed in dull black-coloured seeds, while very low (97.27 ppm) in medium brown-coloured seeds (Table 4; Fig. 3). Zn content was estimated to be high (65.32 ppm) in light brown-coloured seeds, while minimum (59.23 ppm) being in medium brown-coloured seeds. Cr content was high (0.90) in dull

Table 4 Comparison of mineral content among different coloured sesame genotypes

Seed coat colour	Fe	Zn	Cu	Mn	Co	Cr
White						
Mean	108.14	62.84	20.81	21.95	42.78	0.44
Standard error	15.23	3.12	0.704	1.08	2.50	0.09
Range	170	28.94	8.2	12.7	27.4	1.09
Light brown						
Mean	123.33	65.32	19.18	24.7	32.3	0.43
Standard error	26.89	2.753	0.75	1.68	3.59	0.21
Range	173.4	17.53	4.9	11.5	23.2	1.2
Beige						
Mean	107.02	64.07	18.12	21.37	43.70	0.30
Standard error	36.24	6.13	0.90	2.83	1.67	0.19
Range	153.2	26.18	4	13	7.2	0.8
Medium brown						
Mean	97.27	59.23	18.70	22.69	34.56	0.40
Standard error	9.22	2.06	0.53	0.78	2.16	0.10
Range	132.7	33.84	10.9	9.7	28.8	1.2
Dark brown						
Mean	104.46	60.778	18.35	21.31	26.51	0.66
Standard error	13.91	2.661	0.72	1.382	3.16	0.26
Standard deviation	34.08	6.518	1.77	3.38	7.74	0.63
Range	99.8	22.36	7.7	13.3	44.0	1.8
Dull black						
Mean	134.12	62.5	20.46	24.24	22.8	0.90
Standard error	30.23	4.45	0.80	3.40	5.35	0.45
Range	152.5	4.16	1.2	13.5	7.4	0.4
Bright black						
Mean	115.60	61.56	20.03	24.40	42.83	0.27
Standard error	27.15	2.39	0.34	0.34	4.75	0.23
Range	54.3	8.29	1.2	1.2	9.5	0.2

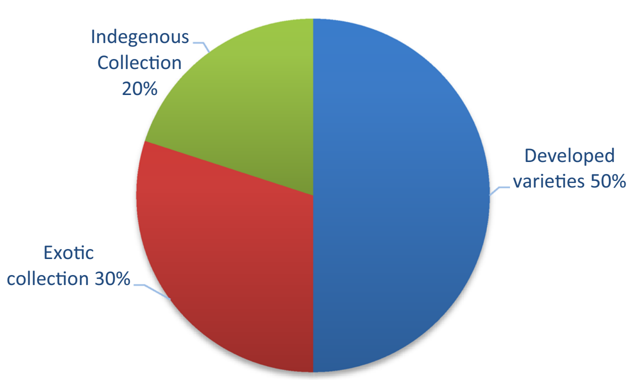

Fig. 3 Percentage of different collection of genotypes in mini core collection of sesame

black-coloured seeds, but very low (0.27 ppm) was in bright black-coloured seeds. Co content was observed to be high (43.7 ppm) in beige, followed by bright black (42.88 ppm) and white (42.78 ppm)-coloured seeds and lowest (22.8 ppm) in dull black-coloured seeds. On the contrary, Mn content was high in light brown-coloured seeds, while low in beige-coloured seeds. White-seeded genotypes were associated with high Cu (20.81 ppm) content, while beige-coloured seeds showed low (18.12 ppm) Cu content (Table 4). White-seeded sesame serves as a good source of Cu, while black-seeded sesame was found to be rich in Fe, Co and Mn content. This result is in congruence with the study on white sesame by Sani et al [18]. Light brown-coloured seeds were good reservoir of nutrients like Zn and Mn content, whereas beige-coloured seeds contain good amount of Co. Dull black-coloured seeds have high amount of Cr content. In order to improve the Fe and Zn content of seeds, black- and brown-seeded genotypes may be utilized in future breeding program with other desirable coloured seed coat to obtain favourable seed coat with high nutrients.

Correlation Analysis Between Mineral Concentration and Yield Attributing Traits

Relationships of micronutrients with seed yield and yield attributing traits have a direct influence on developing effective approaches for breeding bio-fortified crop cultivars. Correlation coefficient between yield and yield components assumes special importance in formulating the basis of selection. Correlation analysis was worked out among all the thirteen traits (Table 5). Fe was found to be positively and significantly correlated with Cu while a significant negative association existed with capsule length. Furthermore, Fe was highly and positively correlated with Zn. This emphasized that any selection for higher Fe content would likely to improve Zn content through correlated response. Zn on the other hand was positively and significantly correlated with Mn and Cu. Cr was significantly correlated with Cu in positive direction and with Mn in negative direction. Significant negative relationship was found between numbers of seeds/capsule, seed yield/plant with cobalt content. The present findings of high positive correlation between Fe and Zn find support from the study by Morgounov et al [11] in wheat. Highly significant positive phenotypic correlations coefficient was observed between seed yield and number of capsules per plant and number of seeds per capsules. The results agreed with earlier works by Uzun et al [22]. Capsule length was positively and significantly correlated with number of seeds per capsules and 1000 seed weight. On the contrary, days to 50% flowering had significant negative correlation with seed yield per plant. Such negative effect of days to 50% flowering with seed yield was earlier reported by many researchers [25]. It is important to improve the microelements along with augmenting productivity of crops. Top 10% of mini core collection having high microelement content for Fe, Zn, Cu, Mn, Co and Cr has been identified (Table 6). Exotic collection genotype, EC-90, can be

Table 5 Correlation analysis for thirteen characters of 60 sesame genotypes

	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Co (ppm)	Cr (ppm)	DTF	DTM	CL (cm)	NCP	NSC	SW (g)	SY (g)
Fe	1.00												
Zn	0.15	1.00											
Cu	0.29*	0.4**	1.00										
Mn	0.23	0.3*	0.03	1.00									
Co	−0.21	0.004	0.12	0.12	1.00								
Cr	0.177	0.116	0.41**	−0.29*	−0.311	1.00							
DTF	−0.27*	0.069	0.045	−0.005	0.6**	−0.139	1.000						
DTM	0.219	0.222	0.147	0.262*	0.047	0.049	0.183	1.000					
CL	−0.258*	−0.115	0.078	−0.250	0.175	−0.055	0.218	−0.084	1.000				
NCP	0.182	−0.002	0.012	−0.016	0.086	−0.210	0.106	−0.141	−0.010	1.000			
NSC	−0.120	−0.118	−0.068	−0.124	−0.275*	0.032	−0.217	0.053	0.36**	−0.085	1.000		
SW	−0.131	−0.005	0.003	−0.099	0.27*	−0.100	0.090	−0.096	0.220	−0.119	−0.052	1.000	
SY	0.192	−0.062	−0.116	0.029	−0.303*	−0.184	−0.431**	−0.141	0.111	0.59**	0.37**	0.218	1.000

* Significant at 5% level of significance; ** significant at 1% level of significance; days to 50% flowering (DTF), days to maturity (DTM), capsule length (CL), number of capsules/plant (NCP), number of seeds/capsule (NSC), 1000 seed weight (SW) and seed yield/plant (SY)

Table 6 List of top 10% of mini core collection having high microelement content for Fe, Zn, Cu, Mn, Co and Cr

Genotypes for Fe content	Genotypes for Zn content	Genotypes for Cu content	Genotypes for Mn content	Genotypes for Co content	Genotypes for Cr content
NIC-8316	TKG-22	OSC-207	TKG-22	RT-348	EC-79
EC-87	AMRIT	V15	UMA	GUJARAT TIL-2	EC-72
EC-90	IC-41	DSS-09	IC-54	TILLOTAMA	EC-91
IC-42	IC-59	IC-41	EC-90	B-76	EC-107
IC-59	EC-107	EC-107	EC-87	DSS-09	EC-108
EC-91		IC-59		TMV-6	IC-49
EC-67				SAHEB	
EC-107					
IC-54					
V10					

incorporated in nutrient breeding program as it possessed more than six times iron content than the popular high-yielding variety 'Savitri'. Similarly, EC-107 and IC-59 have high Fe, Zn, and Cu content in seeds and can be utilized as parent in breeding program for improvement of microelements (Table 6). It suggested that light brown-seeded sesame could be the better dietary resource for Zn deficiency. Both Fe and Zn were found to be positively associated, and simply by conventional breeding program, it is possible to improve Fe and Zn content in seeds. Moreover, among the morphological traits, seed yield was correlated positively with number of capsules/plant and number of seeds/capsule. Thus, it is possible to increase seed yield further by augmenting these two traits. The significant correlation between microelement content and morphological traits can help in the indirect selection for simultaneous improvement of both mineral contents and yield traits. Interestingly, Fe and Zn content were not correlated to either of the traits, and thus, restructuring of plant type with high yield with higher content of Fe and Zn is achievable targets through breeding approach like transfer of gene for high Fe and Zn content to high-yielding genotypes.

Conclusions

In present study, most of the indigenous collections have been found to be rich in mineral contents and hence can be used as breeding material for further research to understand the genetic mechanisms responsible for mineral absorption and accumulation. It was also evident from the study that seed coat colour of the seeds may differentiate the genotypes in relation to their microelement concentrations. Genotypes like EC-107 and IC-59 having higher Fe, Zn, and Cu have great potential to be utilized as parent in breeding programs. Of the different coloured seeds studied, the concentration of Fe and Mn in black-seeded genotypes was significantly higher than those in white seeded.

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