



Nutritional and morphological diversity in promising okra (*Abelmoschus Esculentus* L.) genotypes: linking pod pigmentation to mineral content

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Abstract

This study explored the relationship between pod pigmentation and mineral accumulation in 20 genetically diverse okra (*Abelmoschus esculentus* L.) genotypes. Significant genotypic variability was observed for calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), and manganese (Mn). The variegated pod genotype AOL-03-01 recorded the highest calcium content (1409.92 mg/100g D/W), while the red pod genotype JOL-12-12 exhibited superior levels of magnesium (565.76 mg/100g D/W), iron (98.87 mg/kg D/W), and manganese (43.60 mg/kg D/W). The purple pod genotype JOL-12-13 accumulated the highest zinc (64.56 mg/kg D/W). In contrast, the dark green pod genotype JOL-21-02 consistently showed the lowest mineral values across all parameters. The findings revealed a strong correlation between pod color intensity and mineral density, suggesting that pigmented genotypes—particularly red, purple, and variegated—may possess enhanced nutrient uptake efficiency. This variation offers a valuable insight for breeding programs targeting mineral-rich okra cultivars.

Keywords: *Abelmoschus esculentus*, okra, mineral content, pigmented genotypes, calcium, magnesium, zinc, iron, manganese

Introduction

Okra (*Abelmoschus esculentus* L.), commonly known as lady's finger, is an economically and nutritionally important vegetable crop widely cultivated in tropical and subtropical regions, particularly in South Asia and Africa. It belongs to the Malvaceae family and is known for its edible green pods that are rich in mucilage, dietary fiber, vitamins, and essential minerals such as calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), and manganese (Mn). According to Gopalan *et al.* (2007) [7], 100 grams of edible okra provides 66 mg calcium, 103 mg potassium, 13 mg vitamin C, and a range of other beneficial micronutrients. The nutritional potential of okra has attracted attention for its role in promoting health and addressing micronutrient deficiencies, especially in developing countries where access to diversified diets is limited. Micronutrient malnutrition, particularly deficiencies of iron, zinc, and calcium, is a global public health concern, often referred to as "hidden hunger" (FAO, 2021) [6]. Biofortification of commonly consumed vegetables like okra represents a sustainable strategy to enhance dietary mineral intake. Given the observed genetic variability in mineral content among okra genotypes, it is essential to identify and utilize nutrient-dense accessions in crop improvement programs. This study, therefore, focuses on evaluating the mineral content—specifically calcium, magnesium, zinc, iron, and manganese—in 20 genetically diverse okra genotypes. The findings aim to identify nutrient-rich accessions suitable for breeding programs targeting biofortified okra varieties to enhance human nutrition.

Materials and Methods

Twenty genetically diverse okra (*Abelmoschus esculentus* L.) genotypes were cultivated during the *kharif* season at the

Vegetable Research station, Junagadh Agricultural University, Junagadh (Gujarat), under uniform agronomic practices.

For mineral content estimation, marketable okra pods were harvested, dried, and ground to fine powder at the Department of Biotechnology, College of Agriculture, Junagadh Agricultural University, Junagadh (Gujarat). The analysis was carried out on a dry weight (D/W) basis using standard procedures. Atomic Absorption Spectrophotometry (AAS) was employed to determine the concentrations of calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), and manganese (Mn), following the methods described by AOAC (2005) [1] and Sadasivam and Manickam (1996) [11]. All measurements were performed in triplicate, and results were expressed in appropriate unit. The significance of differences among genotypes was assessed using Analysis of Variance (ANOVA) as per the CRD format (Panse and Sukhatme, 1985) [9].

Results and Discussion

Pod pigmentation is an easily scorable morphological trait in okra and is genetically regulated. Interestingly, it also appears to correlate—though variably—with certain biochemical traits, particularly mineral accumulation. In this study, the pod colors observed among the 20 okra genotypes included light green, green, dark green, red, purple, and variegated types. When analyzed alongside mineral content, clear trends emerged linking certain pod colors with high or low mineral levels.

Calcium (Ca) is a critical mineral element for human bone health, enzymatic functions, and cellular signalling. The calcium content among the 20 evaluated okra genotypes varied significantly, indicating strong genotypic influence on mineral accumulation. The Ca content ranged from 596.48 mg/100g D/W in JOL-21-02 to 1409.92 mg/100g D/W in AOL-03-01, with a mean value of 908.63 mg/100g D/W (Table 1).

Table 1: Calcium and Magnesium Content in Different Pod Color Genotypes

Sr No	Name of Genotype	Calcium (mg/kg)	Magnesium (mg/kg)	Name of Genotype	Calcium (mg/kg)	Magnesium (mg/kg)
Light Green Pod				Dark Green Pod		
1.	GJO-3	709.321	380.981	GO-6	878.889	403.484
2.	JOL-18-12	1644.74	547.705	JOL-20-06	1087.06	487.485
3.	JOL-18-07	863.683	410.021	JOL-20-02	870.55	427.108
4.	JOL-20-04	834.68	468.763	JOL-21-02	596.483	329.712
5.	PUSA SWARNI	760.128	388.674	JOL-21-09	650.458	397.476
	Mean	880.26	439.26	Mean	816.68	409.06
Variegated Pod				Red Pod		
1.	JOL-09-03	875.01	448.81	JOL-12-08	959.10	514.145
2.	JOL-09-06	1152.8	480.406	JOL-12-09	798.03	442.771
3.	JOL-13-03	597.44	495.171	JOL-12-10	1088.51	551.451
4.	JOL-11-12	652.15	422.179	JOL-12-12	1028.53	565.763
5.	AOL-03-01	1409.99	539.612	JOL-12-13	1126.46	518.138
	Mean	937.46	477.210	Mean	1000.12	518.46
S. Em ±	0.743	0.486				
C.D. at 5%	2.138	1.395				
C.V.%	0.142	0.183				

This wide variation reflects underlying genetic diversity and potential for calcium biofortification. These results align with findings reported by Yuan *et al.* (2022) [13] and Nwangburuka *et al.* (2021) [8], who highlighted significant genetic variability in mineral composition among okra genotypes, emphasizing the potential of integrating biochemical data with molecular analysis to guide breeding strategies. Overall, genotypes like AOL-03-01 can serve as valuable parental lines in future okra improvement programs targeting enhanced mineral nutrition.

Magnesium is essential for plant photosynthesis and human health, functioning as a cofactor in over 300 enzyme systems. Among the 20 genotypes analyzed, Mg content exhibited significant genotypic variation, ranging from 329.71 mg/100g D/W in JOL-21-02 to 565.76 mg/100g D/W in JOL-12-12, with a mean value of 461.00 mg/100g D/W (Table 1). The red pod genotype JOL-12-12, which showed the highest Mg level, also demonstrated high concentrations of iron and copper, highlighting its nutrient-dense nature and potential as a parent in biofortification breeding. The lowest Mg content recorded in JOL-21-02 aligns with its overall lower mineral profile observed across

all parameters. These findings are in line with earlier reports by El-Raheem *et al.* (2020) [4], who highlighted wide Mg variability in okra as a function of genotype and pod pigmentation.

Zinc is vital for immune function and metabolic activities in humans. In the present study, Zn content varied widely among okra genotypes, ranging from 23.46 mg/kg D/W in JOL-21-02 to 64.56 mg/kg D/W in JOL-12-13, with a mean value of 40.18 mg/kg D/W (Table 2). Zinc accumulation in plant tissues is known to be genetically governed and influenced by root uptake efficiency. The superior Zn content in JOL-12-13 reflects its potential use in breeding programs focused on enhancing micronutrient density, corroborating findings from Yuan *et al.* (2022) [13] and Rani *et al.* (2020) [10], who emphasized genotype-specific Zn uptake in okra and other vegetables.

Iron plays a crucial role in haemoglobin synthesis and energy metabolism. The iron content in the studied okra genotypes ranged from 28.60 mg/kg D/W in JOL-21-02 to 98.87 mg/kg D/W in JOL-12-12, with a mean value of 59.27 mg/kg D/W (Table 2).

Table 2: Fe (mg.kg⁻¹ dry weight) and Zn (mg.kg⁻¹ dry weight) content in promising okra genotypes.

Sr No	Name of Genotype	Calcium (mg/kg)	Magnesium (mg/kg)	Name of Genotype	Calcium (mg/kg)	Magnesium (mg/kg)
Light Green Pod				Variegated Pod		
1	GJO-3	58.83	33.26	JOL-09-03	56.75	42.84
2	JOL-18-12	94.00	47.04	JOL-09-06	72.83	35.62
3	JOL-18-07	33.60	39.36	JOL-13-03	98.03	49.35
4	JOL-20-04	41.43	36.92	JOL-11-12	39.72	31.41
5	PUSA SWARNI	33.18	29.44	AOL-03-01	42.41	41.17
	Mean	52.207	37.204	Mean	63.349	40.079
Dark Green Pod				Red Pod		
1.	GO-6	40.95	35.49	JOL-12-08	41.67	39.70
2.	JOL-20-06	31.66	29.56	JOL-12-09	54.78	41.17
3.	JOL-20-02	64.84	37.62	JOL-12-10	97.10	45.47
4.	JOL-21-02	28.60	23.46	JOL-12-12	98.87	60.48
5.	JOL-21-09	97.44	39.58	JOL-12-13	58.86	64.56
6.	Mean	53.164	33.141	Mean	73.123	50.275
	S. Em ±	0.666	0.141			
	C.D. at 5%	1.912	0.404			
	C.V.%	1.947	0.607			

The high Fe content of JOL-12-12, along with its rich Mg and Cu content, underscores its potential as a multi-nutrient biofortified line. The significant Fe variability among genotypes agrees with Nwangburuka *et al.* (2021) [8] and Cheng *et al.* (2023) [3], who reported genotype-dependent Fe accumulation in leafy vegetables. The dark green genotype JOL-21-02 consistently exhibited the lowest Fe, Zn, Mg,

Ca, and Mn, suggesting limited mineral translocation or uptake efficiency. Manganese is necessary for enzymatic activities related to metabolism and antioxidant defenses. Among the okra genotypes, Mn levels ranged from 29.55 mg/kg D/W in JOL-21-02 to 45.42 mg/kg D/W in JOL-09-06, with a mean value of 38.94 mg/kg D/W (Table 3).

Table 3: Mn (mg.kg⁻¹dry weight) and Cu (mg.kg⁻¹dry weight) content in promising okra genotypes.

Sr No	Name of Genotype	Manganese (mg/kg)	Copper (mg/kg)	Name of Genotype	Manganese (mg/kg)	Copper (mg/kg)
Light Green Pod			Variegated Pod			
1	GJO-3	41.36	1.75	JOL-09-03	39.11	9.75
2	JOL-18-12	45.22	2.19	JOL-09-06	45.42	5.92
3	JOL-18-07	45.07	2.17	JOL-13-03	35.33	7.87
4	JOL-20-04	42.93	7.24	JOL-11-12	42.80	5.82
5	PUSA SWARNI	33.45	5.92	AOL-03-01	41.13	7.82
	Mean	41.60	3.853	Mean	40.75	7.44
Dark Green Pod			Red Pod			
1.	GO-6	26.57	7.87	JOL-12-08	37.87	7.98
2.	JOL-20-06	37.79	5.96	JOL-12-09	33.39	7.83
3.	JOL-20-02	31.62	9.88	JOL-12-10	39.52	11.73
4.	JOL-21-02	26.55	5.91	JOL-12-12	42.88	11.78
5.	JOL-21-09	43.75	7.96	JOL-12-13	41.22	11.65
	Mean	34.45	7.5166	Mean	38.95	10.20
	S. Em ±	0.037	0.046			
	C.D. at 5%	0.106	0.131			
	C.V.%	0.164	1.125			

The highest Mn concentration in JOL-09-06 highlights its role as a potential donor for breeding Mn-rich okra lines. The lowest Mn concentration in JOL-21-02, consistent with its poor performance across all minerals, further emphasizes its limited use in nutritional breeding unless improved. Studies by El-Sherbeny *et al.* (2018) [5] and Younis *et al.* (2015) [14] have similarly identified such genotypic gaps that can be addressed through molecular marker-assisted selection.

In general, Red pod genotype JOL-12-12 consistently ranked among the highest for magnesium (565.76 mg/100g D/W), iron (98.87 mg/kg D/W), and manganese (43.60 mg/kg D/W). Variegated pod genotype AOL-03-01 recorded the highest calcium (1409.92 mg/100g D/W) and was among the top for zinc and iron. These pigmented pods may possess enhanced antioxidant systems and higher phenolic content, which aid in better mineral chelation and transport—an observation also supported by Rani *et al.* (2020) [10] and Cheng *et al.* (2023) [3] in coloured vegetables.

Conclusion

The observed patterns highlight a genotypic and phenotypic convergence, where genotypes with red, purple, and variegated pods tend to accumulate higher levels of Ca, Mg, Zn, and Fe. This correlation suggests that pod pigmentation—linked to phenolic and flavonoid content—may contribute to higher micronutrient density, likely via enhanced metal chelation, uptake, and antioxidant defense mechanisms. Thus, pod colour can serve as a visual pre-selection trait in okra breeding programs focused on mineral enrichment, though it should be complemented with biochemical and molecular validation.

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