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Chapter 5

Agronomic Performance, Nutritional Phenotyping and Trait Associations of Okra (*Abelmoschus esculentus*) Genotypes in South Africa

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Additional information is available at the end of the chapter

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Abstract

Okra, *Abelmoschus esculentus* L. (Moench), is an important fruit vegetable crop which belongs to the family Malvaceae. It is a good source of protein, carbohydrates, vitamins, minerals, and enzymes that are often consumed in small quantities in developing country. Okra is a highly nutritious underutilized fruit vegetable crop in South Africa. However, despite its importance for food, nutritional, and health benefits, the crop is rarely produced in some areas of South Africa. The study was carried out to assess the genetic diversity using agro-morphological traits and nutritional contents towards future use in the okra breeding programme. The experiment was carried out at the Roodeplaat research farm of the Agricultural Research Council in a randomized complete block design replicated three times. Agro-morphological traits and selected nutrients were determined. The analysis of variance for both showed highly significant differences for most traits recorded. The multivariate analysis showed a wide genetic diversity among the okra genotypes, which could be exploited in selecting suitable and potential parents when breeding for high yield and nutritional qualities. The present study revealed the genetic potential of the genotypes studied and their importance for use in the breeding programme aimed toward addressing malnutrition, food security, and poverty alleviation by breeding for increased yields, and nutritional contents in South Africa.

Keywords: fruit, genetic diversity, multivariate analysis, nutritional content, okra

1. Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is an annual fruit vegetable crop propagated through seed and commonly grown commercially in tropical and sub-tropical regions of the world. It is also grown in warmer temperate regions of the Mediterranean region [1]. Currently, this crop is found all over the African continent [2–5]. It is one of the most important

African indigenous fruit vegetable crops belonging to the family Malvaceae. It originated in Ethiopia [6], the former Abyssinia, and was cultivated by the ancient Egyptians. Its cultivation spread throughout Middle East and North Africa [7, 8]. In Ethiopia it is also called Kenkase (Berta), Andeha (Gumuz), and Bamia (Oromica/Amharic) [9]. Authors of Refs. [4, 9–11] reported that okra is a multipurpose crop due to its various uses of the pods, fresh leaves, buds, flowers, stems, and seeds. The immature fruits can be consumed as vegetables, in the form of salads, soups and stews, fresh or dried, fried or boiled. The plant contains mucilage in various plant parts, which is associated with other important substances including tannins [12]. The biological functions of mucilage within the plant includes aiding in water storage, decrease diffusion in plants, aid in seed dispersal and germination, and act as a membrane thickener and food reserve. Okra contains proteins, carbohydrates, and vitamins [8] that plays a substantial role in food security, human health [5], and nutritional security. Consumption of young and green immature okra fruits is very important as fresh fruits, and it can be consumed in different forms [13] such as boiled, fried, or cooked. Okra seeds contain about 20% protein and 20% oil [7]. It was reported that the seeds can be dried and the dried seeds are a nutritious material that can be used to prepare vegetable curds or roasted and ground to be used as coffee additive or substitute [14]. Moreover, okra leaves can also be used as animal feed. In similar fashion, the green leaf buds and flowers are also edible [15]. Okra mucilage is used for industrial and medicinal applications [16] in different parts of the country in the world. Industrial use of mucilage is usually for glace paper production and has a confectionery use. Okra has found medical application as a plasma replacement or blood volume expander [17, 18]. A study conducted in China suggested that an alcohol extract of okra leaves can eliminate oxygen free radicals, alleviate renal tubular-interstitial diseases, reduce proteinuria, and improve renal function [19].

Okra is a traditional crop, which requires relatively low agronomic input, but can contribute substantially to sustainable agricultural production and productivity in South Africa and beyond. This species is under-exploited and have potential for contributing toward food, nutritional, and health security for current alarmingly growing population, contributes a vital role in income generation and poverty alleviation. It is a valuable source of nutrients [20] with important medicinal properties [21]. Its wide range of biodiversity contributes to food, nutritional security, health benefit, and income diversification in the subsistence farming system that predominates in the different parts of the world. Therefore, improving the genetic potential of indigenous fruit vegetables like okra species is of paramount importance for yield, and nutritional quality. Evaluation and characterization of germplasm is important and the first step to the breeders who desire sources of genes for novel traits. It was reported that characterization of genetic resources refers to the process by which accessions are identified, differentiated, or distinguished according to their morphological and/or nutritional quality traits [22]. Currently, there is no clear record on genetic characterization and evaluation of the genetic resources of this crop under South African condition. Okra production and productivity is negatively due to the use of low yielding local landraces and use of poor agronomic management practices. Furthermore, production technology, development of new cultivar, and okra management practices are very limited in South Africa. To date, there are no reports of any improved cultivars developed in South Africa for high yield, nutritional contents as well as disease and pest tolerance. In addition,

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the variation in the agro-morphological and nutritional composition of okra has not been determined in the country. Therefore, it is important to profile okra genotypes using agro-morphological traits and nutritional contents in the immature fruits of okra for future breeding purposes in South Africa.

2. Agronomic performance and nutritional quality of okra

For field evaluation, 50 genotypes of okra (**Table 1**) were obtained from the AVRDC (World Vegetable Center), Taiwan. In this study, the field experiment was conducted in the Gauteng province of South Africa under rain-fed conditions during the 2015 and 2016 summer growing seasons at Roodeplaat (25°59′S; 28°35′E) research farm of the Agricultural Research Council. It is situated at an altitude of 1168 m above sea level. Roodeplaat has annual maximum average temperature ranged from 15.38 to 30.36°C and receives an average annual rainfall of 584.21 mm during the cropping seasons. The experimental site has loam clay type of soil. Two seeds of each okra genotype was planted in three rows of 4 m length spaced at 0.85 m between rows and 0.4 m between the plants. The seedlings were thinned into one when fully establishment in the field. A randomized complete block design with three replications was applied. Trial management such as plot preparation, and hand weeding were done when required and supplementary irrigation was employed when rainfall is not enough for the growth and development of the crop under research.

2.1. Agronomic characterization

Morphological phenotypic traits were evaluated and recorded using the International Plant Genetic Resources [23] okra descriptor list. The agro-morphological traits record includes plant height (PH), number of fruits per plant (NFP), number of branches per plant (NB), number of leaves per plant (NL), number of internodes (NI), internode length (IL), stem diameter (SD), leaf length (LL), leaf width (LW), days to 50% flowering (D50%F), fruit length (FL), fruit diameter (FD), fresh fruit yield (FYLD), number of seeds per fruit (NSF), 1000 seed weight (TSwt), shell weight (Swt), fruit harvest index (FHI) and grain yield per plant (GY) (**Table 1**).

2.2. Nutritional characterization

The fresh and immature fruits of the okra genotypes were harvested and analyzed for total protein content and selected mineral elements (calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, aluminum, boron and zinc) at the analytical laboratory of the Agricultural Research Council in Pretoria, South Africa. Fruits of okra were collected from each replicate in the field for analysis of mineral elements and protein content. Laboratory analysis were performed in triplicate and the results were expressed as mean for analysis (**Table 2**).

Protein analysis: A dry oxidation method was used to determine the total nitrogen and the crude protein contents (N × 6.25) of the samples [24, 25].

Genotypes	Morphological phenotypic traits																	
	PH	NFP	NB	NL	NI	IL	SD	LL	LW	D50%F	FL	FD	FYLD	GY	NSF	TSwt	Swt	FHI
VI033778	84.50	22.33	6.89	37.83	8.50	69.18	17.60	17.06	7.89	56.33	27.91	25.47	136.80	61.21	65.07	47.36	110.73	35.51
VI041763	124.82	22.06	7.11	43.72	11.61	86.44	16.38	18.21	7.96	48.33	23.66	21.22	127.30	53.65	61.30	43.05	79.42	39.13
VI037993	81.52	31.00	8.78	55.56	8.00	61.08	16.06	16.32	8.98	56.33	21.85	25.17	130.76	53.20	67.78	38.63	81.95	33.16
VI060803	150.31	13.50	9.28	47.39	17.72	83.84	28.18	17.33	7.09	69.00	15.10	17.56	85.71	45.90	57.92	43.00	61.79	54.47
VI046567	79.01	26.17	7.72	41.50	6.78	47.02	17.83	17.73	7.26	56.33	23.64	24.07	262.88	63.58	63.87	42.76	116.50	20.59
VI055219	114.29	14.33	9.61	53.72	8.06	60.14	17.31	17.78	8.56	53.00	17.40	18.93	87.67	42.27	61.80	42.23	66.07	50.54
VI060802	89.68	26.28	7.56	49.28	7.11	38.22	20.76	13.28	5.69	54.17	22.18	23.95	126.96	65.90	74.02	43.02	101.19	41.35
VI055996	107.96	10.33	7.93	21.00	8.52	55.72	21.67	18.44	7.55	55.00	25.03	24.27	113.44	44.06	68.00	38.46	75.97	34.23
VI037996	77.49	13.11	8.94	46.67	6.61	61.20	16.10	16.58	8.75	74.50	14.58	23.74	253.58	39.02	69.44	42.21	156.03	23.04
VI060824	102.64	13.56	7.83	59.61	8.56	73.47	22.66	15.07	8.08	52.50	14.30	20.46	198.34	33.36	61.82	39.86	103.69	23.78
VI047672	121.06	25.78	5.17	38.17	6.83	57.54	20.49	13.61	7.09	53.00	21.19	22.89	105.86	65.04	65.58	43.16	91.81	38.39
VI033803	78.71	4.83	7.44	39.78	10.11	48.94	22.80	17.74	8.80	53.83	18.21	17.73	94.29	45.00	60.45	38.58	75.28	45.35
VI033796	91.75	12.72	5.50	34.44	8.17	87.80	19.77	20.83	9.36	53.67	23.44	17.57	110.27	37.13	64.32	35.19	80.03	31.20
VI033777	87.73	13.39	8.61	48.50	5.67	60.91	17.57	15.93	7.51	55.67	32.32	18.44	91.20	42.07	56.58	43.37	68.09	53.73
VI060679	96.77	20.61	4.17	24.44	8.11	67.51	13.36	14.33	7.08	53.33	22.25	22.70	115.59	62.75	60.35	42.23	91.18	67.39
VI033775	126.96	14.78	6.83	33.56	12.00	70.37	14.02	16.77	8.94	48.33	18.98	17.49	95.42	48.07	56.27	37.67	68.69	40.96
VI050958	121.87	12.06	6.44	40.11	8.50	72.05	21.94	14.99	8.26	49.17	15.89	15.27	90.92	42.46	59.20	40.69	66.82	43.52
VI055110	93.30	14.06	5.56	41.72	7.22	51.05	19.85	16.48	7.20	51.67	15.46	18.59	94.61	36.02	61.72	43.98	71.36	49.33
VI049632	69.02	15.83	5.67	51.61	9.61	55.56	24.95	15.70	7.72	56.33	14.10	18.98	79.15	42.44	56.95	37.28	65.70	48.16
VI056069	110.68	11.17	4.33	34.89	6.11	60.84	18.91	18.79	8.12	67.17	15.25	18.65	84.43	37.89	59.65	39.10	66.27	49.73
VI056457	75.88	27.61	6.28	37.39	8.61	86.20	14.22	12.34	5.28	49.67	17.86	23.79	105.96	59.66	55.23	38.51	65.03	60.03
VI033797	90.07	9.11	8.89	37.22	10.39	40.91	20.56	15.70	7.11	48.33	17.81	20.26	97.37	41.32	55.04	42.31	75.54	48.15
VI060131	75.59	11.22	6.94	57.42	6.00	72.39	24.05	15.58	9.81	55.26	14.91	17.66	78.69	37.19	51.57	37.66	64.43	55.98
VI060817	87.28	10.39	6.00	40.67	7.89	62.44	14.06	14.47	8.01	56.67	14.32	22.86	93.18	41.72	64.90	37.42	69.70	43.06
VI050150	90.61	15.61	6.00	39.61	12.28	51.19	15.52	16.13	8.75	53.00	14.17	17.58	84.10	41.80	53.42	34.73	80.40	49.31

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Genotypes	Morphological phenotypic traits																	
	PH	NFP	NB	NL	NI	IL	SD	LL	LW	D50%F	FL	FD	FYLD	GY	NSF	TSwt	Swt	FHI
VI039652	111.73	27.11	4.61	26.56	5.78	47.60	16.59	14.69	6.60	48.00	21.78	25.47	108.13	52.64	55.22	48.50	71.67	64.70
VI050957	78.80	3.44	8.33	47.83	12.22	52.10	25.89	15.92	8.89	67.17	12.48	18.62	88.92	31.67	57.40	34.98	53.64	36.05
VI060678	75.84	19.72	4.17	37.83	7.17	50.05	14.94	12.85	5.43	48.00	24.12	24.45	123.21	56.86	67.06	45.90	78.92	41.90
VI055220	94.83	12.39	5.33	38.72	6.78	84.58	20.00	15.61	7.13	55.83	16.08	18.14	122.06	42.04	58.80	37.60	63.17	30.86
VI039618	113.47	27.17	5.11	31.78	10.50	50.51	10.98	14.36	4.96	49.33	22.91	24.54	132.82	62.65	58.63	32.08	96.62	24.19
VI060313	122.90	2.39	10.44	55.56	10.78	70.84	19.18	16.94	8.22	68.33	12.47	15.01	78.23	32.86	48.72	31.36	40.17	39.22
VI046561	72.54	7.61	5.47	39.78	7.59	42.81	14.74	15.93	8.30	56.33	15.10	22.08	130.58	41.00	55.82	45.12	97.95	34.71
VI055119	111.20	16.17	6.67	56.22	11.06	51.42	21.48	15.19	7.52	49.17	12.99	13.32	68.00	37.33	44.40	38.50	54.51	74.69
VI060823	107.59	2.78	9.00	46.56	7.72	72.87	23.58	16.86	5.84	66.83	11.73	14.26	52.41	25.88	50.62	28.66	31.57	55.64
VI056449	76.63	11.61	5.50	34.28	6.83	70.99	18.67	16.67	6.49	56.33	17.90	16.24	88.55	41.01	56.38	35.76	64.74	43.17
VI060822	77.78	3.92	6.78	40.57	6.72	46.53	19.22	15.82	9.01	69.67	8.06	21.14	65.91	33.76	64.72	30.17	38.44	46.08
VI041215	73.36	8.44	5.50	40.78	6.50	71.14	17.97	13.43	5.69	49.17	15.67	15.13	95.29	46.08	59.68	39.35	68.90	43.36
VI055421	90.93	8.28	5.89	26.28	7.28	73.64	21.88	16.80	8.28	53.33	13.36	14.39	50.36	25.33	34.79	32.08	24.64	71.22
VI056450	75.69	15.28	6.72	38.11	6.17	58.47	12.54	14.21	6.63	52.50	12.61	18.06	75.82	37.19	52.74	42.96	59.90	69.45
VI039651	86.17	23.17	4.39	27.94	7.33	35.07	11.52	9.77	5.74	51.83	19.26	22.39	111.85	41.58	56.35	33.26	72.58	39.02
VI055423	89.17	12.11	3.83	33.89	5.61	51.65	17.64	18.18	5.59	54.17	15.25	17.06	81.64	36.94	51.92	36.03	61.89	49.48
VI039638	112.89	14.58	5.39	21.67	8.11	93.21	13.68	12.43	6.16	47.50	13.95	16.36	95.93	35.92	47.75	38.72	58.86	40.98
VI056079	88.43	11.72	4.72	29.83	4.56	49.11	11.60	17.45	6.60	55.83	16.08	15.67	82.29	34.27	50.81	36.69	61.46	53.27
VI041210	58.63	4.33	7.89	53.56	6.67	47.36	12.68	15.96	7.75	56.33	13.68	15.89	69.70	28.86	40.81	32.26	39.69	44.81
VI050960	88.79	4.06	5.94	38.17	7.17	41.82	17.43	15.24	7.00	68.17	8.98	21.13	64.07	19.85	62.72	26.36	32.41	40.33
VI055884	47.15	1.56	5.67	39.61	12.50	38.48	13.95	15.43	7.94	74.33	13.41	11.91	77.61	30.93	47.10	30.57	33.83	38.32
VI056081	70.67	4.22	4.94	47.83	4.78	34.08	18.16	14.82	7.52	68.33	11.29	12.77	51.65	28.32	39.63	26.57	41.49	48.64
VI050956	57.26	2.06	8.33	60.67	5.50	52.15	17.74	15.57	7.57	46.83	12.51	11.42	40.49	19.58	34.71	17.75	31.69	43.86
VI050959	57.20	2.61	7.39	42.56	5.94	27.33	20.85	16.09	7.12	69.33	10.04	10.40	68.61	19.51	31.82	19.24	24.39	28.08
VI060790	45.81	4.00	4.50	36.50	4.22	23.93	12.13	17.23	8.38	66.17	9.03	16.77	120.07	19.07	31.80	27.37	61.17	24.32

Genotypes	Morphological phenotypic traits																	
	PH	**NFP**	**NB**	**NL**	**NI**	**IL**	**SD**	**LL**	**LW**	**D50%F**	**FL**	**FD**	**FYLD**	**GY**	**NSF**	**TSwt**	**Swt**	**FHI**
MS Genotype (G)	2851.36 ns	380.18**	16.20**	564.85**	37.77**	1581.03**	97.02*	21.74 ns	8.08	358.03**	157.33**	96.42**	10797.12**	907.67**	570.52**	261.47**	3779.95**	947.40**
MS Season (S)	715.43**	2062.66**	641.63**	126.00 ns	37.02 ns	15599.48**	9490.11**	10045.17**	3991.76**	128.76 ns	1937.33**	16.18 ns	54306.32**	32019.06**	7945.44**	1791.23**	125752.76**	46954.33**
MS G x S	7787.95**	223.42**	18.23**	283.97**	22.84**	1453.34**	199.89**	120.91**	48.12**	180.32**	156.01**	103.28**	10195.02**	1221.83**	688.83**	235.34**	5114.72**	1395.51**
CV (%)	7.91	22.29	25.87	7.76	22.27	8.17	16.15	16.16	27.18	3.73	6.77	5.65	7.57	7.02	5.32	5.05	7.83	7.07
LSD (0.05)	57.48	4.63	2.95	3.87	2.69	19.98	9.31	7.77	4.92	2.36	7.25	5.68	50.2	20.28	15.55	8.52	41.91	22.67

*, ** significant at 0.05 and 0.01, respectively; MS: mean squares; CV: coefficient of variation; LSD: least significant difference; **: highly significant at the 0.01 probability level; G: genotype; S: season; PH: plant height; NFP: number of fruits per plant; NB: number of branches per plant; NL: number of leaves per plant; NI: number of internodes; IL: internode length; SD: stem diameter; LL: leaf length; LW: leaf width; D5%F: days to 50% flowering; FL: fruit length; FD: fruit diameter; FYLD: Fresh fruit yield; NSF: number of seeds per fruit; TSwt: 1000 seed weight; Swt: shell weight; FHI: fruit harvest index and GY: grain yield per plant.

Table 1. Mean, mean squares, and least significant differences for morphological phenotypic traits of okra genotypes.

Genotypes	Concentration of mineral elements (mg kg^{-1}) and total protein content (%) in dry basis											
	K	Ca	P	Mg	Na	Fe	Al	B	Zn	Mn	Cu	Protein[a]
VI033775	21777.4667	4919.5200	3784.0067	3113.6567	566.6250	305.4650	66.4567	34.1087	33.8938	22.1936	6.9753	16.2625
VI033777	20199.5500	4049.4267	3364.8200	3049.9750	365.9400	243.1507	63.6460	26.5820	32.9281	15.0279	7.3294	14.9563
VI033778	20976.1833	4039.0500	3728.2700	2848.3783	427.8367	587.3322	248.2663	29.1645	39.4484	21.5503	9.5204	11.7188
VI033796	24781.3500	5659.1100	4910.4033	3933.0633	316.2057	580.2120	286.3238	27.1184	48.0576	33.4163	8.6937	13.1500
VI033797	19496.4000	5459.1100	3628.6400	3283.7150	465.3840	319.8758	87.9778	35.3847	39.5059	21.5607	5.7575	13.8500
VI033803	29732.9667	5251.9117	5086.1233	3859.9633	360.7653	244.4440	86.3564	33.0417	43.5501	23.3683	9.0871	14.6688
VI037993	25140.4000	5251.9967	4474.0133	3384.7550	346.3737	196.7373	50.2557	30.8226	41.6551	21.2625	9.1599	18.2500
VI037996	19549.6333	3625.8133	3758.7700	3042.0667	465.9550	314.0100	52.6698	27.7749	39.8695	18.1510	7.7360	19.1750
VI039618	20532.6667	6145.3900	4137.7267	3254.7100	473.0543	327.1998	134.5552	35.0339	37.3512	19.3329	7.1605	20.1375
VI039638	19143.2500	6434.1967	3634.2800	3239.2133	541.3173	237.0652	58.1016	33.6771	35.9769	21.1262	7.0842	18.0125
VI039651	18187.3667	5633.1733	3561.0367	3248.9417	445.8867	543.2582	198.0592	32.4005	35.5071	25.3214	8.8091	15.4750
VI039652	20332.4500	6799.6683	4230.5233	3538.3867	458.9537	229.6398	53.5867	38.2204	35.1689	21.8068	6.1323	16.1688
VI041210	22947.1500	5933.6300	3882.7467	3427.8833	358.7303	364.1095	122.3338	38.2099	34.9044	31.9749	8.3166	21.4531
VI041215	26819.2833	5868.2317	5023.2233	4119.1067	334.1373	450.2562	167.4110	31.2438	46.4874	25.0930	8.3696	15.8063
VI041763	21640.4833	7854.9067	4073.6100	3443.6567	647.6400	300.9452	123.0660	34.3759	36.9295	26.4952	7.4171	17.0000
VI046561	22492.4000	5654.5283	3447.9233	3464.2400	407.2767	229.2835	53.4742	33.3572	33.5706	23.6109	7.0620	14.6813
VI046567	21929.6667	5400.8167	4072.6400	3506.6067	354.7370	343.1148	97.5733	28.1606	42.7555	21.9402	9.2944	16.4313
VI047672	21399.2833	7307.9933	4188.6933	4308.0267	580.9880	163.1217	48.7502	38.8493	41.6830	23.0591	6.6877	16.3625
VI049632	26532.9667	7061.0317	4871.0333	4544.9117	565.4510	219.7217	46.9941	37.2903	46.2990	20.4599	9.7918	20.4813
VI050150	19739.6833	4545.3967	3529.1033	2866.0400	375.8160	349.8102	131.2670	36.4835	36.8622	22.2440	6.6769	13.7375
VI050956	25174.1333	5645.9150	3523.6000	3844.0583	550.9303	267.0100	39.8715	32.6595	33.1479	22.7143	7.6115	16.8250
VI050957	18911.7167	6711.7317	3341.8667	3097.9567	605.7137	213.1867	73.3786	48.9588	35.9209	18.8477	7.8291	13.2563

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Genotypes	Concentration of mineral elements (mg kg^{-1}) and total protein content (%) in dry basis											
	K	Ca	P	Mg	Na	Fe	Al	B	Zn	Mn	Cu	Protein[a]
VI050958	30384.6500	7192.0783	4773.4067	4264.1850	371.8990	311.4003	88.2743	29.7895	46.0846	29.7776	7.8219	12.7063
VI050960	22861.0000	4190.5433	3760.5800	3129.9400	244.8727	214.4395	42.9363	31.1971	36.5446	21.9904	6.8090	16.6438
VI055110	22807.7500	5744.4700	3869.0600	3454.7217	390.3277	524.4017	235.1390	33.6967	38.6857	23.5905	8.1426	13.6375
VI055119	19443.2833	5290.2550	3633.6933	3186.2433	410.1533	305.7237	98.7495	37.6476	36.2588	21.0558	7.2133	17.1688
VI055219	23070.6500	4870.4083	3764.9300	3397.6450	602.0480	320.4245	69.9319	27.1459	31.2486	26.2729	6.6490	13.1188
VI055220	22039.1167	4959.4950	3930.5167	3313.6267	470.6367	331.5973	170.5438	31.1861	37.3141	24.7236	8.7069	13.9250
VI055421	22250.2333	5170.7733	4055.0100	3382.7017	541.3853	329.6240	154.7592	36.9024	37.6627	25.2132	7.3251	16.9313
VI055423	26855.7833	8242.4900	5246.9500	4346.0583	387.0487	269.0805	77.1162	37.6389	46.8939	38.4287	9.8883	10.5063
VI055884	26798.8667	6911.8150	4562.8467	4272.4200	378.2300	211.1957	43.7957	35.2969	43.8937	25.6543	9.8447	15.1625
VI055996	23505.8000	7743.9483	4134.1000	4332.8850	487.7183	312.7035	62.6846	34.3182	44.9328	27.8276	8.7146	0.0000
VI056069	28706.5167	6461.0400	4559.9067	4027.2917	458.7717	568.4727	248.5053	32.3390	41.9579	26.1344	7.8264	13.5438
VI056079	25276.4667	5577.5167	4487.2500	4071.8733	611.6603	248.1673	200.1460	37.7277	40.0674	25.4336	7.1736	14.5063
VI056081	24805.6667	7059.3000	4299.2600	4213.8217	606.2797	138.0773	61.8873	38.9608	43.3255	20.0586	8.8108	14.1344
VI056449	22553.7000	5359.5200	4707.8667	3515.1033	440.1860	275.8338	110.4897	28.1297	29.1162	19.2992	7.3364	15.8969
VI056450	20130.4667	5227.5867	3508.4967	2993.3767	435.4760	615.2870	217.4698	27.4518	33.7007	30.4491	8.6698	0.0000
VI056457	19639.6500	4436.3000	2992.7300	2935.7233	688.4357	184.4547	55.1700	34.1046	29.9832	15.7108	4.7011	18.3469
VI060131	18126.8833	6714.2217	3888.1533	2935.2733	753.2457	231.2972	55.9428	34.7359	40.4822	15.7953	8.1000	13.1188
VI060313	22134.4167	6565.3033	3187.5967	3537.5250	778.8260	258.7387	36.2318	31.8077	26.9255	22.8010	7.0514	15.7750
VI060678	20507.9667	4557.0733	3709.7167	2944.3133	454.7623	339.4737	136.0335	37.2839	36.7775	22.4670	6.3063	0.0000
VI060679	17983.3167	6812.6650	3331.1167	3023.8683	630.4910	524.9860	250.7027	35.8244	34.4461	22.9563	7.3806	13.3813
VI060802	23664.0333	3282.7067	4423.4400	3438.6433	338.7350	626.8430	315.8953	26.7719	45.3539	23.1645	7.8676	14.1031
VI060803	20822.4333	5370.3683	3266.7200	3014.2350	505.6263	292.1103	66.6540	34.0651	35.9979	21.4352	6.7664	13.2188

Genotypes	Concentration of mineral elements (mg kg^{-1}) and total protein content (%) in dry basis											
	K	Ca	P	Mg	Na	Fe	Al	B	Zn	Mn	Cu	Protein[a]
VI060822	23264.7500	6857.1450	4022.7600	3973.4783	505.8723	118.2778	40.3196	36.9215	35.6317	29.4834	6.6292	16.8844
VI060824	24137.4500	4564.6567	3796.4967	3204.3767	346.6313	746.5115	462.5675	31.2123	38.4833	29.4813	5.9867	16.6813
G. mean	22591.4630	5748.1354	4003.6012	3507.1444	475.1095	333.2189	121.5722	33.5885	38.3313	23.6905	7.7005	14.5054
LSD (0.01)	950.10	95.05	79.43	60.04	29.61	15.39	8.26	1.50	2.79	0.69	1.10	0.33
M. squares	25960000.00**	3993160**	901596.00**	690456.00**	43058.20**	63194.89**	24920.75**	56.08**	76.06**	63.46**	4.04**	60.65**
CV(%)	2.60	1.00	1.20	1.10	3.80	2.80	4.20	2.80	4.50	1.80	8.80	1.40

G. mean: grand mean; M. square: mean squares; CV: coefficient of variation; LSD: least significant difference; **: highly significant at the 0.01 probability level; [a] conversion factor of 6.25; K^{+}: potassium; calcium: Ca^{2+}; phosphorus: P^{3-}; magnesium: Mg^{2+}; sodium: Na^{+}; iron: Fe^{2+}; manganese: Mn^{2+}; B^{3+}; aluminum: Al^{3+}, Zn^{2+} and copper: Cu^{+}.

Table 2. Mean values for the concentration of selected mineral elements and crude protein content in the immature fruits of okra genotypes.

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Mineral analysis: K^+, Ca^{2+}, P^{3-}, Mg^{2+}, Na^+, Fe^{2+}, Mn^{2+}, B^{3+}, Al^{3+}, Zn^{2+} and Cu^+ contents in the samples of immature fruits were determined using the inductively coupled plasma-optical emission spectrometric method [26].

2.3. Data and analysis

The morphological phenotypic and nutritional data were subjected to analysis of variance using Agronomix computer software [27]. The means of all okra genotypes were compared by the least significance difference (LSD) at 0.05 probability level. The mean data were standardized and subjected to multivariate analysis [28] using principal component analysis (PCA). The correlation coefficients were also computed to determine the degree of trait association [28].

3. Results and discussion

3.1. Variation in agronomic traits

Characterization and evaluation of crop species is essential in crop improvement programme [29] to identify potential parents according to their traits [22]. In the present study, 50 okra genotypes were characterized for agro-morphological and nutritional traits. The mean squares for the analysis of variance for most of the agro-morphological traits and nutritional values recorded showed highly significant differences (**Tables 1** and **2**) among the genotypes indicating that there were the existence of wide genetic and phenotypic and nutritional variability among the 50 okra genotypes evaluated. Furthermore, the existence of significant genotype by season interaction showed the influence of the growing season on the agronomic performance of traits. The maximum variation was observed in leaf width, branches, number of fruits closely followed by number internodes. Other characters also showed considerable variability. Even though plant height and leaf length was not significantly different, the genotype VI060803 appeared to have the tallest plant compared to the rest of the genotypes (150 cm) and the shortest genotypes was VI060790 (45.81 cm) (**Table 1**) and these traits were influenced by the gene factor. It is usually observed that tall and thin plants easily lodge due to environmental factors such as excessive flooding, rain, wind and when they produce high fruit during favorable growing seasons, however, they are also essential for firewood, construction of houses, fences and for livestock feed. Furthermore, selection for tallness gene might be important when the yield performance is low during unfavorable environmental conditions. This okra genotype may produce high dry biomass compared to the rest of the genotypes and can be used as livestock feed during the dry season. Plant height and leaf length were not significantly different which might be due to these traits are controlled by dominant gene. The present values were double higher than the values (17.96–76.65 cm) reported in 21 okra genotypes in Ghana [30]. This might be due to the variation in genetic and environmental factors which prevailed during the growth period. According to Ref. [31], the plant height is controlled by gene. He also reported that it is closely associated with number of flowering nodes, average fruits per plant and number of internodes.

The number of fruits per plant varied from 2.00 in genotype VI055884, VI060313, and VI050956 to 31 in genotype (VI037993) followed by genotypes VI056457 (27) and VI039618 (27). Ref. [30]

reported the average mean value of 6.00, which was lower than the values reported in the current study. They also reported 20.00 fruits per plant, which was lower than the values found in the current investigation. Furthermore, [32] reported the number of fruits per plant that varied from 3.22 to 5.67 in Nigeria. The immature fruits of okra are consumed as a vegetable and should be fresh, tender, and green without indication of coloration. Selection of potential parents based on this phenotypic trait would be essential in okra breeding programmes to develop new cultivar in the country.

Number of branches ranged from 3.83 to 10.44 and the highest value was recorded in genotype VI060313 and closely followed by VI055219. Moreover, the number of leaves ranged from 21.00 in genotype VI055996 to 60.67 in genotype VI050956 followed by VI060131, VI055119 and VI037993 during flowering. Leaves are the primary sources of photosynthesis to produce better yield and yield-related traits in okra genotypes. The values currently reported were higher than the values what [32] reported in Nigeria. Highly significant variation was also observed in the number of internodes, internode length, stem diameter, leaf length and width. The genotype that had tallness gene had highest number of internodes, internode length, and thick stem. The thicker the stem, resists the environmental influences from lodging and can withstand high fruit yield. Days to 50% flowering varied from 46.63 to 74.50 and influenced by genotype and genotype by season interaction. The genotype VI050956 was the first to flower, which is significantly flowered early compared to the rest of the genotypes. Some of the genotypes were expected to be similar in early flowering (**Table 1**). This genotype could be selected for earliness trait. Early maturing in okra genotypes can be useful to escape drought condition and can be cultivated as climate change crop in drought prone areas of South Africa. Therefore, this trait is potentially very important in okra improvement programmes for earliness and drought escaper genes. Depending on the traits of interest, the user of this crop can select the genotypes for early maturity or late maturity groups for future use. These values reported in the present study were lower than the values reported in Nigeria for days to 50% flowering among the genotypes [30]. Fruit length significantly varied from 10.41 to 32.32 in which the highest value was recorded in genotype VI055777. This trait is the most economically important trait, which affects the yield of okra. As a fruit vegetable crop, the longer pods are very important for consumption and preferred by the consumers in the South Africa, therefore, this trait is important as selection criteria for the improvement programme of okra in the county. Ref. [30] reported that fruit length is the most important determinants in okra production. The wider the size and the longer the fruit is associated with higher number of seeds in the fruit per plant. In this study, the widest fruit was recorded in the genotypes VI037993 and VI039652 with the highest number of seed (67.78) per plant and thousand seed weight, which were the primary determination of the ultimate yield in okra. Hence, widest fruit, highest number of seeds and thousand seed weight were considered as selection criteria for the breeding of okra genotypes for yield and yield related traits. Ref. [33] reported that seed weight is largely a function of seed components such as protein, fat, ash, and nitrogen free extracts. The highest fresh fruit yield, number of seeds per fruit and grain yield per plant were found in the genotypes VI046567 and VI060802. The values reported in the present study were higher than the values reported by [30] in 21 okra genotypes. The genotypes that produced the heaviest pod wall (fruit shell wall) could be selected for parental lines to produce high fodder

yield for animal feed compared to the rest of the genotypes where the highest pod wall were recorded in VI037996, VI046567 followed by VI033778 and VI060802. This could help to provide the type of okra which is useful as fodder during the dry season. In this experiment, it is clearly seen that the late maturing genotypes produced significantly higher fodder yield compared to other genotypes. Fruit harvest index is one of the most important trait for drought tolerance and results in yield gains in both drought, irrigated or rain fed environmental conditions. In the present study, the highest fruit harvest index was recorded in the genotypes VI055421 and VI056450 and could be used as parental lines in the development of new cultivar for drought condition in the South Africa.

3.2. Variation in nutritional traits

Vegetables are major sources of essential minerals and vitamins and are often low in calories, fat, and sugar that are an important addition to any diet consumed, particularly for resource poor community. Deficiency of mineral elements and crude protein content is a wide problem in alarmingly growing human populations in the world. The mineral elements play an important role in the development of the human body [34]. The existence of wide genetic differences among the crop plants for the nutritional quality would assist the improvement of the crop of interest for high quality through breeding in the available germplasm collection/gene pool [34–36]. Identification of okra genotypes based on selected mineral elements and crude protein content will help in the selection of the best parents for breeding nutritionally enhanced okra for food and nutritional security in South Africa [36]. Calcium and phosphorus are very important in the formation of strong bones and teeth, for growth, blood clotting, heart function and cell metabolism [37, 38]. In the present study, the mean squares for the analysis of variance for the concentration of mineral elements and protein content recorded showed highly significant differences for all the nutritional traits (**Table 2**) in the immature fruits of okra genotypes indicating that there was a wide genetic variability among the genotypes evaluated. It was reported that potassium is the major cation of intracellular fluid, which helps to regulate the acid base balance, osmotic pressure and water balance [39, 40]. The concentration of potassium varied from 17983.32 to 30384.65 mg kg^{-1} and the highest concentration and uptake of potassium was observed in the genotype VI050958 closely followed by genotype VI033803, while significantly the lowest uptake was observed found in the genotype VI060679, respectively (**Table 2**). The overall mean value of the genotypes recorded in this study was much higher than the values what [41] reported in okra in Cameroon. Okra is a good source of potassium for human health. The predominant mineral element in the current study was potassium and the concentration of this mineral element is superior to that of the rest of the elements evaluated. It is a primary mineral element found in the body and plays an important role in maintaining fluid balance.

Genotypes VI055423 (8242.49 mg kg^{-1}), VI041763 (7854.91 mg kg^{-1}) and VI055996 (23505.800 mg kg^{-1}) were significantly higher in calcium content compared to all other genotypes (**Table 2**), respectively. The mineral element, calcium plays a significant function in the growth and development of plant meristems, root hairs and root tips as well as for bone development

and strength [42]. Calcium deficiency in plants leads to stunted growth and development of roots [38]. The values detected in this study were higher than the values reported by [43, 44].

The highest concentration of phosphorus was 5246.95 mg kg^{-1} and found in genotype VI055423; while significantly lowest concentration was recorded in genotypes VI060313 (3187.60 mg kg^{-1}) and VI056457 (2992.73 mg kg^{-1}) (**Table 2**). The concentration of phosphorus in immature and green fruits of okra determined in this study (expressed in mg kg^{-1}) were higher than the values reported by [44] in the previous study. Furthermore, the genotype VI055423 showed the highest concentration of micronutrients such as zinc, manganese and copper are the essential micro-elements that plays a great role in the human growth and development. Ref. [45] reported that zinc is one of the essential trace mineral nutrient for human nutrition. The values reported in current study for zinc content in okra fruits was higher than the values reported previously by [43]. This genotype also contributed to the substantial concentration of magnesium next to the genotype VI049632 (4544.91 mg kg^{-1}) with the concentration of 4346.06 (mg kg^{-1}). The overall concentration of mean value of magnesium (3506.61 mg kg^{-1}) determined in the genotype VI046567 mg kg^{-1}) was higher than the values reported by [43]. The sodium concentration varied from 244.87 to 778.83 mg kg^{-1} (**Table 2**). The highest significant concentration was found in VI060313 and VI060131, respectively, compared to other okra genotypes.

The iron content of genotype VI060822 (118.28 mg kg^{-1}) was significantly lower than that of the other genotypes studied, while genotypes VI060824, VI060802 and VI056450 had the highest concentration compared to the rest of the genotypes evaluated for this mineral element which is higher than the values reported by [43, 44]. In similar fashion, the genotype VI060824 had showed significantly highest concentration of aluminum (462.57 mg kg^{-1}). Among all genotypes, significantly highest concentration of boron was recorded in the genotype VI050957 (48.96 mg kg^{-1}) and the lowest in VI060802 (26.77 mg kg^{-1}). Okra had a mineral concentration mean values in the order of K > Ca > P > Mg > Na > Fe > Al > Zn > B > M > Cu, that magnifies the importance of macro- and micro-elements in health, growth and development of human body. The existence of mineral elements such as iron, zinc, manganese and nickel has been reported in the immature pods of okra [44, 46]. Okra provides an important source of vitamins and mineral elements which are often lacking in the diet in developing countries [44].

Protein is an essential component of the diet of animals and human and supplies the required amino acids [47]. Protein played a significant role in growth, development and replacement of lost tissues in the human body. It is an important nutritional component in the body to build and repair body tissues that is a building block of bones, muscles, cartilage, skin and blood. Protein is a macronutrient, which the human body needs relatively in a large amount. In this experiment, the crude protein content of immature fruits of okra was analyzed and it varied from negligible amount, of which nitrogen was not detected in genotypes VI055996, VI056450 and VI060678 to 21.45% in VI041210 followed by VI049632 and VI039618 (**Table 2**) indicating that there was a high significant variation among the genotypes due to the effect of genes they carry. Similarly, [48] reported 21.40% of crude protein in the fruits of okra. Ref. [49] also found 21% protein content in okra pods. Moreover, the current value was also almost similar to the

values what [41] reported in the fruits of okra; while higher than the values reported by [43] in Nigeria. Ref. [50] reported 19.5% crude protein content in the fruits of okra, which is lower than the values reported in the current study. This difference might be due to genetic and environmental conditions prevailed during the growth period. Ref. [51] reported 23.40% of crude protein in the fruits of okra in dry basis in Nigeria, which is relatively higher than the current study. Similarly, [52] reported that 23.68% of protein content in two okra genotypes in Pakistan. The green okra fruit showed slightly lower protein content, when compared to the protein contents reported in the immature green pods and fresh young leaves of cowpea genotypes [53, 54] evaluated in South Africa, and hence, okra could be considered as protein fruit vegetable in the dietary requirements. It was earlier reported that okra is a good source of protein among a few protein vegetables such as spinach, cauliflower, broccoli, asparagus and others. The genetic variation existed in this study would assist the breeders in selection of potential parental okra lines for the development of new okra cultivars with high protein content. Okra pre-breeding for nutritional quality would start with the selection of potential parents based on their individual nutritional values determined in the current evaluation. Due to the current prevalence of malnutrition in the world, particularly in sub-Saharan Africa and South Africa, breeding for higher nutritional quality which is suitable for human are so quite important for end users. Therefore, quantification and identification of the nutritional composition in the immature and green fruits of collection of okra genotypes is important to develop new okra cultivar with high nutritional composition of interest in the South Africa.

3.3. Trait association

3.3.1. Morphological phenotypic traits

The results of the association analysis for 18 morphological phenotypic traits are presented in **Table 3**. A strong positive and highly significant association was observed between grain yield and number of fruit per plant (r = 0.85), fruit length (r = 0.75), and fruit diameter (r = 0.73). Grain yield was also positively and significantly associated with number of seeds per plant as well as thousand seed weight, which indicates that all yield components are important for the improvement of grain yield in okra genotypes. Number of fruit was positively and significantly associated with yield contributing traits such as fruit length, fruit diameter, fruit yield, grain yield, number of seeds per fruit, thousand seed weight as well as shelled fruit weight without seeds. Moderately positive and significant association was also observed between grain yield and fruit yield (r = 0.48) and plant height (r = 0.34). Plant height was moderately and positively significantly associated with number of fruits per plant, number of internodes, number of seeds per fruit, internode length, and thousand seed weight. Moreover, fruit length was also positively and significantly associated with grain yield and its related traits. The strong positive association between the different phenotypic traits would allow the breeder for simultaneous selection and improvement of these traits. In this study, plant height, number of fruits per plant, fruit length, fruit diameter, fruit yield, grain yield, number of seeds per fruit, and thousand seed weight were identified as selection criteria for obtaining potential and good parents for the development of new cultivar in the okra breeding programme in the South African condition.

Phenotypic traits	PH	NFP	NB	NL	NI	IL	SD	LL	LW	D50%F	FL	FD	FYLD	GY	NSF	TSwt	Swt
PH	1.00																
NFP	0.33*	1.00															
NB	0.17	−0.18	1.00														
NL	−0.14**	−0.18	0.60**	1.00													
NI	0.47**	0.05	0.35**	0.10	1.00												
IL	0.52**	0.20	0.15	−0.03	0.29*	1.00											
SD	0.25	−0.24	0.41**	0.37**	0.31*	0.21	1.00										
LL	0.12	−0.30*	0.27	0.08	0.10	0.13	0.30*	1.00									
LW	−0.06**	−0.33**	0.33**	0.34**	0.16	0.06	0.27	0.53**	1.00								
D50%F	−0.23	−0.52**	0.22	0.19	0.05	−0.27	0.20	0.27	0.28	1.00							
FL	0.26	0.66**	0.00	−0.23	0.04	0.21	−0.13	0.04	−0.16	−0.46**	1.00						
FD	0.18	0.71**	−0.07	−0.24	0.00	0.03	−0.20	−0.18	−0.13	−0.22	0.58	1.00					
FYLD	0.03	0.48**	0.10	−0.02	−0.03	0.06	−0.14	0.03	0.02	−0.03	0.40**	0.61**	1.00				
GY	0.34**	0.85**	−0.10	−0.20	0.20	0.22	−0.13	−0.22	−0.28*	−0.44	0.75**	0.73**	0.48**	1.00			
NSF	0.34**	0.51**	0.08	−0.08	0.16	0.24	0.09	0.00	−0.01	−0.12	0.53**	0.76**	0.51**	0.67**	1.00		
TSwt	0.40**	0.61**	−0.03	−0.16	0.16	0.31*	0.02	−0.04	−0.06	−0.40	0.60**	0.61	0.47**	0.71**	0.65**	1.00	
Swt	0.15	0.61**	0.00	−0.07	0.03	0.10	−0.14	0.00	0.02	−0.21	0.55**	0.70	0.86**	0.67**	0.67**	0.67**	1.00
FHI	0.17	0.02	−0.11	−0.07	0.02	0.15	0.09	−0.14	−0.13	−0.24	−0.10	−0.22	−0.58	−0.04	−0.24	0.15	−0.39**

*, **: significant at 0.05 and 0.01, respectively; PH: plant height; NFP: number of fruit; NB: number of branch; NL: number of leaves; NI: number of internodes; IL: internode length; SD: stem diameter; LL: leaf length; LW: leaf width; D50%F: days to 50% flowering; FL: fruit length; FD: fruit diameter; FYLD: fruit yield; GY: grain yield; NSF: number of seed per fruit; TSwt: thousand seed weight; Swt: shell weight; FHI: fruit harvest index.

Table 3. Association analysis for 18 morphological phenotypic traits of okra genotypes.

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3.3.2. Nutritional traits

Moderate to highly significant association was observed for the mineral and protein content determined in the okra genotypes (**Table 4**). Highly to moderate significant positive associations were observed between K and Ca, P, Mg, Zn, Mn, and Cu; while negative and moderate correlation was observed between K and Na. Similarly, there were significantly positive association between Ca and P, Mg, Na, B, Zn, Mn and Cu. It was also observed that there were highly significant associations between P and Mg, Zn, Mn, and Cu. These results suggested that high P content might be accompanied with increased concentration of Mg, Zn, Mn, and Cu contents of okra fruits and vice-versa. Na was negatively and significantly associated with all micronutrients except B indicating that high Na content associated with the low contents of the Fe, Al, Zn, Mn, and Cu. An extremely strong association was observed between Al and Fe (0.91) which might be the indication of the existence of genetic control compared to the rest of the traits evaluated. Strong association was also found between K and P as well as K and Mg. Significantly, negative association was observed between protein and Fe, and between protein and Mn. In general, in the current study most of the traits evaluated showed highly and significantly positive and moderate associations among them indicating that there were some functional interaction existed among the mineral elements and protein content. Ref. [55] reported the positive correlation among the mineral elements in rice was due to the interaction between ions whose chemical properties were sufficiently similar, and they compete for site of absorption, transport, and function in plant tissues. Hence in the present study, positive association between and among the mineral elements and protein contents showed that

Mineral elements and protein	**Concentration of mineral elements (mg kg^{-1}) and total protein content (%) in dry mass basis**										
	K	**Ca**	**P**	**Mg**	**Na**	**Fe**	**Al**	**B**	**Zn**	**Mn**	**Cu**
K	1.00										
Ca	0.24**	1.00									
P	0.75**	0.34**	1.00								
Mg	0.75**	0.63**	0.74**	1.00							
Na	−0.32**	0.35**	−0.36**	−0.06	1.00						
Fe	−0.01	−0.33**	−0.00	−0.23**	−0.34**	1.00					
Al	0.05	−0.30**	0.09	−0.16	−0.29**	0.91**	1.00				
B	−0.14	0.50**	−0.07	0.14	0.36**	−0.42**	−0.27**	1.00			
Zn	0.55**	0.26**	0.73**	0.58**	−0.37**	0.14	0.18**	0.001	1.00		
Mn	0.46**	0.35**	0.42**	0.45**	−0.32**	0.35**	0.34**	−0.05	0.33	1.00	
Cu	0.37**	0.23**	0.48**	0.38**	−0.25**	0.111	0.039	−0.110	0.54**	0.27**	1.00
Protein	0.03	−0.06	0.05	0.02	0.04	−0.26**	−0.16	0.064	−0.11	−0.27**	−0.11

** significant at the 0.01 probability level.

Table 4. The correlation coefficients between mineral elements and total protein contents evaluated in immature fruits of okra genotypes.

selecting and improving the primary traits of interest would have a positive effect on the secondary traits in the breeding programme for nutritional quality.

3.4. Multivariate analysis

3.4.1. Morphological phenotypic traits

The principal component analysis (PCA) was used for the reduction of data set and transforming the available raw data set into principal components or component factors, which are equal to the number of evaluated morphological phenotypic traits (**Table 5**). From the current experiment, the PCA transformed 18 raw set of data into 18 factors loadings or principal components with the pattern that the first principal component (PC1) contributed the most variability and the last principal component (PCn) contributed the lowest variability, which accounted for the entire (100%) variability. However, the PC1, PC2, PC3, and PC4 showed high significant variability compared to the rest of the PCs (**Table 5**) with the eigenvalues greater than one and cumulatively accounted for 68.49% of the total variation among the okra genotype. These PCs had eigenvalue more than 1 [56, 57]; while the rest of the PCS had eigenvalue less than 1 [58], and would not be considered in the interpretation of the results obtained and removed, as they were not significantly influencing and contributing to the variability among the genotypes. Morphological phenotypic traits showed different pattern of contribution to the variability in the principal components loading suggesting the existence of genetic variability that would be used in the okra improvement programme. The current cumulative variation explained by the first four PCs was comparable with what [59, 60] reported in contributing to the variations among different okra genotypes. In the first principal component, grain yield, number of fruits, fruit diameter, shelled pod weight, thousand seed weight, number of seeds per fruit and fruit length, respectively, contributed high variability with positive loading compared to the rest of the traits. This principal component alone explained 33.10% of the total variability among the okra genotypes with the eigenvalue of 5.96. The PC2 accounted for 16.10% of the total variation and was mainly influenced by vegetative growth traits such as number of branches, stem diameter, leaf width, leaf length, number of internodes and number of leaves with positive loading. The PC3 with 12.72% variance distinguished the okra genotypes based on fruit harvest index, plant height, fruit yield, and internode length with all positive loading except fruit yield. Similarly, the PC4 was associated and dominantly influenced by the number of leaves, leaf length and number of branches with all positive loadings except leaf length and this PC accounted 6.58% variances. The remaining phenotypic traits had no any significant contribution to the variation in the four PCs and hence were of minor importance in the characterization of okra genotypes.

Biplot analysis was carried out based on the first two PCs. The genotypes and morphological phenotypic traits were shown on a biplot to clearly visualize their associations and differences (**Figure 1**). This PCA biplot more explained the 49.20% of total variability among the genotypes, displaying that number of branches, number of seeds, grain yield, number of fruit, fruit harvest index, and days to 50% flowering were considered as the most discriminating parameters (**Figure 1**). The genotypes that were positioned on the right top quadrant were closely associated and characterized by longest fruit, largest seed size, heavy fruit shell, highest fruit yield, highest number of seeds per fruit, tallest plant, longest internode, and highest number of

Phenotypic traits	Factor loadings																	
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**
PH	0.16	0.22	0.40	−0.15	0.29	0.09	−0.06	0.04	−0.18	−0.16	0.67	0.08	0.06	0.32	−0.02	−0.05	−0.10	0.13
NFP	0.35	−0.10	0.08	0.16	−0.05	0.06	0.10	0.01	0.00	−0.04	0.14	0.56	−0.25	−0.14	0.10	0.00	0.49	−0.40
NB	−0.04	0.44	−0.02	0.36	−0.05	0.17	0.13	0.21	−0.48	−0.07	−0.01	−0.38	−0.28	−0.09	−0.16	0.21	0.10	−0.18
NL	−0.11	0.31	−0.10	0.59	−0.30	0.08	−0.03	−0.07	0.01	0.01	0.09	0.35	0.44	0.03	0.19	−0.15	−0.16	0.14
NI	0.05	0.32	0.25	0.07	0.50	0.08	0.54	−0.17	0.30	−0.04	−0.26	−0.06	0.10	−0.19	0.09	−0.19	0.03	0.02
IL	0.11	0.21	0.35	−0.19	−0.04	0.44	−0.47	−0.28	−0.19	0.23	−0.40	0.14	−0.06	−0.07	0.06	−0.02	−0.11	−0.05
SD	−0.07	0.39	0.17	0.11	0.00	−0.34	−0.42	0.31	0.54	−0.01	−0.01	0.00	−0.35	−0.02	0.01	−0.02	−0.02	−0.03
LL	−0.07	0.34	−0.07	−0.56	−0.26	−0.01	0.13	0.34	−0.07	−0.21	0.03	0.20	0.25	−0.44	0.05	0.08	−0.03	−0.02
LW	−0.10	0.36	−0.15	−0.25	−0.35	−0.10	0.31	−0.47	0.11	0.34	0.16	0.06	−0.28	0.27	−0.09	0.07	0.07	0.05
D50%F	−0.19	0.18	−0.29	−0.09	0.41	−0.37	−0.08	−0.02	−0.38	−0.13	−0.31	0.38	−0.05	0.32	0.05	−0.02	−0.01	−0.09
FL	0.32	0.01	0.04	−0.09	−0.24	0.10	0.23	0.51	−0.04	0.14	−0.28	−0.03	−0.06	0.46	0.09	−0.40	−0.01	0.11
FD	0.35	−0.02	−0.15	0.04	0.08	−0.26	0.04	−0.03	−0.23	0.29	0.16	−0.03	−0.29	−0.38	0.39	−0.15	−0.46	0.09
FYLD	0.27	0.11	−0.38	−0.01	0.05	0.20	−0.17	−0.15	0.05	−0.41	−0.04	−0.03	−0.21	−0.08	0.01	−0.09	0.28	0.61
Grain yield	0.37	−0.02	0.08	0.11	0.03	−0.06	0.15	0.10	0.09	0.05	−0.18	0.27	0.03	0.06	−0.35	0.64	−0.29	0.25
NSF	0.32	0.17	−0.07	−0.01	0.12	−0.31	−0.20	0.01	−0.11	0.45	0.04	−0.16	0.43	−0.12	−0.29	−0.10	0.42	0.06
TSwt	0.33	0.08	0.12	−0.04	−0.19	−0.28	−0.04	−0.22	0.01	−0.32	−0.13	−0.31	0.22	0.21	0.51	0.30	0.09	−0.18
Swt	0.34	0.09	−0.26	−0.02	−0.06	0.03	−0.06	−0.19	0.13	−0.30	0.01	−0.07	0.07	0.03	−0.45	−0.31	−0.37	−0.46
FHI	−0.06	−0.12	0.49	0.08	−0.30	−0.43	0.09	−0.19	−0.26	−0.27	−0.14	0.05	−0.11	−0.16	−0.28	−0.28	0.02	0.23
Eigenvalue	5.96	2.90	2.29	1.18	0.97	0.81	0.67	0.63	0.50	0.45	0.39	0.36	0.28	0.23	0.13	0.10	0.08	0.06
Variability (%)	33.10	16.10	12.72	6.58	5.41	4.52	3.73	3.48	2.77	2.50	2.18	1.99	1.55	1.26	0.73	0.58	0.47	0.33
Cumulative %	33.10	49.20	61.91	68.49	73.91	78.42	82.15	85.63	88.41	90.91	93.09	95.08	96.63	97.89	98.62	99.20	99.67	100.00

Table 5. Principal component factors, eigenvalues, individual, and cumulative variability for the morphological phenotypic traits.

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Figure 1. Plant characteristics.

internodes. The genotypes demarcated on the top left quadrant were associated with highest number of branches and leaves, widest stem and leaves, longest leaves as well as late maturing genotypes. Furthermore, the biplot demarcated the genotypes on the left bottom quadrant based on derived traits called fruit harvest index. This trait is the most important trait to select the genotypes for drought tolerance and these traits were suggested to have drought tolerance traits. Similarly, the right bottom quadrant consists of genotypes with highest grain yield, fruits per plant and widest fruits. The genotypes concentrated around the origin had similar genetic characteristics, while the genotypes that were found far from the origin are discriminated from the rest of the group due to their peculiar genes/alleles and considered as unrelated genotypes. Therefore, selection of these genotypes as potential parents would result in successful hybridization to develop heterotic groups in the okra-breeding programme (**Figure 3**).

3.4.2. Nutritional traits

The data set of all the mineral elements and crude protein contents were subjected to principal component analysis (PCA), which removed the highly inter-correlated and redundancy nature of the prevalent variations among the okra genotypes (**Table 6**). The PCA grouped the mineral

Mineral elements and protein	Factor loadings											
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
K	0.410	−0.037	0.199	0.128	−0.320	0.102	−0.181	0.597	0.056	−0.201	−0.479	−0.017
Ca	0.215	−0.392	−0.399	0.089	0.039	0.144	0.196	−0.392	−0.394	−0.245	−0.424	−0.155
P	0.441	−0.048	0.176	0.080	0.028	0.002	−0.214	−0.133	−0.380	0.725	0.017	0.176
Mg	0.407	−0.250	−0.003	0.115	−0.176	0.142	−0.130	−0.017	−0.082	−0.389	0.726	0.073
Na	−0.208	−0.322	−0.321	0.106	0.095	0.669	−0.268	0.130	0.339	0.268	0.009	0.081
Fe	0.070	0.522	−0.257	0.186	0.168	0.166	−0.010	−0.023	−0.131	−0.218	−0.087	0.703
Al	0.089	0.475	−0.257	0.388	0.229	0.080	−0.179	0.133	−0.151	0.032	0.126	−0.633
B	−0.035	−0.376	−0.349	0.230	0.364	−0.579	−0.048	0.419	−0.023	0.050	0.061	0.176
Zn	0.402	0.021	0.057	−0.113	0.394	−0.171	−0.389	−0.375	0.546	−0.143	−0.160	−0.038
Mn	0.325	0.124	−0.368	0.172	−0.376	−0.123	0.506	−0.063	0.467	0.277	0.055	−0.001
Cu	0.313	0.020	0.056	−0.453	0.520	0.270	0.481	0.324	−0.027	0.027	0.088	−0.062
Protein	−0.058	−0.146	0.521	0.677	0.276	0.121	0.348	−0.106	0.132	−0.043	−0.031	0.041
Eigenvalue	4.043	2.867	1.374	0.895	0.774	0.643	0.541	0.307	0.200	0.185	0.119	0.051
Variability (%)	33.693	23.893	11.454	7.455	6.449	5.359	4.508	2.560	1.669	1.540	0.993	0.426
Cumulative %	33.693	57.586	69.040	76.495	82.944	88.303	92.811	95.371	97.040	98.581	99.574	100.000

Table 6. Principal component analysis of mineral elements and protein traits in 46 okra genotypes showing eigenvectors, eigenvalues, individual, and cumulative percentage of variation explained by the first three PC axes.

Figure 2. Fruit characteristics.

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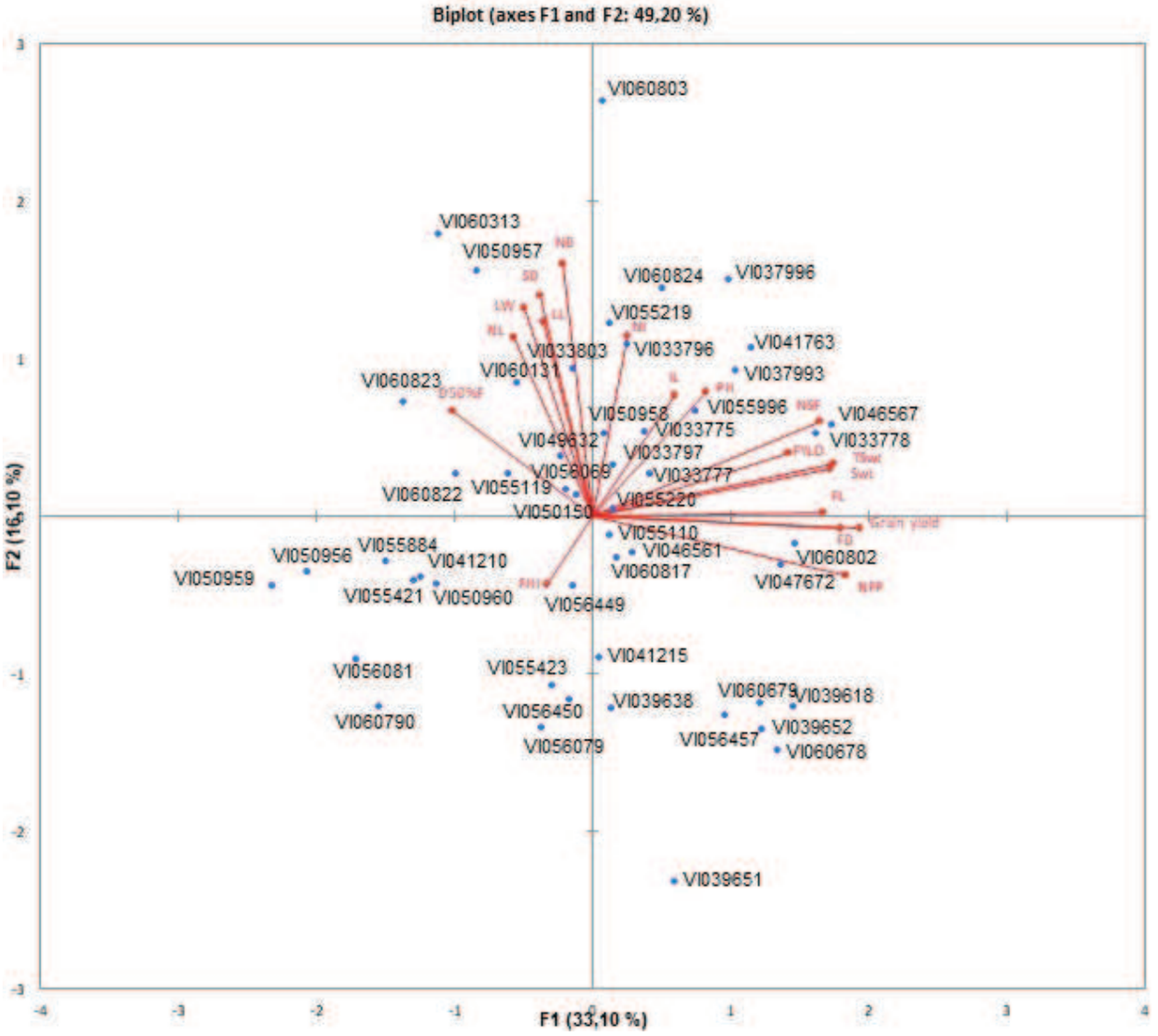

Figure 3. Scatter plot of the first and second principal component analysis for morphological phenotypic traits and okra genotypes.

elements and protein traits into 12 components, which accounted for the entire (100%) genetic variability among the evaluated okra genotypes. According to Chatfied and Collins [58, 61], components with an eigenvalue of less than one should be removed so that fewer components with significant meanings are considered. Furthermore, Ref. [56] suggested that eigenvalues greater than one are considered significant and component loadings greater than ±0.3 were considered meaningful. Hence, from this study, as it can be seen clearly that only the first three eigenvectors which had eigenvalues greater than one and cumulatively explained about 69.04% of the total variation by the first, second and third principal components in the whole data set for the genotypes and provide discriminatory information in respective to the mineral elements and protein. The first principal component, that is the PC1 alone describes and explains 33.69% of the total variability among the okra genotypes, which was mainly contributed by the variances due to K, P, Mg, Zn, Mn and Cu (**Table 6**) with positive loading. The second principal component

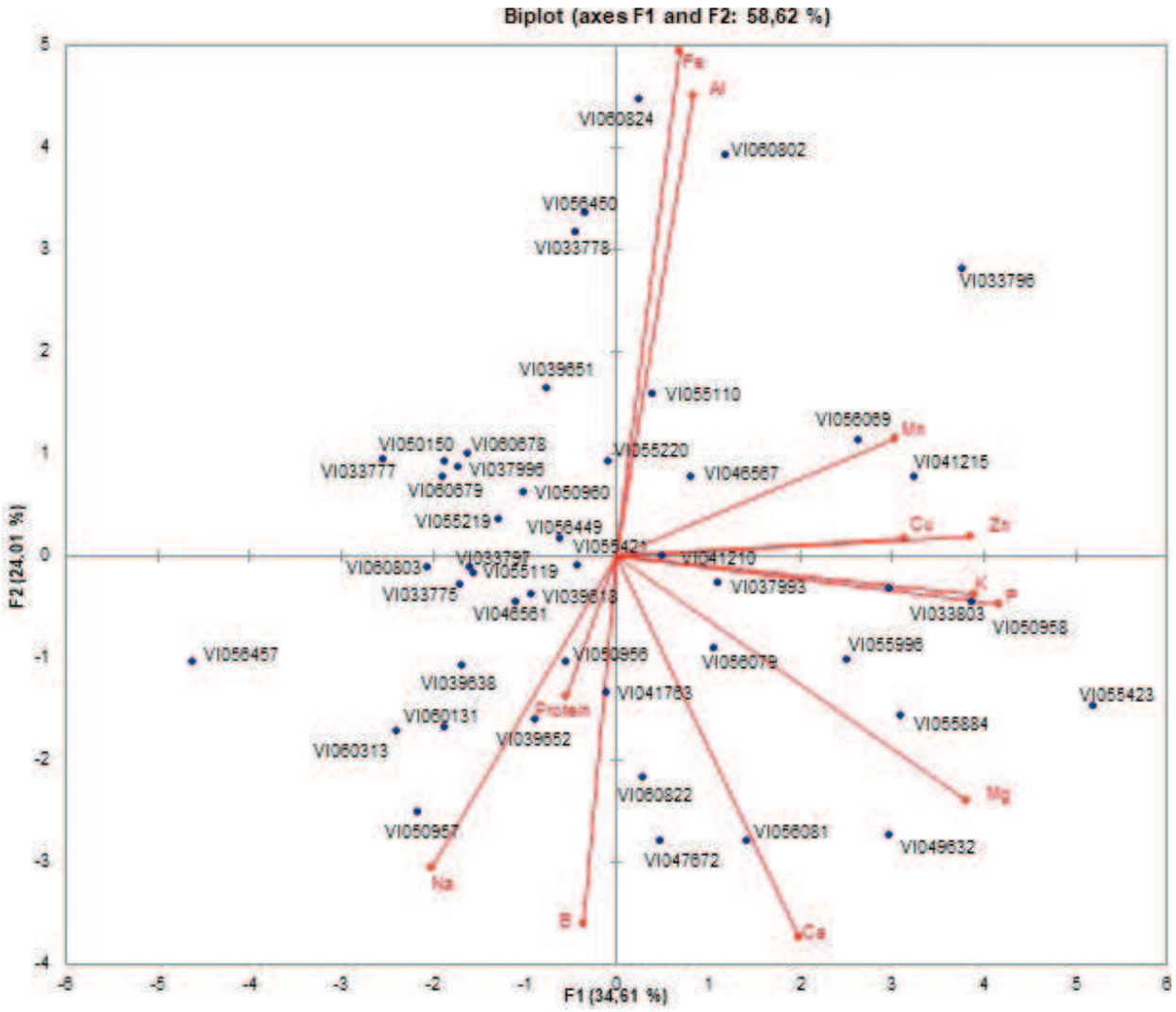

Figure 4. Biplot generated using the concentration of mineral elements and protein content data set of okra genotypes.

(PC2) represents and accounted for 23.89% with eigenvalue of 2.87 had dominantly influenced by the mineral elements such as Ca, Na, Fe, Al, and B with the highest loading vector of Fe followed by Al with positive loading. The nutritional trait that contributed great variability among the genotypes showing 11.45% of variation were protein with the highest positive loading. The mineral elements Ca, Na, B, and Mn also contributed differences in this PC.

The existence of wider nutritional variability among okra genotypes studied was further described by the PCA biplot (**Figure 2**) using multivariate technique. The PCA biplot provided important information regarding the similarities as well as the pattern of differences among the nutritional traits of the different okra genotypes and of the interrelationships between the quantified nutritional traits. The PCA clustered the okra genotypes into different groups over the four quadrants based on the nutritional traits determined (**Figure 2**). The okra genotypes scattered in all four quadrants on the axes, indicating that there were a wide genetic variability for the traits studied. Accessions that overlapped and closer to each other in the principal component axes had similar genetic relationships in the nutritional traits. However, genotypes which are far from each other could be considered as genetically

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distinct [54]. The okra genotypes in the top right quadrant were closely associated with the mineral elements such as Al, Fe, Cu, Zn, and Mn (**Figure 2**). The right bottom quadrant consists of the okra genotypes that are closely related with the mineral elements such as K, Mg, P, and Ca. Those genotypes that found on the left bottom quadrant were mostly associated with the low concentration of mineral elements such as Na and B and protein content. In the present study, the genotypes VI056457, VI033796, VI060824, VI060802, VI055423, and VI049632 stand out clearly as the most genetically divergent okra genotypes for the nutritional traits evaluated. This indicated that they might have a peculiar gene/allele that separated them from the group of the genotypes assessed for the nutritional composition and could be used as parental genotypes for hybridization to develop new cultivar for the traits of interest in our breeding programme (**Figure 4**).

4. Conclusion

In the present study, the existence of genetic variability in the morphological, phenotypic and nutritional traits would help the breeder in selection of the okra genotypes for the improvement for these traits, which would help to increase the frequency of favorable genes in the pre-breeding programme. This is a first pre-breeding programme of okra in South Africa established recently as a prerequisite for the development of new cultivar in the country and beyond for yield and nutritional quality. The okra genotypes in this study showed enormous phenotypic and nutritional variations that would help in the okra improvement programme. The significant positive association between grain yield and yield traits as well as nutritional quality traits could be used as selection criteria for potential and good parental lines in okra breeding programme in South Africa. Understanding and the knowledge of variability and trait association in this study is important in the okra-breeding programme as an initial step to develop new cultivar for the traits of interest. To my best knowledge, this is the first study on this under-utilized fruit vegetable crop species in South Africa that would contribute to food, nutritional and health security.

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