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Genetic Differentiation of ARC Soybean [*Glycine Max (L.) Merrill*] Accessions Based on Agronomic and Nutritional Quality Traits

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Abstract

Soybean is one of the most important leguminous crops grown globally for food and feed. The study of genetic diversity is invaluable for efficient utilization, conservation and management of germplasm collections. The study aims at assessing genetic diversity present among the soybean genotypes using phenotypic markers. The restriction maximum likelihood revealed highly significant differences among the genotypes for eight quantitative traits. The principal component analysis revealed three most important PCs contributing 63.19%, 25.43% and 8.88% to the total variation of 97.5%, respectively. Seed yield was highly significant and highly correlated with seed number per plant, pod weight per plant, pod number per plant, and hundred seed weight but negatively correlated with seed number per pod. The hierarchical clustering revealed three major clusters with further sub-clusters. The accessions 2015/06/12, 69 S 10, PR 154-14, R 5-4-2 M, Hawkeye (USSR), and PR 145-2 were the most diverse. There were significant differences among the accessions based on nutritional quality traits such as oil, protein and stearic acid across the locations. The protein content varied from 29.1% to 35.6%, oil content varied from 10.6% to 20.7% whereas oleic acid and ash varied between 6.8% and 30.8%, and 4.3% and 8.2%, respectively. There was vast genetic diversity among the soybean genotypes. The presence of genetic diversity will aid breeders in selections and hybridization programmes for crop improvement.

Keywords: Agro-morphology, Genetic diversity, Nutritional quality, Soybean.

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Contents

1. Introduction

Soybean [*Glycine max* (L.) Merrill] (2n=2x=40) is one of the most important legumes produced worldwide. According to Food and Agriculture Organisation of the United Nations [1] the three major world-producing countries are U.S.A (90.6 million metric tonnes), Brazil (68.5 million metric tonnes) and Argentina (52.6 million metric tonnes). The total production in Africa was 1.5 million tonnes with West Africa producing 437,115 metric tonnes. Nigeria is the leading producer in West Africa with 393,860 metric tonnes [2]. In South Africa soybean is produced in almost all provinces with the Free State being the major producer. In 2014, South Africa produced 8851 metric tons in an area of 502900 hectares. Soybean is grown primarily for the production of seed and has several uses in the food and industrial sectors. It is the most important crop provider of proteins and oil used in animal nutrition and for human consumption. It contains 40 to 42% good quality protein and 18 to 22% oil comprising 85% unsaturated fatty acids and is free from cholesterol, it is highly desirable in the human diet [3]. Besides fixing the atmospheric nitrogen, this crop has the ability to grow in a wide range of environments, to reduce soil erosion, to suppress weeds and to suit inter and sequential cropping patterns.

It is valued finding to understand genetic diversity and relationship for facilitating the transfer of useful genes among cultivated species and maximizing the use of available germplasm resources. The extent of genetic diversity in germplasm can be assessed through morphological characterization. The characterized material then helps the plant breeders to select the accessions to be utilized in hybridization programme [4]. An investigation of genetic relatedness at a broad level may provide important information about the historical relationship among different genotypes. It reveals genetic backgrounds and relationships of germplasm and also provides strategies to establish unitize and manage crop core collections [5].

Therefore the knowledge of the genetic variation within accessions from germplasm collections is essential to the choice of strategies to incorporate useful diversity into the program to facilitate the introgression of genes of interest into commercial cultivars, to understand the evolutionary relations among accessions, to better sample germplasm diversity and to increase conservation efficiency [6].

Morphological characters, both quantitative and qualitative have long been used to identify species, genera, to evaluate systematic relationships, and to discriminate between varieties [7]. In breeding practice and seed production, the role of morphological descriptor is very important, since the distinguishing between varieties can be done quickly and precisely.

Qualitative traits are usually controlled by a few genes, thus easily observable and suitable for cultivar differentiation and identification. On the other hand, quantitative traits have more limitations in cultivar description, since they are affected by environmental effects, developmental stage of the plant and the generation of selfing of breeding material. According to Khalid, et al. [8] scientific classification of the plant still relies on morphological traits. They are easier to work with, cost effective and easy to score and requires less time and finally they do not need any technical knowledge. Kumar, et al. [9] evaluated genetic diversity and interrelationship of agro-morphological traits in soybean genotypes. Vesna, et al. [10] determined genetic relatedness of soybean genotypes based on agro-morphological traits and DNA markers and they found genetic differences among the genotypes. Malek, et al. [11] also assessed genetic variability and association of characters among the soybean mutants and reported a vast genetic variability. Khatab, et al. [12] reported the presence of genetic diversity among soybean genotypes assessed through agro-morphological descriptors.

Soybean has nutritional quality attributes such as protein and oil that makes it an important food crop. It has 40–42% high quality protein and 18–22% oil comprising up of 85% unsaturated fatty acid as well as 12% carbohydrates [13].

Soybean not only contains high quality protein, but the protein content is also much higher than that of other plant foods. Soy protein is valued as a healthy protein due to containing a balanced proportion of all of the important and essential amino acids required by the human body [14]. It can provide two fold more proteins as compared to any other vegetable crop or grain [15]. Soy oil can serve as a good source of oleic and linoleic acid, even the partially hydrogenated soy oil contains 25% linoleic and 3% linolenic acid [16]. Soybean oil is also a good source of vitamin E [17]. Some recent studies revealed variations among the soybean accessions based on quality traits such as oil [18].

However, the nutritional quality traits vary depending on the varieties grown. There are limited studies on the analysis of genetic diversity among the soybean accessions based on nutritional quality traits in South Africa. There is still need to understand and record variations due to other nutritional quality traits that soybean cultivars possess. This will aid breeders to improve the quality of soybean cultivars and for selection of best accessions for both quality agronomic attributes. The objective of the study was to assess genetic diversity using agro-morphological and nutritional quality traits among soybean genotypes grown in South Africa.

2. Materials and Methods

2.1. Plant Material. Experimental Layout and Management

Ninety-eight soybean genotypes maintained at the Agricultural Research Council-Grain Crops Institute were planted in Potchefstroom (26.7145° S. 27.0970° E) and Brits (25.6100° S. 27.7960° E) in alpha lattice design replicated two times. Each plot consisted of two 4 m length rows with a spacing of 75 cm between the rows and 10 cm between the plants. Fertilizer 2:3:4 was applied before planting. The plants were irrigated using sprinkler irrigation system. The pre-emergent weeds were controlled by herbicide Bateleur Gold and post emergent weeds were controlled by both Basagran EC and manually. Lime Ammonium Nitrate was top dressed 45 days after germination i.e. before the plants flower. The cultural practices were applied as per soybean planting recommendations.

2.2. Data Collection and Analysis

The agro-morphological data recorded is indicated in Table 2.

At harvest, five plants were randomly taken from each plot to measure days to 50% flowering; number of branches per plant; hundred seed weight (g); pod weight (g); seed number per pod; seed number per plant; pod

number per plant; and seed yield (g). Analysis of variance was performed for all traits in order to test the significance of variation among the genotypes. The data were further subjected to principal component analysis and correlations. The dendrogram was constructed to study the genetic relatedness among the tested accessions using hierarchical clustering in GenStat 18th version.

Table-1. List of names of the soybean accessions used in the study.

Serial Number	GM number	Accession Name	Serial Number	GM number	Accession Name
1	220	69 S 10	50	673	1935/06/15
2	223	69 S 13 Seleksie	51	675	1971/06/06
3	231	69 S 19	52	678	105/5
4	266	Nim	53	679	2012/01/05
5	267	Yubelejuaja	54	681	2015/06/12
6	268	Hawkeye (USSR)	55	688	85/05/
7	278	Shelby	56	691	1964/06/17
8	284	Gx Gous	57	699	Essex
9	290	Chippewa 63	58	707	DB 1601
10	291	R 5-4-2 M	59	715	Crawford
11	292	R 2-11-3M	60	724	D64-4636
12	297	B 66 S 365	61	725	D66-8666
13	304	B 66S 385	62	861	ORIBI
14	544	Columbia M 8 A	63	862	Impala
15	568	Grant	64	864	SSS 3
16	571	Hampton 266 A	65	873	ND 85
17	575	Hawkeye	66	1120	AGS 239
18	578	Hernon	67	1363	IPB 212-81
19	582	Jackson	68	1371	Coc Chum
20	592	Mack 6	69	1380	F 82-7824
21	593	Mandarin	70	1386	MTD 63
22	595	Maksura	71	1390	Jupiter
23	597	Mojiana	72	1403	F 82-7145
24	598	N69-2774	73	1409	F 82-7656
25	604	PI 170889/(R56-49)	74	1449	UFV-1
26	607	Pikett	75	1552	PR 118 (278)
27	617	S4-A.P.4	76	1554	PR 133 (484)
28	621	Santa Rosa	77	1555	PR 144-4
29	623	Soja (pautena)	78	1556	PR 144-9
30	624	Solar 12	79	1558	PR 145-2
31	626	SSS 2	80	1572	PR 154-13
32	630	Vaschadaka	81	1573	PR 154-14
33	631	Vicoja	82	1575	PR 154-22
34	637	Yeluanda	83	1578	PR 154-47
35	646	54 S 116	84	1590	PR 161-40
36	648	54 S 219	85	1594	PR 162-18
37	649	54 S 95	86	1595	PR 164-20
38	650	14/6/32	87	1596	PR 164-22
39	651	2017/06/11	88	1597	PR 165-3
40	652	2020/06/18	89	1598	PR 165-31
41	653	21/6/23/2	90	1599	PR 165-50
42	654	28/6/35	91	1600	PR 165-52
43	655	28/6/54	92	1659	TN 81-46
44	659	89/05/	93	IBIS	IBIS
45	660	104/5	94	EGRET	EGRET
46	662	165/5	95	HERON	HERON
47	664	Rhosa ligte hilum	96	NGUTHU	NGUTHU
48	666	2017/06/26	97	DUNDEE	DUNDEE
49	668	2020/06/25	98	JIMMY	JIMMY

Note: Agricultural Research Council-Grain Crops in South Africa

Table-2. List of abbreviations

Full name	Abbreviation
Hundred seed weight (g)	HSW
Number of branches per plant	BNP
Days to 50% flowering	DFW
Pod number per plant	PNP
Pod length (mm)	PDL
Pod weight/plant (g)	PDW
Seed number per pod	SNP
Seed number per plant	SDP
Seed yield (g)	SDY

3. Results

3.1. Agro-Morphological Diversity

3.1.1. Analysis of Variance of Nine Agro-Morphological Traits

There were significant differences ($P \leq 0.05$) observed among the accessions grown in Potchefstroom based on seed number per plant and seed yield; and highly significant differences based on days to 50% flowering, pod weight per plant, and seed number per pod ($P \leq 0.001$) (Table 3). Seed number per plant ranged between 46 and 47, and seed yield ranged between 5.58 and 156.3 g. Days to 50% flowering ranged between 55 and 121,5. Pod weight per plant ranged from 13.33 to 4.21 g. Seed number per pod ranged between 1 and 7 pods. In Brits, significant differences ($P \leq 0.05$) were observed among the accessions based on number of branches per plant and pod number per plant (Table 4). Number of branches ranged between 3.8 and 8.3, and pod number per plant also ranged between 31.7 and 47.0. The genotypic effects were highly significantly different across the two locations based on number of branches per plant and seed number per plant; and there were significant differences on pod length, seed number per pod, and seed yield (Table 5). Hundred seed weight, days to flowering, pod number per plant and pod weight per plant were non-significant.

Number of branches per plant ranged between 3.6 and 8.0. Seed number per plant ranged between 71.9 and 418.2, whereas pod length, seed number per pod, and seed yield ranged from 27.8 to 44.3 mm, 1 to 3, and 11.6 to 96.8 g, respectively.

The two sites showed highly significant differences ($P \leq 0.001$) in quantitative traits such as number of branches per plant, pod weight per plant, seed number per pod, seed number per plant, and seed yield and significant differences on days to 50% flowering. On the other hand, highly significant differences were observed on the genotype x site interaction for days to 50% flowering, seed number per plant and seed yield. The significant differences on genotype x site interaction could be attributed to the different reactions of the accessions to sites or due to differences between the sites.

3.1.2. Principal Component Analysis

The agronomic data were subjected to principal component analysis (PCA), which revealed that the three most important PCs contributed 63.2%, 25.4% and 8.9% of the total variation, respectively (Table 6). Seed number per plant, pod number per plant, and pod weight were the traits that contributed the most variation in the first PC. Seed number per plant and pod number per plant were the traits that contributed the most variation in the second PC, whereas pod number per plant, and seed number per plant were the largest contributors to the variation observed in the third PC. The principal component biplot (Figure 1) grouped the tested soybean accessions into two major groups. The accessions exhibiting early flowering, high seed number per plant, high pod weight and high seed yield were grouped together.

3.1.3. Correlation Analysis among Phenotypic Traits

The phenotypic traits were analysed using pair-wise rank correlations coefficients. The results and association of the traits are reported based on the significance levels of 5% ($p < 0.05$) and 1% ($p < 0.001$). Seed yield was highly significant and highly correlated with seed number per plant, pod weight per plant, pod number per plant, and hundred seed weight but negatively correlated with seed number per pod. However, was also positively and significantly associated with pod length and days to 50% flowering. Seed number per plant was highly significant and positively correlated with pod weight per plant, pod number per plant, days to 50% flowering but negatively correlated with seed number per pod. It was also significant and positively correlated with pod length. Seed number per pod was highly significant and negatively associated with pod weight per plant, days to 50% flowering, but positively correlated with number of branches. Pod weight per plant was highly and positively associated with pod length, pod number per plant, days to 50% flowering. Pod length was significant and positively correlated with pod number per plant, and number of branches. Pod number per plant was highly and significantly associated with branch number and days to 50% flowering, respectively.

3.1.4. Cluster Analysis

The agro-morphological traits were analysed using agglomerative hierarchical clustering to construct a dendrogram (Figure 2). Three major clusters were formed among the soybean accessions. Cluster I was composed of two accessions, S4-A.P.4 (54) and Columbia M 8 A (41) which were genetically closely related. Cluster II consists of two accessions, 04-Apr-2000 (16) and 03-Apr-2000 (15) which were closely related. The third cluster was composed of 94 accessions, which were sub-clustered into three groups. The accessions within each sub cluster were closely related whereas the accessions between the clusters were unrelated. The accessions that were mainly distantly related from the other accessions were 2015/06/12 (54), 69 S 10 (1), PR 154-14 (81), R 5-4-2 M (10), Hawkeye (USSR) (6), and PR 145-2 (79).

Table-3. Means of agro-morphological traits of 96 soybean accessions planted in Potchefstroom.

GM	HSW	BNP	DFW	PNP	PDL	PDW	SDP	SNP	SDY
1120	16.57	14.00	70.50	114.8	40.01	102.00	260.1	7.000	49.58
1363	12.07	19.00	109.50	164.0	35.01	89.50	231.5	6.500	33.08
1371	13.23	13.00	77.51	100.3	38.33	75.00	223.1	6.500	28.19
1380	12.57	16.50	97.00	239.7	37.51	67.00	435.6	7.000	61.25
1386	13.57	10.50	55.00	108.2	39.51	92.00	300.5	7.000	41.08
1390	14.45	20.50	81.50	145.5	35.23	86.00	232.0	5.500	32.29
1403	15.95	13.00	76.00	188.0	39.23	137.00	399.5	7.000	64.79
1409	12.57	9.50	98.00	107.8	26.67	65.50	138.8	4.500	17.91
1449	16.57	9.50	94.50	117.2	31.67	63.00	178.3	4.000	21.58
1552	9.00	20.50	105.51	131.7	0.00	28.50	176.3	4.000	20.00
1554	19.57	13.50	74.00	134.2	40.84	43.00	309.3	7.000	59.41

1555	17.45	15.00	84.00	174.4	34.23	48.50	310.6	5.500	54.46
1556	18.23	17.00	83.01	140.1	43.00	122.50	243.6	7.000	45.52
1558	16.41	17.00	99.50	158.1	34.99	26.00	230.8	5.500	35.67
1572	13.00	23.00	116.00	47.9	39.99	39.50	68.5	7.000	7.17
1573	11.00	14.00	121.45	89.7	40.00	28.00	102.3	4.000	12.33
1575	12.00	18.00	97.04	74.3	34.00	23.00	91.3	4.000	10.67
1578	16.48	10.00	76.04	113.1	26.20	69.00	194.7	4.500	29.74
1590	10.00	16.50	96.54	38.6	37.87	71.00	46.4	7.000	5.58
1594	10.00	14.50	90.58	141.3	41.67	41.50	223.3	4.000	22.67
1595	14.33	10.50	103.00	157.6	39.41	69.50	181.5	6.000	24.40
1596	13.83	17.50	101.00	220.6	39.75	113.00	334.8	5.500	45.56
1597	12.98	23.00	104.54	174.7	40.37	66.00	331.1	7.000	51.08
1598	17.48	17.00	76.04	97.7	43.70	71.50	191.7	7.000	30.74
1599	14.26	11.00	77.45	172.1	44.08	101.00	274.8	7.000	43.09
1600	15.83	9.50	74.00	119.6	45.08	105.00	277.0	7.000	44.40
1659	13.66	19.00	107.58	176.4	39.23	124.00	360.1	7.000	52.56
220	16.00	15.00	73.48	136.4	26.99	55.00	294.4	3.500	48.61
223	22.03	13.50	69.48	154.4	39.99	60.00	323.2	7.000	67.61
231	23.45	13.50	67.97	110.8	42.54	61.50	202.8	7.000	54.54
266	17.00	17.00	68.97	165.7	40.33	4.50	374.7	4.000	74.00
267	20.03	13.50	79.98	189.3	39.82	122.50	210.7	7.000	54.77
268	18.03	16.00	74.48	241.6	39.32	35.00	570.4	7.000	126.44
278	19.90	18.50	63.49	159.0	40.83	49.00	343.5	7.000	59.54
284	18.53	21.50	75.48	207.1	39.99	17.00	436.4	7.000	81.77
290	18.45	15.00	74.47	169.2	42.54	71.50	375.7	7.000	72.87
291	20.40	17.00	70.49	141.7	41.67	34.50	309.7	7.000	63.04
292	19.45	14.00	77.47	180.5	38.38	57.00	318.3	6.500	71.04
297	21.45	12.50	72.97	131.5	39.38	111.00	272.0	7.000	55.20
304	18.95	21.00	78.47	221.7	41.71	85.50	434.3	7.000	83.04
544	15.95	19.50	77.47	216.0	43.38	35.00	517.2	7.000	79.04
568	23.53	19.50	70.98	141.4	40.65	130.50	258.5	7.000	61.11
571	24.95	11.50	66.47	79.2	36.71	82.50	153.5	7.000	37.87
575	17.90	18.50	107.99	81.3	40.00	64.50	135.0	7.000	20.04
578	14.95	8.50	89.47	90.0	45.04	103.00	135.0	7.000	20.20
582	18.53	21.00	107.48	125.3	43.32	89.00	191.0	7.000	29.27
592	13.53	14.00	61.98	179.1	41.65	135.00	457.0	7.000	65.77
593	18.29	19.50	75.97	82.9	36.64	94.50	150.8	6.000	24.28
595	20.59	13.00	76.96	130.6	31.70	109.00	239.0	5.500	48.94
597	23.09	16.50	75.96	166.6	39.20	21.50	328.7	7.000	75.78
598	19.79	17.50	73.97	113.7	40.81	94.00	216.3	6.500	43.78
604	20.05	13.50	72.98	141.6	39.17	51.50	330.8	7.000	60.94
607	78.55	13.00	94.48	107.1	37.00	48.50	158.5	6.000	84.27
617	22.05	23.50	74.48	309.6	40.00	40.00	688.0	7.000	156.27
621	17.55	14.50	70.98	92.2	36.67	99.50	217.3	7.000	35.77
623	59.09	17.50	76.46	134.4	31.03	79.00	205.0	4.000	60.28
624	15.00	23.50	83.47	157.0	36.67	52.50	248.0	2.500	37.33
626	17.09	15.00	91.96	127.4	43.36	87.00	201.3	6.500	35.11
630	22.00	9.00	85.48	201.7	31.67	3.50	310.7	2.500	65.67
631	16.59	14.00	90.46	90.7	45.86	69.00	170.3	7.000	26.94
637	16.55	12.50	72.98	179.2	40.83	136.00	373.0	7.000	60.77
646	18.59	12.00	71.96	106.1	30.03	78.50	185.3	4.000	33.44
648	18.05	11.00	73.98	114.1	36.67	91.50	226.5	5.000	59.61
649	16.59	10.00	71.46	104.4	41.86	84.00	190.2	6.500	34.61
650	16.79	15.00	78.47	234.1	36.64	71.00	432.0	5.500	72.78
651	20.42	13.00	76.98	123.5	49.21	44.50	246.3	7.000	54.58
652	14.92	9.00	78.98	89.2	27.55	69.00	202.0	4.500	30.08
653	19.23	14.50	73.98	143.7	36.56	57.50	241.2	7.000	50.08
654	14.04	14.00	68.49	117.5	37.51	87.50	251.5	6.500	39.05
655	15.04	15.00	71.99	255.2	41.34	73.00	608.5	6.500	101.21
659	17.00	12.50	79.98	72.7	13.33	30.00	148.7	1.500	25.33
660	18.98	18.50	77.47	126.4	39.09	121.50	247.1	7.000	51.40
662	61.23	13.50	74.48	144.4	37.40	54.00	311.7	6.000	73.25
664	17.04	20.50	72.99	165.2	36.67	129.50	291.3	6.500	60.38
666	17.54	15.50	65.49	134.4	40.01	139.50	341.1	7.000	64.71
668	20.54	15.50	72.99	158.9	40.01	82.50	350.0	7.000	73.38
673	20.06	11.00	67.98	90.0	37.37	94.00	191.8	5.500	40.33
675	19.56	14.50	76.48	160.3	37.54	53.00	313.9	7.000	55.83
678	0.00	15.00	75.49	0.0	0.00	1.00	0.0	1.000	0.00
679	18.04	18.00	77.99	137.2	41.67	43.50	302.5	7.000	53.88
681	22.23	15.50	77.48	137.9	27.40	65.50	333.6	4.500	72.08
688	21.23	16.00	71.98	114.2	39.06	66.50	240.6	7.000	49.42
691	15.56	16.00	75.98	192.8	42.37	28.50	391.3	7.000	89.16
699	6.98	21.50	104.97	87.4	25.75	39.00	136.6	4.000	8.30
707	18.93	16.00	90.99	225.8	39.11	19.50	464.0	6.500	90.14
715	18.54	18.00	70.99	141.5	41.67	52.50	291.0	7.000	59.38
724	15.23	14.00	83.48	124.2	42.40	93.00	265.2	7.000	37.75

725	16.23	14.50	76.51	139.6	40.00	37.50	283.9	7.000	47.85
861	20.23	13.50	74.01	600.9	42.67	34.00	236.1	7.000	66.85
862	16.95	16.50	72.50	119.4	41.73	97.50	255.8	6.500	43.29
864	12.07	15.00	75.50	179.8	41.51	62.00	363.3	7.000	55.25
873	16.57	14.00	70.50	179.3	36.67	101.50	351.1	7.000	54.25
DUNDEE	17.98	18.33	65.01	149.4	39.87	33.33	344.7	5.000	62.58
DUNDEE*	20.95	16.00	66.02	152.5	43.84	128.00	314.9	7.000	57.89
EGRET	12.94	13.72	67.01	111.2	39.89	75.12	247.5	6.328	35.31
EGRET*	19.95	15.00	68.02	127.7	43.17	102.00	233.9	6.500	45.56
HERON	15.33	11.50	66.00	130.6	36.75	88.50	282.1	6.500	40.06
IBIS	16.83	17.50	66.50	153.1	40.58	122.50	328.1	7.000	56.90
F-prob	0.490	0.193	<.001	0.487	0.090	0.012	0.002	<.001	0.003
LSD	25.78	4.870	11.239	191.6	11.820	77.84	230.5	2.870	48.96
CV	66.61	31.83	7.19	63.77	15.25	55.11	40.70	23.69	47.05
SE	12.57	4.843	5.745	94.70	5.876	38.97	113.9	1.437	24.20

Table-4. Means of agro-morphological traits of 98 soybean accessions planted in Brits.

Genotype	HSW	BNP	DFW	PDL	PNP	PDW	SDP	SDY
1120	24.02	4.135	58.49	39.51	80.2	62.00	114.8	31.30
1363	16.00	5.302	56.99	37.00	138.3	55.33	213.3	31.67
1371	16.61	6.838	68.98	38.32	156.5	61.57	210.3	34.66
1380	15.02	6.968	57.99	37.18	84.0	27.66	113.8	15.30
1386	21.02	3.635	66.99	37.51	82.8	49.33	118.8	31.97
1390	14.55	6.654	46.98	34.30	82.4	29.02	114.6	16.42
1403	19.00	5.654	57.48	42.13	111.6	47.52	142.1	31.25
1409	16.00	6.135	58.49	40.00	55.3	21.67	82.7	12.67
1449	17.52	7.635	67.99	34.18	114.0	39.50	152.3	22.80
1552	12.61	7.338	60.48	35.15	148.0	50.57	239.0	32.16
1554	17.52	5.333	60.99	47.01	94.0	57.50	172.8	37.30
1555	18.00	6.154	49.48	36.97	82.4	31.68	108.7	19.42
1556	18.11	8.338	69.98	41.65	161.0	67.24	219.8	39.83
1558	17.14	8.165	61.08	38.32	187.4	65.57	267.2	47.55
1572	11.64	6.832	76.08	41.82	81.8	34.40	147.7	31.39
1573	0.00	6.373	56.28	0.00	0.0	0.00	0.0	0.00
1575	15.00	4.844	62.26	41.67	128.0	51.67	192.7	31.67
1578	16.00	7.344	70.26	31.67	111.7	42.00	156.0	25.33
1590	16.00	6.510	60.26	37.33	91.3	43.33	124.3	21.67
1594	14.00	5.038	55.76	35.00	158.7	60.00	253.3	34.33
1595	14.10	7.647	64.91	39.28	158.9	51.92	223.3	31.88
1596	17.10	7.647	73.41	37.11	162.9	70.92	249.0	42.55
1597	13.61	6.177	47.26	35.09	131.3	55.69	209.1	34.10
1598	20.11	6.677	47.76	36.92	147.1	72.03	200.8	44.60
1599	19.65	5.206	49.78	39.20	125.8	64.72	211.3	41.26
1600	22.10	4.647	68.91	39.11	97.6	52.09	128.0	33.88
1659	14.29	6.705	44.76	39.25	102.3	44.05	174.7	26.10
220	21.43	5.012	46.49	39.33	107.2	51.35	171.2	33.50
223	22.43	3.845	63.99	41.00	119.2	65.52	180.5	39.50
231	25.00	3.848	47.50	40.11	38.8	23.40	53.0	12.89
266	25.00	5.181	55.50	43.28	64.4	32.74	76.9	19.89
267	26.00	7.012	67.49	36.67	67.2	48.68	101.4	23.50
268	21.93	6.512	44.99	38.67	105.5	60.18	168.5	36.67
278	21.87	5.348	59.50	41.55	86.6	44.88	124.9	28.42
284	25.00	5.345	60.99	36.67	46.5	27.52	68.7	16.50
290	19.00	7.348	51.50	41.45	75.1	42.07	119.9	70.89
291	17.37	5.181	53.00	39.30	85.0	36.88	116.9	23.50
292	22.00	7.015	59.00	41.33	55.3	33.00	90.3	20.33
297	25.00	6.681	63.50	40.78	59.6	40.24	91.5	26.39
304	13.41	5.515	57.50	42.95	65.6	28.74	104.2	16.89
544	13.91	8.015	47.00	41.61	163.4	71.74	240.4	42.39
568	0.00	4.512	48.99	38.00	49.7	22.02	58.7	11.50
571	19.91	5.515	68.00	39.61	135.3	71.90	205.5	47.39
575	20.37	5.514	63.50	41.97	129.2	74.72	197.7	36.17
578	15.41	6.681	56.50	39.95	198.8	85.40	272.2	47.39
582	11.43	7.345	65.49	39.17	172.0	79.85	233.4	42.84
592	17.43	4.345	69.99	40.50	56.0	26.02	86.9	15.00
593	20.00	5.163	50.01	40.67	77.3	34.67	98.7	19.33
595	23.01	6.666	60.50	42.42	102.1	48.93	140.7	31.83
597	20.51	6.166	56.50	38.42	117.8	65.76	186.3	36.83
598	24.10	6.496	55.01	41.34	113.1	60.10	161.8	38.12
604	23.55	6.499	53.99	40.81	111.1	62.33	185.8	41.89
607	21.00	5.332	54.99	32.00	106.7	47.33	146.3	30.00
617	23.55	6.832	53.49	37.47	247.6	50.50	141.8	35.23
621	20.55	5.832	50.49	41.14	101.2	60.00	180.8	39.56
623	20.00	6.333	59.50	35.08	72.0	32.43	89.3	18.33
624	17.60	6.996	55.51	37.51	137.3	55.60	177.8	31.12

626	18.00	7.666	57.50	31.67	69.0	26.00	75.0	13.33
630	22.00	6.999	53.49	34.97	91.7	44.17	131.8	29.56
631	24.01	4.999	48.00	39.58	102.8	47.76	135.0	29.66
637	16.55	5.832	53.49	37.47	116.9	51.50	208.5	33.23
646	20.51	5.166	58.00	36.58	70.5	31.10	104.3	20.66
648	20.05	4.665	46.49	37.81	79.7	32.17	99.0	19.56
649	19.01	4.833	53.00	41.08	64.0	29.76	107.5	20.66
650	17.10	6.996	56.01	38.17	105.9	53.10	178.9	32.45
651	19.00	5.324	60.49	39.32	71.9	35.05	114.0	19.48
652	16.00	4.491	45.49	36.32	40.4	17.05	56.5	10.15
653	17.00	4.143	46.00	37.49	74.9	31.48	106.3	18.41
654	17.00	5.661	45.99	36.67	187.7	83.67	329.0	56.00
655	15.88	6.495	47.49	33.82	76.2	30.49	118.5	18.25
659	24.77	7.840	61.05	40.84	109.3	57.87	159.6	54.55
660	23.00	7.180	48.49	40.00	70.3	31.67	94.3	21.00
662	22.01	4.643	46.50	33.82	74.5	39.64	118.9	26.24
664	20.38	5.328	60.49	31.65	104.3	49.66	166.2	34.75
666	21.38	5.828	43.99	38.82	82.2	38.82	120.7	23.75
668	21.38	5.328	64.99	38.82	93.8	53.49	140.0	28.75
673	23.00	4.000	56.05	40.00	56.2	31.21	88.8	19.38
675	17.00	6.006	47.55	39.67	83.2	45.71	94.8	17.22
678	23.00	5.661	66.49	37.48	53.7	27.32	78.5	15.58
679	121.88	4.328	53.99	40.15	87.2	56.82	157.3	36.42
681	26.00	5.309	56.00	40.00	100.3	53.00	141.0	35.33
688	23.00	6.809	45.00	45.00	116.3	51.00	148.3	43.67
691	19.27	6.340	57.55	40.00	161.5	73.54	200.1	44.38
699	8.66	7.680	46.99	37.26	133.5	28.26	200.4	17.00
707	9.75	5.512	61.49	39.98	68.8	33.71	108.1	22.44
715	22.88	4.495	50.99	39.15	90.2	61.82	153.8	37.58
724	16.51	7.309	57.50	43.49	163.2	74.98	246.9	45.41
725	19.00	7.838	64.98	44.00	134.3	60.67	222.3	37.00
861	24.00	6.338	55.98	38.32	79.7	44.07	126.2	27.99
862	20.55	5.320	45.98	33.63	107.9	53.18	165.6	34.58
864	23.02	4.302	47.99	39.85	86.7	57.16	163.0	38.64
873	17.02	4.635	48.49	37.85	148.3	66.83	211.6	43.97
DUNDEE	21.65	5.552	47.50	39.62	111.5	57.70	172.9	38.74
DUNDEE*	18.87	5.029	45.38	37.90	95.0	49.06	122.1	26.39
EGRET	19.91	3.865	62.12	40.03	85.0	45.06	149.5	30.06
EGRET*	23.37	5.695	44.00	44.90	142.6	76.56	195.3	45.72
HERON	20.10	3.981	43.00	38.28	91.3	46.59	167.1	29.72
IBIS	21.60	4.647	60.41	40.61	130.3	69.09	218.1	43.22
F-prob	0.863	0.006	0.163	0.064	0.367	0.382	0.214	0.599
LSD	39.65	2.401	19.59	6.221	104.52	43.14	134.8	32.60
CV	86.77	20.60	17.32	7.67	47.97	42.02	42.07	50.54
SE	17.72	1.216	9.700	2.985	50.15	20.70	64.67	15.64

Table-5. Means and mean squares of combined analysis of variance of agro-morphological traits of 96 soybean accessions planted across two sites. Potchefstroom and Brits. 2016/17

Genotype	HSW	BNP	DFW	PNP	PDL	PDW	SNP	SDP	SDY
1120	19.94	4.415	64.50	98.6	39.75	65.97	3,00	189.8	40.80
1363	13.22	5.833	83.31	156.0	35.67	58.40	2,83	226.0	32.67
1371	14.84	5.574	73.25	130.9	38.34	56.24	2,83	218.9	31.70
1380	13.60	6.243	77.54	163.9	37.34	66.61	3,00	278.5	38.86
1386	16.94	3.580	60.97	96.5	38.51	55.67	3,00	212.3	36.81
1390	14.67	6.747	64.28	114.9	34.76	42.21	2,50	174.8	24.51
1403	16.90	4.994	66.76	150.9	40.65	70.96	3,00	273.4	48.32
1409	13.48	4.823	78.29	91.5	31.00	35.75	2,00	121.3	16.25
1449	16.90	7.580	81.27	116.4	32.91	40.08	2,00	166.7	22.39
1552	11.15	7.079	83.05	142.7	35.17	44.84	3,00	218.1	28.07
1554	18.50	4.777	67.51	115.2	43.89	73.07	3,00	243.3	48.75
1555	17.60	5.577	66.78	129.6	35.57	59.28	2,50	211.9	37.25
1556	18.20	6.990	76.51	153.3	42.34	75.54	3,00	234.0	43.05
1558	16.67	6.907	80.29	173.4	36.65	66.01	2,50	250.0	41.53
1572	12.02	7.249	96.04	65.5	40.91	26.79	3,00	108.7	19.09
1573	11.00	8.005	89.07	89.7	40.00	32.67	3,00	102.3	12.33
1575	13.40	5.417	79.78	100.7	37.79	36.76	3,00	141.2	21.00
1578	16.30	5.320	73.25	111.7	27.77	43.39	2,00	181.6	28.28
1590	12.95	5.994	78.53	55.1	37.45	22.53	3,00	71.9	11.59
1594	11.87	4.913	73.28	149.9	38.37	57.29	3,00	238.1	28.40
1595	13.94	7.747	84.04	155.8	39.34	47.18	2,67	199.1	28.03
1596	15.07	6.742	87.27	189.7	38.43	73.13	2,50	289.7	44.03
1597	13.87	6.917	76.06	151.5	37.69	75.84	3,00	268.8	42.70
1598	19.30	6.161	62.02	120.2	40.29	59.31	3,00	193.9	37.53
1599	16.77	4.410	63.77	149.5	41.53	66.02	3,00	244.7	42.24
1600	18.47	3.910	71.49	106.3	42.12	61.24	3,00	200.8	39.17

1659	13.94	6.496	76.32	142.4	39.17	63.49	3,00	266.8	39.57
220	19.40	4.997	60.02	121.8	33.10	60.05	1,67	233.1	41.12
223	22.17	4.165	66.75	136.8	40.50	85.40	3,00	252.3	53.73
231	23.90	4.165	57.76	75.9	41.35	59.31	3,00	130.0	33.99
266	20.73	5.415	62.26	100.7	42.31	59.74	3,00	182.4	38.33
267	21.85	5.741	73.75	129.0	38.27	66.36	3,00	156.2	39.34
268	19.80	5.911	59.78	174.4	39.01	115.21	3,00	372.0	82.23
278	20.87	5.749	61.49	123.9	41.21	66.75	3,00	234.9	44.19
284	20.50	6.252	68.26	127.9	38.35	76.62	3,00	254.8	49.62
290	18.62	6.158	63.02	123.4	42.01	74.92	3,00	250.7	71.84
291	19.04	5.415	61.76	114.4	40.51	56.30	3,00	213.8	43.55
292	20.19	5.824	68.26	139.6	39.31	77.06	2,83	243.5	53.99
297	22.56	5.407	68.25	96.6	40.08	57.85	3,00	184.1	40.97
304	16.37	6.251	68.02	145.4	42.33	79.46	3,00	272.8	50.44
544	15.00	7.243	62.28	190.6	42.51	117.80	3,00	381.9	60.95
568	23.44	5.502	60.02	96.0	39.35	55.54	3,00	159.5	36.66
571	22.60	4.659	67.24	107.2	38.15	64.27	3,00	179.9	42.49
575	19.10	5.832	85.79	105.4	40.99	57.97	3,00	164.8	27.93
578	15.17	6.915	73.03	144.0	42.53	78.11	3,00	203.3	33.51
582	15.17	7.163	86.54	148.0	41.27	68.40	3,00	211.1	35.89
592	15.30	4.498	65.98	118.3	41.09	59.62	3,00	274.2	40.75
593	18.93	5.834	63.02	80.6	38.00	53.01	2,67	132.9	22.57
595	21.87	5.491	68.76	116.2	37.03	61.27	2,50	190.9	40.54
597	22.04	5.829	66.26	142.2	38.84	102.84	3,00	258.9	56.64
598	21.80	6.162	64.51	113.2	41.08	62.20	2,83	189.3	40.99
604	21.84	5.492	63.51	126.7	39.99	76.98	3,00	258.4	51.59
607	61.92	4.828	74.79	107.2	35.38	79.17	2,67	152.7	66.72
617	22.90	7.333	64.02	279.2	38.77	122.06	3,00	418.2	96.75
621	19.10	5.328	60.76	96.8	38.89	63.30	3,00	198.3	37.65
623	47.03	6.079	68.01	103.3	33.06	42.91	2,00	148.3	39.66
624	16.58	7.416	69.52	144.1	37.22	60.09	2,00	201.8	33.24
626	17.60	6.323	74.78	107.8	39.54	48.11	2,83	159.9	27.90
630	22.00	5.154	69.53	129.7	33.86	65.11	2,00	194.0	42.17
631	20.20	4.829	69.29	96.3	42.79	46.05	3,00	153.2	28.30
637	16.70	4.993	63.26	148.7	39.19	72.58	3,00	291.0	47.24
646	19.64	4.577	65.01	88.2	33.30	42.00	2,00	145.7	27.18
648	19.14	4.161	60.27	97.3	37.25	47.49	2,33	162.7	39.93
649	17.87	4.076	62.26	84.1	41.51	42.36	2,83	149.7	27.77
650	16.94	5.992	67.27	170.8	37.41	85.35	2,50	307.4	52.94
651	19.99	4.828	68.76	97.5	44.31	59.39	3,00	180.4	37.32
652	15.27	3.911	62.28	64.5	31.87	31.57	2,00	129.6	20.28
653	18.37	4.499	60.02	109.4	37.08	60.46	3,00	175.0	34.52
654	14.90	5.161	57.27	141.0	37.22	67.44	2,83	277.7	44.84
655	15.64	5.743	59.77	167.2	37.63	68.78	2,83	367.8	60.45
659	21.96	6.155	70.51	96.6	31.43	51.49	1,00	156.1	44.22
660	20.13	6.661	63.03	110.0	39.44	66.11	3,00	200.8	41.93
662	42.74	4.580	60.52	109.6	35.69	62.87	2,67	217.0	50.14
664	18.80	6.084	66.75	135.3	34.20	69.15	2,83	230.1	47.81
666	19.54	5.495	54.77	108.7	39.43	67.71	3,00	233.0	44.60
668	21.14	5.246	69.00	126.9	39.43	91.36	3,00	247.0	51.47
673	20.84	3.776	62.00	74.2	38.74	47.68	2,50	142.4	30.04
675	18.67	5.411	62.03	123.2	38.66	67.26	3,00	207.5	36.85
678	23.00	5.329	71.00	53.4	37.50	27.25	-	78.3	15.52
679	66.70	5.168	66.02	112.6	40.93	70.81	3,00	231.4	45.33
681	23.13	5.246	66.77	125.1	31.56	88.01	2,00	271.3	60.11
688	21.54	6.076	58.52	114.2	41.06	86.23	3,00	210.5	47.50
691	17.30	5.828	66.76	178.2	41.27	116.26	3,00	298.6	67.15
699	7.64	7.412	76.06	111.9	31.52	25.02	2,00	171.3	12.86
707	14.74	5.413	76.28	151.0	39.58	83.71	2,83	290.2	57.03
715	20.77	5.251	61.01	116.3	40.43	74.54	3,00	223.9	48.70
724	15.64	5.990	70.52	143.0	43.00	68.90	3,00	256.4	41.53
725	17.19	6.323	70.75	141.5	41.30	72.60	3,00	266.2	44.69
861	21.56	5.409	65.01	347.5	39.78	60.76	3,00	184.2	48.07
862	18.80	5.414	59.27	114.2	37.71	59.01	2,83	212.0	39.03
864	17.07	4.665	61.77	134.8	40.68	76.72	3,00	266.0	47.29
873	16.67	4.664	59.52	164.9	37.25	68.18	3,00	283.7	49.40
DUNDEE	19.22	5.899	59.48	128.9	39.62	73.86	3,00	256.2	48.30
DUNDEE*	19.77	5.164	55.76	124.6	40.95	68.89	3,00	221.3	42.41
EGRET	16.44	4.232	64.66	95.6	40.01	48.16	2,88	197.1	32.73
EGRET*	21.34	5.329	60.06	135.4	44.08	73.43	2,83	216.1	45.65
HERON	17.27	3.913	58.31	108.8	37.49	52.94	2,83	222.7	34.92
IBIS	18.77	5.250	63.50	139.4	40.58	75.87	3,00	271.1	50.12
	HSW	BNP	DFW	PNP	PDL	PDW	1,00	SDP	SDY

Genotype	236.7	3.851***	278.09	5837	36.31**	1290.5	3,00	13538***	686.9**
Site	334.6	32.707***	56339.34***	182894***	9.27	81648.5***	0.4953***	1491290***	39431.5***
Genotype *Site	177.8	1.935	189.56***	5384	23.93	1092.0	0.0000	14512***	631.2***
Mean	19.10	5.49	67.68	123.79	37.82	62.68	0.0000	211.88	19.10
LSD	22.50	2.089	15.59	160.8	6.791	58.88	2,78	196.0	29.75
CV	75.53	27.04	11.62	62.26	12.04	44.93	0.7721	44.22	49.55
SE	14.80	1.516	7.900	78.99	4.661	28.93	13.77	96.31	20.49
R^2									

Table-6. Factor loadings of the three PCs based on agronomic traits

Trait	**Factor Loadings**		
	1	**2**	**3**
HSW	-0.00436	0.00148	0.00187
BNP	0.00058	0.00631	-0.00191
DFW	0.03408	-0.10372	-0.05010
PNP	0.41799	0.26113	-0.86868
PDL	0.00519	0.00590	0.00401
PDW	0.20975	0.04508	0.07626
SNP	-0.22688	0.95126	0.17318
SDP	0.83968	0.11403	0.45054
SDY	0.15344	0.03245	0.06380
Eigen values	6983426	2810062	981647
Percentage variation	63.19	25.43	8.88
Cumulative variation	63.19	88.62	97.50

Table-7. Correlations among nine agro-morphological traits of 96 soybean accessions

	SDY	**SDP**	**SNP**	**PDW**	**PDL**	**PNP**	**DFW**	**BNP**	**HSW**
SDY	-								
SDP	0.8805***	-							
SNP	-0.1863***	-0.2436***	-						
PDW	0.9186***	0.8634***	-0.1831***	-					
PDL	0.1564**	0.1547**	0.0500	0.1946***	-				
PNP	0.6144***	0.6451***	-0.0446	0.6164***	.1151**	-			
DFW	0.1219**	0.2074***	-0.6303***	0.1749***	-0.0375	0.1422**	-		
BNP	0.0423	0.0690	0.3093***	0.0756	.1668**	.1799***	0.0334	-	
HSW	0.1808***	-0.0536	0.0212	0.0687	-0.0170	-0.0351	-0.0962	-0.0528	-

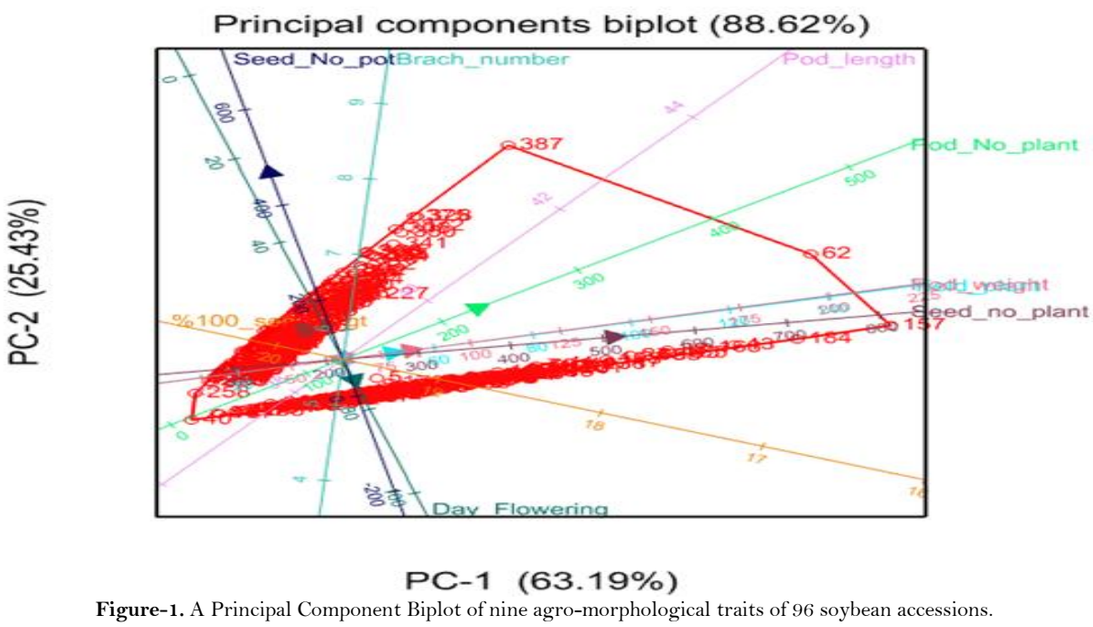

Figure-1. A Principal Component Biplot of nine agro-morphological traits of 96 soybean accessions.

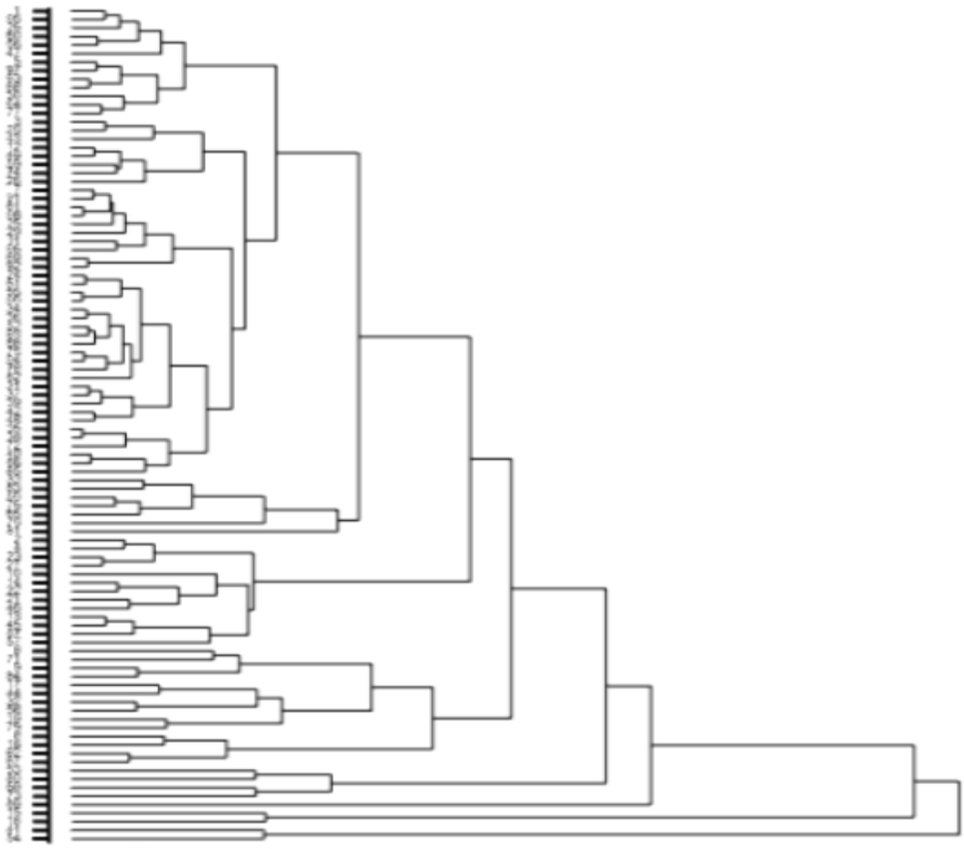

Figure-2. A dedrogram on agro-morphological traits of 96 soybean accessions.

3.2. Nutritional Quality Diversity

The nutritional quality traits were analysed using analysis of variance. There were significant differences (P< 0.05) among the soybean accessions planted in Potchefstroom based on ash, moisture, and oil contents (Table 8). The ash content varied between 4.3 and 10.9%. Moisture content varied between 1.7 and 12.8% whereas oil content ranged between 7.1 and 23.9%. In Brits, highly significant differences were observed in fiber, moisture, oil, palmitic acid, and protein contents, and significant differences were observed for linolenic acid (Table 9). Fiber content varied between 4.5 and 5.5%.

Moisture varied between 3.1 and 4.6%. Oil content varied between 12.0 and 21.8%. Palmitic acid ranged from 55.9 to 64.2% and protein content varied between 29.6 and 35.8% whereas linolenic acid ranged from 3.1 to 4.7%. When assessing the reaction of the soybean accessions across the two locations, highly significant differences were observed for ash, moisture, oil, oleic acid and stearic acid and significant differences were observed for protein content (Table 10). Ash content varied between 4.3% and 8.2%. Moisture content ranged from 2.8% to 12.8%. Oil content varied between 10.6% and 20.7%. Oleic acid varied between 6.8% and 30.8% and stearic acid ranged between 31.6% and 263.5% whereas protein content was ranging between 29.1% and 35.6%. The two sites showed highly significant differences among the genotypes based on linolenic acid, moisture content, oleic acid, stearic acid and significant differences were observed for linoleic acid and oil content. The genotype x site interaction was significant for ash and non-significant for all other quality traits.

4. Discussion

The principal component analysis (PCA) is a statistical method commonly used in population genetics to identify structure in the distribution of genetic variation across geographical location and ethnic background [19]. The goal is to evaluate the importance of each variable in relation to the total available variation among genotypes. The method provides an opportunity to exclude less important traits in the group studied [20] and simultaneously determine which traits are the most important. In this study, the traits that contributed to the most variation were seed number per pod, pod number per plant, seed number per plant and seed yield.

The correlation information of the tested traits can be provided to the breeders in the direct and indirect selection programmes. The genotypes with significant correlations and desirable traits can be selected concurrently. Moreover, understanding the relationship between yield and its component traits is of great importance to a breeder for making the best use of these relationships in selecting desirable genotypes for yield improvement programs [21, 22].

Significant positive correlations of days to flowering, number of branches and pods per plant, pod length, seed number per pod with seed yield were reported by Malek, et al. [11] which concur with the results in this study. This means that in selecting high yielding genotypes these characters should be given more emphasis as the best selection criteria. Seed yield always showed a positive correlations with other desirable yield traits [23, 24] which indicates that the increase in one trait would result in the increase of the other; that is, simultaneous increase or decrease of both traits would be easy. The strong positive correlation of seed yield with other yield traits indicated that it would be very easy to identify a soybean genotype having higher seed yield simultaneously with higher number of pods per plant and but difficult with number of seeds per pod. Similar results were reported in other studies [25-28].

Traditional cluster analysis could provide an easy and effective way in determining the genetic diversity of germplasm collections [29]. It is commonly used to study genetic diversity and for forming core subset for

grouping accessions with similar characteristics into one homogenous category [30]. It is also used to summarize information on relationships between accessions by grouping similar units so that the relationship is easily understood. In this study, the accessions were clustered into three major groups of which two of them were further sub clustered into three groups based on the agro-morphological traits measured. The most diverse lines can be used as parents for hybridization for improvement of genes of novelty.

Genetic diversity evaluation among germplasm is a necessity and a prerequisite in any hybridization program and would promote the efficient use of genetic variations [31, 32]. To improve an efficient crop, it is essential to obtain the information on genetic diversity and relationships among breeding materials for a plant breeder. This is because the assessment of genetic diversity is important not only for crop improvement but also for efficient management and conservation of germplasm resources. In this study, the nutritional quality traits showed a vast diversity among the accessions. The oil and protein content were within the range recorded in other studies [33]. The oil content ranged from 13.8% to 22.5% whereas protein ranged between 37.0% and 50.1%) with a mean of 19% and 42.9%, respectively. The vast divergence of the accessions will assist breeders in selecting accessions with good quality for hybridization and conservation.

The analysis of genetic diversity plays a fundamental role in identification of parents [34] and it can help to achieve long-term selection gain [35]. As a traditional method, morphological traits used to assess genetic divergence and classify existing germplasm materials. However, this technique is a low level but powerful taxonomic tool and has been utilized for the preliminary grouping of germplasm prior to their characterization using more precise marker technologies. Although the genetic base of soybean cultivars is considered to be extremely narrow [36] studies of genetic diversity in soybean have been conducted using morphological characteristics [37, 38].

Recently, De Chavez, et al. [39] reported a vast phenotypic diversity among the soybean accessions in Phillipines. Khatab, et al. [12] reported the presence of genetic diversity among soybean genotypes assessed through agro-morphological descriptors. Hamzekhanlu, et al. [40] studied 34 mutant lines including one control cultivar and detected variability for ten quantitative traits in soybean. Iqbal, et al. [41] reported significant differences among all the assessed phenotypic traits.

5. Conclusion

Most of the traits showed positive correlations between each other, which will assist in the combined improvement of these traits by selecting only highly and positively correlated and easily measurable phenotypic traits although most were highly significant and positively correlated with seed yield per plant. The accessions were clustered into three major groups with subgroups, which showed existence of a vast genetic diversity among the accessions. The most divergent accessions were 2015/06/12, 69 S 10, PR 154-14, R 5-4-2 M, Hawkeye (USSR), and PR 145-2. The nutritional quality traits also varied significantly among the accessions. The presence of genetic diversity can be useful for breeding and selection of parents for transgressive segregation.

Table-8. Means of nutritional quality traits of 96 soybean accessions planted in Potchefstroom.

GM	Ash	Fiber	Linoleic acid	Linolenic acid	Moisture	Oil	Oleic acid	Palmitic acid	Protein	Stearic acid
1120	5.667	5.145	9.284	2.486	6.527	15.19	21.03	61.93	33.90	3.967
1363	5.952	5.215	9.489	3.886	6.272	16.10	23.59	60.36	33.70	4.232
1371	5.429	5.195	9.056	3.959	6.368	13.72	24.41	59.49	34.50	4.405
1380	5.552	5.000	9.974	4.111	8.677	13.90	22.87	60.02	33.77	4.007
1386	5.867	5.240	10.539	4.556	6.042	13.72	19.85	60.95	35.21	6.242
1390	4.983	4.932	10.179	4.318	7.569	14.11	25.29	58.55	33.76	4.595
1403	5.480	5.260	10.290	4.100	5.540	12.33	19.95	62.26	35.90	3.210
1409	5.040	4.870	8.360	3.750	12.450	17.26	30.02	57.60	31.86	5.590
1449	4.837	4.900	9.709	4.241	11.297	15.78	22.91	60.29	34.75	4.617
1552	6.190	5.220	10.110	4.410	7.130	17.15	23.15	60.14	31.80	4.920
1554	5.242	5.225	8.874	3.911	6.172	15.68	21.39	62.40	35.54	3.392
1555	5.123	5.207	9.129	4.098	6.484	14.87	24.51	61.01	35.49	2.225
1556	5.534	5.140	9.101	4.229	7.023	14.60	25.30	60.94	34.23	3.240
1558	5.051	5.030	8.378	3.566	9.278	17.17	29.86	56.36	32.98	5.793
1572	7.136	5.235	8.413	3.556	7.298	18.14	23.50	62.33	30.45	4.578
1573	5.456	4.819	8.846	3.892	12.784	17.46	26.54	59.14	31.34	7.295
1575	6.970	5.460	10.220	4.440	7.130	16.97	23.96	57.05	30.18	9.390
1578	5.299	5.348	9.399	4.193	5.395	14.88	25.29	61.33	35.70	3.672
1590	6.754	5.418	9.724	4.013	7.395	16.70	26.45	56.36	31.39	6.877
1594	10.938	2.350	29.234	15.461	-1.714	7.10	-33.03	55.74	28.55	10.460
1595	5.478	5.205	9.044	4.106	6.993	16.90	26.66	59.68	33.55	4.008
1596	5.108	5.335	10.424	3.966	6.468	16.37	21.65	60.71	33.61	3.693
1597	5.294	4.808	6.754	3.933	9.320	15.20	30.15	64.35	34.16	2.177
1598	4.469	5.153	9.529	4.093	8.230	16.61	23.57	60.18	34.48	4.442
1599	4.621	5.339	9.041	3.992	6.274	17.31	24.34	61.63	34.46	2.550
1600	5.008	5.365	9.689	4.036	6.133	16.79	22.29	61.73	34.66	2.493
1659	5.698	5.285	9.694	3.981	7.121	15.36	23.93	60.57	34.29	4.710
220	5.855	5.369	10.600	4.012	5.760	14.81	21.19	59.37	33.66	6.642
223	6.205	5.224	11.060	4.292	5.920	15.20	19.23	60.70	33.37	5.997
231	4.902	5.197	9.012	3.788	6.397	17.46	22.19	62.75	33.15	3.991

266	5.072	5.152	9.687	4.258	5.942	14.11	23.09	59.86	34.70	4.866
267	4.950	5.234	9.710	3.922	5.965	14.28	19.94	61.29	35.58	4.992
268	5.140	5.164	9.680	4.252	6.340	14.61	23.31	59.86	35.46	4.317
278	5.342	5.152	9.396	4.084	5.757	13.56	30.40	59.59	34.93	1.981
284	4.770	5.204	9.405	3.912	6.320	16.76	20.86	61.25	33.94	4.932
290	4.782	5.107	9.047	4.133	6.087	14.95	21.95	60.73	34.10	5.741
291	4.662	5.212	9.016	4.089	6.207	15.83	22.22	60.86	34.77	5.021
292	5.192	5.187	10.017	4.073	5.857	14.07	21.79	59.79	34.88	4.331
297	4.857	5.142	8.892	3.938	6.092	15.51	21.81	60.86	33.99	5.366
304	4.587	5.162	8.782	3.973	5.932	16.74	21.69	61.92	33.99	5.291
544	5.107	5.132	10.362	4.448	5.937	13.78	22.94	59.23	34.65	4.891
568	5.000	5.164	10.230	3.917	5.965	13.43	23.38	55.52	35.76	3.497
571	5.842	4.302	16.497	9.988	5.912	22.58	15.15	63.07	26.23	5.891
575	5.137	5.272	9.836	4.239	7.212	17.13	23.89	60.13	33.36	2.721
578	5.482	5.177	8.937	3.783	6.012	18.28	26.01	60.20	32.48	4.026
582	5.000	5.229	8.920	4.102	7.115	17.11	25.44	60.06	33.53	1.987
592	5.345	5.159	9.425	4.132	6.095	12.84	23.94	59.64	35.59	4.352
593	4.304	5.104	7.879	3.956	8.242	16.44	27.93	59.13	34.27	2.980
595	5.177	5.201	9.463	4.026	6.669	15.76	23.28	60.71	35.51	3.263
597	5.102	5.221	9.033	3.881	6.354	15.54	23.78	60.49	35.40	2.818
598	5.159	5.224	8.529	3.916	6.597	16.17	23.63	61.31	34.98	2.590
604	5.153	5.314	9.553	3.918	5.920	15.50	22.87	60.50	35.05	3.008
607	5.088	5.169	8.213	3.718	6.370	16.44	24.43	62.18	34.76	2.273
617	4.878	5.234	9.528	4.003	5.860	14.48	20.01	61.45	35.75	5.613
621	4.743	5.164	8.638	4.143	6.020	15.38	24.89	59.69	34.62	5.428
623	5.112	5.181	8.743	4.056	6.274	17.93	22.89	62.27	32.44	4.563
624	5.054	5.159	9.219	4.221	6.402	16.49	23.73	60.77	33.90	3.795
626	5.087	5.011	9.943	4.036	9.414	17.59	24.72	59.85	34.66	4.443
630	4.370	5.060	8.380	3.830	8.650	18.39	28.17	58.57	32.17	3.360
631	5.542	3.941	13.968	9.856	6.344	23.90	16.71	46.62	24.46	2.373
637	5.103	5.169	9.518	4.103	6.845	15.07	22.32	60.43	34.12	4.918
646	5.157	5.131	9.113	4.151	6.394	17.02	22.83	59.95	33.41	7.483
648	5.938	5.369	7.493	6.868	6.475	16.08	13.38	41.59	33.73	33.723
649	4.387	5.126	5.118	4.916	5.399	18.87	20.04	61.29	33.25	3.568
650	5.134	5.069	8.774	4.246	5.682	14.45	22.78	62.33	34.89	5.160
651	4.831	5.153	9.445	4.110	6.015	17.04	23.79	59.84	33.18	4.519
652	5.941	5.128	9.805	4.445	5.875	14.44	21.66	59.92	32.98	6.599
653	5.293	5.229	10.036	4.036	6.031	15.45	12.09	61.07	34.62	4.009
654	5.184	5.195	9.086	4.249	5.785	15.57	22.68	61.96	33.80	4.522
655	4.869	5.180	9.071	4.139	5.395	14.32	22.28	62.96	34.82	3.577
659	5.720	4.920	9.260	4.050	5.240	10.83	22.18	60.25	35.27	8.500
660	4.619	5.228	8.759	3.764	6.234	17.25	22.03	62.23	33.75	4.525
662	5.083	5.184	8.866	4.006	6.431	14.58	23.94	60.78	34.19	2.099
664	5.054	5.145	9.086	3.914	6.285	15.43	23.44	59.93	34.11	3.772
666	4.809	5.150	9.021	3.979	6.220	16.37	21.66	61.51	34.33	4.497
668	5.004	5.045	9.356	3.994	6.195	14.28	22.88	59.44	33.90	4.572
673	5.532	5.276	9.296	3.895	5.642	15.31	22.64	61.62	34.37	5.398
675	5.177	5.251	9.551	3.985	6.012	15.29	22.99	60.59	34.77	3.373
678	4.894	5.195	9.626	3.884	6.080	16.71	22.18	60.25	33.61	4.907
679	5.474	5.130	10.371	4.384	5.575	13.30	23.11	59.60	34.39	3.247
681	4.748	5.064	7.856	4.106	6.421	17.04	27.41	59.14	33.78	4.844
688	4.898	5.104	9.986	4.086	6.036	14.81	21.40	60.03	34.15	4.814
691	5.327	5.226	10.631	3.970	6.707	15.88	21.00	60.60	34.35	3.913
699	6.404	5.318	8.919	4.309	6.794	20.25	26.43	60.59	30.60	4.705
707	5.418	5.244	9.576	3.934	6.617	14.95	23.45	60.24	34.72	3.763
715	5.289	5.185	9.136	3.809	5.945	13.93	21.78	61.84	35.65	3.602
724	5.158	5.019	8.686	4.151	5.326	14.32	24.83	61.34	32.45	4.229
725	5.190	5.080	9.120	4.650	6.180	15.18	26.75	58.94	31.94	5.470
861	5.144	5.265	9.466	3.964	6.253	16.93	21.56	61.14	33.62	4.635
862	5.103	5.102	9.704	4.308	5.599	14.66	21.66	60.26	34.39	5.625
864	5.002	5.185	9.464	3.866	5.927	15.94	20.59	60.99	33.72	5.617
873	5.077	5.130	10.029	4.041	6.187	13.79	19.55	61.08	34.45	4.967
DUNDEE	5.764	5.112	9.966	4.083	5.968	11.99	22.34	59.17	34.70	4.383
DUNDEE*	5.362	5.225	9.413	3.776	6.089	14.96	22.98	60.08	34.20	3.849
EGRET	5.521	5.053	10.072	4.244	6.261	15.13	20.19	59.91	33.16	4.892
EGRET*	5.137	5.235	9.133	3.796	6.114	14.28	21.85	61.57	35.17	3.814
HERON	5.273	5.175	9.399	3.791	5.588	14.34	21.16	60.75	34.45	4.278
IBIS	5.513	5.175	9.659	3.981	6.018	13.97	21.10	61.07	34.60	4.573
F-prob	0.02	0.42	0.622	0.492	0.038	0.047	0.802	0.771	0.396	0.512

LSD	1.720	9626	7.039	4.214	3.524	4.509	20.47	8.438	4.649	9.342
CV	16.02	9.30	36.13	48.41	26.95	14.31	45.42	6.95	6.80	96.94
SE	0.8506	0.4762	3.482	2.085	1.743	2.231	10.12	4.174	2.300	4.621

Table-9. Means of nutritional quality traits of 96 soybean accessions planted in Brits

Genotype	Ash (%)	Fiber (%)	Linoleic acid (%)	Linolenic acid (%)	Moisture (%)	Oil (%)	Oleic acid (%)	Palmitic acid (%)	Protein (%)	Stearic acid (%)
1120	5.511	5.063	9.472	4.178	7.726	15.25	23.15	60.16	33.51	3.413
1363	4.621	4.733	8.207	3.618	11.121	15.84	30.18	55.87	32.49	5.443
1371	5.726	5.084	9.129	3.877	6.014	12.46	22.49	60.08	34.53	4.279
1380	4.766	4.903	8.517	4.053	8.676	16.28	27.32	59.20	33.35	3.553
1386	5.746	5.283	9.627	3.898	5.241	15.00	21.38	61.78	35.26	3.618
1390	5.679	5.112	9.662	4.138	5.570	13.35	21.43	61.74	33.77	3.039
1403	5.859	5.277	9.687	4.298	5.415	14.72	24.31	61.46	34.90	1.619
1409	5.046	4.753	8.732	4.008	11.141	14.63	24.91	61.78	35.04	4.673
1449	5.331	5.068	7.622	3.088	5.951	15.15	21.49	64.23	33.69	3.593
1552	5.761	5.069	8.939	4.007	6.599	12.34	20.89	61.43	34.32	4.124
1554	5.921	5.243	9.012	3.728	5.861	14.85	22.02	61.98	34.85	3.083
1555	5.634	5.092	8.512	4.193	7.485	12.01	27.41	61.85	34.48	3.599
1556	6.011	5.114	8.959	3.982	5.849	14.39	22.04	62.60	32.98	3.694
1558	3.920	4.660	9.350	4.060	11.300	16.29	25.66	57.51	33.71	6.810
1572	4.724	4.511	8.359	3.809	13.055	16.60	24.42	60.51	32.23	7.096
1573	4.763	4.641	9.899	3.836	12.802	16.77	21.92	60.20	32.75	7.536
1575	4.865	4.739	8.732	3.892	10.789	13.52	26.00	58.65	33.96	5.822
1578	5.020	4.954	8.957	3.977	10.129	17.18	25.38	59.46	32.74	4.577
1590	4.730	4.844	8.937	4.097	10.764	15.98	24.09	59.59	32.87	4.192
1594	5.263	4.991	9.644	4.168	7.704	14.71	21.73	60.45	33.31	3.963
1595	5.283	5.167	8.376	4.174	8.012	16.31	23.11	62.55	33.13	5.225
1596	5.028	5.072	9.066	3.914	8.742	18.04	22.83	61.20	32.44	4.700
1597	5.660	5.169	7.837	3.842	6.614	14.85	26.16	62.01	33.83	3.127
1598	4.215	5.194	7.627	3.897	7.564	18.84	29.36	58.55	32.99	2.277
1599	4.738	5.276	9.069	4.001	5.597	17.77	24.59	61.12	33.97	2.191
1600	4.653	5.177	9.086	4.064	7.522	17.50	25.75	57.49	33.39	2.925
1659	5.508	5.111	8.919	4.048	7.034	13.85	22.07	63.04	35.10	3.188
220	4.621	4.980	8.438	4.435	5.853	15.84	25.74	61.12	33.95	2.471
223	5.186	5.065	8.848	4.395	5.168	17.82	23.88	62.27	32.87	2.421
231	5.255	5.078	8.329	3.955	7.664	17.96	28.31	59.36	31.26	2.216
266	5.185	5.188	8.994	3.111	5.934	15.87	22.93	62.60	34.25	2.571
267	4.466	4.950	8.738	4.210	10.298	18.04	23.03	59.75	33.07	4.056
268	6.310	5.230	8.750	3.340	5.810	16.66	23.73	62.38	33.66	2.450
278	4.770	4.999	8.859	4.591	6.883	15.31	30.95	58.00	34.78	0.953
284	4.260	4.930	8.850	4.100	10.320	17.71	24.35	60.10	32.85	4.400
290	4.825	5.258	9.069	4.040	5.854	16.98	22.98	62.98	34.76	3.776
291	5.395	5.224	8.659	3.581	5.138	17.29	25.83	62.11	33.81	0.928
292	4.640	4.680	9.830	4.240	11.910	16.97	26.03	56.44	32.59	6.420
297	4.340	5.078	7.804	3.875	7.104	17.40	27.07	58.74	34.09	3.166
304	4.900	5.030	7.680	3.860	8.040	18.83	24.67	61.52	31.42	4.400
544	5.400	5.250	8.420	3.880	5.360	16.38	24.39	62.49	34.49	1.780
568	5.540	5.180	8.870	4.000	5.320	16.77	25.02	61.43	33.08	1.910
571	5.415	5.518	8.619	4.095	5.134	15.50	24.35	63.03	34.47	0.991
575	5.290	5.229	9.004	4.606	5.358	17.35	21.30	63.40	32.68	3.538
578	5.085	5.243	8.254	3.880	6.449	17.87	25.23	60.86	32.89	3.716
582	5.081	5.215	7.783	3.935	5.478	19.92	23.28	63.27	31.39	3.376
592	4.796	4.915	9.248	4.095	8.703	16.99	30.87	57.01	33.58	3.326
593	4.809	4.965	7.562	3.866	8.112	18.12	28.42	59.12	31.99	3.220
595	5.201	5.186	8.956	4.398	6.523	16.88	24.88	60.73	34.11	1.035
597	5.201	5.116	8.706	4.033	6.813	13.53	24.79	60.36	35.77	2.425
598	5.044	5.055	8.607	3.901	6.782	13.63	23.84	61.46	35.40	2.740
604	5.370	5.260	9.600	4.220	5.780	14.49	23.76	60.74	35.65	1.740
607	5.310	5.190	9.110	4.020	5.650	15.53	22.08	62.03	34.04	3.090
617	4.320	5.020	8.530	3.840	8.730	16.89	24.84	58.43	33.21	5.340
621	4.520	4.970	8.570	4.320	8.780	13.53	27.00	57.83	35.10	4.540
623	4.516	4.956	7.176	3.708	8.358	19.85	28.21	60.96	31.07	3.085
624	4.799	5.005	7.532	3.891	8.162	17.36	25.71	60.04	32.22	4.365
626	5.291	5.036	9.201	4.028	8.833	16.80	25.46	60.46	33.75	4.480
630	5.081	5.305	7.952	3.687	5.888	18.86	23.46	63.57	31.41	3.763
631	4.971	4.981	7.211	4.148	7.793	13.54	33.05	56.50	33.98	1.360
637	5.456	5.235	9.242	3.772	5.483	16.52	21.18	63.03	33.57	4.063
646	5.306	5.171	8.776	3.803	6.663	15.94	23.16	60.11	33.59	4.210
648	4.961	5.055	8.402	3.937	7.608	17.85	14.17	61.54	31.93	3.428
649	4.466	5.121	8.301	4.028	5.898	16.47	25.97	61.16	34.12	2.720
650	4.969	5.115	8.122	4.451	6.837	18.22	24.76	63.32	32.86	2.420
651	5.194	5.231	13.829	4.645	5.617	17.10	25.38	60.94	33.25	2.148
652	5.714	5.126	8.424	3.955	5.682	16.22	26.71	60.96	32.97	1.638
653	5.609	5.254	8.592	3.871	5.610	17.03	22.92	63.58	32.52	1.248

654	4.921	5.049	8.714	4.234	8.584	15.89	31.67	60.53	33.66	3.780
655	5.626	5.129	8.809	4.029	6.554	17.58	22.07	62.74	34.75	2.995
659	4.642	4.853	7.912	3.935	8.086	14.24	26.63	60.17	35.29	2.756
660	5.714	5.248	9.547	4.052	6.912	18.19	22.18	60.74	32.34	5.453
662	5.640	5.200	9.630	3.970	5.580	13.18	23.75	60.25	34.89	1.860
664	4.186	4.934	7.704	4.224	6.489	15.72	26.12	60.17	33.87	3.505
666	5.306	5.229	9.314	3.949	5.769	15.55	21.39	61.71	34.25	3.115
668	4.430	4.790	8.310	4.310	9.880	14.89	30.60	56.22	33.40	4.700
673	5.357	5.168	7.767	3.615	5.961	17.50	24.28	63.57	33.68	2.436
675	5.497	5.253	8.372	3.990	5.591	18.07	24.66	63.44	32.95	1.351
678	5.356	5.114	9.439	4.019	6.874	14.52	21.87	60.76	33.42	4.285
679	4.781	5.009	9.349	4.179	7.534	14.38	27.25	58.13	34.66	2.235
681	4.659	4.869	8.202	3.631	8.825	17.01	27.35	59.37	32.43	4.498
688	4.399	5.089	8.232	4.061	7.475	18.24	27.97	59.05	33.14	3.323
691	4.790	5.100	8.690	4.070	7.300	15.37	24.31	60.73	33.77	4.020
699	5.870	5.310	8.700	3.510	5.930	21.75	26.34	62.21	29.58	4.040
707	4.730	4.740	9.350	4.300	11.520	14.62	28.05	57.34	34.40	3.800
715	5.031	5.159	8.614	3.874	7.839	17.28	26.45	59.85	33.73	2.135
724	5.449	5.164	8.877	4.536	5.580	16.80	26.04	61.12	32.94	1.113
725	5.510	5.240	9.190	4.070	5.540	17.92	24.15	61.46	32.20	2.230
861	5.510	5.280	9.880	4.050	5.840	17.39	23.23	60.94	33.62	2.340
862	5.939	5.202	9.892	3.998	5.410	13.68	20.99	60.66	33.86	4.224
864	5.131	5.193	8.082	4.113	6.686	15.71	27.48	60.53	33.89	-0.610
873	5.631	5.228	9.792	4.058	5.721	14.84	25.23	60.90	34.46	2.433
DUNDEE	5.763	5.160	9.701	4.137	5.509	14.29	24.18	59.75	34.30	2.896
DUNDEE*	5.745	5.238	9.254	4.009	5.664	16.58	24.84	60.19	33.25	2.894
EGRET	4.911	5.031	8.949	4.072	8.081	16.14	25.65	58.18	33.02	3.510
EGRET*	5.245	4.968	8.694	3.724	8.944	17.75	28.28	59.01	32.43	4.264
HERON	5.028	5.162	7.781	3.994	6.667	16.09	29.54	58.16	34.15	2.325
IBIS	5.383	5.092	8.151	3.819	6.972	13.85	25.89	60.42	35.55	2.775
F-prob	0.224	0.004	0.079	0.030	0.012	0.001	0.217	0.018	0.002	0.069
LSD	1.1530	0.3602	2.105	0.6042	4.113	3.218	7.386	4.319	2.199	3.300
CV	10.55	3.33	11.30	7.10	26.81	9.35	13.94	3.34	3.09	47.16
SE	0.5428	.1696	0.9908	0.2844	1.936	1.515	3.477	2.024	1.035	1.547

Table-10. Means of nutritional quality traits across the two sites. Potchefstroom and Brits in 2016/17.

Genotype	Ash (%)	Fiber (%)	Linoleic acid (%)	Linolenic acid (%)	Moisture (%)	Oil (%)	Oleic acid (%)	Palmitic acid (%)	Protein (%)	Stearic acid (%)
1120	5.605	5.114	9.359	3.292	7.049	15.24	22.07	61.09	33.70	134.3
1363	5.319	4.990	8.851	3.741	8.565	15.99	26.79	58.21	33.11	184.0
1371	5.594	5.132	9.164	3.955	6.157	13.08	23.28	59.84	34.50	171.6
1380	5.184	4.962	9.251	4.068	8.617	15.07	25.04	59.64	33.56	142.7
1386	5.821	5.270	10.080	4.222	5.594	14.35	20.60	61.37	35.23	191.8
1390	5.319	5.023	9.894	4.220	6.583	13.78	23.54	60.08	33.75	147.3
1403	5.726	5.273	9.906	4.229	5.450	13.90	22.78	61.77	35.24	59.7
1409	5.058	4.803	8.606	3.921	11.537	15.58	26.69	60.31	33.90	181.9
1449	5.090	4.990	8.680	3.667	8.644	15.49	22.23	62.21	34.23	163.9
1552	5.915	5.124	9.353	4.153	6.783	14.05	21.70	60.99	33.42	175.9
1554	5.585	5.243	8.925	3.807	5.962	15.29	21.70	62.21	35.20	109.8
1555	5.370	5.155	8.796	4.133	6.953	13.52	26.04	61.41	34.98	97.6
1556	5.786	5.118	9.105	4.145	6.415	14.48	23.52	61.81	33.61	121.2
1558	4.702	4.908	8.715	3.739	9.917	16.93	28.40	56.73	33.18	250.1
1572	5.984	4.886	8.401	3.689	10.060	17.37	23.88	61.43	31.31	227.1
1573	5.128	4.723	9.362	3.881	12.784	17.07	24.14	59.59	32.03	263.5
1575	5.605	4.994	9.257	4.086	9.523	14.80	25.31	58.07	32.59	252.4
1578	5.147	5.144	9.197	4.117	7.730	16.01	25.34	60.34	34.23	154.7
1590	5.755	5.126	9.355	4.082	9.067	16.37	25.31	57.84	32.08	199.7
1594	8.197	3.611	19.842	10.049	2.843	10.75	-6.76	58.03	30.83	110.5
1595	5.378	5.178	8.749	4.162	7.493	16.61	24.83	61.02	33.33	178.4
1596	5.064	5.199	9.794	3.964	7.577	17.18	22.12	60.90	33.02	158.0
1597	5.455	4.970	7.292	3.917	8.045	15.05	28.22	63.14	33.97	108.7
1598	4.329	5.160	8.619	4.026	7.945	17.71	26.38	59.31	33.73	117.3
1599	4.686	5.299	9.060	4.013	5.936	17.48	24.30	61.32	34.24	67.2
1600	4.830	5.266	9.425	4.073	6.813	17.13	23.86	59.63	34.02	83.3
1659	5.618	5.180	9.430	4.081	7.066	14.59	22.73	61.78	34.66	150.2
220	5.249	5.176	9.559	4.216	5.926	15.29	23.53	60.00	33.80	148.6
223	5.703	5.143	9.995	4.341	5.676	16.45	21.62	61.24	33.12	159.1
231	5.087	5.140	8.621	3.860	7.036	17.80	25.23	61.10	32.16	105.9
266	5.140	5.170	9.291	3.692	5.963	15.06	23.09	61.17	34.40	134.2
267	4.707	5.092	9.247	4.061	8.188	16.09	21.58	60.33	34.35	189.0
268	5.528	5.187	9.365	3.950	6.169	15.29	23.47	60.68	34.86	137.9
278	5.068	5.073	9.141	4.338	6.384	14.45	30.78	58.76	34.82	35.7
284	4.603	5.115	9.214	3.973	7.644	17.08	22.04	60.86	33.57	190.6
290	4.816	5.181	8.998	4.079	5.999	16.03	22.52	61.81	34.34	187.9
291	5.021	5.213	8.848	3.850	5.769	16.58	24.08	61.41	34.26	115.7
292	5.010	5.022	9.936	4.113	7.864	15.00	23.24	58.65	34.14	200.6

297	4.620	5.112	8.305	3.898	6.608	16.53	24.43	59.82	33.96	166.4
304	4.691	5.121	8.399	3.920	6.637	17.41	22.73	61.75	33.16	209.1
544	5.204	5.173	9.701	4.245	5.756	14.62	23.48	60.26	34.62	150.5
568	5.180	5.170	9.773	3.943	5.756	14.54	23.95	57.45	34.87	96.5
571	5.648	4.893	12.615	7.120	5.559	19.24	19.69	63.04	30.15	31.6
575	5.215	5.246	9.438	4.425	6.393	17.28	22.74	61.65	32.99	109.7
578	5.303	5.210	8.546	3.821	6.249	18.18	25.70	60.51	32.60	146.0
582	5.032	5.218	8.376	4.020	6.441	18.45	24.53	61.40	32.49	83.5
592	5.071	5.037	9.347	4.113	7.481	14.83	27.44	58.15	34.61	153.6
593	4.550	5.040	7.756	3.901	8.185	17.20	28.22	59.08	33.20	103.8
595	5.199	5.201	9.217	4.179	6.559	16.26	24.09	60.73	34.87	65.3
597	5.161	5.177	8.874	3.927	6.538	14.53	24.31	60.44	35.62	74.8
598	5.104	5.146	8.598	3.897	6.693	14.89	23.78	61.33	35.22	78.6
604	5.223	5.295	9.598	4.017	5.867	15.17	23.09	60.62	35.24	74.4
607	5.160	5.173	8.522	3.817	6.137	16.13	23.65	62.18	34.54	71.3
617	4.697	5.161	9.229	3.954	6.798	15.25	21.55	60.50	34.92	228.2
621	4.672	5.098	8.646	4.206	6.921	14.75	25.53	59.12	34.78	214.0
623	4.833	5.079	7.982	3.859	7.246	18.82	25.51	61.65	31.81	134.0
624	4.931	5.088	8.432	4.050	7.262	16.86	24.74	60.37	33.12	153.3
626	5.197	5.030	9.583	4.004	9.093	17.17	25.12	60.15	34.26	168.9
630	4.828	5.218	8.115	3.740	6.875	18.68	25.15	61.78	31.69	129.4
631	5.276	4.453	10.689	7.059	7.008	18.84	24.68	51.41	29.12	57.0
637	5.277	5.200	9.415	3.948	6.178	15.75	21.74	61.71	33.86	171.4
646	5.240	5.158	8.949	3.954	6.486	16.46	23.03	60.04	33.54	219.3
648	5.467	5.215	7.965	5.451	7.018	16.91	13.73	51.27	32.86	184.3
649	4.436	5.131	6.662	4.457	5.602	17.67	22.95	61.24	33.71	102.5
650	5.055	5.095	8.489	4.334	6.248	16.22	23.79	62.76	33.94	134.3
651	4.999	5.195	11.578	4.347	5.836	17.09	24.72	60.35	33.22	121.1
652	5.823	5.131	9.141	4.184	5.796	15.32	24.27	60.40	32.99	148.6
653	5.443	5.248	9.314	3.950	5.779	16.28	17.31	62.33	33.59	85.3
654	5.041	5.125	8.878	4.238	7.149	15.81	27.11	61.30	33.71	162.6
655	5.221	5.156	8.917	4.082	5.964	15.98	22.24	62.88	34.76	112.7
659	5.011	4.879	8.374	3.976	7.064	12.96	25.05	60.19	35.33	149.9
660	5.154	5.243	9.085	3.896	6.498	17.73	22.03	61.61	33.07	169.5
662	5.263	5.190	9.109	3.987	6.163	14.14	23.87	60.61	34.42	47.2
664	4.618	5.044	8.388	4.061	6.390	15.65	24.81	60.08	33.97	133.5
666	5.035	5.189	9.136	3.961	6.008	16.05	21.59	61.63	34.27	142.7
668	4.818	4.966	9.012	4.089	7.349	14.49	25.32	58.43	33.74	192.1
673	5.441	5.225	8.551	3.767	5.794	16.35	23.38	62.55	34.05	143.6
675	5.326	5.253	8.976	3.995	5.804	16.62	23.75	61.96	33.90	70.1
678	5.103	5.157	9.508	3.946	6.472	15.72	22.10	60.53	33.50	187.7
679	5.123	5.072	9.848	4.281	6.532	13.90	25.19	58.91	34.50	83.0
681	4.701	4.976	8.003	3.870	7.539	17.09	27.35	59.30	33.11	189.4
688	4.652	5.103	9.114	4.068	6.686	16.53	24.56	59.60	33.65	156.9
691	5.168	5.187	10.044	4.011	6.893	15.76	21.95	60.64	34.14	149.1
699	6.233	5.317	8.843	4.033	6.520	20.73	26.37	61.08	30.28	183.0
707	5.197	5.072	9.543	4.076	8.228	14.84	24.84	59.32	34.61	141.2
715	5.149	5.173	8.855	3.837	6.870	15.64	24.11	60.91	34.70	94.0
724	5.296	5.096	8.758	4.332	5.401	15.59	25.39	61.28	32.67	93.1
725	5.353	5.161	9.156	4.355	5.855	16.57	25.43	60.21	32.07	144.5
861	5.284	5.256	9.696	4.036	6.078	17.05	21.82	61.14	33.60	150.5
862	5.507	5.154	9.761	4.147	5.491	14.22	21.46	60.44	34.12	197.4
864	5.078	5.198	8.777	3.971	6.236	15.84	23.94	60.84	33.79	165.0
873	5.359	5.187	9.898	4.034	5.901	14.32	22.31	61.01	34.45	136.1
DUNDEE	5.773	5.122	9.907	4.131	5.755	13.08	23.19	59.27	34.47	137.7
DUNDEE*	5.550	5.218	9.397	3.938	5.906	15.71	23.70	60.04	33.72	121.8
EGRET	5.212	5.100	9.277	3.975	7.107	15.77	23.55	58.98	33.15	170.7
EGRET*	5.192	5.092	8.981	3.810	7.510	15.92	24.79	60.24	33.83	159.0
HERON	5.149	5.160	8.643	3.913	6.118	15.19	25.12	59.44	34.28	118.0
IBIS	5.444	5.126	8.956	3.926	6.487	13.91	23.32	60.71	35.04	138.5
Genotype	0.8203***	.1472	0.93	2.282	6.577***	.766***	55.09	12.59	4.906*	8854***
Site	3.0554	0.0670	9.68**	9.210*	9.696***	37.343**	666.57***	25.12	7.737	250321***
Genotype * Site	0.6848*	0.1363	0.79	2.150	3.906	5.117	41.15	8.64	3.219	4359
Mean	5.12	5.00	9.03	4.07	6.70	15.56	23.11	59.15	33.02	139.23
LSD	1.480	0.7804	5.479	3.208	3.865	4.281	15.93	7.018	3.798	129.4
CV	13.77	7.44	28.94	37.55	27.54	13.12	32.90	5.65	5.49	44.54
SE	0.7204	.3799	2.667	1.562	1.882	2.084	7.756	3.409	1.849	62.24
R^2										

Note: *** p<0.001, ** p< 0.025 and *p< 0.05

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