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Genetic diversity, variability and characterization of the agro-morphological traits of Northern Ghana Roselle (*Hibiscus sabdariffa* var. *altissima*) accessions

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Roselle (*Hibiscus sabdariffa* var. *altissima*), a bast fibre crop adapted to the warm climate of Northern Ghana, offers a great economic potential not yet explored for lack of information on its distribution, collection, and genetic diversity. Little variability is reported in exotic genotypes to merit trait improvement. The objective of this study is to investigate distribution and diversity in roselle of Northern Ghana. Twenty-five accessions collected from seven districts were field evaluated in a 5×5 lattice square design in three replications at twelve qualitative and five quantitative morphological traits. Data were analysed for within- and between-population variability and multivariate analysis. Large within-population variability of SDI 0.72 to 0.87 was identified in accessions of Kassena-Nankana East district. The most variable traits, plant height and branch number, varied from 184 cm to 284 cm with six accessions HA-44, HA-47, HA-43, HA-38, HA-52, and HA-42 having the tallest plants and least basal branching of four. Mean flowering time was between 96 and 104 days. Mean Euclidean distance of 3.03 ± 0.90 ranged from 0.41 to 5.17. Based on means across pairwise distances of 2.22 and 3.94, three accessions were divergent, namely, HA-61 (3.94), HA-57 (3.66) and HA-59 (3.63). Clustering and principal components analyses delineated three distinct groups. The first three PCs explained 100% of the variance. The ample diversity in roselle awaits exploitation for genetic improvement, particularly for fibre yield.

Key words: Bast fibre crop, cluster analysis, discriminant analysis, genetic diversity, morphology, PCA, roselle.

INTRODUCTION

Hibiscus sabdariffa var. *altissima* Wester, hereinafter referred to as roselle, is the cultivated fibre type with inedible calyx. Roselle is less known than its vegetable type, *H. sabdariffa* var. *sabdariffa*, and is underutilized for its bast fibre in Sub-Saharan Africa (SSA), although it is an important fibre commodity in Asia. Roselle fibre is ideal for making cordage due to its salt-resistant trait (Crane, 1949; Cook, 1960), for packaging sacs, paper products, upholstery, and a fabric for shoes and bag (Managooli, 2009). New found uses include a bio-composite for automobile parts and building materials such as fibre board (Alves et al., 2010; Junkasem et al., 2006). Roselle accounts for about 20% of bast fibre crops. From 1961 to 2016, bast fibre crop acreage in

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Table 1. Accessions of roselle (var. *altissima*) evaluated by morphological traits in Ghana in 2017

Accession	Collection site	District	Accession	Collection site	District
HA-37	Sumbrungu	Bolgatanga Municipality	HA-50	Yorogo	Bolgatanga Municipality
HA-38	Sirigu	Kassena-Nankana West	HA-51	Nawasa	Gonja North
HA-39	Chuchuliga	Builsa North	HA-52	Korania	Kassena-Nankana East
HA-40	Bolgatanga	Bolgatanga Municipality	HA-53	Nawasa	Gonja North
HA-41	Yua	Kassena-Nankana West	HA-54	Wiasa	West Mamprusi
HA-42	Pungu	Kassena-Nankana East	HA-55	Yua	Kassena-Nankana West
HA-43	Sirigu	Kassena-Nankana West	HA-56	Navrongo	Kassena-Nankana East
HA-44	Manyoro	Kassena-Nankana East	HA-57	Dua	Bongo
HA-45	Korania	Kassena-Nankana East	HA-58	Korania	Kassena-Nankana East
HA-46	Chuchuliga	Builsa North	HA-59	Navrongo	Kassena-Nankana East
HA-47	Manyoro	Kassena-Nankana East	HA-60	Gowrie	Bongo
HA-48	Saboro	Kassena-Nankana East	HA-61	Zaare	Bolgatanga Municipality
HA-49	Bolgatanga	Bolgatanga Municipality			

Sub-Saharan Africa (SSA) increased from 15,000 to 25,000 ha, equivalent to 67% growth, whereas bast fibre yield dropped from 1.15 to 0.67 t/ha, corresponding to 42% reduction. Nine countries, namely, Angola, Central African Republic, Democratic Republic of Congo, Ethiopia, Madagascar, Mali, Mozambique, Nigeria, and South Africa were engaged in bast fibre production. Current bast fibre production in SSA amounts to 16,000 metric tons/year. Research and development in roselle as a potential for bast fibre production in Ghana is lacking, despite a wide range of morphotypes found in the northern sector of the country (Ankrah et al., 2018).

A collection of roselle will control loss of this biodiversity. Assessment of genetic variability and diversity in roselle will provide information for development of improved cultivars and for conservation management. In a preliminary survey of knowledge of roselle in Northern Ghana, the indigenous folk asserted that roselle is threatened, as previous morphotypes are no longer common (personal communication). Moreso, the widely reported lack of variability in exotic roselle germplasm which is hampering efforts for genetic improvement is a legitimate concern (Omalsaad et al., 2014; Yusof and Saud, 2009; Hanboonsong et al., 2000).

Genetic diversity is a dynamic property of germplasm and its estimation may be based on morphological evaluation, biochemical, or molecular assessment (Bhandari et al., 2017). Among the three approaches, morphological characterization offers less costly and readily assessable measurement making them attractive to breeders for a genetic improvement program. Morphological evaluation is labour intensive, requires large plant population size, exhibits low rate of polymorphism and is constrained by environmental sensitivity and higher risks of biased estimates (Botha and Venter, 2000). Despite these drawbacks, morphological evaluation provides sufficient information on crop characteristics and reveals sources of useful genotypes for trait improvement (Camussi et al., 1985). Genetic diversity studies on roselle (var. *altissima*) are rather scanty and limited to work reported by Ankrah et al. (2018) who assessed thirty-six wild roselle accessions in Ghana; a study on a roselle bast fibre characterization study in Kenya (Mwasiagi et al., 2014), and some comparative variability study between kenaf and roselle (Sie et al., 2009; Cheng et al., 2004; Siepe et al., 1997). Further collection of 25 roselle accessions in northern Ghana is hereby evaluated for genetic variability and diversity information. The objective of this research is to estimate genetic diversity in a further collection of twenty-five accessions of roselle in northern Ghana based on agro-morphology evaluation.

MATERIALS AND METHODS

Plant material, experimental design and crop management

Seeds of twenty-five accessions of roselle (Table 1) were supplied by farmers located in seven districts in Northern Ghana covering a geographical area of latitude 9° 39´ to 10° 59´ N and longitude 0° 47’ to 1° 23’ W with an elevation of 119 to 238 masl (Figure 1). Field trial was carried out from June 26, 2017 to November 30, 2017 on the research fields of the Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi. This site is located at latitude 6^{o} 40´39 N and longitude 1° 33´58 W at an elevation of 258 masl in the semi-deciduous forest zone of Ghana. Average monthly rainfall within this period was 4.6 mm. The soil type was sandy loam Auroso Orchrosols with a pH of 5.9.

Seeds were planted in 5×5 lattice square design with three replications on 0.5 m × 2.0 m plot with an alley of 1.0 m to give 20 plants/plot. Irrigation was carried out as and when required. The pre-emergence weeds, nut grass (*Cyperus rotundus*) and *Panicum maximum* were controlled with WeedKill (glyphosate, 400 g/L) at a rate of 3.0 L/ha and post-emergence weeds by hand weeding with a hoe. The predominant insect pests, cotton stainer (*Dysdercus* sp.) and thrips (*Thysanoptera)* were controlled with Sumitex (dimethoate

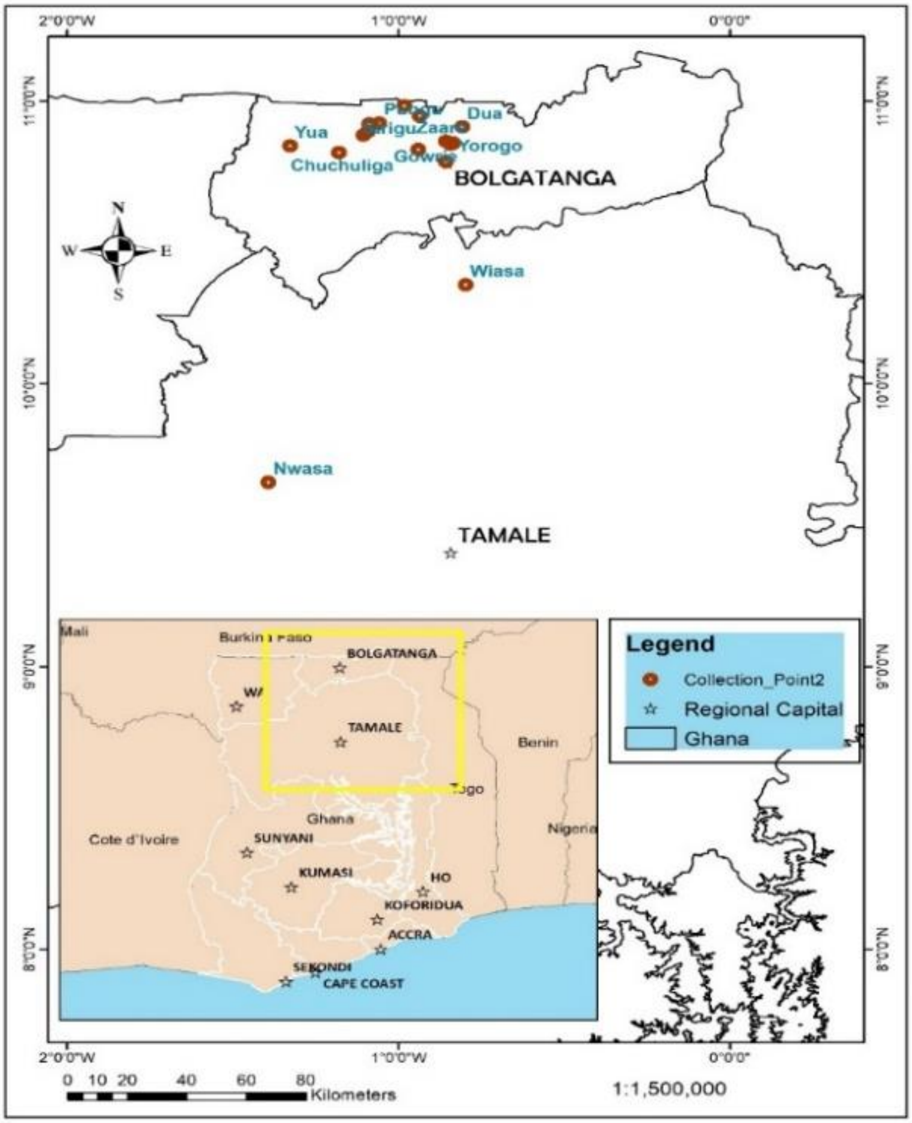

Figure 1. A schematic of Ghana map showing roselle (var. *altissima*) seed collection sites in the Northern and Upper East regions.

400 g/L) at a rate of 1 L/ha.

Data collection

Days to 50 % flowering (DTF) were recorded beginning at 90 days after planting (DAP). At 150 DAP, 12 qualitative and five quantitative traits on 10 competitive plants per plot were collected. The descriptors of roselle (var. *altissima*) were adapted from El-Naim et al. (2012) and Coffie (2016). The qualitative traits included plant type, (PT: predominant colour of the plant; green (1), pigmented (3), red (5)); branching habit (BH: extent of branching; few (1), intermediate (2), extensive (3)); growth habit, (GH: form of growth; non-bushy (1), bushy (2)); stem pubescence (SPB: feel of the stem; smooth (1), hairy (2), rough (3), spiny (4)).

Other traits were leaf form (LF: shape of leaf; entire (1), trilobed (3), pentalobed (5)); size of leaf (LS: shape of the leaf blade; slender (1), broad (2)); leaf pubescence (LPB: presence or absence of hair; smooth (1), hairy (2)). Calyx pigmentation (CPG: predominant colour of the calyx; green (1), pigmented (2), red (3), calyx pubescence (CPB: presence or absence of hair; smooth (1), hairy (2); and capsule shape (CSH: predominant shape of the capsule; ovoid (1), round (2)) were also evaluated. The remaining traits were petal colour (PC: predominant colour of the petals; yellow (1), purple (2)), and throat colour (TC: colour of the flower throat; yellow (1), crimson (3)).

Days to 50% flowering was measured as number of days from planting to 50 % of plants in a plot having at least one open flower. Plant height (PH, cm) was estimated as height from ground level to growing tip; height at first branching (HFB, cm) as distance from ground level to first primary branch, and basal diameter (BD, mm) as diameter of the stem at 5 cm above ground. Finally, branching number (BN) was determined by counting the number of primary reproductive branches along the stem. Micrometre screw gauge and meter rule were used to measure diameter and heights, respectively.

Statistical analysis

Frequencies of occurrence of the twelve qualitative traits and their percentages were computed to reveal morphological variabilities. Principal Components Analysis (PCA) was performed on the qualitative data with PROC PRINQUAL of SAS to reveal the discriminatory power of the traits identifying groups on the basis of their similarities. The quantitative traits were analyzed by computing means, standard deviation, minimum and maximum values and coefficient of variation (CV). Entry means (X_i) and standard deviation (σ) were used to divide accession scores into five phenotypic classes (x_i) of equal width of 1.0σ, for the entire data spanning (xi-2σ)≥ X_i ≥(xi+2σ). The frequency of genotypes in the ith class (P_i) was used to deduce the standardized Shannon-Wiener Diversity Index (SDI) for within-population variation, (Shannon, 1948), where:

$$H' = -\Sigma \frac{(Pi * lnPi)}{\ln n} \tag{1}$$

P_i was computed as n_i/N, where n_i is the number of individuals of the ith class, and N is the total number of individuals; n is the number of classes. The between-population variation was assessed by analysis of variance of the lattice square design based on the random effects model presented as,

$$Y_{ijk} = \mu + R_j + B(R) + G_i + \varepsilon_{ijk} \tag{2}$$

In this model, Y_{ijk} is genotype response, G_i, in replication R_j, in block B_k and ε_{ijk} as the error associated with the genotype i = 1…, t, replication j =1…, r, and block nested within replication k =1…, s. The expected mean squares (EMS) were derived from analysis of variance. Pairwise genetic similarity between accessions was based on Euclidean distance computed as:

$$d(x,y) = \sqrt{\sum_i^n (Px_i - Py_i)}^2 \tag{3}$$

where d = the Euclidean distance; i = trait; n =total number of traits; x_i = value for trait x; and y_i = value for trait y. Mean Euclidean distance for each accession was calculated to estimate dissimilarity between the population. Cluster analysis was performed on the distance matrix using Ward's minimum variance method (Ward, 1963). A stepwise discriminant analysis identified traits that contributed most to the variance by minimizing Wilk's lambda (Wilk, 2006). Principal components analysis (PCA) was performed on the distance matrix to depict relationships among the genotypes and determine the loadings that were effective in discriminating between accessions. A scatterplot of the first and second principal components was constructed to reveal relationships between traits and between accessions. The SAS 9.3 program (SAS Institute Inc, 2011) was employed for all statistical computations.

RESULTS

Variability in qualitative traits

The roselle collection was represented by nine accessions (36%) in Kassena-Nankana East, five accessions (20%) in Bolgatanga Municipal, and four (16%) in Kassena-Nankana West. The others were two accessions (8%) each in Bongo, Builsa-North, and Gonja-North districts and one (4%) accession in West Mamprusi. A total of 750 plants were evaluated. Roselle exhibited large variability in all qualitative traits except growth habit, calyx pubescence and capsule shape. All plants exhibited non-bushy growth, with hairy calyx and round capsules. Leaf size and petal colour were somewhat variable with 80.1% slender leaves, 19.9% having broad leaves, and 72.4% yellow and 27.6% purple petals, respectively.

The highly variable traits were plant type (40.7% uniform green, 31.7% pigmented, 27.6% red), branching habit (25.1% few, 60.1% intermediate, 14.8% extensive), and stem pubescence (44.5% smooth, 26.1% hairy, 27.9% rough, 1.5% spiny). The others were, leaf form (6.0% entire, 30.3% tri-lobed, 63.7% penta-lobed), leaf pubescence (62.1% smooth, 37.9% hairy), calyx pigmentation (40.7% uniform green, 31.7% pigmented, 27.6% red), and throat colour (40.7% yellow, 59.3% crimson) (Table 2). Plate 1 shows variation in calyx, flower, stem and leaf morphology.

Principal component analysis of qualitative data

A scatter plot of the qualitative traits revealed that the first three principal components (PC) with eigenvalues greater than 1.0 had large contribution to the variance. The first two PCs accounted for 65% of the total variance, with PC1 43.64% and PC2 21.71%. Based on length of the vectors, plant type and calyx pigmentation exerted greatest contribution to the variance, followed by petal colour and throat colour, while branching habit contributed least (Figure 2).

Four major groups of roselle (var. *altissima*) were identified, namely, Group I, consisting of three genotypes HA-42, HA-44, HA-49 with predominantly penta-lobed and hairy leaves, and few branched rough and spiny stems; Group II with five genotypes HA-38, HA-51, HA-54, HA-57, HA 59 distinguished by extensive branching; group III having three genotypes, HA-39, HA-41, HA-60 were clustered entirely on their broad leaf trait, and finally, group IV with five genotypes, HA-48, HA-53, HA-55, HA-56, HA-58 were green plant type with few branching, smooth stem, slender and entire smooth leaves, green calyx, yellow petals and yellow throat. Genotypes HA-40, HA-46, HA-47 and HA-50 were not clustered with other genotypes as were HA-37, HA-43, HA-45, HA-52, and HA-61. Growth habit, calyx pubescence, and capsule shape were not discriminatory as these were not represented on the biplot.

Within-population variation in quantitative traits

The Shannon-Weiner Diversity Index (SDI) ranged from 0.00 to 1.00 with a mean of 0.82 ± 0.19. All traits exhibited high mean SDI values of 0.74 to 0.85 (Table 3). Plants of all accessions exhibited variation in number of

Table 2. Distribution of qualitative morphological traits in roselle (var. *altissima*) collected from Northern Ghana and evaluated in 2017.

Trait	Description	Score	No. of plants	Percentage
Plant type (PT)	Uniformly green	1	305	40.7
	Pigmented	3	238	31.7
	Uniformly red	5	207	27.6
Branching habit (BH)	Few	1	188	25.1
	Intermediate	2	441	60.1
	Extensive	3	111	14.8
Growth habit (GH)	Non-bushy	1	750	100
	Bushy	2	0	0
Stem pubescence (SPB)	Smooth	1	334	44.5
	Hairy	2	196	26.1
	Rough	3	209	27.9
	Spiny	4	11	1.5
Leaf form (LF)	Entire	1	45	6.0
	3-lobed	3	227	30.3
	5-lobed	5	478	63.7
Leaf size (LS)	Slender	1	601	80.1
	Broad	2	149	19.9
Leaf pubescence (LPB)	Smooth	1	466	62.1
	Hairy	2	284	37.9
Calyx pigmentation (CPG)	Green	1	305	40.7
	Pigmented	2	238	31.7
	Red	3	207	27.6
Calyx pubescence (CPB)	Smooth	1	0	0
	Hairy	2	750	100
Capsule shape (CSH)	Ovoid	1	0	0
	Round	2	750	100
Petal colour (PC)	Yellow	1	543	72.4
	Purple	2	207	27.6
Throat colour (TC)	Yellow	1	305	40.7
	Crimson	3	445	59.3

days to flowering with SDI values as high as 0.92 to 1.00 except HA-43, HA-46, HA-51, HA-55, and HA-60 whose individual plants consistently flowered on the same day, hence their SDI values were 0.00. Based on accession means across traits, HA-38, HA-42, HA-47, HA-57 and HA-58 were the most variable with SDI values of 0.90 ± 0.08 to 0.93 ± 0.05. The most variable accessions in the individual traits were, for plant height, HA-45, HA-51 and HA-59 (SDI: 0.97 to 1.00); height after first branching, HA-43 and HA-58 (SDI: 0.97); branch number, HA-37, HA-47, HA-50, HA-55, HA-57, HA-58, and HA-60 (SDI: 0.97 to 1.00), and for basal diameter, HA-42 and HA-57 (SDI: 0.95 to 0.96). The district having highest roselle fibre diversity by rank were Kassena-Nankana East (0.87 ± 0.09), Bolgatanga Municipal (0.83 ± 0.10) and West-Mamprusi (0.82 ± 0.09) (Table 3).

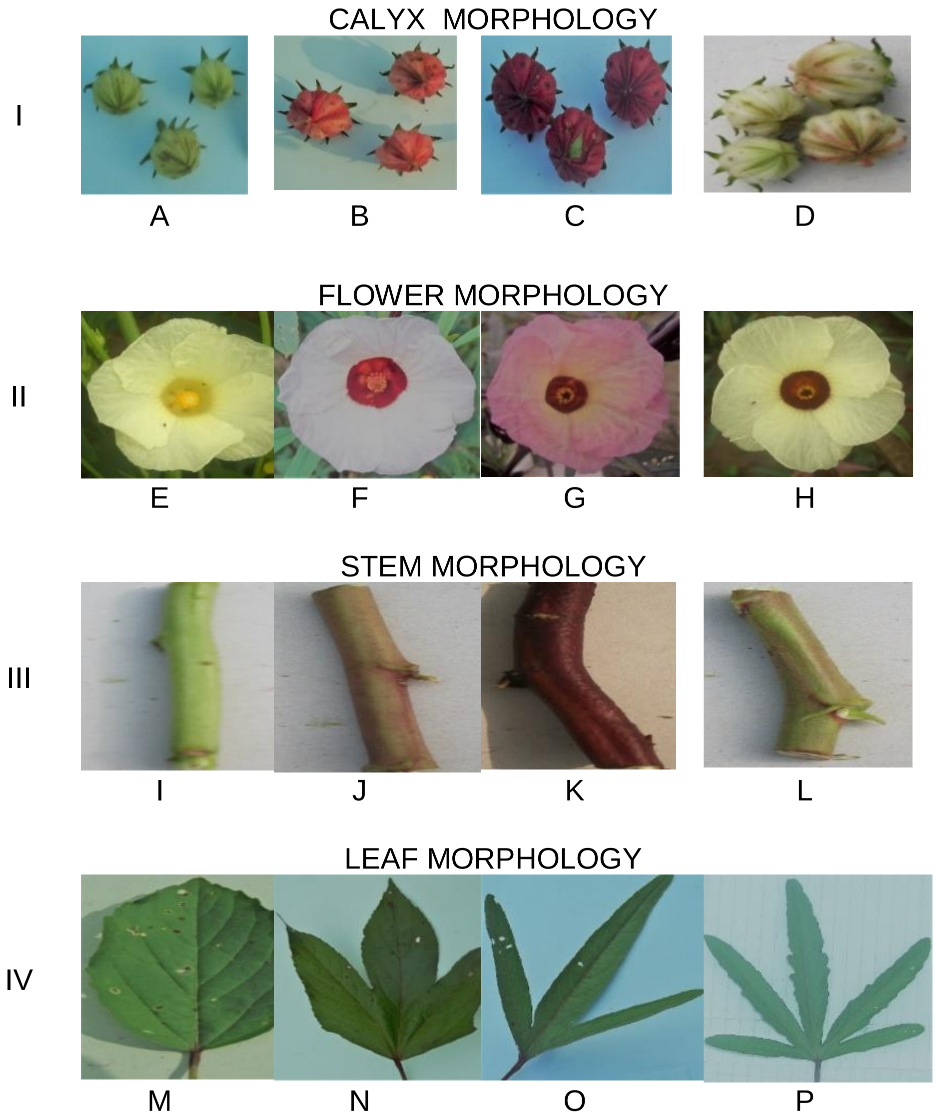

Plate 1. Image of plant parts of mature roselle (var. *altissima*). Panel I: round fruit of a (A) full green plant enclosed in fibrous green calyx; (B) pigmented plant enclosed in fibrous pink calyx; (C) full red plant enclosed in inedible fibrous red calyx; (D) green-pigmented plant enclosed in fibrous green-pigmented calyx. Panel II: (E) Bright yellow flower with deep-yellow throat of a full green plant; (F) pale purple flower with crimson throat on a pigmented plant; (G) purple flower with crimson throat on a red plant; (H) pale yellow flower with crimson throat on a green-pigmented plant. Panel III: (I) full green stem; (J) pigmented stem; (K) full red stem; (L) green-pigmented stem. Panel IV: (M) broad entire leaf; (N) broad trilobed leaf; (O) slender trilobed leaf; and (P) slender pentalobed leaf. Sub-classes: A, E, I are from a full green genotype; B, F, J are from a pigmented (brownish-green with patches of red pigments) genotype; C, G, K are from a full red genotype; D, H, L are from a pigmented (bright green with patches of red pigments) genotype. Variants of leaf morphology are characteristic of all the genotyes in the study.

Between-population variation

Analysis of variance revealed a strong replication effect ($P \leq 0.05$) for all traits except height at first branching. Genotype effect was important ($P \leq 0.05$) except for basal diameter and height at first branching. Block nested within replication was also not important (Table 4). Mean plant height of the collection was 244.85 ± 37.49 cm and ranged from 154 to 342 cm. Mean height at first branching was at 8.05 ± 2.39 beginning at a minimum height of 2.40 cm to 19.50 cm. Branch number ranged from 4 to 21 with mean of 8.71 ± 3.22. Basal diameter

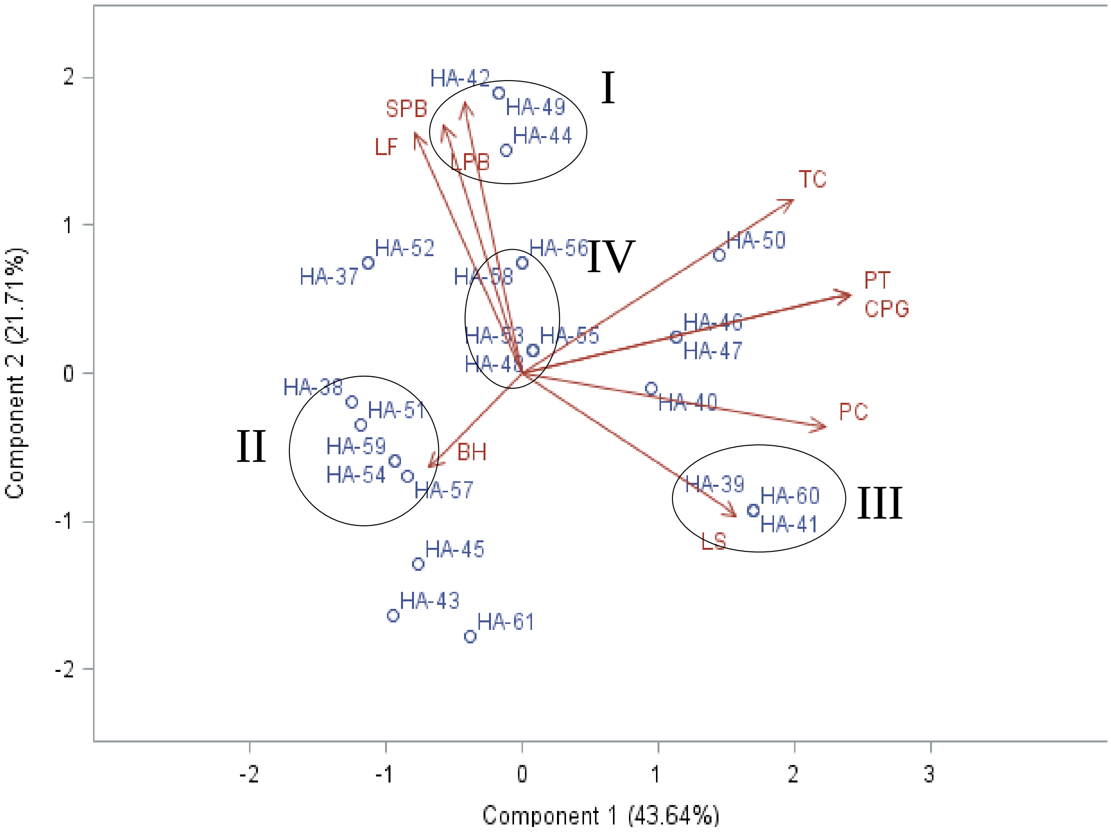

Figure 2. Principal components biplot of PC1 and PC2 of 25 northern Ghana roselle (var. *altissima*) accessions evaluated in 2017 on 12 qualitative traits.

varied within wide limits in a range of 12.19 to 32.59 mm with a mean of 21.04 ± 3.50 mm. Accessions flowered from 96 to 104 days after planting. On average, flowering occurred at 99.40 ± 1.34 days (Table 5).

Based on district means, the maximum plant height of 262.03 ± 17.04 cm was recorded in West Mamprusi populations and the least plant height of 214.82 ± 42.97 cm was recorded in Builsa-North populations. District mean for height at first branching varied from 7.74 ± 0.03 cm in Builsa-North to 8.32 ± 0.31 cm Bolgatanga Municipal. On district mean basis, branch number was least 6.75 ± 0.03 in Builsa-North and highest 10.73 ± 2.59 in Gonja-North. For basal diameter, the district mean ranged from 22.63 ± 3.17 mm in West Mamprusi to 19.25 ± 0.00 in Builsa-North, while days to flowering period varied from 99.84 ± 0.44 in Kassena Nankana-West to 97.67 ± 0.96 in West Mamprusi (Table 6). Ranking based on tallest plants, highest branching points, fewer branch numbers, and largest basal diameter revealed West Mamprusi, Kassena-Nankana West and Bongo districts to be the top three districts having genotypes of high fibre yield potential (Table 6).

Based on accession means, plant height varied from 184.83 ± 14.81 cm to 283.50 ± 27.00 cm. Short genotypes were HA-46 (184.43 ± 14.81 cm), HA-59 (187.30 ± 15.82 cm), HA-61 (202.87 ± 12.37 cm), HA-41 (209.27 ± 21.88 cm), and HA-51 (216.97 ± 28.43 cm). The tall plant genotypes were HA-44 (275.37 ± 30.87 cm), HA-47 (277.40 ± 26.30 cm), HA-43 (277.57 ± 21.88), HA- 38 (279.00 ± 22.92), HA- 52 (280.77 ± 22.54), and HA-42 (283.50 ± 27.00 cm). All accessions exhibited some branching, but to varying extents and somewhat at the same height above ground. On accession mean basis, height at first branching ranged from 6.86 ± 1.62 cm in HA-60 to 9.60 ± 3.69 cm in HA-57 with branches numbering between 6.40 ± 1.45 in HA-49 to 12.97 ± 3.59 in HA-51 (Table 7). On individual plant basis, as few as four and as many as 21 branches were present. Accessions with few branches were HA-49 (6.40 ± 1.45), HA-45 (6.53 ± 1.61), HA-58 (6.73 ± 1.66), HA-46 (6.73 ± 1.91), and HA-39 (6.77 ± 1.36). Accessions with extensive branching were HA-56 (10.40 ± 3.57), HA-48 (10.50 ± 2.87), HA-61 (10.70 ± 2.60), HA-43 (11.63 ± 3.80), HA-42 (11.83 ± 3.31), HA-38 (12.87 ± 3.40), and HA-51 (12.97 ± 3.59).

Mean basal diameter ranged from 18.96 ± 1.89 mm in HA-56 to 24.55 ± 2.99 mm in HA-61. Accessions with large mean basal diameter were HA-57 (22.11 ± 2.86 mm), HA-58 (22.31 ± 3.34 mm), HA-42 (22.38 ± 2.94 mm), HA-54 (22.63 ± 3.17 mm), and HA-55 (23.45 ± 3.45

Table 3. Shannon Weiner Diversity Index of 25 roselle (var. *altissima*) accessions in Ghana in 2017 based on morphological evaluation.

Acc[1]	District	Plant height (cm)	Height at first branch (cm)	Branch number	Basal diameter (mm)	Days to 50% flowering	Accession mean	District mean	Rank
HA-37	Bolgatanga Municipal	0.74	0.87	0.99	0.75	0.92	0.85±0.11	0.83±0.10	2
HA-40		0.69	0.88	0.76	0.84	0.92	0.82±0.09		
HA-49		0.89	0.84	0.81	0.88	0.94	0.87±0.05		
HA-50		0.86	0.81	0.97	0.77	0.92	0.87±0.08		
HA-61		0.57	0.71	0.68	0.82	0.92	0.74±0.14		
HA-57	Bongo	0.89	0.88	1.00	0.95	0.92	0.93±0.05	0.80±0.29	4
HA-60		0.75	0.91	0.97	0.73	0.00	0.67±0.39		
HA-39	Builsa-North	0.84	0.8	0.88	0.61	0.92	0.81±0.12	0.77±0.29	6
HA-46		0.92	0.95	0.92	0.89	0.00	0.74±0.41		
HA-51	Gonja-North	0.98	0.69	0.89	0.80	0.00	0.67±0.39	0.72±0.27	7
HA-53		0.67	0.74	0.74	0.78	0.92	0.77±0.09		
HA-42	Kassena-Nankana East	0.95	0.91	0.75	0.96	0.92	0.90±0.08	0.87±0.09	1
HA-44		0.90	0.82	0.68	0.71	1.00	0.82±0.13		
HA-45		0.97	0.86	0.88	0.82	0.92	0.89±0.06		
HA-47		0.83	0.94	1.00	0.86	0.94	0.91±0.07		
HA-48		0.92	0.78	0.76	0.92	0.92	0.86±0.08		
HA-52		0.87	0.86	0.75	0.72	0.92	0.82±0.08		
HA-56		0.89	0.68	0.96	0.62	0.92	0.81±0.15		
HA-58		0.86	0.97	0.97	0.87	0.92	0.92±0.05		
HA-59		1.00	0.79	0.76	0.88	0.92	0.87±0.10		
HA-38	Kassena-Nankana West	0.94	0.99	0.83	0.88	0.92	0.91±0.06	0.79±0.28	5
HA-41		0.86	0.69	0.81	0.93	0.92	0.84±0.10		
HA-43		0.84	0.97	0.84	0.91	0.00	0.71±0.40		
HA-55		0.83	0.78	0.99	0.91	0.00	0.70±0.40		
HA-54	West Mamprusi	0.72	0.80	0.74	0.90	0.92	0.82±0.09	0.82±0.09	3
Mean		**0.85±0.10**	**0.84±0.09**	**0.85±0.11**	**0.83±0.10**	**0.74±0.38**			

[1] Acc: Accession.

mm) (Table 7). Flowering occurred about the same time in all genotypes with accession means DTF ranging from 97.67 ± 0.96 to 101.33 ± 1.92 DAP. Three accessions HA47, HA-54, and HA-59 flowered earlier than 100 DAP, at 97.67± 0.96 days while only HA-37 flowered at 101.33 ± 1.92 days (Table 7). Based on fibre yield, plant height, branching points, branch number, and largest basal diameter, genotypes HA-42, HA-52, HA-38, HA-43 and HA-47 were considered to be the top five with economic value in terms of fibre yield (Table 7).

Correlation of quantitative traits

The Pearson correlation coefficients, r, were low, -0.01 to 0.13. Basal diameter showed weak positive significant correlation with plant height (r = 0.11; R^2 = 0.012) and branch number (r = 0.13; R^2 = 0.017) but a negative significant correlation with height at first branching (r = -0.08; R^2 = 0.006). Height at first branching showed a low positive significant relationship with days to 50 % flowering (r = 0.12; R^2 = 0.014) accounting for 1.40% of the variation. The remaining traits showed non-significant correlations be it positive or negative (Table 8).

Genetic distances among accessions

The overall mean genetic distance based on Euclidean estimates was 3.03 ± 0.90 covering a range of 0.14 to

Table 4. Mean squares of traits of northern Ghana roselle (var. *altissima*) accessions evaluated in a lattice square design in 2017 in Ghana.

Source	df	Plant height	Height at first branching	Branch number	Basal diameter	Days to 50% flowering
Replication	2	2844.30**	1.00	14.41**	64.35**	4.51*
Block (Replication)	8	191.39	0.70	2.05	4.41	0.81
Genotype	20	2606.79**	1.11	14.48**	6.41	3.39**
Error	40	449.40	1.80	1.76	6.74	1.19

**(P<0.01); * (P<0.05).

Table 5. Means, standard deviations, range, and coefficient of variation of morphological traits evaluated on 25 roselle (var. *altissima*) accessions collected from northern Ghana in 2017.

Trait	Mean	SD	Min - Max	CV (%)
Plant height (cm)	244.85	37.49	154.00 - 342.00	15.31
Height at first branching (cm)	8.05	2.39	2.40 - 19.50	29.67
Branch number	8.71	3.22	4.00 - 21.00	37.01
Basal diameter (mm)	21.04	3.50	12.19 - 32.59	16.65
Days to 50% flowering	99.40	1.34	96.00 - 104.00	1.35

SD: standard deviation; CV: coefficient of variation

Table 6. Mean, standard deviation, and range of phenotypic traits evaluated in 25 roselle (var. *altissima*) accessions from 7 districts in northern Ghana in 2017.

District	Plant height (cm)	Height at first branch (cm)	Branch number	Basal diameter (mm)	Days to 50% flower	Rank
Bolgatanga Municipal	234.38±19.42 (172-305)	8.32±0.31 (4.10-17.50)	7.92±1.72 (4.00-17.00)	21.68±1.70 (14.32-31.09)	99.80±0.87 (99-104)	**5**
Bongo	255.74±15.08 (198-331)	8.23±1.94 (2.40-17.00)	7.12±0.02 (4.00-10.00)	20.97±1.62 (15.20-27.65)	99.84±0.23 (99-100)	**3**
Builsa-North	214.82±42.97 (160-314)	7.74±0.03 (3.50-17.20)	6.75±0.03 (4.00-11.00)	19.25±0.00 (12.47-29.18)	99.00±1.41 (96-100)	**7**
Gonja-North	224.91±10.45 (163-277)	8.32±0.03 (4.10-15.40)	10.73±2.59 (5.00-21.00)	20.88±0.83 (16.65-29.66)	99.34±0.47 (99-100)	**6**
Kassena-Nankana East	251.28±32.02 (154-342)	7.93±0.44 (4.10-19.50)	8.87±1.81 (4.00-21.00)	20.80±1.40 (12.19-30.41)	99.20±1.23 (97-104)	**4**
Kassena-Nankana West	258.17±33.05 (160-331)	7.82±0.53 (3.40-14.30)	10.29±2.55 (5.00-20.00)	21.38±1.39 (12.57-32.59)	99.84±0.44 (99-101)	**2**
West Mamprusi	262.03±17.04 (220-293)	7.82±2.23 (4.10-13.10)	7.47±1.94 (4.00-13.00)	22.63±3.17 (18.13-30.12)	97.67±0.96 (97-99)	**1**

5.17 (Table 9). Very low distances were recorded between accessions HA-40 and HA-53 (0.41), HA-37 and HA-58 (0.84), and HA-38 and HA-43 (0.91), whereas large distances were recorded between accessions HA-55 and HA-59 (5.02), HA-57 and HA-59 (5.11), and HA-60 and HA-61 (5.17). Based on means across pairwise distances, which varied between 2.22 and 3.94, three accessions were divergent, namely HA-61(3.94),

Table 7. Means, standard deviations, and range of phenotypic traits of 25 roselle (var. *altissima*) accessions evaluated in Ghana in 2017

Accession	Plant height (cm)	Height at first branch (cm)	Branch number	Basal diameter (mm)	Days to 50% flower	Rank
HA-37	250.40±19.40 (219-297)	8.05±2.85 (4.40-17.50)	7.07±1.74 (4.00-11.00)	21.83±3.02 (15.67-28.71)	101.33±1.92 (100-104)	**12**
HA-38	279.00±22.92 (231-328)	7.42±2.10 (3.40-10.50)	12.87±3.40 (7.00-20.00)	20.59±2.25 (17.42-25.20)	99.67±0.96 (99-101)	**3**
HA-39	245.20±34.91 (200-314)	7.72±3.19 (3.50-17.20)	6.77±1.36 (5.00-10.00)	19.25±2.76 (15.32-29.18)	98.00±1.44 (96-99)	**14**
HA-40	233.23±26.18 (179-289)	8.19±1.97 (4.60-12.70)	8.43±2.80 (4.00-16.00)	20.62±3.15 (15.67-27.38)	99.67±0.48 (99-100)	**17**
HA-41	209.27±21.88 (160-248)	7.52±1.48 (4.50-11.50)	9.60±3.04 (5.00-18.00)	20.61±5.85 (12.57-31.23)	99.33±0.48 (99-100)	**22**
HA-42	283.50±27.00 (239-341)	7.60±1.75 (4.20-10.30)	11.83±3.31 (8.00-21.00)	22.38±2.94 (17.89-28.18)	99.33±0.48 (99-100)	**1**
HA-43	277.57±21.88 (240-316)	7.75±2.00 (4.20-12.00)	11.63±3.80 (7.00-20.00)	20.87±4.47 (14.80-31.41)	100.00±0.00 (100-100)	**4**
HA-44	275.37±30.87 (229-332)	8.15±2.37 (4.30-15.20)	8.73±2.03 (5.00-14.00)	19.58±1.56 (15.24-22.13)	100.33±1.27 (99-102)	**6**
HA-45	233.03±14.68 (206-261)	7.46±2.07 (4.70-12.50)	6.53±1.61 (4.00-10.00)	20.87±3.09 (15.63-27.80)	98.33±0.96 (97-99)	**18**
HA-46	184.43±14.81 (160-210)	7.76±2.00 (4.10-11.20)	6.73±1.91 (4.00-11.00)	19.25±3.86 (12.47-26.07)	100.00±0.00 (100-100)	**25**
HA-47	277.40±26.30 (212-323)	7.25±1.82 (4.20-11.30)	7.37±1.50 (5.00-10.00)	21.99±3.45 (15.81-29.30)	97.67±0.96 (97-99)	**5**
HA-48	225.37±12.12 (208-251)	8.60±3.2 (4.30-19.50)	10.50±2.87 (7.00-18.00)	19.62±1.96 (16.36-23.81)	100.67±0.96 (100-102)	**20**
HA-49	238.73±32.03 (202-300)	8.69±2.29 (4.50-14.00)	6.39±1.45 (4.00-9.00)	20.34±4.00 (14.32-28.80)	99.33±0.48 (99-100)	**16**
HA-50	250.43±25.84 (213-305)	8.04±3.11 (4.10-16.30)	7.03±1.50 (4.00-10.00)	21.07±3.42 (16.15-29.61)	99.33±0.48 (99.00-100)	**11**
HA-51	216.97±28.43 (163-261)	8.69±2.37 (5.20-15.40)	12.97±3.59 (8.00-21.00)	21.63±3.42 (16.61-29.66)	99.00±0.00 (99-99)	**21**
HA-52	280.77±22.54 (238-317)	8.26±2.90 (4.40-18.30)	8.77±3.02 (5.00-19.00)	21.94±2.58 (18.93-30.00)	98.33±0.96 (97-99)	**2**
HA-53	232.30±20.87 (190-277)	8.34±2.16 (4.10-12.80)	8.90±2.63 (5.00-15.00)	20.29±2.37 (16.55-27.28)	99.67±0.48 (99-100)	**19**
HA-54	262.03±17.04 (220-293)	7.82±2.23 (4.10-13.10)	7.47±1.94 (4.00-13.00)	22.63±3.17 (18.13-30.12)	97.67±0.96 (97-99)	**9**
HA-55	266.82±29.30 (219-331)	8.58±2.14 (4.50-14.30)	7.04±1.35 (5.00-10.00)	23.45±3.45 (18.40-32.59)	100.36±0.49 (100-101)	**7**
HA-56	248.87±30.80 (203-321)	8.16±1.33 (4.70-10.50)	10.40±3.57 (5.00-17.00)	18.96±1.89 (13.15-22.70)	99.67±0.48 (99-100)	**13**
HA-57	266.40±33.10 (208-331)	9.60±3.69 (2.40-17.00)	7.13±1.81 (4.00-10.00)	22.11±2.86 (16.36-27.65)	99.67±0.48 (99-100)	**8**
HA-58	251.40±32.83 (209-342)	8.25±2.34 (4.10-12.40)	6.73±1.66 (4.00-9.00)	22.31±3.34 (17.41-29.24)	100.67±2.40 (99-104)	**10**
HA-59	187.30±15.82 (154-210)	7.71±1.68 (4.10-11.30)	8.97±3.90 (4.00-20.00)	19.52±4.59 (12.19-30.41)	97.67±0.96 (97-99)	24
HA-60	245.07±29.10 (198-319)	6.86±1.62 (4.30-9.70)	7.10±1.54 (4.00-10.00)	19.82±2.07 (15.20-23.77)	100.00±0.00 (100-100)	15
HA-61	202.87±12.37 (172-223)	8.70±2.20 (4.50-17.00)	10.70±2.60 (7.00-17.00)	24.55±2.99 (19.78-31.09)	99.30±0.47 (99-100)	23

Table 8. Pearson correlation coefficients of five quantitative traits of *altissima* accessions.

Variable	Plant height (cm)	Height at first branching (cm)	Branch number	Basal diameter (mm)
Height at first branching	-0.02			
Branch number	0.03	0.01		
Basal diameter	**0.11****	**-0.08***	**0.13****	
Days to 50% flowering	-0.03	**0.12****	-0.02	-0.01

**(P<0.01); * (P<0.05).

Table 9. Euclidean distances of 25 northern Ghana roselle (var. *altissima*) accessions evaluated by morphological characterization in 2017.

Accession	Mean ± SD	Min - Max	Accession	Mean ± SD	Min - Max
HA-37	3.05 ± 0.86	0.84 – 4.73	HA-50	2.30 ± 0.67	1.05 – 3.64
HA-38	3.35 ± 0.93	0.91 – 4.77	HA-51	3.41 ± 0.63	2.41 – 4.63
HA-39	3.04 ± 0.88	1.35 – 4.94	HA-52	2.82 ± 0.69	1.44 – 4.40
HA-40	2.22 ± 0.71	0.41 – 3.31	HA-53	2.30 ± 0.74	0.41 – 3.64
HA-41	2.71 ± 0.66	1.56 – 4.38	HA-54	3.12 ± 0.82	1.21 – 4.39
HA-42	3.19 ± 0.81	1.31 – 4.83	HA-55	3.19 ± 0.89	1.17 – 5.02
HA-43	2.90 ± 0.86	0.91 – 4.24	HA-56	2.73 ± 0.80	1.35 – 4.39
HA-44	2.76 ± 0.80	1.46 – 4.65	HA-57	3.66 ± 0.87	1.95 – 5.11
HA-45	2.82 ± 0.83	1.35 – 4.17	HA-58	2.82 ± 0.86	0.84 – 4.48
HA-46	3.47 ± 0.91	2.06 – 4.83	HA-59	3.63 ± 0.87	2.05 – 5.11
HA-47	3.40 ± 0.92	1.21 – 4.79	HA-60	3.23 ± 0.82	2.16 – 5.17
HA-48	3.04 ± 0.85	1.45 – 4.79	HA-61	3.94 ± 0.64	2.41 – 5.17
HA-49	2.70 ± 0.76	1.33 – 4.06	**Overall mean**	**3.03 ± 0.90**	**0.14 – 5.17**

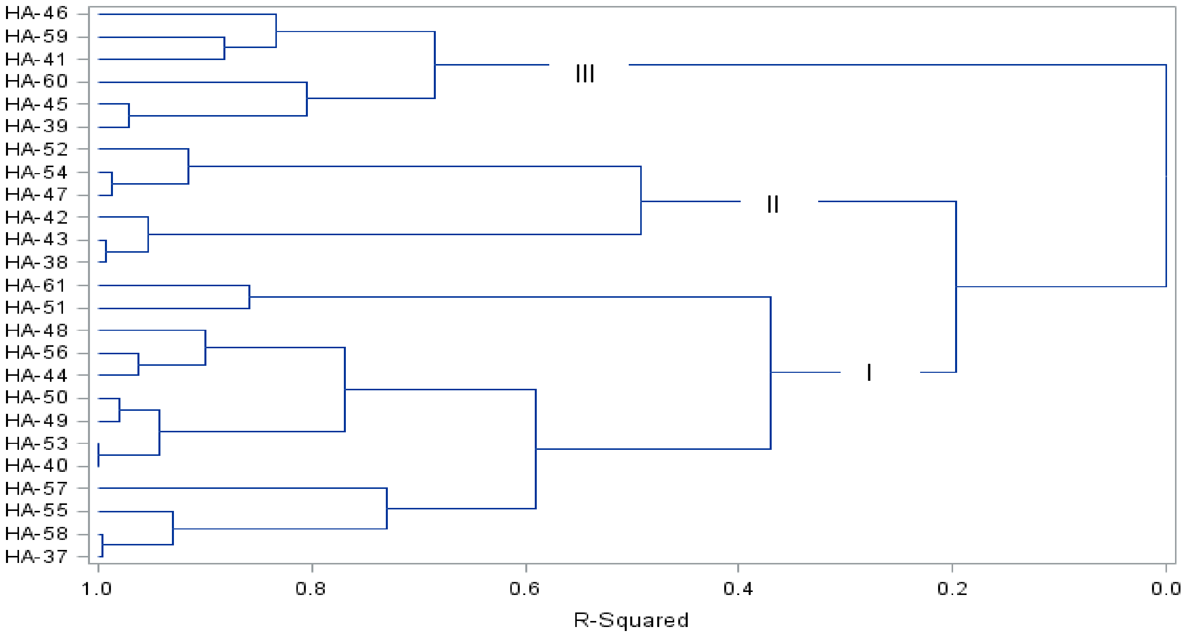

Figure 3. A dendrogram based on Ward's minimum variance of 25 northern Ghana roselle (var. *altissima*) accessions evaluated by morphological traits in field trials in Ghana in 2017.

HA-57 (3.66) and HA-59 (3.63). Accessions HA-40 (2.22), HA-50 (2.30) and HA-53 (2.30) were the least divergent genotypes (Table 9).

Cluster analysis

Accessions were clustered into three distinct groups (Figure 3). Cluster I comprised 13 accessions, HA-37,HA-40, HA-44, HA-48, HA-49, HA-50, HA-51, HA-53, HA-55, HA-56, HA-57, HA-58, and HA-61, with mean genetic distance of 2.58 ± 0.89. Cluster I accessions were grouped based on highest branching points and late flowering (Table 10). Accessions HA-57, HA-61, HA-49, HA-48, and HA-55 exhibited branching points at heights exceeding 8.50 cm above ground. Similarly, accessions HA-37, HA-48 and HA-58, flowered beyond 100 DAP. Mean branching point and flowering were 8.47 ± 2.54 cm and 99.92 ± 1.21 DAP, respectively.

Cluster II was made up of six accessions, HA-38, HA-

Table 10. Means, standard deviations, and differences of clusters of 25 northern Ghana *altissima* accessions evaluated in 2017.

Trait	Overall means	Cluster I	Diff	Cluster II	Diff	Cluster III	Diff
PH	244.85±37.49	242.83±32.92	-2.02	276.71±23.87	31.86	217.38±34.16	-27.47
HFB	8.05±2.39	8.47±2.54	0.42	7.68±2.16	-0.37	7.51±2.08	-0.54
BN	8.71±3.22	8.62±3.05	-0.09	9.98±3.65	1.27	7.62±2.67	-1.09
BD	21.04±3.50	21.25±3.29	0.21	21.73±3.27	0.69	19.89±3.91	-1.15
DTF	99.40±1.34	99.92±1.21	0.52	98.78±1.23	-0.62	98.89±1.25	-0.51

PH = Plant height; HFB = Height at first branching; BN = Branch number; BD = Basal diameter; DTF = Days to 50% flowering; Diff = cluster means – overall means.

Table 11. Principal components analysis of 25 roselle (var. *altissima*) accessions studied based on five quantitative traits.

Trait	PC1	PC2	PC3
Plant height (cm)	0.38	0.69	0.17
Height at first branching (cm)	0.74	-0.42	-0.23
Branch number	0.18	0.12	0.86
Basal diameter (mm)	0.71	0.41	-0.30
Days to 50% flowering	0.48	0.56	0.34
Eigenvalues	1.45	1.16	1.01
Cumulative eigenvalues	1.45	2.61	3.62
Percentages	40.05	31.77	28.18
Cumulated percentages	40.05	71.82	100.00

42, HA-43, HA-47, HA-52 and HA-54 with a mean genetic distance of 2.36 ±0.92. The six accessions of cluster II were separated based on highest mean plant height of 276.71 ± 23.87 cm, high branching number (9.98 ± 3.65), and largest basal diameter (21.73 ± 3.27 mm) (Table 10). The very tall accessions of interest were HA-42 (283.50 ± 27.00 cm), HA-52 (280.77 ± 22.54 cm), HA-38 (279.00 ± 22.92 cm), HA-43(277.57 ± 21.88 cm), HA-47 (277.40 ± 26.30 cm), and HA-54 (262.03 ± 17.04 cm). Accessions with large basal diameter in excess of 22.30 mm were HA-61, HA-55, HA-54, HA-42, and HA-58.

Accessions HA-39, HA-41, HA-45, HA-46, HA-59, and HA-60 of cluster III had an overall mean genetic distance of 2.40 ± 0.48 and were segregated on the basis of short plant height (217.38 ± 34.16 cm), least number of branches (7.62 ± 2.67), smallest basal diameter (19.89 ± 3.91 mm) and lowest branching point (7.51± 2.08 cm) (Table 10). Accessions of interest having the least number of branches were HA-49 (6.39 ± 1.45), HA-45 (6.53 ± 1.61), HA-58 (6.73 ± 1.66), HA-46 (6.73 ± 1.91), and HA-39 (6.77 ± 1.36).

Stepwise discriminant analysis

Three of the five quantitative morphological traits produced adequate discrimination of the accessions based on minimization of Wilk's lambda. Branch number (Wilk's lambda 0.27**; F=5.54), contributed the most variance to the data, followed by plant height (Wilk's lambda 0.08**; F=4.84) and then days to 50% flowering (Wilk's lambda 0.04**; F=2.51). Height at first branching and basal diameter were not discriminatory.

Principal components analysis

The first three principal components (PCs) with eigenvalues greater than 1.00 contributed 100% to the variance in the data. Contributions to the total variance were for PC1, 40.05%, with major loadings in height at first branching (0.74) and basal diameter (0.71). The PC2 contributed 31.77% of the variance with major loadings in plant height (0.69) and days to 50% flowering (0.56). Total contribution of PC1 and PC2 to the variance was 71.82%. The PC3 accounted for 28.18% of the total variance, with much contribution from branch number (0.86) (Table 11).

Biplot of PC1 and PC2 revealed four major uncorrelated groups (Figure 4A). Group I accessions (HA-38, HA-42, HA-43 HA-52, HA-54) had large values of plant height and basal diameter. Accessions of group II (HA-39, HA-45, HA-60) were assembled, based on least number of branches per plant. The eight accessions of group III (HA-37, HA-40, HA-44, HA-49, HA-50, HA-51, HA-53, HA-56, HA-58) had least values of plant height,

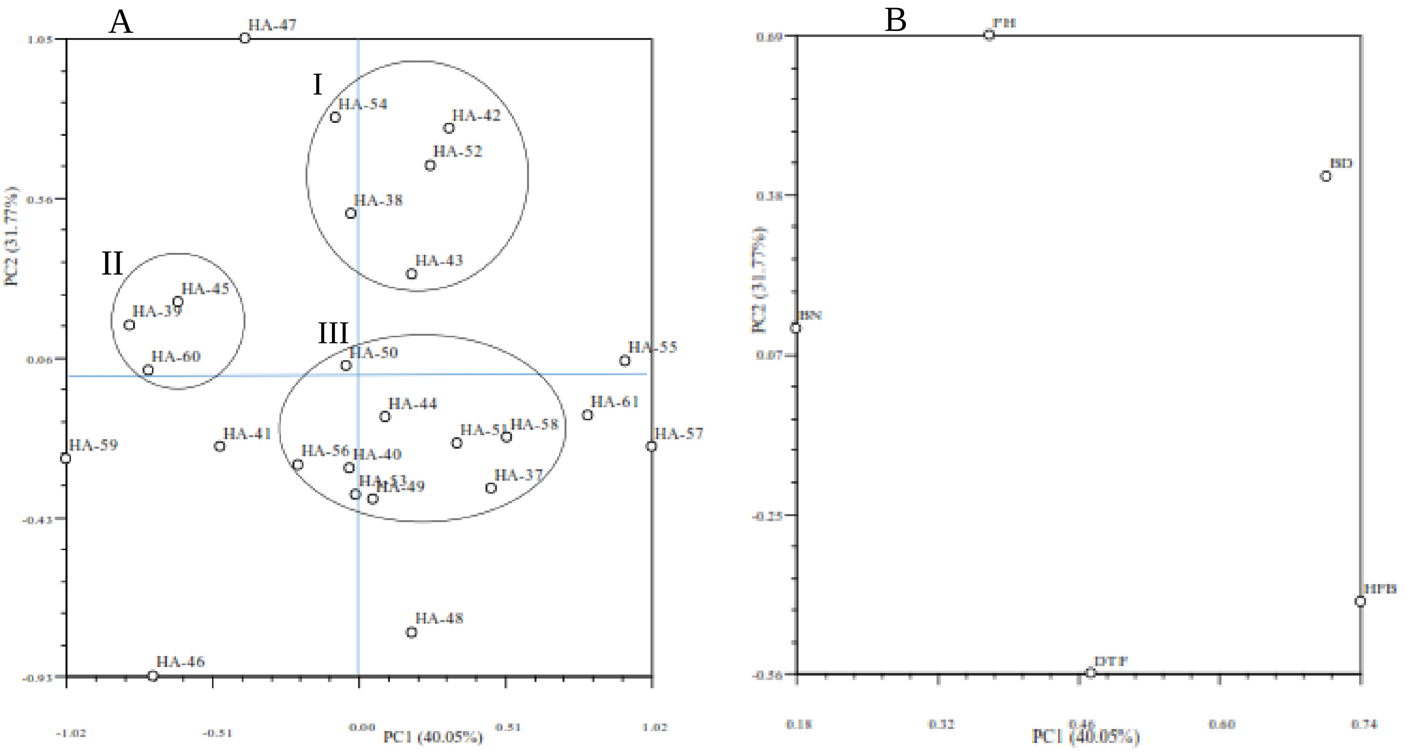

Figure 4. Principal components biplots of (A) 25 roselle (var. *altissima*) accessions and (B) five quantitative traits evaluated in a field trial in Ghana in 2017.

basal diameter, branch number and medium values of height at first branching and days to flowering. Accessions HA-41, HA-46, HA-47, HA-48, HA-55, HA-57, HA-59, and HA-61 were separated from the rest. All traits contributed positively to the total variance as they grouped to the right of the origin, 0.00, of the PC1 axis. Positive correlation was observed between plant height and basal diameter as well as plant height and branch number. Negative correlation was observed for height at first branching and days to flowering (Figure 4B).

DISCUSSION

Roselle is a crop well adapted to the hot climates of SSA and has thrived over several decades in limiting soil nutrients and marginal environments. In Ghana, indigenous communities that have fair knowledge of roselle (var. altissima) utilize them in homesteads for domestic fibre production for making ropes. In contrast, roselle is commercially cultivated in Asian countries where its bast fibre is exploited in many industries. Since the study of Coffie (2016), who reported that the center of diversity of roselle (H. sabdariffa var. sabdariffa) lies along a northern Ghana- Ouagadougou-Mali belt, no study has been carried out to investigate the distribution and diversity in roselle (var. altissima) in northern Ghana. Additionally, there is dearth of knowledge on the economic potential of roselle (var. altissima) in Ghana. The distribution and assessment of genetic diversity in roselle is herein reported. The roselle seed collection was obtained from seven districts in northern Ghana where Kassena-Nankana East was represented more than the other districts. This non-uniform collection could not be avoided owing to the widespread lack of knowledge on roselle. In addition, similarity in seed morphology with the vegetable type roselle posed challenges in obtaining adequate information on the fibre type. Despite these drawbacks, indigenous knowledge of the aged farmers provided sufficient guide to the locations of roselle (var. *altissima*) cultivation. Chivenge et al. (2015) stated that aged folk possessed sufficient indigenous knowledge about under-utilized crops in SSA, and that, this knowledge needs to be harnessed in a rapid manner for utilization, conservation, and cultivar development in the midst of climate change threats.

The large variability in qualitative traits which depicted diverse leaf forms, plant type, calyx and flower pigmentation were consistent with the morphology of the vegetable roselle. Coffie (2016), in her study of 35 roselle (var. *sabdariffa*) genotypes from across West Africa reported on substantial variability among the accessions. On plant type, roselle (var. *altissima*) had more green genotypes (40%) with substantially fewer branching genotypes (25%) than the vegetable type (9% green; 1% with few branching). In current study, roselle (var. *altissima*) leaves were predominantly slender (80%) and penta-lobed with few tri-lobed (64% and 30%, respectively) forms, contrasting with the fundamentally broad (68%), tri- (49%) and pentalobed (36%) leaves of var. *sabdariffa*. Calyx pigmentation was similar to that in var. *sabdariffa*, but majority of the plants had yellow petals (72%) and somewhat equal distribution of yellow (41%) and crimson (59%) throats. In var. *sabdariffa*, however, 39% had yellow petals and 91% crimson throat.

The qualitative characteristics of roselle concur with an earlier report on 36 roselle fibre genotypes from northern Ghana (Ankrah et al., 2018), which exhibited ample variability in plant type, branching habit, stem pubescence and leaf form. The absence of variability in growth habit, calyx pubescence and capsule shape indicates that these traits are conserved in roselle (var. *altissima*). On the contrary, there are reports of variability in growth habit and capsule shape of roselle (var. *sabdariffa*) (El-Tahir and El-Gabri, 2013; Coffie, 2016). Because qualitative traits are not influenced by environment, the variations identified in roselle could be largely genetic. For the purpose of fibre production, roselle with tall green stem and few or no branches at high branching points are most desirable. Indigenous knowledge purports that green stems produce higher fibre yield of better quality. While selection methods based on the phenotypic expression would likely achieve the desired improvement in fibre yield, further work is needed to verify this claim.

Principal components analysis of the qualitative data revealed that the first two PCs cumulatively explained 65% of the total variance. Of the nine qualitative traits that were significant for the structuring of roselle genotypes the contribution of four traits, namely, plant type, calyx pigmentation, petal and throat colour were substantial (Figure 2). Further studies on structuring of roselle should concentrate on these four traits.

The high SDI values observed in the 25 roselle populations and within the seven districts is indicative of a large within-population variation. Notwithstanding, the high values could have been caused to some extent, by mixture of seeds. Further work is needed to clean up the seeds. To the best of our knowledge, this is the first report, which estimates SDI in roselle (var. *altissima*). Medagam et al. (2015) estimated SDI values of agro-economic traits of roselle (var. *sabdariffa*) to be 0.32 to 2.00.

On the basis of large values of plant height, high branching points, and large basal diameter, the most desired accessions with high fibre yield potential included HA-38, HA-42, HA-47, HA-57 and HA-58. The districts of largest diversity in a decreasing order were Kassena-Nankana East, Bolgatanga and West Mamprusi. The import of this finding is that, future collection of roselle in Ghana should focus on these districts. The other notable districts with large diversity in roselle were Bongo and Kassena-Nankana West.

Except for height at first branching and basal diameter, a strong genotype main effect for plant height, branch number and days to 50% flowering indicated a large between population variability. The large replication effect confirmed mixing up of seeds at the various collection points. Strong genotype effect in plant height and branch number was identified in some Sudan, Egypt, and Iran roselle (var. sabdariffa) collections, respectively (Javadzadeh and Saljooghianpour, 2017; Abou El-Nasr et al., 2014; Ibrahim et al., 2013). Similarly, a large genotype effect in number of days to flowering in roselle (var. *sabdariffa*) was reported by Ibrahim et al. (2013). The large variability was unexpected as roselle is cleistogamous, and selfing more often restricts variability. Phenotypic differences arise from genotypic and environmental components. Chief among the environmental factors in roselle development is the day length effect (Warner and Erwin, 2003; Mansour, 1975). At flowering, growth in height and stem diameter slow down and limit increase in plant height as occurs in kenaf (Dempsey, 1975). The wide differences in plant height could be attributed to the significant genotype effect for days to flowering. In contrast, no accession differences were observed for basal diameter as all stems were of almost similar girth. This characteristic of roselle warrants further study into the performance of roselle at various geographical areas in Ghana.

The large values of branch number at predominantly low branching points in roselle was unexpected. Although there is no defined planting distance for roselle, the planting distance of 20 × 50 cm within and between rows, respectively, may have contribued to the extensive branching, together with other environmental influences. The import of this finding suggest a much narrower planting distance to increase plant height and decrease number of branches. Sermsri et al. (1987) suggested planting distance of 5 to 15 cm for within row spacing and 20 to 40 cm for between row spacing as ideal to maximizing fibre yield potential of roselle (var. *altissima*) as well as its plant density. In addition, few reports have confirmed that wider plant spacing of 50 to 80 cm in roselle (var. *sabdariffa*) increased branching and reduced plant height (Okosun et al., 2006; Shalaby and Razin, 1989).

Basal diameter was found to have significant positive correlation with plant height and branch number, but negative correlation with height at first branching. This association appears to be beneficial since tall plants with large basal diameter would also have branching, if any, at high points. For high yield and good quality fibre, plants with high branching points are desired as the long fibre strands would have few or no interruptions. The low correlation coefficients indicate that only 1.21 and 1.70% of the variation in plant height is explained by variation in basal diameter and branch number, respectively. Similarly, 0.64% of the variation in basal diameter is explained by height at first branching (Table 8). Coffie (2016) reported low to moderate positive correlation coefficient of $r = 0.11$ to 0.41 in plant height with number of internodes, branch number, leaf area and height at first branching in var. *sabdariffa* genotypes. Very low to moderate correlation coefficients were reported in basal diameter and plant height of 0.56 ($P < 0.01$), basal diameter and number of branches of 0.42 ($P < 0.05$), basal diameter and days to 50% flowering of 0.047 ($P>0.05$), in kenaf genotypes in Bangladesh (Mostofa et al., 2002). Knowledge regarding association of agronomic traits and their yield potential provides guidelines in crop improvement based on correlated traits, especially for characters that are difficult to evaluate or take long time to express. Roselle is ambiphotoperiodic as it can flower both in short days or long days (Mansour, 1975). The duration of the growing season and length of day are critical factors that have significant influence on the fibre yield characteristics of roselle (Dempsey, 1957).

Roselle (var. *altissima*) typically grows to a height exceeding 250 cm in height with very few branches at high branching points at optimal environmental conditions, which includes adequate irrigation, good soil nutrients, warm temperature and minimum day length of about 12 h 30 min. With a typical tropical day length that consisted of 12 h 30 min and average temperature of 25°C (World Weather and Climate Information, 2017) of the growing season, the genotypes studied were expected to have tall plant height. Plant height ranged from 154 to 342 cm and majority exhibited extensive branching at the lower stem. Low branching points and extensive branching are hindrance to fibre quality as fineness of fibre strands are reduced by the knotty branch points. Of the 25 roselle genotypes, only five accessions, HA-39, HA-45, HA-46, HA-49 and HA-58 exhibited few branches to merit selection for improvement. On the basis of tall plants exceeding 250 cm and large stem diameter greater than 20 mm, twelve accessions, HA-37, HA-38, HA-42, HA-43, HA-44, HA-47, HA-50, HA-52, HA-54, HA-55, HA-57, and HA-58 were selected for further studies on yield improvement.

The mean genetic distance of 3.03 ± 0.90 based on Euclidean estimates represents a substantial genetic diversity in the region. Coffie (2016) reported a mean genetic similarity of 0.27 ± 0.26 based on squared correlation coefficient among 35 var. *sabdariffa* landraces from West Africa. The fairly large genetic distances of the current roselle population suggest that the accessions were divergent. Because the genetic distance was based on morphological evaluation, influence of environment on the Euclidean estimates cannot be ruled out. Despite being a self-pollinating plant, the unexpected wide genetic variability may have arisen from forces such as gene or seed flow, climate and environmental variability, or mutation. An outcrossing rate of less than 1% in roselle (Young, 1995; Vaidya, 2000) over many generations could create ample variability.

Clustering of the accessions was independent of geographical origin, suggesting movement of seeds across the region. Each of the three clusters comprised at least one desirable trait of economic value. Hence, for any genetic improvement in bast fibre potential, there should be selection of parents across the three clusters. The findings of Bakasso et al. (2013) revealed two major clusters in 124 roselle (var. *sabdariffa*) collections from Niger on the basis of ten agro-morphological traits which included plant height, branch number and basal diameter. Coffie (2016) reported three main clusters in 35 roselle (var. *sabdariffa*) accessions based on six agro-morphological descriptors. Satyanarayana et al. (2015) reported of clustering of 60 roselle (var. *sabdariffa*) genotypes from India into seven clusters based on eleven agro-phenological traits. In their work, they showed that fibre yield per plant and dry stick weight were the most important while plant height and basal diameter were the least contributors to the variance.

Three of the five quantitative traits, namely, branch number, plant height, and days to 50% flowering achieved the largest minimization of Wilk's lambda and were the most efficient discriminatory traits. Further studies on structuring and genetic diversity in roselle should consider these three traits. In roselle (var. *sabdariffa*) discriminatory triats were found to be plant height, number of internodes, basal diameter, flowering time. and 100-seed weight (Coffie, 2016; Bakasso et al., 2013).

The first three PCs that explained 100% of the total variance revealed that all five traits were relevant in structuring of roselle.. However, from the PCs, height at first branching, number of branches and plant height were critical in providing a selection guide when considering fibre potential of roselle plants. On this basis, it is beneficial to select tall plants at high branching points rather than at low branching points. Delineating accessions into different groups have proved relevant for selecting desirable parents to maximize genetic variance in breeding programs (Chakravarty and Basu, 1972). Hybridization of genotypes from uncorrelated groups is therefore expected to result in beneficial improvement in agronomic character performances. In contrast, the tetraploid nature rather promotes breeding success with members in similar groups than in uncorrelated groups. The biplots of the PCA showed a good contribution of the accessions HA-46, HA-47, HA-57 and HA-59 to the variance. Overall, a large diversity residing in roselle (var. *altissima*) genotypes was revealed, hence, trait improvement in these accessions is possible.

Conclusion

The qualitative and quantitative descriptors revealed wide differences in morphology in roselle. Variability estimates were highest for Kassena-Nankana district. The predominant morphotype was non-bushy, uniform green, basal branching, and variable plant heights, with smooth slender pentalobed leaves, yellow petals, crimson throats, hairy calyxes, and round capsule. The extensive branching was unexpected and represented a departure from roselle accessions previously described, highlighting the existence of other morphotypes in roselle gene pool awaiting collection and characterization. The variable plant height, number of branches, and days to 50% flowering with some accessions having heights as high as 300 cm, few branches and early flowering offer the possibility of selection for improvement in these traits. The substantial genetic distance highlights the existence of polymorphic alleles for the quantitative traits. The three distinct clusters represent diverse groups that can be hybridized to exploit heterotic effect. Sixteen accessions were considered useful for roselle breeding program on the basis of tall plant height and few branches, namely, HA-37, HA-49, HA-50, HA-55, HA-57, and HA-58 in Cluster I, HA-38, HA-42, HA-43, HA-47, HA52, and HA-54 in Cluster II, and finally, HA-39, HA-44, HA-45, HA-46 in Cluster III. The correlated accessions that were grouped on the biplot was in agreement with the clustering based on Euclidean distance. This observation indicate the power of cluster analysis and PCA in identifying relationships among genotypes. The most important discriminatory traits, branch number, plant height, and days to 50% flowering should be considered in future studies on roselle. Because roselle is day-length sensitive, evaluation in other geographical locations in Ghana would be necessary.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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