Phenotypic Diversity of Jute Mallow (*Corchorus olitorius* L.) Germplasm

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Summary

Corchorus olitorious L. is a leafy vegetable with antibacterial properties useful in the treatment of numerous diseases and having the potential to alleviate malnutrition. Despite the efficient role that varietal evaluation plays in breeding programmes to improve traits, *C. olitorious* is still under-researched. The objective of this study was to (i) characterize phenotypic variation in agronomic traits of germplasm collection of *C. olitorious* and (ii) identify superior accessions exhibiting desirable traits useful in a breeding programme for further improvement. The study examined 40 core collections of *C. olitorious* held at the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Nigeria. The experiment was laid out under field conditions in an 8×5 α-lattice design with three replicates over two years. Qualitative and quantitative data were collected and analysed. Combined analysis of variance revealed highly significant ($P < 0.001$) mean squares between accessions for all measured traits. This variability can be exploited when selecting for these traits and can also speed up the identification of outstanding *Corchorus* accessions. The shift in mean performance of some accessions from the mean of the 40 accessions suggests that these accessions are potential sources of favourable alleles that may be useful for *C. olitorious* improvement. The results of the principal component analysis revealed discriminating features. The cluster patterns indicate intra-specific variability useful in selecting complementary parental lines. Accessions NGB00215, NGB00229, NGB00200, NGB00205, NGB00221, NGB00224, NGB00230 and NGB01261 were identified as outstanding in their performance with desirable traits. These accessions will be useful in future *Corchorus* breeding programmes.

Key words

breeding, *Corchorus olitorious* L., characterization, selection, variability

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Introduction

Corchorus olitorious L. belongs to Malvaceae family and is widely known as jute mallow (Ghosh et al., 2013; Ngomuo et al., 2017b). Africa is considered the centre of diversity and origin (Dube et al., 2019). The genus *Corchorus* comprises about 215 species, subspecies, varieties and landraces, with about 60 species distributed across tropical, subtropical and warm temperate regions of the world (Adjatin et al., 2019). Of these, only wild white jute (*C. capsularis* L.) and cultivated tossa jute (*C. olitorious* L.), each with 2n = 14, which have evolved through conventional breeding, are distributed in Africa (Mukul and Akter, 2021). *C. olitorious* has the potential to contribute to improved nutrition as the leaves and tender shoots are a source of vitamins (A, C, D), nutrients (carbohydrates, fat, ash, protein) and minerals (potassium, calcium, iron, zinc). *C. olitorious* is also useful for treating various diseases as it contains essential nutrients (β-carotene, amino acids), phytochemicals and antioxidants (Mensah et al., 2008; Mavengahama et al., 2013; Nyadanu et al., 2017; Adjatin et al., 2019).

A major constraint to the production of this important but underutilised vegetable is the unavailability of improved cultivars. Producers and consumers grow local landraces that are quite poor in terms of adaptability, productivity and nutrient composition, leading to a drastic decline in returns on investment (Dinssa et al., 2016; Sogbohossou et al., 2018). Improvement of *C. olitorious* and other wild relatives of jute mallow consumed as vegetables is very limited (Nyadanu et al., 2017).

Studies on the morphological variability of the leaves of *C. olitorius* have been reported (Nath and Denton, 1980; Akroda, 1985). Due to the great interest in the leafy vegetable, several accessions have been divided into segregating populations of different leaf types (National Horticultural Research Institute, 1986; Opabode and Adebooye, 2005). In addition, heritability, genetic advantage and association of quantitative vegetative traits with leaf yield of *C. olitorius* were reported by Nwangburuka and Denton (2012). In *C. olitorius*, only a few studies on leaf yield traits have been conducted with few accessions.

Germplasm collection and conservation is important for creating variation, but genetic variation within *C. olitorius* is low due to self-pollination (Hossain et al., 2002). This narrow genetic base makes it vulnerable to biotic and abiotic challenges (Kamannavar et al., 2016). *Corchorus* species have a high degree of interspecific variability but a low degree of intra-specific variability (Kar et al., 2009). Characterisation of genetic variation in newly collected *C. olitorious* through in-depth study of leaf yield and other agronomic traits is of utmost importance for their improvement and utilisation (Ngomuo et al., 2017b). Although molecular genotyping is a tool for plant characterization, information on phenotype obtained from morphological characterization is only a starting step towards improvement. Phenotypic characterization would give a clear overview of the traits of interest to breeders and divergent genotypes could be identified (Adebola and Morakinyo, 2006).

This study was conducted to: (i) characterise phenotypic variation in *C. olitorious* germplasm traits; and (ii) identify superior accessions that have desirable traits useful in breeding for further improvement.

Materials and Methods

Genetic Material

Forty accessions of *C. olitorius* were provided by the seed genebank of the National Center for Genetic Resources and Biotechnology (NACGRAB) Ibadan, Nigeria for this study.

Experimental Site and Climatic Condition

The trials were conducted during the rainy season in 2019 and 2020 at the experimental field of NACGRAB (7°23'N latitude and 3°53'E longitude), Ibadan, Nigeria.

Experimental Setup and Cultural Practices

The experiment was set up in two phases. The accessions were first sown in the greenhouse, and then the seedlings were transplanted to the field. In the greenhouse, the seeds were sown with sterilised soil in plastic and the germinated seedlings were watered as needed. The seedlings were transplanted to the field after 28 days. The field trial was laid out in an 8 x 5 α- lattice design with three replicates. Each experimental plot was a single row of 5 m × 0.5 m. The experimental field was ploughed and harrowed with a tractor before the start of the trial. One week after transplanting and thereafter, the fertilizer was applied as needed. To keep the plots weed-free, hand weeding was done when needed.

Data Collection

Both quantitative and qualitative morphological traits were used to assess the extent of variation between accessions from seedling stage to maturity. For the quantitative traits, five plants per plot were sampled. Data were collected as described by Loumerem and Alercia (2016) and Ngomuo et al., (2017a).

Days to flowering were measured as the number of days from seed germination to flowering of 50% of the plants. Plant height (PH) was measured at the time of average flowering (cm). Petiole length (PTL) was measured from the petiole (cm). Leaf length (LL) was measured on a mature leaf lamina from the proximal end of the mid vein to the distal end (cm). Leaf width (LW) was measured on a mature leaf at the widest point (cm). Leaf length to width ratio (LWR) was measured as the ratio between the length of the leaf blade and the leaf width. Stem width (SW) was measured as the diameter of the plant base at ground level. The number of primary (PB) and secondary branches (SB) was counted as the number of branches of the main stem and the number of branches of the secondary stem, respectively, and the number of days to maturity (DM) was measured as the number of days from sowing to maturity of the pods of the whole plot.

Seed characteristics that were measured included the total number of mature pods per plant (NPP), the length of the pod (PDL) excluding the stem (cm), the total number of mature seeds in a pod (S) and the weight of 1,000 dry seeds (WTHS) in grams.

The qualitative traits measured were: plant growth habit (3 = upright 5 = intermediate and 7 = prostrate), leaf colour (1 = light green, 2 = dark green, 3 = glossy light green, 4 = glossy dark green and 5 = red), leaf shape (1 = ovate, 2 = elliptical, 3 = lanceolate, 4 = orbicular and 5 = palmate), leaf margin (1 = entire, 2 = serrulate, 3 = dentate, 4 = serrate 5 = double serrate, 6 = cleft and 7 = crenate), stem colour (1= light green, 2 = dark green, 3 = light red and 4 = dark red) stem hair (0 = absent and 1 = present), leaf base (1 = acute, 2 = round).

Data Analyses

Data on qualitative characteristics were recorded and expressed in frequencies. The analysis of variance (ANOVA) was first conducted on a year-by-year basis before a combined ANOVA was conducted across the year to determine significant mean squares for all quantitative traits measured. The collected data were subjected to ANOVA using the general linear model procedure (PROC GLM) of the Statistical Analysis System software (SAS Institute, 2011) using a random statement with test option to assess the main effects of year, replication, accession and their interaction. Replications and years were treated as random factors and accessions as fixed factors. Input means were adjusted for block effects according to the lattice design (Cochran and Cox, 1992). Mean, range, standard error (S.E.) and coefficient of variation (CV) for each trait were estimated, and the least significant difference (LSD) test was applied for pairwise comparisons of trait means ($P < 0.05$). The phenotypic and genotypic coefficients of variation (PCV, GCV) as well as heritability in a broad sense (H^2) were estimated using standard formulae (Johnson et al., 1955; Mather, 1982; Falconer, 1989). Percentage heritability was categorised as low (< 50%), moderate (50%) and high (> 50%) as reported by Robinson et al. (1949) and Afolayan et al. (2020).

Pearson's correlation coefficients (r) were used to determine the relationships between the traits. Multivariate analysis was performed to identify traits that captured morphological variation among accessions. Prior to multivariate analysis, the means of the data were standardised to eliminate effects resulting from the use of different scales. Principal component analysis (PCA) was used to identify traits contributing to variation between accessions, using SAS version 9.4 (SAS Institute, 2011). Hierarchical cluster analysis was performed for the accessions, using the Euclidean distance matrix as input to the clustering algorithm and Ward's minimum variance criterion (Ward, 1963) to minimise the total variance within the cluster. The result of the clustering was presented as a dendrogram that grouped the accessions based on their phenotypic similarity patterns (R statistical software, version 4.2.0, 2022). Base index selection (Williams, 1962; Kolawole and Olayinka, 2022) and rank summation index (RSI) (Mulamba and Mock, 1978; Kolawole et al., 2021) were used to identify outstanding accessions over two years.

Results

Variation in Qualitative Traits

Qualitative traits were recorded on the same day to avoid variation, and the two years of assessment had no effect on these traits. Clear variations were found in the growth habit of the plants and some morphological traits (colour, base, shape and margin). Two growth forms were identified, with 67.5% of the accessions having a medium growth form and 32.5% having an erect growth form. The leaf colour of most (60%) accessions was dark green, 22.5% had a light green colour and 17.5% had a glossy dark green colour. The majority of the accessions (75%) had a pointed leaf base, while 25% had a round leaf base. The leaf shapes identified were elliptic (37.5%), lanceolate (30.0%), ovate (17.5%) and palmate (15%). The variation observed in leaf margins showed that serrated margins predominated (85%), while 15% of the accessions had split margins. There was no variation in stem colour and pubescence, as all *C. olitorius* accessions evaluated had green stem colour without pubescence (Table 1).

Table 1. Qualitative variation at vegetative and maturity stages among the 40 evaluated *Corchorus olitorius* L. accessions

Qualitative traits	Observation	Frequency	Percentage
Plant growth habit	Intermediate	27	67.5
	Upright	13	32.5
Leaf color	Dark green	24	60.0
	Glossy dark green	7	17.5
	Light green	9	22.5
Leaf base	Acute	30	75.0
	Round	10	25.0
Leaf shape	Elliptical	15	37.5
	Lanceolate	12	30.0
	Ovate	7	17.5
	Palmate	6	15.0
Leaf margin	Cleft	6	15.0
	Serrate	34	85.0
Stem color	Green	40	100
Stem hair	Absent	40	100

Variation in Quantitative Traits

Combined analysis of variance (ANOVA) revealed significant ($P < 0.001$) mean squares for years of assessment for all traits except pod length (Table 2). A significant effect of replication was observed for all traits measured except leaf width, days to maturity, number of pods per plant and pod length. Plant height, stem width and number of pods per plant were influenced by the block. There were highly significant ($P < 0.001$) mean squares between accessions for all traits measured. Similarly, the mean squares of the interaction between the accessions and the year were significant ($P < 0.001$) for all measured traits.

Mean squares for all measured traits were larger than variances due to accession × year interaction and residual variance. The coefficient of variation (CV) ranged from 0.96 to 14.3% for most measured traits, indicating high experimental precision, except for leaf width, number of pods per plant and number of primary and secondary branches. There were considerable differences between the minimum and maximum values for all evaluated traits (Table 3).

Table 2. Combined analysis of variance for quantitative traits of *Corchorus olitorius* L. accessions evaluated

Source of variation	df	Plant height (cm)	Stem width (cm)	Leaf length (cm)	Leaf width (cm)	Leaf length-width ratio	Petiole length (cm)	Days to flowering (days)
Year (Y)	1	58337.46***	22.96***	511.79***	187.62***	0.73***	930.20***	2076.82***
Replication (Rep) (Y)	4	1026.23***	0.26***	9.08***	1.93	0.78***	0.48***	48.80
Block (Y x Rep)	42	218.51***	0.03***	0.40	1.60	0.07	0.05	40.52
Accession	39	423.01***	0.05***	6.25**	8.56***	1.06***	2.98***	146.63***
Accession x Y	39	268.87***	0.04***	4.20***	5.94***	0.27***	2.50***	64.67**
Error	144	69.03	0.01	0.4	1.64	0.09	0.05	31.68
CV		9.0	10.81	0.96	38.64	12.8	7.75	6.66

	df	Days to maturity	Number of primary branches	Number of secondary branches	Number of pods/plant	Weight of 1000 seeds (g)	Seeds per pod	Pod length (cm)
Year (Y)	1	624.04***	531.78***	460.73***	125694.49***	0.91***	119207.52***	0.02
Replication (Rep) (Y)	4	36.93	141.19***	42.04**	357.76	0.38***	857.63**	0.24
Block (Y x Rep)	42	20.38	7.71	14.44	448.37***	0.05	234.82	0.20
Accession	39	76.48***	10.14**	20.53**	2330.12***	0.17***	1594.08***	0.81***
Accession x Y	39	58.27***	18.11***	34.02***	2244.85***	0.10**	1455.89***	0.30*
Error	144	16.53	5.52	11.69	204.92	0.05	217.50	0.19
CV		3.05	23.72	35.04	22.85	14.13	12.26	9.19

Note: *, **, *** significant at 0.05, 0.01 and 0.001 probability levels, respectively

Table 3. Descriptive statistics for quantitative traits of *Corchorus olitorius* L. accessions evaluated over two years

Traits	Range		LSD (0.05)	% Difference	Mean±SE
	Minimum	Maximum			
Plant height (cm)	76.07	117.41	9.5	35	92.34±1.48
Stem width (cm)	0.79	1.27	0.12	38	0.99±0.02
Leaf length (cm)	5.17	10.35	0.72	50	6.94±0.18
Leaf width (cm)	1.94	9.82	1.47	80	3.32±0.21
Leaf length-width ratio	1.24	2.89	0.34	57	2.32±0.07
Petiole length (cm)	1.08	4.59	0.26	77	2.90±0.14
Days to flowering (days)	65.1	97.4	6.44	33	84.48±0.86
Days to maturity	126.13	143.94	4.65	12	133.41±0.60
Number of primary branches	7.26	13.91	2.69	48	9.91±0.24
Number of secondary branches	5.79	12.89	3.91	55	9.75±0.31
Number of pods/plant	34.38	140.54	16.37	76	62.66±3.32
Weight of 1000 seeds (g)	1.19	2.19	0.27	46	1.54±0.03
Seeds per pod	82.2	162.22	14.4	49	121.03±2.76
Pod length (cm)	3.96	5.88	0.54	33	4.73±0.06

The largest range (> 50%) was found for leaf length, leaf length to leaf width ratio, number of pods per plant, petiole length, leaf width and number of primary and secondary branches. The smallest range (< 35 %) was for the number of days to maturity, pod length and the number of days to flowering. Variations in vegetative traits were the result of a wide range of values in traits such as plant height, stem width, leaf length and leaf width, with values ranging from 76.1 to 117.4 cm, 0.8 and 1.3 cm, 5.2 and 10.4 cm and 1.9 and 9.8 cm, respectively. A wide range of values was also observed for traits such as number of primary and secondary branches, the weight of 1000 seeds and number of pods per plant. The number of days to 50% flowering and the number of days to maturity also varied considerably, with values ranging from 65 to 97 days and 126 to 144 days, respectively. Looking at the overall average performance of the *Corchorus* accessions assessed, 23 to 50 % of the accessions had a higher mean value for each measured trait compared to the overall mean value of the 40 accessions assessed (Table 4).

The average performance of the accessions showed that the shortest number of days to flowering was observed in accession NGB00195, which flowered in 65 days, and the accession that flowered late (97 days) was NGB00652. The accession NGB00232 was the tallest (117.4 cm), while the accession NGB00193 was the shortest with a height of 76.1 cm. The stem width of all cultivars was comparable, with cultivar NGB00237 having the thickest stem at 1.3 cm, while cultivar NGB00200 had a slender stem with a diameter of 0.8 cm.

The leaf, the most important edible part of the vegetable, also showed significant differences. Leaf length was 5.2 cm in NGB00210 and 10.3 cm in NGB00224 with a mean of 6.9 cm. Leaf width ranged from 1.9 cm in NGB00217 to 9.8 cm in NGB00207 with a mean of 3.3 cm, while the ratio between leaf length and width ranged from 1.2 to 2.9 in NGB00207 and NGB01261 with a mean of 2.3 cm. The longest petiole (4.6 cm) was recorded for accession NGB00226 and the shortest for NGB00200 (1.1 cm). The number of primary branches ranged from 7.3 (NGB00212) to 13.9 (NGB00236) with a mean of 9.9, while the number of secondary branches ranged from 5.8 (NGB00195) to 12.9 (NGB00207) with a mean of 9.8. The number of days to maturity ranged from 126.1 (NGB01261) to 143.9 days (NGB00207) with a mean of 133.4 days. The longest pod (5.9 cm) was found in the variety NGB00277, the shortest was NGB00217 with 4.0 cm. The variety NGB00229 had more pods than the other varieties with 140.5 pods per plant, while NGB00232 had the lowest number of pods (34.4). The variety NGB00192 had the highest number of seeds per pod (162.2), while NGB00199 had the lowest number of seeds per pod (82.2) with a mean of 121.0. The weight of 1000 seeds ranged from 1.2 g (NGB00222) to 2.2 g (NGB00210) with a mean of 1.5 g.

Table 4. Mean performance of agronomic traits in *Corchorus olitorius* L. accessions over two years

Accession	PH	SW	LL	LW	LWR	PTL	DTF	DM	PB	SB	NPP	WTHS	SP	PDL
NGB00189	89.1±3.94	0.9±0.05	6.3±0.30	3.4±0.61	2.5±0.14	1.7±0.11	78.6±2.67	132.9±1.93	11.3±1.11	11.0±1.62	57.7±6.78	1.4±0.10	114.5±6.99	5.0±0.21
NGB00192	87.2±3.98	1.0±0.05	7.3±0.30	3.4±0.61	2.6±0.14	3.2±0.11	79.8±2.69	131.2±1.95	11.0±1.13	9.5±1.64	70.8±6.85	1.5±0.10	162.2±7.06	4.8±0.21
NGB00193	76.1±3.89	1.2±0.05	8.0±0.30	4.4±0.60	2.2±0.14	4.1±0.11	92.0±2.63	138.4±1.90	9.1±1.10	6.9±1.60	38.2±6.70	1.5±0.10	91.5±6.94	4.7±0.21
NGB00195	95.8±3.93	0.9±0.05	7.0±0.30	4.0±0.61	1.9±0.14	3.5±0.11	65.1±2.66	132.1±1.92	8.8±1.11	5.8±1.62	49.9±6.78	1.6±0.10	134.9±6.98	4.9±0.21
NGB00196	82.1±3.92	0.8±0.05	6.7±0.30	2.6±0.61	2.4±0.14	2.9±0.11	87.0±2.66	133.7±1.92	9.8±1.11	9.0±1.61	60.3±6.76	1.4±0.10	120.6±6.97	4.8±0.21
NGB00197	94.6±3.98	1.0±0.05	7.2±0.30	2.7±0.61	2.9±0.14	3.1±0.11	82.8±2.70	133.2±1.95	8.5±1.13	11.3±1.64	60.8±6.86	1.7±0.10	129.8±7.07	5.0±0.21
NGB00198	84.4±3.88	1.0±0.05	6.1±0.30	3.4±0.60	1.9±0.14	2.0±0.10	79.8±2.63	134.7±1.90	9.2±1.10	8.8±1.60	61.6±6.68	1.5±0.10	107.6±6.89	5.1±0.20
NGB00199	87.8±3.87	0.9±0.05	5.4±0.29	2.4±0.60	2.1±0.14	2.1±0.10	83.4±2.62	136.7±1.89	9.4±1.09	7.9±1.59	47.2±6.67	1.5±0.10	82.2±6.92	4.0±0.20
NGB00200	85.0±3.97	0.8±0.05	5.6±0.30	2.0±0.61	2.8±0.14	1.1±0.11	81.8±2.69	129.4±1.94	7.8±1.12	11.4±1.63	119.5±6.83	1.4±0.10	127.2±7.04	5.0±0.21
NGB00202	83.2±3.92	1.0±0.05	8.0±0.30	3.0±0.60	2.6±0.14	3.3±0.11	87.6±2.65	130.4±1.92	8.9±1.11	7.9±1.61	59.6±6.75	1.6±0.10	143.5±6.95	4.7±0.21
NGB00204	82.1±3.88	1.0±0.05	7.0±0.30	3.1±0.60	2.1±0.14	2.8±0.10	87.0±2.63	132.5±1.90	9.4±1.10	9.5±1.59	62.4±6.68	1.6±0.10	98.4±6.88	4.7±0.20
NGB00205	103.8±3.95	1.1±0.05	7.4±0.30	3.3±0.61	2.5±0.14	3.4±0.11	86.0±2.67	131.4±1.93	8.5±1.12	10.2±1.62	62.0±6.80	1.6±0.10	152.7±7.01	5.6±0.21
NGB00207	87.6±3.92	1.0±0.05	6.1±0.30	9.8±0.60	1.2±0.14	1.9±0.11	83.2±2.66	143.9±1.92	9.4±1.11	12.9±1.61	76.6±6.75	1.7±0.10	143.3±7.01	4.4±0.21
NGB00208	78.2±3.96	0.9±0.05	5.5±0.30	4.2±0.61	1.6±0.14	1.8±0.11	82.0±2.69	134.2±1.94	8.8±1.12	7.5±1.63	45.3±6.83	1.4±0.10	101.6±7.04	4.5±0.21
NGB00209	80.1±3.94	1.1±0.05	7.4±0.30	2.4±0.61	2.7±0.14	3.8±0.11	86.0±2.67	134.5±1.93	11.3±1.11	12.1±1.62	67.2±6.78	1.2±0.10	124.8±6.99	5.1±0.21
NGB00210	100.0±3.94	1.0±0.05	5.2±0.30	3.4±0.61	1.5±0.14	1.7±0.11	75.2±2.67	126.7±1.93	10.5±1.11	9.6±1.62	101.8±6.79	2.2±0.10	104.3±7.00	4.4±0.21
NGB00212	89.1±3.88	0.9±0.05	6.1±0.30	2.8±0.60	2.4±0.14	1.7±0.10	81.3±2.63	128.5±1.90	7.3±1.10	8.9±1.59	58.5±6.68	1.6±0.10	128.8±6.92	4.5±0.20
NGB00213	88.6±3.93	0.9±0.05	5.7±0.30	2.7±0.61	2.3±0.14	2.6±0.11	86.8±2.66	136.6±1.92	11.8±1.11	11.6±1.62	56.7±6.78	1.4±0.10	119.3±6.98	4.5±0.21
NGB00215	107.9±3.88	1.1±0.05	9.2±0.30	3.9±0.60	2.9±0.14	4.4±0.10	80.8±2.63	132.3±1.90	11.9±1.10	9.0±1.59	73.6±6.68	1.7±0.10	136.4±6.88	4.4±0.20
NGB00217	86.0±3.91	0.9±0.05	5.4±0.30	1.9±0.60	2.2±0.14	2.1±0.11	85.9±2.65	129.6±1.91	8.2±1.11	8.1±1.61	70.9±6.74	1.3±0.10	82.2±6.92	4.0±0.20
NGB00218	92.3±3.93	1.0±0.05	5.5±0.30	3.0±0.61	1.9±0.14	2.9±0.11	83.3±2.66	135.5±1.92	8.6±1.11	8.6±1.62	58.1±6.78	1.3±0.10	101.4±7.04	4.1±0.21
NGB00221	101.8±3.99	1.1±0.05	8.3±0.30	3.4±0.62	2.5±0.14	2.9±0.11	90.6±2.70	131.4±1.95	8.7±1.13	8.3±1.64	46.5±6.87	1.6±0.11	159.2±7.14	5.0±0.21
NGB00222	87.7±3.93	1.1±0.05	6.6±0.30	2.4±0.61	2.7±0.14	3.8±0.11	86.4±2.66	136.4±1.93	11.0±1.11	12.1±1.62	69.2±6.78	1.2±0.10	118.8±6.98	4.3±0.21
NGB00224	106.2±3.91	1.0±0.05	10.3±0.30	4.1±0.60	2.4±0.14	3.8±0.11	86.4±2.65	128.1±1.92	9.9±1.11	10.8±1.61	67.6±6.74	1.7±0.10	114.9±7.00	4.7±0.21

Table 4. Continued

Accession	PH	SW	LL	LW	LWR	PTL	DTF	DM	PB	SB	NPP	WTHS	SP	PDL
NGB00225	99.4±3.99	1.1±0.05	6.7±0.30	2.7±0.62	2.4±0.14	3.1±0.11	89.9±2.70	136.9±1.95	8.9±1.13	12.6±1.64	69.9±6.87	1.5±0.11	135.2±7.16	4.3±0.21
NGB00226	99.2±3.90	0.9±0.05	6.7±0.30	4.3±0.60	1.7±0.14	4.6±0.11	79.1±2.64	136.2±1.91	8.9±1.10	9.3±1.61	55.9±6.73	1.6±0.10	110.7±6.93	4.3±0.20
NGB00228	85.0±4.14	0.8±0.05	6.0±0.32	2.5±0.64	2.2±0.15	2.4±0.11	87.2±2.80	130.5±2.02	11.4±1.17	12.3±1.70	40.0±7.12	1.5±0.11	115.6±7.34	4.5±0.22
NGB00229	110.8±4.00	1.1±0.05	7.5±0.30	2.7±0.62	2.6±0.14	3.1±0.11	84.6±2.71	129.2±1.96	9.4±1.13	12.6±1.64	140.5±6.89	1.5±0.10	121.7±7.09	5.1±0.21
NGB00230	93.3±4.08	1.0±0.05	9.0±0.31	3.4±0.63	2.6±0.15	4.1±0.11	81.8±2.76	132.1±1.99	10.7±1.15	8.8±1.68	44.4±7.02	1.6±0.11	125.3±7.23	4.8±0.21
NGB00231	99.1±4.14	1.0±0.05	6.9±0.32	2.5±0.64	2.6±0.15	3.7±0.11	84.5±2.80	137.6±2.02	11.9±1.17	6.0±1.70	82.0±7.12	1.6±0.11	119.6±7.34	4.3±0.22
NGB00232	117.4±3.93	1.2±0.05	6.6±0.30	5.1±0.61	1.4±0.14	4.2±0.11	86.6±2.66	132.9±1.92	8.5±1.11	9.5±1.62	34.4±6.76	1.8±0.10	134.6±6.97	5.1±0.21
NGB00233	88.7±3.93	1.0±0.05	6.6±0.30	2.0±0.61	2.7±0.14	2.3±0.11	82.0±2.66	132.7±1.92	10.1±1.11	10.4±1.62	48.8±6.77	1.6±0.10	118.1±7.02	4.9±0.21
NGB00235	94.5±3.91	1.0±0.05	6.6±0.30	2.4±0.60	2.7±0.14	2.3±0.11	90.6±2.65	139.6±1.91	13.1±1.11	10.9±1.61	69.9±6.74	1.7±0.10	109.6±6.98	4.6±0.21
NGB00236	96.1±3.93	1.0±0.05	7.1±0.30	3.5±0.61	2.6±0.14	2.9±0.11	84.3±2.66	130.9±1.92	13.9±1.11	11.3±1.62	55.9±6.76	1.5±0.10	119.9±6.97	4.9±0.21
NGB00237	92.4±3.89	1.3±0.05	7.0±0.30	4.0±0.60	2.0±0.14	3.4±0.11	94.4±2.63	139.8±1.90	11.6±1.10	8.4±1.60	38.9±6.70	1.6±0.10	112.1±6.90	4.9±0.20
NGB00277	102.8±3.87	1.0±0.05	8.2±0.30	2.7±0.60	2.7±0.14	2.3±0.10	85.0±2.62	132.0±1.90	8.0±1.10	7.9±1.59	52.4±6.67	1.9±0.10	126.9±6.93	5.9±0.20
NGB00651	90.8±3.87	0.9±0.05	6.3±0.29	2.3±0.60	2.7±0.14	2.7±0.10	87.2±2.62	134.7±1.89	11.7±1.09	11.3±1.59	68.0±6.66	1.4±0.10	123.1±6.87	5.2±0.20
NGB00652	79.6±3.94	1.2±0.05	7.9±0.30	5.1±0.61	1.7±0.14	3.6±0.11	97.4±2.67	139.0±1.93	9.9±1.11	6.4±1.62	34.5±6.78	1.3±0.10	102.3±6.99	4.2±0.21
NGB00653	92.7±3.88	0.9±0.05	7.7±0.30	2.7±0.60	2.7±0.14	2.6±0.11	87.1±2.63	131.9±1.90	9.0±1.10	11.9±1.60	54.6±6.69	1.3±0.10	101.8±6.89	4.6±0.20
NGB01261	95.2±3.93	1.0±0.05	7.6±0.30	3.0±0.61	2.9±0.14	2.2±0.11	79.2±2.66	126.1±1.92	10.3±1.11	11.9±1.62	74.2±6.77	1.4±0.10	110.4±6.97	5.1±0.21
Mean	92.34	0.99	6.94	3.32	2.32	2.90	84.48	133.41	9.91	9.75	62.66	1.53	119.68	4.72
Standard Deviation	9.34	0.10	1.12	1.32	0.44	0.86	5.43	3.83	1.51	1.94	20.97	0.19	18.29	0.41
Minimum	76.07	0.79	5.17	1.94	1.24	1.08	65.10	126.13	7.26	5.79	34.38	1.19	82.20	3.96
Maximum	117.41	1.27	10.35	9.82	2.89	4.59	97.40	143.94	13.91	12.89	140.54	2.19	162.22	5.88
Range	41.34	0.48	5.18	7.89	1.65	3.51	32.30	17.81	6.65	7.10	106.16	1.00	80.02	1.92

Note: PH = plant height; SW = stem width; LL = leaf length; LW = leaf width; LWR = leaf length-width ratio; PTL = petiole length; DTF = days to flowering; DM = days to maturity; PB = number of primary branches; SB = number of secondary branches; NPP = number of pods per plant; WTHS = weight of 1000 seeds; SP = seeds per pod; PDL = pod length

Selection of Superior Accessions and Estimation of Variability Components

The results obtained using the selection indices showed that the Mulamba and Mock Index (RSI) and the Williams Base Index jointly identified 12 accessions as either best or worst performers (Table 5). The weight-based (base index) and weight-free (RSI) selection indices identified similar accessions as the best (NGB00215 and NGB00229) and the worst (NGB00217, NGB00208, NGB00199 and NGB00652) performers in selecting the top five accessions. For each of the selection indices used, about 2 to 4 of the identified outstanding accessions showed high performance on all measured traits compared to the overall mean of the selected accessions. The highest selection differences for most of the measured agronomic traits were predicted by RSI, except for the number of pods per pod, seeds per pod and pod length. Of the 40 accessions evaluated, the other outstanding *Corchorus* accessions in the top five of the two selection indices were NGB00200, NGB00205, NGB00221, NGB00224, NGB00230 and NGB01261.

To identify traits that can be improved later, the estimates of genetic parameters are essential. The values of phenotypic variance were higher than genotypic variance in all years for all traits measured (Table 6). High phenotypic and genotypic variance values were found for plant height, number of days to flowering, number of secondary branches, number of pods per plant and seeds per pod. Other traits measured, however, had low phenotypic and genotypic variance values. The highest PCV was recorded for the number of secondary branches and the lowest for the number of days to maturity. Broad-sense heritability estimates were high (58-75%) for leaf length to leaf width ratio, number of days to flowering, pod length and number of primary and secondary branches. Other traits had low broad-sense heritability estimates (7-29%).

Correlation among Agronomic Traits

Pearson's correlation coefficient (r) measures the degree of association between two traits and provides information about the direction and magnitude of the relationships. In this study, the correlation coefficient (r) showed either positive or negative significant ($P < 0.001$) relationships between the traits (Table 7). Of the 14 quantitative characteristics, 10 were observed to have high positive significant correlations. The strongest positive significant ($P < 0.001$) correlation was observed between leaf petiole length and stem width (r = 0.83). On the other hand, the strongest negative significant ($P < 0.001$) correlation was found between leaf length-width ratio and leaf width (r = -0.48). A strong positive correlation was found between stem width and plant height (r = 0.82). Leaf length was positively associated with plant height (r = 0.65) and stem width (r = 0.71). Similarly, leaf width was positively correlated with the following traits: plant height (r = 0.29), stem width (r = 0.41) and leaf length (r = 0.40). A strong positive correlation was found between leaf stem length and the following traits: plant height (r = 0.72), leaf length (r = 0.80) and leaf width (r = 0.39). On the other hand, the number of days to flowering was negatively associated with plant height, stem width, leaf length and leaf petiole length, while the number of days to maturity showed a positive correlation with these traits.

The number of primary and secondary branches was similarly related to other agronomic traits. The number of pods per plant was positively correlated with all growth-related traits, but had a negative correlation with the number of days to flowering (r = -0.31). All measured traits showed a moderate negative correlation with 1000 seed weight. The number of seeds per pod showed a strong positive relationship with other traits, except for the number of days to flowering and the weight of 1000 seeds (r = -0.28 and r = -0.18). Pod length was positively correlated with plant height, leaf length to width ratio and number of seeds per pod, while it was negatively correlated with number of days to maturity.

Principal Component Analysis and Cluster Analysis

In order to get a clearer overview of the traits that contribute persistently to the variation observed between accessions and the similarities between accessions in the traits measured, principal component analysis (PCA) and cluster analysis were effective. The PCA results showed the contribution of each agronomic trait to the variation observed within the accessions. The eigenvalue indicating the relative distinctiveness of the principal axes was 5.09 for axis 1 to 1.11 for axis 4 (Table 8). The first four major axes had eigenvalues > 1 and accounted for 67% of the total cumulative variation among the agronomic traits of *Corchorus* accessions. About 50% (7) of the measured traits, namely plant height, stem width, leaf length, petiole length, number of primary branches, number of pods per plant and seeds per pod, were associated with PC1 and accounted for 36% of the total variation. The other PC axes had only one trait each, as the highest coefficient for a given trait represents relatedness to a PC axis. PC2 was characterized by the relationship between leaf length and width and contributed 16% to the total variation. The only trait related to PC3 was the number of days to flowering and PC 4 was associated with pod length; both traits contributed 9% and 8% to the total variation between accessions, respectively. It was also observed that leaf width, days to maturity, number of secondary branches and 1000 seed weight had negative loadings on PCs 2 to 4 with -0.46, -0.45, -0.63 and -0.66, respectively.

Cluster analysis from this study revealed two distinct groups. The clusters highlight the genetic diversity between accessions and group together those with similar traits (Fig. 1). Cluster I had only one unique accession (NGB00207), which had the widest leaf, the longest number of days to maturity and the highest number of secondary branches, but had the smallest leaf length-width ratio, while cluster II was further divided into subgroups according to Gower distance (Gower 1971). In this cluster, accession NGB00210 was isolated, having the shortest leaf length and the highest 1000-seed weight; the subgroup further isolated accession NGB00200, which had the smallest stem width and the shortest leaf petiole length.

This large cluster (II) was further subdivided into five (a, b, c, d, e) smaller units with at least two accessions. Five accessions grouped in the cluster II 'a' are characterized by short leaves and 80% of the accessions have an acute leaf base. The two accessions in the cluster II 'b' flowered early and both had medium plant growth, a dark green leaf colour, a round leaf base, a palmate leaf shape and a split leaf margin.

Table 5. Ranking and mean of fourteen traits of *Corchorus* accessions, identified by selection index and rank summation index

Accessions	PH	SW	LL	LW	LWR	PTL	DTF	DM	PB	SB	NPP	WTHS	SP	PDL
Top 5							**BASE INDEX**							
NGB00229	110.8	1.1	7.5	2.7	2.6	3.1	84.6	129.2	9.4	12.6	140.5	1.5	121.7	5.1
NGB00215	107.9	1.1	9.2	3.9	2.9	4.4	80.8	132.3	11.9	9.0	73.6	1.7	136.4	4.4
NGB00205	103.8	1.1	7.4	3.3	2.5	3.4	86.0	131.4	8.5	10.2	62.0	1.6	152.7	5.6
NGB00200	85.0	0.8	5.6	2.0	2.8	1.1	81.8	129.4	7.8	11.4	119.5	1.4	127.2	5.0
NGB00221	101.8	1.1	8.3	3.4	2.5	2.9	90.6	131.4	8.7	8.3	46.5	1.6	159.2	5.0
Mean of top 5	101.9	1.0	7.6	3.0	2.6	3.0	84.8	130.7	9.3	10.3	88.4	1.6	139.4	5.0
Grand mean	92.3	1.0	6.9	3.3	2.3	2.9	84.5	133.4	9.9	9.8	62.7	1.5	121.0	4.7
Selection differential (%)	10.3	2.5	9.6	-8.1	13.7	2.4	0.3	-2.0	-6.5	5.7	41.2	1.4	15.2	6.1
Bottom 5														
NGB00217	86.0	0.9	5.4	1.9	2.2	2.1	85.9	129.6	8.2	8.1	70.9	1.3	82.2	4.0
NGB00208	78.2	0.9	5.5	4.2	1.6	1.8	82.0	134.2	8.8	7.5	45.3	1.4	101.6	4.5
NGB00199	87.8	0.9	5.4	2.4	2.1	2.1	83.4	136.7	9.4	7.9	47.2	1.5	82.2	4.0
NGB00652	79.6	1.2	7.9	5.1	1.7	3.6	97.4	139.0	9.9	6.4	34.5	1.3	102.3	4.2
NGB00193	76.1	1.2	8.0	4.4	2.2	4.1	92.0	138.4	9.1	6.9	38.2	1.5	91.5	4.7
Mean of bottom 5	81.5	1.0	6.5	3.6	1.9	2.8	88.1	135.6	9.1	7.4	47.2	1.4	92.0	4.3
Top 5							**RANK SUMMATION INDEX**							
NGB00215	107.9	1.1	9.2	3.9	2.9	4.4	80.8	132.3	11.9	9.0	73.6	1.7	136.4	4.4
NGB00224	106.2	1.0	10.3	4.1	2.4	3.8	86.4	128.1	9.9	10.8	67.6	1.7	114.9	4.7
NGB00229	110.8	1.1	7.5	2.7	2.6	3.1	84.6	129.2	9.4	12.6	140.5	1.5	121.7	5.1
NGB01261	95.2	1.0	7.6	3.0	2.9	2.2	79.2	126.1	10.3	11.9	74.2	1.4	110.4	5.1
NGB00230	93.3	1.0	9.0	3.4	2.6	4.1	81.8	132.1	10.7	8.8	44.4	1.6	125.3	4.8
Mean of top 5	102.7	1.0	8.7	3.4	2.7	3.5	82.6	129.6	10.4	10.6	80.1	1.6	121.7	4.8
Grand mean	92.3	1.0	6.9	3.3	2.3	2.9	84.5	133.4	9.9	9.8	62.7	1.5	121.0	4.7
Selection differential (%)	11.2	3.1	25.5	3.1	14.8	20.6	-2.3	-2.9	5.4	8.7	27.8	1.5	0.6	1.8
Bottom 5														
NGB00652	79.6	1.2	7.9	5.1	1.7	3.6	97.4	139.0	9.9	6.4	34.5	1.3	102.3	4.2
NGB00218	92.3	1.0	5.5	3.0	1.9	2.9	83.3	135.5	8.6	8.6	58.1	1.3	101.4	4.1
NGB00208	78.2	0.9	5.5	4.2	1.6	1.8	82.0	134.2	8.8	7.5	45.3	1.4	101.6	4.5
NGB00217	86.0	0.9	5.4	1.9	2.2	2.1	85.9	129.6	8.2	8.1	70.9	1.3	82.2	4.0
NGB00199	87.8	0.9	5.4	2.4	2.1	2.1	83.4	136.7	9.4	7.9	47.2	1.5	82.2	4.0
Mean of bottom 5	84.8	1.0	6.0	3.3	1.9	2.5	86.4	135.0	9.0	7.7	51.2	1.4	93.9	4.2

Note: PH = plant height; SW = stem width; LL = leaf length; LW = leaf width; LWR = leaf length-width ratio; PTL = petiole length; DTF = days to flowering; DM = days to maturity; PB = number of primary branches; SB = number of secondary branches; NPP = number of pods per plant; WTHS = weight of 1000 seeds; SP = seeds per pod; PDL = pod length. Selection differential is estimated as a proportion (%) of the grand mean.

Table 6. Estimates of variability parameters and broad-sense heritability for agronomic traits among 40 accessions of *Corchorus olitorius* L.

Trait	δ^2_p	δ^2_g	PCV (%)	GCV (%)	H^2 (%)
Plant height (cm)	88.04	21.34	10.19	5.01	26.36
Stem width (cm)	0.01	0.00	11.11	2.91	9.14
Leaf length (cm)	0.65	0.26	11.69	7.37	21.56
Leaf width (cm)	2.10	0.46	43.79	20.51	28.89
Leaf length-width ratio	0.24	0.15	20.99	16.92	73.24
Petiole length (cm)	0.20	0.15	15.29	13.22	19.56
Days to flowering (days)	47.48	16.67	8.15	4.83	57.60
Days to maturity	19.54	3.60	3.31	1.42	25.04
Number of primary branches	8.23	3.02	28.92	17.53	70.49
Number of secondary branches	23.44	11.62	53.79	37.88	74.69
Number of pods/plant	233.33	30.15	24.51	8.81	6.84
Weight of 1000 seeds (g)	0.06	0.02	16.37	8.48	47.23
Seeds per pod	240.50	29.29	12.89	4.50	9.43
Pod length (cm)	0.29	0.11	11.45	6.92	66.90

Note: δ^2_p = Phenotypic variance, δ^2_g = Genotypic variance, PCV = Phenotypic coefficient of variation; GCV = Genotypic coefficient of variation; H^2 = Heritability in broad sense (%)

Table 7. Pearson correlation coefficients (r) for quantitative traits of *Corchorus olitorius* L. accessions

	PH	SW	LL	LW	LWR	PTL	DTF	DM	PB	SB	NPP	WTHS	SP
SW	0.82***												
LL	0.65***	0.71***											
LW	0.29***	0.41***	0.40***										
LWR	0.00	-0.09	0.16***	-0.48***									
PTL	0.72***	0.83***	0.80***	0.39***	-0.08								
DTF	-0.31***	-0.19**	-0.14*	-0.11	0.03	-0.25***							
DM	0.06	0.23***	0.13*	0.32***	-0.18**	0.25***	0.04						
PB	0.53***	0.53***	0.41***	0.18**	0.10	0.39***	-0.09	0.04					
SB	0.39***	0.34***	0.27***	0.22***	0.06	0.22***	-0.21**	-0.04	0.38***				
NPP	0.65***	0.58***	0.42***	0.21***	0.13*	0.42***	-0.31***	-0.03	0.34***	0.46***			
WTHS	-0.09	-0.21***	-0.14*	-0.07	-0.13*	-0.19**	-0.09	-0.11	-0.20**	-0.22***	-0.09		
SP	0.61***	0.61***	0.51***	0.30***	0.12	0.60***	-0.28***	-0.01	0.31***	0.26***	0.51***	-0.18**	
PDL	0.14*	0.01	0.09	-0.12	0.23***	0.02	-0.02	-0.19**	0.08	0.00	0.09	0.08	0.23***

Note: *, **, *** significant at 0.05, 0.01 and 0.001 probability levels, respectively

PH = plant height; SW = stem width; LL = leaf length; LW = leaf width; LWR = leaf length-width ratio; PTL = petiole length; DTF = days to flowering; DM = days to maturity; PB = number of primary branches; SB = number of secondary branches; NPP = number of pods per plant; WTHS = weight of 1000 seeds; SP = seeds per pod; PDL = pod length

Table 8. Eigenvalues, percentage of total variance and agronomic traits that contributed to the first four principal components of *Corchorus olitorius* L. accessions

Traits	PC1	PC2	PC3	PC4
Plant height (cm)	**0.39**	0.07	-0.11	0.03
Stem width (cm)	**0.40**	-0.09	0.06	0.10
Leaf length (cm)	**0.36**	0.00	0.09	0.27
Leaf width (cm)	0.22	**-0.46**	-0.13	-0.05
Leaf length-width ratio	0.00	**0.56**	**0.31**	0.12
Petiole length (cm)	**0.38**	-0.12	0.02	0.26
Days to flowering (days)	-0.15	-0.08	**0.52**	0.29
Days to maturity	0.08	**-0.45**	0.24	0.18
Number of primary branches	**0.27**	0.11	0.22	-0.15
Number of secondary branches	0.22	0.12	0.07	**-0.63**
Number of pods/plant	**0.31**	0.19	-0.14	-0.24
Weight of 1000 seeds (g)	-0.11	0.00	**-0.66**	0.21
Seeds per pod	**0.33**	0.14	-0.09	0.15
Pod length (cm)	0.04	**0.40**	-0.17	**0.42**
Eigenvalue	5.09	1.86	1.26	1.11
% of total variance	36	13	9	8
Cumulative variance (%)	36	50	59	67

Note: only eigenvectors with values ≥0.30 which largely controlled each PC axes are boldfaced

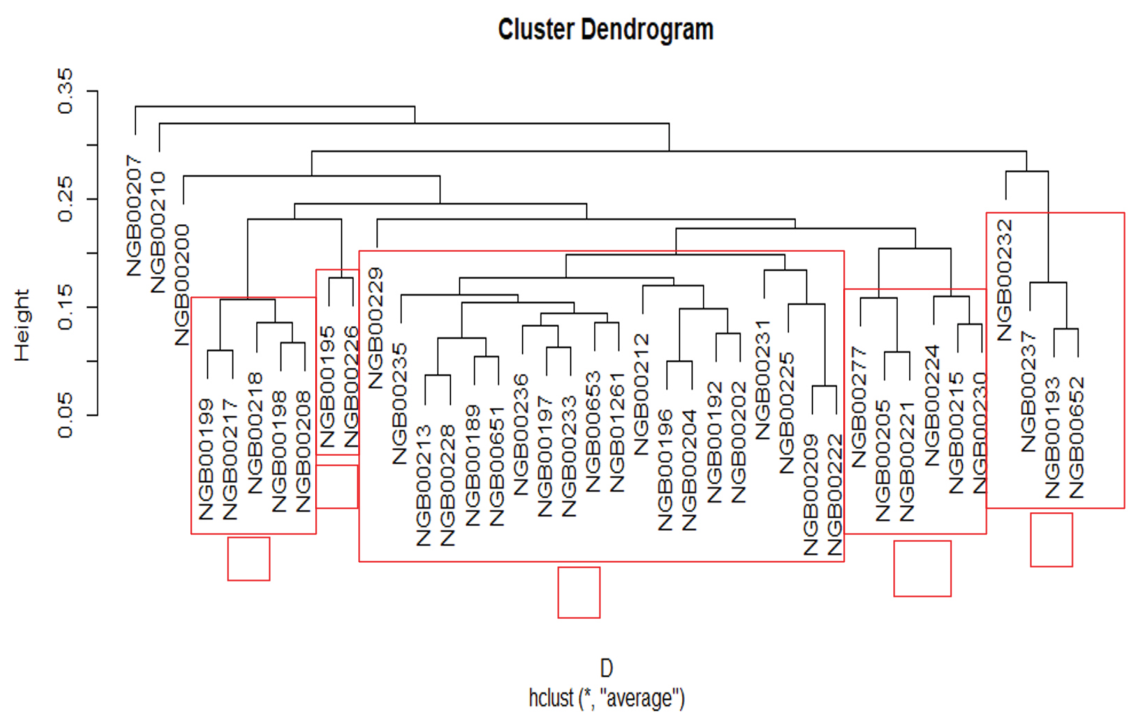

Figure 1. Dendrogram for the 40 *Corchorus olitorius* L. accessions following Ward's cluster analysis based on the Euclidean distance

The cluster II 'c' was the largest with 20 accessions and had the highest number of seeds per pod, primary and secondary branches. The growth habit of the plants in this large group was mostly medium, 95% had a pointed leaf base, but all had serrated leaf margins. The cluster II 'd' included 6 accessions that were superior in terms of plant height, leaf length, pod length and 1000-seed weight. Another characteristic of this cluster is the serrated leaf margin and 83% of the accessions had a pointed leaf base as well as a lanceolate leaf shape. The 4 accessions in the cluster II 'e' had broad stems and leaves. All accessions had a round leaf base, 75% had an erect growth habit, a dark green leaf colour, an ovate leaf shape and a serrated leaf margin.

Discussion

In order to identify and select outstanding *Corchorus* accessions useful for breeding programmes, characterisation of the germplasm is a prerequisite. In this study, considerable variation in qualitative traits was found among the 40 *Corchorus* accessions. A significant proportion of the accessions had leaves with dark green colour, acute base, elliptical shape and serrated margin with a medium growth habit. Leaf shape was the most diverse trait among the quality traits. The stems of the accessions were all green and hairless, comparable to the report of Adebo et al. (2015) who looked at the variability of cultivars of *C. olitorius* in Benin. Stem and leaf morphology of *C. olitorious* have been described as informative phenotypic traits useful for classification (Ghosh et al., 2013; Ngomuo et al., 2017a).

For all quantitative traits measured, analysis of variance revealed significant variation among accessions for all agronomic traits measured. Our results are consistent with the report of Ghosh et al. (2013), who reported significant variability in a different gene pool of *C. olitorius* accessions from East Africa and Asian countries. Similarly, variability in quantitative traits of different *Corchorus* germplasm collections has been reported (Adebo et al., 2015; Ngomuo et al., 2017a; Biswas et al., 2018). The presence of variation among accessions suggests that they will respond to improvement through selection in future breeding programmes. The highly significant interaction between accession and year for all measured traits can be attributed to the different edaphic and climatic factors of the experimental environment in the years of evaluation. These results suggest that further evaluation of accessions across locations and years is needed if the objective is to identify those adapted for the measured agronomic trait.

In addition, the variations in agronomic traits showed that some accessions had the highest average performance for two or more traits. NGB00207 had the widest leaf, the longest number of days to maturity, the highest number of secondary branches, but the smallest leaf length-to-width ratio. In leafy vegetables, the selection of a promising genotype for leaf production depends primarily on leaf size. Accessions NGB00207 and NGB00224 showed significantly high performance in both leaf length and leaf width and can be considered as potential candidates for broad leaves that are edible and useful for the treatment of various diseases (Mensah et al., 2008; Mavengahama et al., 2013). Accession NGB00210 had the shortest leaf length and the highest weight of 1000 seeds and can be considered as source material for *Corchorus* seed production. In addition, Isuosuo et al. (2019) report that the seeds of *C. olitorius* have the potential to be incorporated into human diets and livestock feed. Accession NGB00195 flowered early and had the least number of secondary branches. This accession may not be desirable for *Corchorus* improvement as early flowering is a limiting factor for leaf production (Stoilova et al., 2015). Plant height of *Corchorus* plant plays an important role in fibre production (Mukul and Akter, 2021), and accession NGB00232 was the tallest but with the lowest number of pods per plant. Variety NGB00200 had the smallest stem width and the shortest petiole length. The variety NGB00217 had the smallest leaf width and the shortest pod length. Variety NGB01261 had the highest leaf length to width ratio and early maturity. This accession could be a useful gene source for earliness, a trait desirable in areas with a short rainy season or in areas where crops are grown repeatedly in the year to benefit from residual moisture.

Based on the two selection indices used to identify the top five accessions, NGB00215 and NGB00229 were selected using both the base index and the RSI method. These two accessions can be considered well adapted to the test environment as they were selected independently by the two indices. The other six accessions selected as outstanding by the two indices were NGB00205, NGB00200, NGB0022, NGB00224, NGB01261 and NGB00230. These accessions are promising as they performed relatively better in the trait combinations and can be considered for further improvement. Moreover, farmers will get more money if these accessions are developed into varieties with farmers' preferred traits. The baseline selection index showed a good selection differential only for number of pods per plant, seeds per pod and pod length. The RSI had the highest selection differential for all other traits, indicating the efficiency of the RSI selection method in crop improvement (Ajala, 2010; Oloyede-Kamiyo, 2019). This could be due to the simplicity of the method as no genetic parameters need to be estimated (Crosbie et al., 1980). In contrast, Adebayo et al. (2017) and Kolawole and Olayinka (2022) reported the efficiency of the basic index in selecting superior genotypes.

The information obtained from PCV and GCV provides insight into the response of the accessions to their environment. The large discrepancy between PCV and GCV indicates a strong environmental influence for these traits. High PCV and GCV estimates for leaf width and number of secondary branches are further evidence that there is variation between accessions for these two traits. On the other hand, the number of days to flowering and maturity had low PCV and GCV values, indicating a narrow genetic base. Estimates of heritability are crucial in breeding as they deal with the reliability of phenotypic performance of a genotype (Alake and Porbeni, 2019). The high heritability of *Corchorus* accessions for some agronomic traits suggests that they are highly heritable, less influenced by the environment and that selection for improvement of these traits is effective. Conversely, plant height, stem width, leaf length, leaf width, leaf petiole length, days to maturity, number of pods per plant, weight of 1000 seeds and seeds per pod reflect a strong influence of the environment on their expressions.

In a breeding programme, the correlation coefficient determines the strength of the relationship between the traits. A strong positive correlation between plant height and stem width means that the taller the plant grows, the thicker the stem, which is an indication of the plant's vigour (Adeyinka and Akintade, 2015). The varieties that were taller produced more pods and had longer leaves, which means more foliage; a trait that is highly desirable in *Corchorus*. Accessions with thick stems had longer petioles and were taller. The correlation of plant height with most of the measured traits indicates its importance for agronomic improvement in *Corchorus*. Comparable positive relationships between plant growth traits were reported by Dube et al. (2019). In contrast to the reports by Ghosh et al. (2013) and Nyadanu et al. (2017), our results showed that *Corchorus* accessions that flowered early produced more secondary branches, pods and seeds per pod. We also found that accessions with longer pods contained more seeds. A strong and positive relationship between these measured traits means that an improvement in the primary trait is likely to have an effect on the secondary trait with which it is associated through indirect selection. It can also be concluded that they are most likely controlled by a similar gene. This may be a result of linkage or pleiotropy, suggesting that these pairs of traits may be simultaneously improved.

Principal component analysis measures the contribution of each trait to the total variance, and each trait is considered an important contributor to the observed variation if its factor loading has an overall value ≥ 0.30 (Nachimuthu et al., 2014). In this study, the first two PCs accounted for 50% of the total phenotypic variation between accessions. This variation was higher than that reported by Ngomuo et al. (2017a). Some agronomic traits describe the total variability observed among accessions. The traits grouped in each PC are associated and controlled by same gene action. Consequently, traits with high loading value within the first four PCs such as plant height, stem width, leaf length, leaf length to width ratio, days to flowering, number of primary branches, number of pods per plant, seeds per pod, pod length and petiole length are of great importance and should be considered for selection in the *Corchorus* improvement programme.

The clustering of the 40 *Corchorus* accessions into two different groups and then into subgroups makes the differences between the accessions even clearer. The arrangement of the groups showed no correlation with the six geographical areas (Kwara, Niger, Ondo, Ogun, Osun and Oyo) where they were collected. The plausible explanation for the lack of relationship between cluster pattern and collection area could be the effect of natural or artificial selection and exchange of desirable seeds by farmers across the country. The divergence was between NGB00207 and the other 39 accessions clustered into subgroups. The close grouping of the accessions could be due to the low degree of intra-specific variability (Kar et al., 2009) in *C. olitorius*, as they are naturally self-pollinated. However, accessions in each subgroup are similar to each other and different from those in other groups. Considering the grouping, the performance of an accession for a trait with maximum contribution to divergence should be duly considered in the selection of the progeny. Three accessions (NGB00207, NGB00210 and NGB00200) were identified as singletons because they were isolated from the other accessions. These accessions were superior in two or more desirable traits and offer a great opportunity for their use as a source of variability, as suggested by Choudhary et al. (2013). Genetic diversity in *Corchorus* germplasm has been reported using cluster analysis (Ghosh et al., 2013; Adebo et al., 2015; Dube et al., 2019). *Corchorus* accessions grouped within the same cluster are expected to be comparable, while those between clusters may show high heterogeneity. Consequently, crosses between accessions from different clusters are likely to produce useful recombinants in the segregating populations. Moreover, hybridization between accessions with large distance between clusters may benefit from heterosis as a result of genetic divergence between parental lines (Bhadari et al., 2017). The diversity observed among *Corchorus* accessions in this study can support the development of new varieties, which is an important objective in crop improvement programmes. Therefore, this study is crucial for the efficient conservation of *Corchorus* accessions and their future use in breeding programmes.

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