Floral and Seed Variability Patterns among Ethiopian Mustard (*B. carinata* A. Braun) of East Africa

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Keywords: *Brassica carinata*- Floral characters- Anther-stigma separation- Silliqua- Seed yield- Tanzania

Summary

*In East Africa, Ethiopian mustard (*Brassica carinata *A. Braun) is cultivated primarily for its leaves, but in Ethiopia preference is high for oil in the seed. Dual purpose importance of the seeds for planting and for oil suggests the need to improve seed production efficiency through understanding variation pattern for floral morphology and seed characters. We investigated genetic diversity and correlations for floral and seed characteristics among 14 accessions of Ethiopian mustard to improve seed set and yield. Field trials were conducted during 2008 and 2009; flowers were examined for short stamen height, long stamen height, pistil height, and silliqua for seed weight, seeds/silliqua and silliqua/plant. Results were largely consistent between years, indicating that the variation measured was mainly controlled by genetic factors. High genetic variation for seed characters and reproductive phenology among the accessions was noted. The number of days to appearance of flowers showed high discriminatory ability among the accessions. A wide continuous variation was observed among accessions for anther-stigma separation. Accessions 1, 3 and 14 were identified as early flowering. A significant and positive correlation coefficient between short stamen height and seed weight indicated a substantial complementation among these characters for seed yield improvement. The short stamen height is a good indicator for selection in favour of seed commercialization and indices for selection of pollen parent for seed yield improvement. Accessions 5, 7, 14, 16 and 22 are best for multiple characters and are recommended for seed production for any of the seasons in Arusha, Tanzania.*

Résumé

Variabilité florale et de semence modèle parmi la moutarde éthiopienne (*B. carinata* A. Braun) d'Afrique de l'Est

*En Afrique de l'Est, la moutarde éthiopienne (*Brassica carinata *A. Braun) est cultivée principalement pour ses feuilles, et sa préférence en Ethiopie est due à sa haute teneur en huile contenue dans les graines. L'importance double pour la production de semences et la production de l'huile suggère le besoin d'améliorer l'efficacité de production de semence par le modèle de variation bienveillant pour la morphologie florale et les caractères de semences. Nous avons examiné la diversité et les corrélations génétiques des caractéristiques florales et de semences parmi les 14 accessions de moutarde éthiopienne pour améliorer la série de semence et le rendement. Les essais de champ ont été dirigés pendant 2008 et 2009 ; les fleurs ont été examinées pour la hauteur courte d'étamine, la hauteur longue d'étamine, la hauteur de pistil, et silliqua pour le poids de semence, ensemence/silliqua et silliqua/plante. Les résultats étaient principalement cohérents entre les années, indiquant que la variation mesurée a été principalement contrôlée par les facteurs génétiques. La haute variation génétique pour les caractères de semence et phénologique reproducteur parmi les accessions a été notée. Le nombre de jours à l'apparence de fleurs a montré la haute capacité discriminatoire parmi les accessions. Une large variation continue a été observée parmi les accessions pour la séparation d'anthère-stigmate. Les accessions 1, 3 et 14 ont été identifiées comme fleurissant tôt. Un coefficient de corrélation significatif et positif entre la hauteur courte d'étamine et le poids de semence a indiqué une complémentation substantielle parmi ces caractères pour l'amélioration de rendement de semence. La hauteur courte d'étamine est un bon indicateur pour la sélection dans le service de commercialisation de semence et l'index pour la sélection de parent de pollen pour l'amélioration de rendement de semence. Les accessions 5, 7, 14, 16 et 22 sont meilleures pour les caractères multiples et sont recommandés pour la production de semence pour n'importe lequel des saisons dans Arusha, Tanzanie.*

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Introduction

Ethiopian mustard (*B. carinata* A. Braun) is amphidiploid with one genome from *B. nigra* (L.) (BB) and *B. oleracea* (L) (CC). The genus Brassica includes a total of 41 species (7) of which six species, *Brassica rapa* (AA), *B. nigra* (BB), *B. napus* (AACC), *B. oleracea* (CC), *B. juncea* (AABB) and *B. carinata* (BBCC) are widely cultivated, Ethiopia is the center of diversity of *B. carinata*. Genetic diversity in Brassica amphidiploids is generated by multiple hybrids between different diploid parents with a large intraspecific genetic diversity (17). It is cultivated primarily as leafy vegetable and for oil in the seeds, annual, occasionally biennial and grows up to 150 and 200 cm, branched, glabrous to slightly hairy at stem and petiole bases, leaves are alternate and simple. It can adapt to highland areas (2600 msl), with cool climate [10-15 °C*] (11). Cool weather followed by high temperature induces flowering, but decrease leaf production. Inflorescences are initially rather loose umbel-like raceme, flowers are perfect, four numerous and pedicel ascending, pale-yellow and occasionally cream colour, with some forms showing deep yellow without clasping auricles. Pollen is dispersed by wind as much as 10 meters from its source, and transfer via insects had been detected up to 3-4 km away (13), it sets seeds efficiently. Spatial relationship of the stigmas and anthers strongly influences pollination efficiencies (17), (11), (7), (18), (24), (25), (27), (8), (14), (5), (9), (16), (6) resulting in high seed yield.

Floral morphology has the potential to increase or decrease seed production in both self-fertilizing and out-crossing crops (22), this necessitates the need to determine the sources of variation in floral morphology and seed characters. Floral size and number are important in attracting pollinating insects (3) and (23). Variability pattern in floral and seed characteristics could be important to identify important genes for breeding, germplasm conservation, quantifying genetic diversity and eco-geographic variability. From the stand point of seed production, transition from vegetative to generative stage is important for seed yield. Seed number/silliqua decreases during development (28). This may be associated with rapid failure during embryo development, competition for assimilates may be responsible and bear a close relationship to environment. Increase consumption of fresh leaves as vegetables necessitated high demand for seeds of promising varieties in Tanzania.

Multivariate techniques have been used widely to measure diversity and assess contribution of characters to total variability in germplasm collection. We evaluated the extent of genetic variability among floral morphology characters, especially the spatial relationship between stigma and anthers, and their influence on seed yield. These relationships can improve existing varieties by breeding productive varieties with good perspective for commercialization. Our objectives were to quantify the magnitude of variation in floral morphological and seed characteristics, investigate association among floral characters and their contribution to seed yield.

Materials and methods

Plant material, location and designs

Thirteen advanced breeding lines and one registered variety (Mbeya green) of Ethiopian mustard used in this study were obtained from the Genetic Resources and Seed Unit of –the World Vegetable Center, Regional Center for Africa, originally collected from different locations in Tanzania, Rwanda and Malawi. There has been no information on floral and seed characteristics for the accessions included in the experiment. The study was conducted at AVRDC, the World Vegetable Center, Regional Center for Africa, Arusha Tanzania during the cold season of 2008 and 2009. The cold season starts in July through October and is characterized by low temperature (18-20 °C). For each year field experiment was laid out on a clay loam soil with pH between 6.0 and 6.5. A randomized complete block design with three replications was adopted; each plot consisted of two ridges 6 meter long, spaced at 0.60 meter and 30 centimeter high. Seedlings were raised in multipot–trays filled with sterilized soil for 3 weeks, and were transplanted into the sides of the ridges at 0.40 meters between plants; 30 plants were established per plot for both trials. The experiment was furrow irrigated after every two days for the first two weeks after transplanting, then once a week thereafter. Fertilizer NPK (20:10:10) was applied at the rate of 200 kg/ha (15 g/plant) at transplanting. Urea was applied at the rate of 90 kg/ha in a split application at transplanting and thirty thereafter. Weeding was carried out manually; insecticidal spray of Selecron EC (Profenofos) at the rate of 10 ml/10 lit of water was applied using a Knapsack sprayer at 2-weekly intervals beginning 21 days after planting.

This investigation was conducted on five plants per plot; each plot was covered in a fiber net cage to exclude insect pollinators. Fourteen floral and seed characteristics were measured. Data was collected on floral and seed attributes included: days to beginning of flowering (number of days from the date of transplanting to the date which the flowers appear). Number of silliqua per plant (the average number of silliqua counted from the same plant). At flowering, we randomly sampled 10 newly opened flowers from the main stem of each accession. Petals were removed for measurement of petal length (PL) and width in centimeters. The short stamen height (SSH) and long stamen height (LSH) and pistil height (PSH) were determined using a graduated scale (mm), and converted to centimeters. The ratio of the PSH to LSH was used to generate the index of the Anther-Stigma Separation. At harvest, by random sampling 10 pods from the main stem of three plants per replication the following parameters were measured (cm): peduncle length (cm), silliqua length (cm), silliqua width (cm), silliqua beak length (cm). Seeds/silliqua, loculli/silliqua and silliqua/plant was counted. Both silliqua weight and seed weight from 10 pods were determined in grams. Both individual and combined analyses of variances were conducted using PROC GLM procedure of SAS program (20). The entry means were separated using Duncan Multiple Range Test (DMRT). To identify characters responsible for majority of the variation in floral and seed structures, a principal component analysis and dendogram (21) and (19) were performed using the procedure of PROC PRIN of SAS (20) on 14 operational taxonomic units (OTUs) based on 15 characters (variables) pooled over seasons.

Results and discussion

Over two years sixteen characters investigated showed significant ($p < 0.01$ and 0.05) effects and consistent for each year (pistil height, petal length, petal width, short stamen height, long stamen height, silliqua length, silliqua beak length, silliqua length, silliqua width, long stamen height, seeds per silliqua, seed weight, pod wall weight, days to first flowering, anther stigma separation, silliqua/plant). Significant differences recorded for most characters was a clear indication of ample variability among component characters of Ethiopian mustard accessions examined, as in other brassicas species (5), (10), and (22). Combined analysis indicated that accessions by year interaction was not significant for most floral morphological and seed characters (Table 1), and could be that genotypic response was similar over years and environmental influence was minimal during the study period for this location.

Over trial periods, accessions 16, 15, 7, 21, and 5 recorded high and consistent values for spatial relationship between pistil and long stamen heights. Values of pistil height and anther-stigma separation varied widely in *B. carinata* and are consistent with those reported for *Brassica rapa* (22). The pistil height was greatest in accession 21, while accessions 22, 21 and 6 were consistent over years for number of seed/silliqua and loculli per silliqua, and accession 21 for number of silliqua. Accessions 14, 7, 16, 22 and 23 performed best for seed weight for each year, but were not consistent with performance over years except for accession 23. Empirical evidence showed that over years, accessions 8 and 21 had elongated petals, while accession 5 had wider petals than the other accessions.

Additionally for multiple characters accessions 8 and 5 outperformed other accessions for petal length and

Table 1

Mean separation for floral and seed characteristic among Ethiopian mustard accessions pooled for 2008 and 2009 seasons. All traits except SSL, LS, DFF, ASS, and SPT are in Cm

Acc code	Index number	Place of collection	PSH Pistil Height	PL Petal Length	PW Petal Width	SSH Short Stamen Height	LSH Long Stamen Height	SL Silliqua Length	SBL Silliqua Beak Length	PdL Peduncle length	SW Silliqua Width	SSL Seed Per Silliqua	LS Loculli per Silliqua	Swt Seed Weight	Pwt Pod Weight	Dff Days to First Flower	ASS Anther-Stigma Separation	SPT Number of Silliqua per plant
21	TZ 35-5	Tanzania	1.04^{a}	1.37^{b}	0.67^{bc}	0.66^{a}	0.97^{a}	4.50^{abc}	0.23^{e}	0.7^{e}	0.53^{abc}	20.00^{b}	21.67^{a}	0.57^{c}	5.6^{a}	37^{c}	1.07^{d}	868
7	TZ52-9	Tanzania	1.03^{a}	1.00^{c}	0.58^{bcd}	0.6^{abc}	0.74^{ab}	4.27^{bcd}	0.33^{d}	1.00^{cd}	0.63^{a}	17.00^{c}	19.00^{b}	0.67^{b}	2.03^{b}	34^{cd}	1.26^{c}	897
16	TZ 44-6	Tanzania	0.83^{ab}	0.96^{c}	0.43^{de}	0.63^{ab}	0.72^{b}	4.57^{abc}	0.43^{dc}	0.90^{cde}	0.50^{abc}	17.00^{c}	18.00^{bcd}	0.63^{b}	2.63^{ab}	63^{a}	3.02^{a}	329
8	ST25B	Tanzania	0.80^{ab}	1.63^{a}	0.58^{bc}	0.60^{abc}	0.80^{ab}	4.50^{abc}	0.43^{dc}	0.70^{e}	0.50^{abc}	12.00^{f}	16.00^{c}	0.57^{b}	1.50^{b}	34^{cd}	1.00^{e}	318
15	ST15	Tanzania	0.78^{ab}	1.07^{bc}	0.56^{bc}	0.36^{e}	0.50^{ab}	4.47^{bc}	0.57^{abc}	1.33^{b}	0.60^{ab}	11.00^{f}	16.67^{d}	0.45^{d}	1.66^{b}	36^{cd}	1.56^{b}	816
22	TZ1-1	Tanzania	0.77^{ab}	0.93^{c}	0.53^{bcd}	0.70^{a}	1.04^{a}	5.00^{bc}	0.60^{ab}	0.90^{cde}	0.50^{abc}	21.33^{a}	23.00^{a}	0.63^{b}	1.70^{b}	58^{b}	0.74^{h}	361
14	ST68A	Tanzania	0.77^{ab}	1.08^{bc}	0.60^{bc}	0.65^{a}	0.80^{a}	4.83^{bcd}	0.40^{d}	0.70^{e}	0.57^{abc}	14.67^{e}	16.67^{dc}	0.70^{b}	1.53^{b}	22^{fg}	0.96^{e}	313
5	TZ-35-6	Tanzania	0.73^{ab}	1.17^{cb}	0.82^{a}	0.40^{de}	0.72^{ab}	4.24^{d}	0.63^{a}	0.80^{de}	0.53^{abc}	15.00^{de}	18.33^{cd}	0.73^{a}	1.20^{b}	37^{c}	1.01^{e}	736
1	RW-B-1	Malawi	0.72^{ab}	1.07^{bc}	0.63^{b}	0.40^{de}	0.87^{a}	5.60^{a}	0.40^{d}	1.10^{bc}	0.43^{abc}	16.00^{cd}	19.00^{b}	0.30^{de}	0.37^{b}	18^{g}	0.83^{fg}	779
19	TZ61-4	Tanzania	0.71^{ab}	1.34^{b}	0.43^{de}	0.60^{abc}	0.82^{ab}	3.63^{e}	0.37^{de}	0.73^{de}	0.40^{c}	17.00^{c}	19.33^{b}	0.57^{b}	1.20^{b}	53^{b}	0.87^{f}	791
6	TZ 44-6	Tanzania	0.70^{ab}	0.89^{c}	0.40^{de}	0.52^{bc}	0.74^{ab}	3.33^{e}	0.60^{ab}	2.60^{a}	0.47^{abc}	20.33^{ab}	22.00^{a}	0.50^{b}	1.78^{b}	30de	0.95^{e}	714
23	TZ-56	Tanzania	0.64^{ab}	1.07^{bc}	0.57^{bc}	0.63^{ab}	0.80^{ab}	5.10^{ab}	0.47^{bcd}	1.33^{b}	0.47^{abc}	16.67^{c}	19.33^{b}	0.59^{b}	2.03^{b}	38^{c}	0.80^{g}	152
3	TZ-56	Malawi	0.53^{bc}	1.34^{b}	0.50^{bcd}	0.50^{dc}	1.04^{a}	4.57^{bcd}	0.40^{d}	1.10^{bc}	0.60^{ab}	14.00^{e}	19.33^{b}	0.30^{b}	0.57^{b}	24^{ef}	0.51^{i}	265
17	ML-EM-6	Malawi	0.23^{c}	1.04^{c}	0.50^{bcd}	0.50^{dc}	0.84^{a}	4.40^{cd}	0.40^{d}	0.97^{cde}	0.60^{ab}	16.00^{cd}	17.33^{bcd}	0.50^{b}	1.80^{b}	25^{ef}	0.27^{j}	309
Acc x Year Interaction			.ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Means within the same column followed by the same letter(s) are not significantly different at 5% probability level by DMRT.

width. However, it remained to be determined whether a large floral structure is advantageous to pollination success in open and controlled fertilization. In terms of length of time to reach flowering, there were accessions which flowered within 22 days and others 63 days after transplanting. This range of variation provided ample scope for selection of early, medium and late flowering accessions. Accessions 1, 14, 3, 17 were found to be consistent for earliness within and over years; they flowered on average of 22 days after transplanting, and could serve as breeding parents for earliness. At the other extreme, accessions 16, 22 and 19 flowered between 53 and 63 days after transplanting, and constitute the late maturing group. However, for seed production irrespective of years top five accessions are 14, 7, 16, 22 and 23; they could possibly be selected for seed production in Arusha, northern Tanzania. The number of seeds/silliqua ranged between 11 (Acc 17) and 21 (Acc 22), while number of loculli per silliqua was lowest (6) in Accession 6 and highest (22) in Acc 22.

To assess the pattern of variation based on floral and seed characters, the principal component analysis was done considering all the 16 variables simultaneously. The first to five axes of the PCA accounted for 81% of the total variation, and all had eigenvalues greater than 1.00 (Table 2). The contribution of the first principal axis was moderate and predicted 29% of the total variation illustrated primarily by variation in floral characters (days to flowering, pod wall weights, short stamen heights). All three traits have positive weights and equal magnitude. Conversely, petal length and width had negative weights on the same axis. The second principal axis explained additional 17% of the total variation depicted primarily the pattern of variation for seed characters, highest negative coefficients on this axis turned out to be peduncle length. Other characters (silliqua beak length and petal length) recorded high and positive coefficients on the second axis. The third principal component constituted 14% of the total variation; unexplained by both PC 1 and 2, characters of high variability on this axis included long stamen height, loculli per silliqua and seeds/silliqua; they had positive coefficients and high magnitude. The fourth principal component emphasized high variation for silliqua length and petal width, which increased but charged on petal length, while the fifth principal components described inverse relationship between silliqua width and earliness.

Figure 1 is a plot of principal components analysis loadings for the first two axes, which accounted for about half of the total variation, this provide adequate representation of diversity among the population. Five accessions from Malawi and Tanzania dispersed in the first quadrant, Accession 16 had the highest positive contribution to the first quadrant and recorded positive coefficients on both PC 1 and 2. Ordination in this quadrant showed high discriminatory ability for short stamen height and pistil height. Accessions 22 and 6 originally collected from Tanzania were ordered in the second quadrant; Accession 22 had high positive contribution compared to Acc

Table 2
Mean of variation and component score for the first seven principal components of genetic divergence in twenty-five accessions of Ethiopian mustard

Characters	PCA1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6
Pistil Height	0.20	0.24	-0.01	0.03	-0.09	0.58
Petal Length	-0.11	0.39	0.11	-0.38	0.27	0.04
Petal Width	-0.16	0.22	-0.04	0.44	0.16	0.50
Short stamen height	0.36	0.21	0.13	-0.0005	-.034	-0.32
Long stamen height	-0.04	0.08	0.60	0.17	0.11	-0.18
Silliqua length	-0.10	0.19	0.12	0.51	0.24	-0.15
Silliqua beak length	-0.01	0.40	-0.28	0.31	0.23	0.13
Peduncle Length	-0.01	-0.52	0.06	-0.14	-0.26	0.15
Silliqua width	-0.11	0.15	-0.13	0.26	-0.64	-0.11
Seed per silliqua	0.33	-0.20	0.35	0.08	-0.03	0.09
Loculli per silliqua	0.27	-0.25	0.43	0.07	0.07	0.21
Pod wall weight	0.36	-0.06	-0.10	0.35	-0.03	-0.24
Seed weight form 10 pods	0.32	0.19	-0.22	0.16	-0.18	-0.10
Pod wall weight from 10 pods	0.27	0.23	0.12	-0.11	-0.33	0.29
Days to first flowering	0.36	-0.005	-0.30	-0.07	0.32	-0.02
Number of silliqua	-0.04	-0.17	-0.17	-0.02	0.73	-0.16
Eigen value	4.36	2.66	2.17	1.70	1.31	0.95
Difference	1.70	0.49	0.50	0.34	0.37	0.33
Proportion	0.29	0.17	0.14	0.11	0.09	0.06
Cumulative	0.29	0.47	0.61	0.72	0.81	0.87

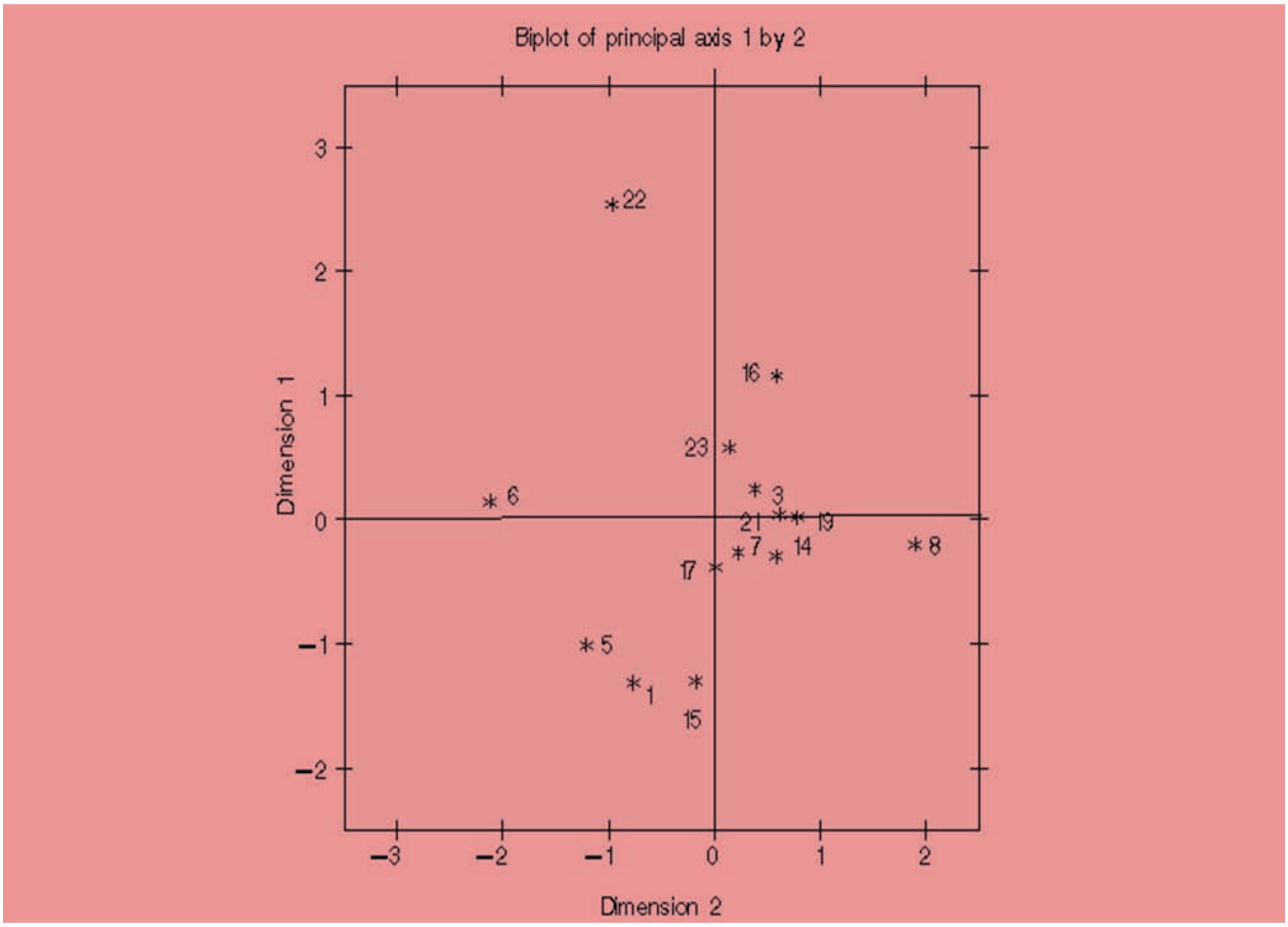

Figure 1: Plot of the first and second component scores for the fourteen accessions of *B. carinata*.

6. Acc 22 had high and positive coefficients on PC 1 and low negative coefficients on PC 2, and could be a potential pollen source of earliness, pod wall weight and seeds per silliqua. Accessions 5, 1 and 15 had negative contribution to the third quadrant with negative coefficients on both PC 1 and 2. The dispersion in third and fourth quadrant showed high variability for peduncle length and petal length and width respectively.

The pattern of variation illustrated by the PCA was very well substantiated for by the correlation coefficient determined for pair wise association of characters, consistent to the outputs of the PCA, the traits that contributed the most to the first PC (days to 50% flowering and pod wall weight) was negatively associated with major traits of the 2^{nd} PC (peduncle length). Correlation analysis among floral and seed characters returned a strong, significant and positive correlation coefficient between seed weight and short stamen height (r= 0.74**), pod weight (r= 0.64**), number of days to first flower (r= 0.49**), number of days to 50% flowering (r= 0.58**). In the same vein the silliqua/plant correlated positively with the pistil height (0.73**). This was a clear indication of complementation among floral and seed characters and that short stamen height could be reliable indicator of seed yield and pistil height for silliqua number. Consistent with this result are the complementary relationships between number of seeds/silliqua and seed weight. On one hand the association between short stamen length and seeds per silliqua was positive (r= 0.51**), but the number of loculli per silliqua recorded an independent association though not significant with seed weight (r= -0.003), this could be that genetic potential for seed set is limited by the locules. The seeds/silliqua and loculli per silliqua are positively correlated with high magnitude (r= 0.90**). Accessions 22, 6 and 21 had high values for loculli per silliqua and seed set/silliqua over seasons, consequently high percentage of seed set/silliqua could be promising for seed yield, but Accession 3 is poor seed yielder. Additionally the number of days to first flowering showed positive and perfect association with seed weight. This implied that late flowering accessions could possibly have high seed yield and vice-versa. On the other hand the association between days to first flowering and seed/silliqua, seed weight and seeds/silliqua marked positive though insignificant correlation coefficient. Correlations coefficients observed in this investigation are in support of the views of Leon and Becker (13) that various yield component are strongly inter-correlated

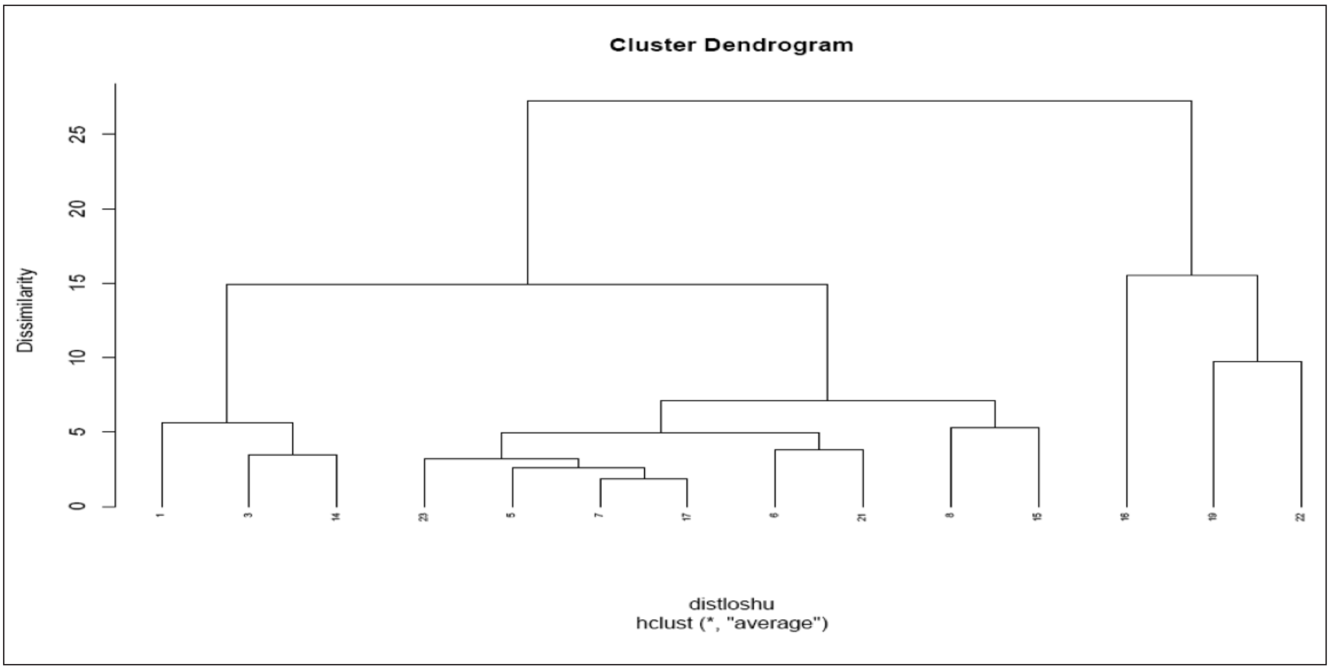

Figure 2: Dendogram of 14 *B. carinata* accessions derived from unweighted average linkage cluster analysis.

in brassicas. In this investigation compensatory relationship between components of seed weight including seeds/silliqua and seed weight, seeds/silliqua and loculli per silliqua was recorded.

The outcome of the dendogram (Figure 2) is consistent with the ordination of the PCA, whereby the major differences between clusters were attributed to the same traits that contributed most to the 1st and 2nd components. Individuals within a cluster are more closely related than are individuals in different clusters.

Cluster 1 comprised of accessions 1, 3, 14 sourced from Rwanda Malawi and Tanzania; they flower 21 days on the average after transplanting, and constitute the early maturing group and could possibly be selected as donor parents whenever genetic improvement favour earliness, but are not suitable for simultaneous improvement in yield components characters as number of seed per silliqua, seed number per silliqua and seed weight for which accessions 16,19 and 22 all from Tanzania could be donor parent since they contributed high positive coefficients on the first principal component. However, it was evident that earliness was not restricted to specific provenance; and for selection purposes emphasis has to be put at the population level than the geographical origin as source of diversity for earliness.

Cluster 2 comprised of eight accessions sourced from Tanzania and divided into three groups. Accessions 23, 5, 7 and 17 constituted a group; they flowered on the average 34 days after transplanting on the average, and belong to the medium maturity group. Accession 6 and 21 constituted second group, they marked on the average of 20 seeds per silliqua and 22 loculli per silliqua, while accessions 8 and 15 are grouped together, and on the average they had 12 seeds per silliqua. Accession 5 had a short stamen height alongside high seed weight and could possibly be selected for seed yield in this environment. Still in cluster 2, Accession 6 and 21 are characterized by high number of loculli per silliqua, seed/silliqua and a short height of the stamens, and could be considered as a source of genes for seed improvement and other seed yield contributing characters, seed/silliqua, loculli per silliqua, and seed weight, both having low to moderate contribution on 1st principal components. For late flowering and maturity and seed yield, donor parents can be sought from the 3rd cluster. Characteristically they required on the average 62 days to flower, and are best for seed set and seed yield potential compared with accessions in clusters 1 and 2. Divergence studies using the techniques of principal component and cluster analyses have been reported in lablab (12) and mustard (1), (2); and findings are in support of the present investigation that the two methods can disclose complex relationships between populations of diverse origin. The interrelationships between the number silliqua and silliqua width described by the 5th principal components entailed a very important point of practical significance in that improvement in the latter will further reduces the number of silliqua.

Inter cluster hybridization between accessions in cluster 2 and 3 may develop hybrids and open pollinated individuals that are of high seed yield and late maturing. While hybridization among members in cluster 1 and 2 may provide populations that are early or medium flowering maturing with moderate seed yield potential. The average intra-class genetic divergence of the three clusters (Table 3) showed that differences between the clusters were mainly attributed to the variations in the short stamen height and days to first flowering. However, the seed weight contributed to the cluster constellations. This further buttresses the result of dispersion of accessions in quadrant 1. The average number of seeds per silliqua, seed weight, and loculli per silliqua was higher in cluster 3 compared with cluster 1; the number of days to flowering was a reverse. Although inter-cluster variation in characters was relatively large, differences between clusters were eminently explicit. Improving these traits, therefore emphasis should focus on variation within accession.

For improvement in seed yield, hybridization between accessions 5 and 14 in cluster 2 and 1 respectively could develop F_1 hybrid and open pollinated populations that are of high seed yield. The number of seed per silliqua and loculli per silliqua was high in accessions 22, 21, 6 and 19. These characters do not correspond for high seed weight; accessions with high seed weight recorded a moderate number of loculli and seed set/loculli. Low seed weight may correspond with inefficiency of production and distribution of assimilate between the source and the sink. Consistent with this is low correlation coefficient between seed weight and seeds/silliqua, and a negative correlation coefficient between seed weight and loculli per silliqua. Accession 22 was located in cluster 3, while accession 21 and 6 are grouped in cluster 2. For genetic improvement in seed weight, inter cluster hybridization in favour of accession 22 and 21 may evolve hybrids with high seed yield. A comparison of results generated from trials over years for seed yield indicated that top five accessions for seed yield within year and over years were consistent in accession 7, 16, 22 and 14.

This implied that any of these accessions may be promoted for seed commercialization irrespective of seasons. The top three accessions for number of seed/silliqua and loculli per silliqua are accessions 21, 22, and 6. Seed weight was best in accession 7, 16, 22, and 14. Accession 14 belongs to the early maturing group and is found in cluster 1; accession 7 is medium maturing and grouped in cluster 2; while accessions 22 and 16 are late maturing, and are located in cluster 3. This provides the possibility of developing varieties of high seed yield with varying maturity periods (early, medium and late). For high number of loculli/silliqua and seeds/per silliqua which are important components of seed yield, accessions 22, 21, 6, 7, and 16 performed best. In this present investigation emphasis has to be placed on the population level than geographical level as source of diversity. However, the number of accessions studied from the regions was unequal and small; this doesn't warrant any conclusive remarks about concentration

Table 3
Intra-class average and range of genetic divergence in morphological and seed traits of the four clusters of *B. carinata*

Characters	Cluster 1		Cluster 2a		`Cluster 2b		Cluster 2c		Cluster 3	
	1, 3, 14		23,5,7, 17		6, 21		8, 15		16, 19, 22	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Pistil Height	0.67	0.53 - 0.77	0.47	0.23 - 1.04	1.22	0.70 - 1.04	1.02	0.78 - 0.80	0.77	0.71 - 0.83
Petal Length	1.16	1.07 - 1.34	1.09	1.00 - 1.17	1.13	0.89 - 1.37	0.98	0.89 - 1.07	1.14	0.93 - 1.34
Petal Width	0.57	0.50 - 0.63	0.61	0.40 - 0.82	0.54	0.40 - 0.67	0.57	0.56 - 0.58	0.46	0.43 - 0.53
Short stamen height	0.52	0.40 - 0.65	0.59	0.40 - 0.63	0.59	0.52 - 0.66	0.48	0.36 - 0.60	0.65	0.60 - 0.70
Long stamen height	1.32	0.80 - 1.04	0.78	0.72 - 0.84	0.86	0.74 - 0.97	0.56	0.50 - 0.80	0.87	0.70 - 1.04
Silliqua length	5.00	4.57 - 5.60	9.50	4.40 - 5.10	3.92	3.35 - 4.50	4.49	4.47 - 4.50	4.40	3.63 - 5.00
Silliqua beak length	0.40	0.40 - 0.41	0.40	0.33 - 0.47	0.42	0.23 - 0.60	0.50	0.43 - 0.57	0.47	0.37 - 0.60
Peduncle Length	0.90	0.70 - 1.10	1.47	0.80 - 1.33	1.65	0.70 - 2.60	1.02	0.70 - 1.33	0.84	0.73 - 0.90
Silliqua width	0.53	0.43 - 0.60	0.55	0.47 - 0.63	0.50	0.47 - 0.53	0.55	0.50 - 0.60	0.61	0.40 - 0.50
Seed per Silliqua	14.89	14.00 -16.00	16.00	15.00 - 17.00	20.17	20.00 - 20.33	12.00	11.00 - 12.00	19.17	17.00 - 21.33
Loculli per Silliqua	18.33	16.67 -19.33	18.34	17.33 - 19.33	21.84	21.67 - 22.00	16.34	16.00 - 16.67	20.00	18.00 - 23.00
Pod wall weight	1.08	0.57 - 1.53	2.20	1.80 - 2.03	3.68	0.95 - 1.07	1.50	1.50 - 1.66	1.92	1.20 - 2.63
Seed weight	0.43	0.30 - 0.70	0.62	0.50 - 0.73	0.54	0.50 - 0.57	0.51	0.45 - 0.57	0.61	0.57 - 0.63
Days to first flowering	21	15 - 24	32	25 - 38	34	x 30 - 37	36	34 - 37	61	53 - 68
Silliqua/plant	289	265 - 313	524	152 - 897	791	714 - 868	567	318 - 816	560	329 - 791

of alleles in a particular geographical location. The predominance of additive genetic variance for days to flowering, seeds/silliqua, seed yield/plant 1000 seed weight (4), (15), (26) also means that, besides hybrid and synthetic breeding, opportunity exist for genetic improvement by accumulating favourable alleles from the inter-regional variability through selection.

Conclusion

Our results have generally demonstrated a wide continuous variation among fourteen accessions of Ethiopian mustard for flower morphological and seed characters considered. This investigation showed that entries from Rwanda, Malawi and Tanzania are extra early flowering, medium and are late flowering and maturity respectively. Parents for potential source of earliness and seed yield components and simultaneous improvement for these characters have also been identified. Improvement in these traits could be achieved by exploiting variation within accessions. For seed production in Arusha, short stamen height and petal length could possibly be indicators for selection of potential breeding parent. On another note the number of silliqua can be improved among the accessions by selecting for pistil height and silliqua width. The study was affirmative that for seed commercialization in Arusha, accessions 5, 14, 7 and 16 could provide high seed yield with varying growth cycle (short, medium or late maturity). The study identified potential source of donor parent for earliness, seed yield and multiple characters.

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