GENETIC VARIABILITY AND ASSOCIATION OFTRAITS: VEGETABLE YIELD AND YIELD RELATED TRAITS IN ETHIOPIAN KALE (*Brassica Carinata*A.) ACCESSIONS

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BY

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By

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A Thesis

Submitted to the ***Department of Horticulture and Plant Sciences, School of Post Graduate Studies, College of Agriculture and Veterinary Medicine, Jimma University, for the Partial fulfillment of Degree of Master of Science in Horticulture.***

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DEDICATION

I dedicate this paper to my beloved mother AyelechWolde.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my own work and that all sources of materials used for writing it have been duly acknowledged. This thesis has been submitted to Jimma University in partial fulfillment of the requirements for the Degree of Master of Science and is deposited at the library of the University to be made available to borrowers under the rules and regulations of the library. I declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born on September 30, 1992 in Addis Ababa, Ethiopia. She attained her elementary School at Holy SaviorSchoolandSecondarySchool at St' Marry Catholic School. Then, she joined Jimma University College of Agriculture and Veterinary Medicine and graduated with BSc Degree in Horticulture on June 27, 2013.After graduation, she was employed by EthioAgri CEFT and served for few months and left the company and joined Ethiopian Institution of Agricultural Research at DebreZeitCenter as researchassistance.After two years service, she joined the School of Graduate Studies of Jimma University College of Agriculture and Veterinary Medicine to pursue her M.Sc. degree in Horticulture.

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LIST OF ABREVATIONS AND ACRONYMS

ANOVA	Analysis of Variance
DZARC	DebreZeit Agricultural Research Center
EIAR	Ethiopian Institute of Agricultural Research
EMS	Expected Mean Square
GLM	General Linear Model
MSS	Mean Sum of Square
PC	Principal Component
SAS	Statistical Analysis System
IBPGR	International Board for Plant Genetic Resources
GA	Genetic Advance
GCV	Genotypic Coefficient of Variation
h^2b	Broad sense heritability
LSD	Least Significant Difference
PCA	Principal Component Analysis
PCV	Phenotypic Coefficient of Variation

GENETIC VARIABILITY AND ASSOCIATION FOR VEGETABLE YIELD AND YIELD RELATED TRAITS IN ETHIOPIAN KALE (*Brassica Carinata*A.) ACCESSIONS

ABSTRACT

Lack ofhigh yielding and early maturing varities are the bottlenecks for Kale production. Moreover, there has been little information regarding the level and magnitude of genetic variation present in the collected Ethiopian Kale accessions for green vegetable yield and yield related traits. Therefore,theobjective of this study was to estimate the genetic variability and charcterassociationfor vegetable yield and yield related traits among Ethiopian kale accessions.The experiment was carried out using 7x7 simple lattice design at DZARC during the 2017 main cropping season.Theanalysis of variance revealed highly significant differences ($p \leq 0.01$) among accessionsforall traits except days to second leaf picking. High genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were estimated for number of leaves per plant, leaf fresh weight, leaf dry matter content,fresh biomass and leaf yield.High broad sense heritability (h^2b) estimate were obtained for number of leaves per plant (97.36%), fresh biomass (96.56%), leaf fresh weight (95.51%),leaf dry mattercontent (95.17), leaf yield (93.66%), leaf width (78.92%), leaf petiole thickness (78.26%),leaf petiole length (64.51), days to first leaf picking (61.16%), and leaf length (28.16%). Higher genetic advance as percent of mean values were recorded for number of leaves per plant(131.41),fresh biomass (79.41), leaf dry matter content (73.72), leaf yield (66.52), leaf petiole thickness (40.37), leaf width (36.08), leaf fresh weight (34.02), leaf area (29.83) and leaf petiole length (23.65). High h^2b coupled with high GAM were obtained for number of leaves per plant, leaf fresh weight, leaf dry matter content, leaf width, leaf petiole length, leaf petiole thickness, fresh biomass and leaf yield. Leaf yield showed positive and significant genotypic correlation with number of leaves per plant, leaf fresh weight, leaf dry matter content, days to first leaf picking and days to second leaf picking. Path coefficient analysis at genotypic level revealed positive and direct effect of days to first leaf picking (0.58), leaf dry matter content (0.35),leaf fresh weight (0.15) and number of leaves per plant (0.04) on yield. Cluster and distance analysis of quantitative characters based on multivariate analysis pointed out the existence of three divergent groups.The inter cluster distance was maximum between cluster one and three($D^2 = 147.84$), while the minimum distance was between two and one($D^2 = 40.56$).It can be concluded that variation generated for these traits is manily due to genetic and moderate role of environmental factors and these were the most important for selection criteria in developing high yielding Ethiopian kale accession. In general, the present study revealed the presence of variability among accession for most studied traits. This recalls further confirmation at multi-location and over years to develop high yielder varieties.

Key words: Heritability,Genetic Advance, Multivariate analysis,Selection

1.INTRODUCTION

Ethiopian kale (*Brassica carinata* A. Braun) is one of the oldest African vegetable, previously gathered from the wild (Schippers, 2002**).** It is believed to have originated in the highlands of the Ethiopian plateau and the adjoining portion of East Africa**(**Alemayehu and Becker, 2002**)** and the culture and cultivation of Ethiopian Kale in Ethiopia is old, which is believed to date back in the 4th to 5th Millennia B.C. (Alemayehu*et al.,*1997). According to Nagaharu (1935)it'sevolved as a natural cross between *Brassica nigra* (BB) (n=16) and *Brassica oleracea* (CC) (n=18), and underwent further chromosomal doubling (2n=34).

As reported by Walle *et al.* (2014) in Ethiopia, reliable statistical information on the distribution and production of Ethiopian kale is lacking. The crop has been cultivated widely in many areas of the country with low amount of yield. This might be due to the fact that it has been widely neglected by research and development programs (Jianchu *et al.*, 2001). Also its cultivationis confined to gardensaround homestead or sparsely mixed with thick crop stands of maize, sorghum, teff and finger millet (Velasco *et al.,* 2004). kale is dominantly produced in Gurage and Hadiya zones (HAJI, 2007). It was grown in an area of 36,090.31 ha with productionof green vegetable 3528964.43 ton and a yield of 9.78 ton ha^{-1}(CSA, 2016).

It is cultivated as a leaf vegetable and oilseed crop in the country. It has special nutritional components like vitamins, minerals, trace elements, dietary fiber and protein. It also gives test and flavor of diets (Asfaw, 1997; Genet *et al*., 2005). Apart from vegetable and oil, it is also used as raw materials in industries, where its oil is indeed of immense importance inleather tanning, manufacture of varnishes, diesel fuel, soap and lamps (Alemayehu *et al*., 1997; Tesfaye *et al.*, 2011).

In spite of these strong positive attributes, the crop suffers from several agronomic limitations like longer crop duration. Restricted level of natural variability for specified traits has greatly constrained the breeding programmes aimed at overcoming these limitations (Hirano *et al*., 2009). Ethiopian kale is produced by small holder farmers following traditional practices and there are limited knowledges, access and the use of available genetic resources. As a result,

utilization of traditional varieties, primitive crop husbandary and poor post-harvest handling practices remain as the very limiting factors for kale production. Moreover, lack of early maturing and high yielding varieties are the bottlenecks for its production (EIAR, 2000). Even the regional and national researches have not released any varieties for high yielding and early maturing in Ethiopia, there is a need to develop varieties.

Plant breeders always use their efforts in the development of new varieties. For this, knowledge of genetic variability present in available germplasm is absolutely essential for further improvement of the crop. Variation provides useful information to the plant breeder to determine the genetic potential of the populations for developingnew varieties with desirable characters in any crop species. Locally collected landraces serves as a good source for initiating breeding program, as they have more variability among them. This variability can be manipulated in breeding programs for the development of high yielding and promising varieties. Certain morphological parameters serve as tool for the estimation of genetic variability (Ali *et al*., 2013).The existence of variation alone in the population is not sufficient for improving desirable characters. High heritability is also needed to have better opportunity to select directly for the charactersofinterest.Similarly, information on the extent and nature of interrelationships among character helps in designing efficient scheme of multiple trait selection as it provides means of direct and indirect selection of component characters.

Ethiopia has a huge endowment of Ethiopian kale genetic diversity. However, activities to characterize, classify and identify the genetic wealth are minimal (Tadesse, 2012). In Ethiopia, where it is becoming an important vegetable and oil crop, there has been little effort so far with regard to the estimation of the level and magnitude of genetic variation among the collected genotype of this crop (Walle, 2014). Crop research in Ethiopia has largely concentrated on cereal, oil and industrial crops. Hence, to augment kale production, the only recourse is to boost up productivity. Development of high yielding varieties is necessary to increase the production as well as the quality of the produce. In order to accomplish the task, the breeder must have to device suitable breeding method.

The nature and magnitude of genetic variation among the Ethiopian kale accessions for oil seed and related traits was studied by different authors (Belete *et al*. 2012; Ali *et al.*, 2013;

Walle *et al*., 2014). They reported that the presence of sufficientvariability for oil seed yield and related traits could be used to make selection. However, up to now information on the extent and pattern of genetic variability, inter variables association and variables effect in green vegetable yield and related traits, similarity of the genotypes and divergence of the cluster, and also traits responsible for the gross variability among Ethiopian Kale accessions has not been fully exploited. For this purpose information regarding the nature and magnitude of genetic variation that exist in breeding population is required. Therefore, the present study was designed with the following objectives.

Objectives:

- ✓ To estimate the extent of variability, heritability and genetic advance in the Ethiopian kale accessions.
- ✓ To estimate the extent of correlation between traits at phenotypic and genotypic level, and to determine the direct and indirect effects of traits onvegetable yield.
- ✓ To determinethegenetic relationships among the accessions using cluster and divergence analysis.

2. LITERATURE REVIEW

2.1. Description and Originof Ethiopian Kale

According to Doweny and Robbelen (1989) Ethiopian kale belongs to family *Brassicaceae.* It is self-pollinating amphidiploids species. Gomez-Campo and Prakash (1999) indicate that under open field conditions, an average of 30% out-crossing may result from pollination by wind and/or insects.The genus *Brassica* contains 37 different species. As stated by Christopher *et al*. (2005) this genus comprises a diverse group of species including major six economically important species of *Brassica*, *B. rape* (AA), *B. oleraceae* (CC), *B. nigra* (BB), *B. juncea* (AABB), *B. napus* (AACC) and *B. carinata* (BBCC).

Similarly Nagaharu **(**1935) indicate the botanical close relationship between the six *Brassica* oilseed species was established as a result of taxonomic studies carried out in 1930's .The Triangle of U is a theory about the evolution and relationships between members of the plant genus *Brassica*.Smith *et al.* (1997); De Rougement(1989) stated that *Brassica carinata* (*n* = 34) is an amphidiploid species derived from interspecific crosses between *Brassica nigra* (*n* = 16) and *Brassica oleracea* (*n* = 18). *Brassica carinata* is a polyploid resulting from the combination of sets of chromosomes from both parents and it behaves like a diploid.

Ethiopian kaleis an erect annual, occasionally biannual or perennial crop grown as oilseeds or as a leafy vegetable. It's originated and cultivation is restricted to the Ethiopian plateau, since ancient times. Mnzava and Schippers (2004) indicate that for use as leafy vegetables, such traits are preferred: large leaf size, late flowering, many leaves per plant and tolerance to major diseases and pests. Schippers, (2002) stated that Ethiopian kale have different name in other parts of the world include Abyssinian mustard, Ethiopian mustard, Ethiopian rape seed (Europe), Figiri (Zambia), Loshuu (Tanzania), Sukuma wiki (Kiswahli) and Tamu- Texsel (America).

2.3. Genetic Components of VariancesEstimate

2.3.1. Variability

Accorrding to Burt (2000) genetic variability is a measure of the tendency of individual genotype in a population to vary from one another). As stated by Li *et al*. (2008) genetic variation is the principal raw material for any breeding and/or improvement program. The effectiveness of breeding for trait desired is depends on the extent of this genetic variation. Genetic variation among the available germplasm resources has been a ground work for developing elite genotypes and enhancement of germplasm. Similarly Shah *et al*. (2015) stated that the measurement of genetic variation and mode of inheritance of quantitative and qualitative traits are of prime importance in planning the programme efficiently and effectively.To plan an efficient breeding program, it is necessary to have an understanding of the breeding systems coupled with statistical analysis of inheritance data (Falconer and Mackay, 1996). Singh and Chowdhury (1985) also indicated that, the response to selection is resulted from significant genetic variation and high heritability.

Kahani and Hittalmani (2015) stated that component of genetic parameters such as genotypic coefficient of variation and phenotypic coefficient of variation have an immense contribution in detecting the amount of genetic variation exist in the genotypes. Genetic variability studies provide basic information concerning genetic properties of population following which breeding methods could be formulated for future improvement of the crop. Smith and Smith (1989) indicate many tools are now available for studying variability and the relationships among accessions. However, morphological characterization is the first step in the description and classification of the germplasm. According to Alemayehu and Becker (2002), variation in locally adapted Ethiopian kale population of the species is helpful for identifying important traits and to develop agronomically viable varieties.

Various researchers studied genetic parameters to determine the selection criteria for yield improvement in *Brassica ssps*. Delesa (2006) studied the genetic variability among sixty oilseed Ethiopian kale genotypes for seed production and found that there were significant genetic variations for all characters measured. Similarly studies of Yared (2010); Alemayehu

(2001); Belete (2011) on oilseed Ethiopian kale show that there were significant differences among genotypes for all traits.De Haro *et al.* (1998) also indicate a large degree of variability in oilseed Ethiopian kale genotypes for agromorphological characters. Abebe (2006) studied sixty accessions of oilseed Ethiopian kale for seventeen traits and reported the existence of large amount of genetic variability. In contrast, Rabbani *et al.* (1998) concluded that the oilseed Ethiopian kale genotypes, although distributed over a wide range of geographic conditions, did not exhibit a significant variation in most of the morphological traits.

Gorka *et al.* (2017) reported significant differences in kale (*Brassica oleracea*L.) genotypes for days to first leaf picking, leaf area index, leaf weight per plant, plant height, number of leaves per plant and leaf yield per plant. Vyas *et al*. (2006) studied genetic variability for ten characters in 60 genotypes of Amaranthus and revealed the presence of considerable amount of genetic variability for all characters. Similarly, Mandal and Dhangrah(2012) studied seventeen genotypes of Amaranthus including four improved varieties and 13 local types. They observe significant differences among the entries for all the studied characters *i.e.* plant height, number of leaves/plant, leaf length and width, leaf fresh weight, yield/plant and yield/ hectare. Esiyok *et al*. (2011) studied in fifty-four Swiss chard accessions and cultivars and observed highly significant variations among accessions for all traits. Joshi *et al*. (2011) observed thirty one accessions of Amaranthus and found that germplasm showed a wide range of variability in plant height, leaf length, leaf width, petiole length and leaf weight per plant. Varalakshmi (2016) found wide range of variation in Indian spinach for leaf number (15.33-40.56) and total plant weight /plant (68.50- 260.43 g).

Chauhan (2016) studied on Water Spinach report high magnitude of genotypic as well as phenotypic coefficients of variation for fresh weight leaves (46.18 and 48.15), leaf yield (43.45 and 46.93), leaf width (29.36 and 33.71), dry weight of leaves (23.15 and 27.40) and petiole length (22.51 and 27.99). Shukla *et al*. (2006) evaluated twenty nine strains of vegetable Amaranthus and found that leaves/plant and plant height showed lowest values of GCV. Ahammed *et al.* (2012) studied twenty two genotypes of Amaranthus and reported that lowest PCV was found for plant height and the lowest GCV was found in leaf width. Hasan*et*

al. (2013), reported high GCV and PCV in leaf weight/plant (77.54 and 80.14 %) and dry weight/plant (74.42 and 74.47 %), respectively in Amaranthus.

According to Hasan *et al.* (2013) study, on Amaranthus genotypes the genotypic correlation coefficients were higher than the phenotypic correlation coefficients. Dutta *et al.* (2002) also reported that the magnitudes of genotypic correlation were higher than their respective phenotypic correlations. In other study of oilseed, Ethiopian kale genotypes there were no or little differences between PCV and GCV for most of the characters measured (Tesfaye *et al*., 2013). Esiyok *et al*. (2011) studied in fifty-four Swiss chard accessions and cultivars found phenotypic coefficient of variation (PCV) was higher than the magnitude of genotypic coefficient of variation (GCV) for all agronomic characters.

2.3.2 Heritability and Genetic Advance

Acoording to Bagati (2016) Heritability is a statistical measure for how the genetic contribution to a trait might vary in a population, and the broad sense heritability is given by the ratio of the total genetic variance to the phenotypic variance. The transmission of characters from parent to its progeny is directed by the heritability of a trait in crop. Khan and Naqvi (2011); Konate *et al.* (2016) stated that the transmission of a trait from one generation to the next generation, knowledge on heritability have a significant role. The extent of trait transmission from parent to progeny can be estimated through heritability and serve as analytical role in crop breeding program. Heritability is a parameter which is widely used in the establishment of breeding programs and formation of selection indexes (Falconer, 1985).

Falconer and Mackay (1996) stated that heritability of any trait depends upon genetic properties of breeding material and environmental conditions in which experiments are carried out. As stated by Sial (2007); Mangi *et al*. (2008) studies conducted by various researchers have shown that high heritability alone is not enough for selection; it must be accompanied with substantial amount of genetic advance. Similarly Shukla *et al*. (2004) stated that there is a direct relationship between heritability and response to selection, which is referred to as genetic progress. The expected response to selection is also called genetic advance. The utility of heritability therefore increases when it is used to calculate genetic

advance, which indicates the degree of gain in a character obtained under a particular selection pressure. Thus, genetic advance is yet another important selection parameter that aids breeder in a selection program. The study of the genetics and its components for main agronomy characteristics are the goal of the breeding strategy for crop. So heritability is one of the popular indexes (Falconer, 1989) and direct effect on selection.

Shukla *et al*. (2006) study twenty nine strains of vegetable Amaranthus (*Amaranthus tricolor* L.) genotypes relived that high heritability with highest expected genetic advance as percent of mean for leaf yield (48.30%) and leaf size (29.51%). Anuja (2011) studied genetic variability and heritability in 100 genotypes of Amaranthusgermplasm and found heritability estimates for most of the characters. Ahammed *et al.* (2013) evaluated 22 genotypes of Amaranthus and found heritability estimates in broad sense for leaf weight/plant (91.10%) followed by number of leaves/plant (86.83%) and yield/ha (78.70%). Abe *et al*. (2015) evaluated thirty two Amaranthus genotypes and revealed that the heritability estimates in broad-sense ranged from 2.21 to 99.78. Meena *et al.* (2010) found High estimates of heritability for yield (98.90%) followed by leaf length (97.30%) in Cabbage.

Chauhan (2016) conducted a study on Water Spinach genotypes, and reported highest heritability for fresh weight of leaves (90.6%) followed by foliage yield (85.7%), leaf length (77.1%), leaf width (75.9%), dry matter percent of foliage (75.6%) and dry weight of leaves (71.4%) also genetic advance as percent of mean was high for fresh weight of leaves (90.64%) followed by foliage yield (82.80%), leaf width (52.63%), dry weight of leaves (40.46%) and petiole length (37.35%).

According to Esiyok *et al.* (2011) high genetic advance accompanied with high heritability was obtained in Swiss chard from petiole thickness, petiole width and leaf dry matter. High heritability coupled with high genetic advance was also reported for leaf length and leaf width in Spinach (Srivastava *et al.,* 1977). High heritability in broad sense were observed for leaf width (83.40%) and leaf length (83.20%) and genetic advance as percentage of mean was low for leaf width (18.63%), number of leaves (17.41%), leaf length (13.89%) and plant height (8.74), Also high heritability values coupled with high genetic advance were recorded for leaf

yield in Cabbage (Soni *et al*., 2011). Hasan *et al.* (2013) found high heritability estimates associated with fairly high estimates of genetic advance in Amaranthus for number of leaf, leaf weight and yield.

2.4. Association among Characters

2.4.1 Correlation Coefficients

Sarawgi *et al*. (1997) stated that yield is a very complex trait, polygenic in inheritance, more prone to environmental fluctuations than other traits. Understanding the association between yield and its components is of paramount importance for making the best use of these relationships in selection. Shabir *et al*. (2013) indicate the association between different characters, particularly association of yield with its components like number of leaf /plant, leaf weight per plant, leaf area and also with plant characters such as plant height, plant canopy width and days to leaf picking are the important ones. Therefore the breeding program should consider the association of various factors with yield. Many physiological, morphological and agronomical traits contribute to yield and each of which is correlated with each other and also influenced by environment.

According to Gomez and Gomez (1984), the degree and direction of the relationship between two or more variable could be measured through a statistical measure called correlation coefficient analysis. The association between two traits can directly be observed as phenotypic correlation while genotypic correlation express the extent to which two traits are genetically associated. Both genotypic and phenotypic correlations among and between pairs of agronomic traits provide scope for indirect selection in a crop breeding program (AL-Ahmad 2004; Aydin *et al.,* 2007). Similarly Morakinyo (1996) stated that genotypic and phenotypic correlation coefficients among various plant trait helps to ascertain the degree to which these are associated with economic productivity.

Mary and Gopalan (2006) stated that the association of a particular character in relation to other traits contributing to the yield of a crop would be great objectives of plant breeders. According to Johanson *et al*. (1955) basic knowledge on correlation which exists between

traits serves as the basis for planning efficient breeding program for crop improvement while inadequate knowledge of interrelationship among various traits ends up with less than optimum result in plant improvement program. Similarly Hefena *et al*., (2016) stated that correlation analyses among various agronomic traits enable researchers to predict the performance of complex and quantitative traits. Konate *et al*. (2016) indicate that correlation studies have a significant importance for plant breeder during selection and help to understand yield components to serve as a tool for indirect selection.

Hasan *et al*. (2013) evaluated seventeen genotypes of Amaranthus (*Amaranthus tricolor* L.) and revealed that green yield was positive correlated with leaf weight and dry weight. Abe *et al*. (2015) evaluated Amaranth and revealed that yield per plant showed a moderate positive correlation with leaf width, leaf length, leaf area and plant height, and a strong correlation with fresh biomass and dry biomass. According to Dolma *et al*. (2011), leaf yield per plant exhibited significant positive correlation with plant height, number of leaves per plant, leaf weight and leaf area showed significant negative correlation with days to first picking and dry matter contents in Lattuce. Highly significant and positive correlations were also found between yield and plant diameter (Kibar *et al*., 2014).The correlation studies revealed that the Amaranthusfoliage yield per plant recorded positive and significant correlation with leaf weight per plant, leaf length, leaf width. there was a non-significant negative correlation between yield and and number of leaves per plant. the relationship between yield and number of leaves per plant was found positive but non-significant (Tejaswini *et al*., 2017).

Abe *et al*. (2015) revealed that in Amaranthus plant height was positively correlated with fresh biomass and dry biomass. According to Dolma *et al*. (2011), significant positive association both at genotypic and phenotypic level exist for plant height with number of leaf per plant, leaf area, duration of picking. Significant negative association were observed for days to first picking with plant height, number of leaves per plant, leaf weight, leaf area and leaf yield; dry matter content with plant height, average leaf weight, leaf area and leaf yield; number of leaves per plant with average leaf weight in Lattuce. In Water Spinach genotypes were found that Petiole length showed highly significant positive correlation with leaf length (0.697 and 0.726) and leaf width (0.932 and 0.980) at both phenotypic and genotypic levels.

Leaf width showed highly significant positive correlation with leaf length (0.659 and 0.651) at phenotypic and genotypic level respectively (Chauhan, 2016). plant height was positively and significantly associated with plant diameter, width of leaf, length of leaf and yield. plant diameter had also significant positive association with plant height, width of leaf, length of leaf and yield. Width and length of leaf exhibited significant positive associations with plant height, plant diameter and yield in Cabbage (Kibar *et al.*, 2014).

Hasan *et al*. (2013) studied on Amaranthus genotypes reported that plant height had positive correlation dry weight and leaf yield. Positive significant correlations were also noticed for leaf length with leaf number, weight of leaf with leaf number and leaf length. Length of leaf showed highly significant positive correlation with yield both at phenotypic and genotypic levels. Esiyok *et al.* (2011) conducted experiment on Swiss chard genotypes, they reported that yield estimation is mainly related with leaf weight which is highly ($p<0.01$) positively correlated with petiole length, petiole thickness and petiole width.Varalakshmi (2016) conducted a study on Indian Spinach genotypes, who reporteplant weight was significantly and positively associated with branch number, leaf number and leaf weight. In Swiss chard positive correlation was revealed between petiole length, petiole thickness and petiole width which comprise total yield. high correlation coefficient reported for leaf width, petiole length, petiole thick, and plant weight among accessions (Bozokalfa *et al.*, 2010).

2.4.2. Path coefficient analysis

According to Ali *et al* (2003) use of simple correlation analysis could not fully explain the relationships among the traits. Therefore, the path coefficient analysis has been used by many researchers for a more complete determination of the impact of independent variables on dependent one. Garcia *et al.*(2003); Khaliq *et al.* (2004) stated that using path coefficient analysis, it is easy to determine which yield component is influencing the yield substantially. Having this information, selection can then be based on that criterion thus making possible great progress through selection. Path coefficient analysis has been used by plant breeders to assist in identifying traits that are useful as selection criteria to improve crop yield. It was first applied by Dewey and Lu (1959) for plant selection and it was observed that it permits

acritical examination of specific forces acting to produce a particular correlation. Since then, several workers have used the method for analysis of character association in various crops.

Dolma and Cupta (2011) demonstrated, the study on Lettuce genotypes, who reported path coefficient analysis revealed maximum positive direct effect of number of leaf per plant (0.72) followed by average leaf weight (0.67), days to first picking (0.44) and plant height (0.40) on leaf yield per plant. The positive indirect effect was observed for number of leaves via plant height, leaf area, duration of picking, dry matter content. where as indirect negative effect via average leaf weight and days to first picking.

Varalakshmi (2016) conducted experiment on Indian Spinach parameters, like, branch number, leaf weight, stem weight, plant height, petiole length and leaf wedth exhibited negative, direct effect on total plant weight and the indirect effects seen via these parameters were also negative. Thus, the positive direct and indirect effects of leaf number and leaf length led to significant and positive correlation with total plant weight. Leaf number had the maximum direct positive effect on total plant weight, followed by leaf length.

According to Hasan *et al.* (2013) leaf weight showed the maximum direct positive effect with yield in Amaranthus genotypes. Negative indirect effects were revealed by dry weight, leaf length, and plant height. Dry weight showed the negative and positive direct effect with yield, respectively. Nonetheless, these traits showed positive and negative indirect effect making the total correlation between dry weight and yield positive and highly significant.Similarly Tejaswini *et al.* (2017) revealed that, leaf weight per plant had the highest positive direct effect on yield followed by leaf length, leaf width. Kibar *et al.* (2014) found plant height, plant diameter, width of leaf, length of leaf showed high positive indirect effects on yield in Cabbage. Path coefficient analysis revealed that plant diameter had high positive direct effects on yield and a higher indirect contribution was exhibited via these traits by most of the yield components.

2.5. Genetic distance

As stated by Mahalanobis (1936) multivariate analysis as a potent tool for assessment of diversity was first postulated by. According to Singh (1983) genetic diversity plays an important role in plant breeding because hybrids between lines of diverse origin generally display a great heterosis than those between closely related strains. Jatoi *et al*. (2010); Turi *et al.* (2012) indicated that germplasm of a specific crop collected from the diverse sources offers greater genetic diversity and may furnish useful traits to widen the genetic base of crop species. The successes in the improvement of crop both qualitatively and quantitatively and the development of a species requires the availability and accessibility of genetic diversity. Knowing of duplicates, organization of core collection of a particular population and the selection of parents for the development of new cultivars are directly related to the genetic diversity). Alemayehu and Becker (2002), probably are the first to report a systematic diversity study on the oil seed Ethiopian kale, by studying 36 genotypes of Ethiopian origin showed the presence of large genetic diversity for agronomically important traits. Mekonnen *et al.* (2014) stated that genetic distance is very important for hybridization program to get better yield and best recombinant parents in oil seed Ethiopian kale.

2.6. Cluster Analysis

According to Hair *et al.* (1995) cluster analysis refers to a group of multivariate techniques whose primary purpose is to group individuals or objects based on the characteristics they possess, so that individuals with similar descriptions are mathematically gathered into the same cluster. The resulting clusters of individuals should then exhibit high internal (within cluster) homogeneity and high external (between clusters) heterogeneity. Thus, if the classification is successful, individuals within a cluster shall be closer when plotted geometrically and different clusters shall be farther apart. Cluster analysis assigns genotypes into qualitative homogenous groups based on response similarities and also assists to classify genotypes. The method among group means and produces a dendrogram showing successive fusion of individuals.

Belete *et al*. (2011) evaluated 49 genotypes of oil seed Ethiopian kale that were collected from 12 different Ethiopian agro ecological zones of the country sources were grouped in to four clusters. Cluster 1 the largest of all included 28 (57.14 %) of the genotypes. Among seventeen genotypes of Amaranthus studied by Akther *et al*. (2013) also categorizedthe genotypes into 4 clusters. Similarly Akaneme and Ani (2013) studied five accessions of the Amaranthus, where all of the accessions divided into two clusters.

Experment counducted by Bozokalfa (2016) showed that the multivariate cluster analysis performed for all the agromorphological plant traits categorized the Swiss chard accessions examined into four independent clusters. The first were characterized by the highest plant height, plant canopy and the lowest leaf dry matter. The second cluster were characterized by lower leaf weigh, petiole thickness and petiole width. The third cluster represented the highest leaf weigh and petiole length. The fourth cluster characterized by higher petiole thicknes, petiole width and leaf dry matter, while registering lower values for plant height, plant canopy and petiole length.

Sinha and Singh (2004) evaluated 19 Indian mustard genotypes and divided them into five genetically diverse clusters, with cluster I having highest number of genotypes based on D^2 analysis. Similarly Patel and Patel (2006) analyzed forty genotypes of Indian mustard for ten quantitative traits and grouped the forty strains into four different clusters with cluster I comprising of the maximum number of strains. Shalini *et al.* (2000) also analyzed genetic divergence in 81 Indian mustard cultivars for ten quantitative traits. Cluster analysis revealed that the geographical distribution of the cultivars did not significantly contribute to genetic divergence.

2.7. Principal Component Analysis

According to Fellahi *et al.* (2013) Principal component analysis (PCA) is defined as a method of data reduction to clarify the relationship between two or more characters and to divide the total variance of the original characters in to a limited number of uncontrolled new variables. This will allow visualization of difference among the individual and identify possible groups.

The reduction is achieved by linear transformation of the original variable in to a new set of uncorrelated variable known as principal component (PCs). Although principal component analysis grouped accessions together with more morphological similarities.

Saleem *et al*. (2017) carried out PCA based on twenty quantitative morphological characters. The seven principal components account for 73.92% of the overall variability among the studied on Indian mustard accessions for the total phenotypic variations. PCA-I was found to have 23.35% out of the total variability. leaf length (-0.711), leaf width (-0.569), leaves per plant (-0.616) and plant height (-0.513), contributed negatively. According to Bozokalfa *et al.* (2016), PCA explained over 77% of total variation for 27 quantitative and qualitative agromorphological characters in Swiss chard. The first PC (22.66%) was chiefly related to leaf size parameters, of which leaf weight, petiole width, petiole thickness and petiole length.

3. MATERIALS AND METHODS

3.1. Description of the Research Site

The experiment was conducted at DebreZeit Agricultural Research Center (DZARC)which is located at 47 Km East of Addis Ababa, in East ShoaZone Ada district, 08^0 44'N latitude and $38^0$58'E longitude at an altitude of 1860 masl. The area has two growing seasons, main season which is rain fed and off-season which is irrigation based. The area has minimum and maximum temperature of 143.2 and 320.11 ^{0}C respectively, annually and it receives average annual rainfall of 788.5 mm. The soil type of the center is classified as black soil (Vertisol) and light soil (DZARC, 2017).

3.2. Experimental Materials

A total of forty nine Ethiopian kale accessions including one local check wereused for the study. The accessions were collected from SNNPR and Oromia region by DZARC from diverse agro-ecological area.

Table 1. Ethiopian kaleaccessions used for the variability studies and their site of collection

No	Sample/ Coll. Number	Region	Zone	Woreda	Altitude	Longitude	Latitude	Genotypes
1	EK-002	Oromia	Guji	Bore	2705	6.23597	38.35381	Landrace
2	EK-003	Oromia	Guji	Bore	2705	6.23597	38.35381	Landrace
3	EK-004	Oromia	Guji	Bore	2734	6.24129	38.35283	Landrace
4	EK-005	Oromia	Guji	Bore	2740	6.24147	38.35046	Landrace
5	EK-006	Oromia	Guji	Bore	2755	6.24222	38.35046	Landrace
6	EK-007	Oromia	Guji	Bore	2753	6.26577	38.37606	Landrace
7	EK-012	Oromia	Guji	Bore	-	-	-	Landrace
8	EK-018	SNNPR	Sidama	Hula	2680	6.5491	38.5543	Landrace
9	EK-020	SNNPR	Sidama	Hula	2690	6.5423	38.5649	Landrace
10	EK-021	SNNPR	Sidama	Hula	2689	6.5423	38.5651	Landrace
11	EK-022	SNNPR	Sidama	Hula	2689	6.5423	38.5651	Landrace
12	EK-024	SNNPR	Sidama	Hula	2727	6.4633	38.5087	Landrace
13	EK-027	SNNPR	Sidama	Hula	2739	6.4596	38.5027	Landrace
14	EK-028	SNNPR	Sidama	Hula	2739	6.4596	38.5027	Landrace
15	EK-033	SNNPR	Sidama	Hula	2792	6.4567	38.4777	Landrace
16	EK-034	SNNPR	Sidama	Hula	2792	6.4567	38.4777	Landrace
17	EK-035	SNNPR	Sidama	Hula	2792	6.4567	38.4777	Landrace
18	EK-036	SNNPR	Sidama	Hula	2792	6.4567	38.4777	Landrace
19	EK-038	SNNPR	Sidama	Hula	2792	6.4567	38.4777	Landrace
20	EK-039	SNNPR	Sidama	Hula	2793	6.4527	38.4642	Landrace
21	EK-040	SNNPR	Sidama	Hula	2774	6.4476	38.4606	Landrace
22	EK-041	SNNPR	Sidama	Hula	2774	6.4476	38.4606	Landrace
23	EK-042	SNNPR	Sidama	Hula	2774	6.4476	38.4606	Landrace
24	EK-043	SNNPR	Sidama	Hula	2774	6.4476	38.4606	Landrace
25	EK-044	SNNPR	Sidama	Hula	2774	6.4476	38.4606	Landrace
26	EK-046	SNNPR	Sidama	Hula	2774	6.4476	38.4606	Landrace
27	EK-047	SNNPR	Gedeo	Bule	2779	6.2842	38.4091	Landrace
28	EK-048	SNNPR	Gedeo	Bule	2779	6.2842	38.4091	Landrace
29	EK-051	SNNPR	Gedeo	Bule	2992	6.2514	38.4144	Landrace
30	EK-052	SNNPR	Gedeo	Bule	2995	6.2251	38.3907	Landrace
31	EK-053	SNNPR	Gedeo	Bule	3029	6.23027	38.4021	Landrace
32	EK-054	SNNPR	Gedeo	Bule	3029	6.23027	38.4021	Landrace
33	EK-056	SNNPR	Gedeo	Bule	2763	6.2848	38.4086	Landrace
34	EK-057	SNNPR	Gurage	Gumer	2711	7.5962	38.0009	Landrace
35	EK-058	SNNPR	Gurage	Gumer	2711	7.5962	38.0009	Landrace
36	EK-059	SNNPR	Gurage	Gumer	2711	7.5959	38.0087	Landrace

37	EK-060	SNNPR	Gurage	Gumer	2711	7.5959	38.0087	Landrace
38	EK-061	SNNPR	Gurage	Gumer	2711	7.5959	38.0087	Landrace
39	EK-062	SNNPR	Gurage	Gumer	2711	7.5959	38.0087	Landrace
40	EK-063	SNNPR	Gurage	Kebena	1893	8.1138	37.4784	Landrace
41	EK-064	SNNPR	Gurage	Kebena	1893	8.1138	37.4784	Landrace
42	EK-066	SNNPR	Gurage	Ezia	3042	8.0739	38.085	Landrace
43	EK-067	SNNPR	Gurage	Ezia	3042	8.0739	38.085	Landrace
44	EK-069	SNNPR	Gurage	Ezia	3042	8.07209	38.08179	Landrace
45	EK-070	SNNPR	Gurage	Meskan	2050	8.07147	38.22764	Landrace
46	EK-074	SNNPR	Gurage	Silte	2050	8.07147	38.22764	Landrace
47	EK-075	SNNPR	Gurage	Ezia	3042	8.07147	38.22764	Landrace
48	EK-076	SNNPR	Gurage	Meskan	2050	8.07147	38.22764	Landrace
49	EK-081	Oromia	E/Shoa	Adea	1860	-	-	Local check

Source:DebreZeit Agricultural Research Center (DZARC)

3.3. Experimental Design and Trial Management

The study was carried out in a 7x7 simple lattice design and seven accessions were assigned into each incomplete block,using2 m long x 2 m wide plot. The spacing between replications, incomplete blocks and plots were 2m, 1m and 50cm, respectively. Spacing between rows and plants were 50 cm and 30 cm, respectively. Irrigation was supplied based on crop requirement and soil condition. The field managementlike fertilizer, weed control were maintained and plant protection measures weredone.

3.4. Data Collected

Data were collected on fourteen traits on plotbasis, and from randomly taken five plants from the two central rows of each plotbased on descriptors of *Brassica* and *Raphanus* (IBPGR,1990).

Plant height (PH): The height of five randomly selected plants were measured from the ground surface to the tip height of end in centimeter, when the plant reach a desired size for picking and expressed as an average of five plants in each plot.

Plant Canopy Width (PCW): The average canopy width of five randomly selected plants was measured in centimeter from one side of the plant to the other side of the plant extremity, when the leaves reach a desired size of picking.

Leaf fresh weight (LFW): The leaves of five randomly selected plants were picked manually, as they reach a desired size without harming the growing tip of the plants. The freshly harvested leaves were measured with sensitive balance.

Leaf dry matter content(DM): The leaf of five randomly selected plant that are used for the above parameters were kept in an oven at 90 ±5^{o}c temperature and weighted after complete drying of the sample, till a constant weight is reached then their weight were measured using sensitive balance.

Fresh biomass (BM): The weight of the whole above ground fresh biomass measured in gram and then converted into kilo gram from five randomly selected plants of each plots.

Number of leaves per plant (NLP): Counting the number of intactfully grown leaves per plant from five randomly selected plants when itreachto a desired size for harvesting.

Leaf length (LL): Actual measurement in centimeters taken from small, medium and large leaves of five randomly selected plants from the base of the leaf to the apex of leaf blade after harvest.

Leaf width (LW): Actual measurement of widest point of the leaf in centimeters taken after picking from small, medium and large leaves of five randomly selected plants.

Leaf Petiole length (LPL): Recorded by measuring the length of the petioleincentimeters taken from which leaf blade intercept with petiole to the base of the leaf petiole in centimeter after picking from five randomly selected plant from small, medium and large leaf.

Leaf petiole thickness (LPT): Taken by measuring thepetiole from the thickest point in millimeter using caliper from five randomly selected plant of the same leaf used for the above traits.

Leaf area (LA): Measuring leaf area using leaf area meter (model CI-202, USA) from small, medium and large leaf of five randomly selected plants.

Days to first leaf picking (DFLP): Number of days from the time of transplanting to first leaf picking.

Days to second leaf picking (DSLP): Number of days taken from the time of transplanting to the second leaf picking.

Leaf yieldper hectare (LY): Taken by weighing the total leaf yield picked per plantin kilogram obtained from all rows in each plot in repeat cutting system and converted into kilogram per hectare.

3.5. Statistical Analysis

3.5.1 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) was carried out followingthe procedure out lined by Gomez and Gomez (1984) using SAS version 9.3, software (SAS institute, 2009). Least significant difference (LSD) at 5% level of significance was used for mean comparison (Table 2).

$$Y_{ijr} = \mu + A_r + V_{ij} + \alpha_{ir} + \beta_{jr} + e_{ijr}$$

Where,

μ= Grand mean of the experiment

A_r= Replication effect

v_{ij}= Variety effect

α_{ir} = ith block effect if the rth replication is in the X set O, if therth replication is in the Y set

β_{jr}= jth block effect if the rth replication is in the Y set 0, if therth replication is in the X set

eijr= Residual effect

Table 2. Analysis of variance table for simple lattice design

Source of variation	DF	MSS	EMSS
Replication	(r-1)	M_r	
Block (adjusted)	r(b-1)	M_b	
Treatment (unadjusted)	(b^2-1)	$M_{t\ unadj.}$	
Intra-block error	(b-1)(rb-b-1)	M_e	σ^2_e
Treatment (adjusted)	(b^2-1)	$M_{t\ adj.}$	$\sigma^2_e + \sigma^2_g$
Total	rb^2-1		

Where, b = blocks, r = replication, DF = degree of freedom, MSS = mean sum square, M_r= mean square of replication, M_b = mean square of block, $M_{t\ unadj.}$=mean square of treatment unadjusted, M_e= mean square of error, $M_{t\ adj.}$= mean square of treatment adjusted,σg^2 = genotypic variance, σe^2 = environmental variance, EMSS = expected mean sum square

3.5.2. Estimation of genetic parameters

3.5.2.1. Phenotypic and genotypic variances and coefficients of variation

The phenotypic (σ^2p) and genotypic (σ^2g) variances and the corresponding phenotypic (PCV) and genotypic coefficient of variation (GCV) was calculated using the formula suggested by Burton and De vane, (1953),

Environmental variance (σ_e^2) = Error mean square (MSe)

Genotypic variance (σ_g^2) = $\frac{\text{MSg-MSe}}{\text{r}}$

Phenotypic variance $(\sigma_p^2) = \sigma_e^2 + \sigma_g^2$

Phenotypic coefficient of variation (PCV) =$\frac{\sigma_p}{\bar{x}} x100$

Genotypic coefficient of Variation (GCV) =$\frac{\sigma_g}{\bar{x}} x\ 100$

Where; MSe =mean square of error

r = number of replication

$\bar{x}$ = grand mean of traits

Msg = Mean square of genotypes

PCV and GCV values were categorized as low (<10%), moderate (10–20%), and high (>20%) values as indicated by Sivasubramaniah and Menon (1973) as follow.

3.5.2.2. Estimation of broad sense heritability and genetic advance as percentage of mean

Heritability in broad sense for all characters was computed using the formula given by Allard (1960) as,

$$hb^2 = \frac{\sigma_g^2}{\sigma_p^2} x\ 100$$

The heritability percentage was categorized as low (<20%), moderate (20-50%) and high (>50%) as follow by Stansfield (1988).

Expected genetic advances at 5% selection intensity was computed by the formula described by Johnson *et al*. (1955).

Genetic Advances $GA = k\ x\ \sigma\ p\ x\ hb^2$

GAM = $\frac{GA}{\bar{x}} x\ 100$

Where: k = constant (*k = 2.056 at 5% selection intensity*)

σ_p = phenotypic standard deviation

hb^2 = Broad sense heritability

GAM = the genetic advance as percent of mean

The GA as percent of mean was categorized as low (<10%), moderate (10-20%) and high (>20%) as suggested by Johnson *et al.* (1955) as follows.

3.5.3. Association of characters and path coefficient analysis

3.5.3.1. Phenotypic and genotypic correlation coefficient analysis

Phenotypic and genotypic correlations were estimated using the method described by Miller *et al.*, (1958).

$$rp_{xy} = \frac{covp_{xy}}{\sqrt{V_{px}.V_{py}}}$$

Where: rpxy = phenotypic correlation coefficient between character x and y,

Covpxy = Phenotypic covariance between character x and y,

Vpx = Phenotypic variance for character x and

Vpy = Phenotypic variance for character y.

$$rg_{xy} = \frac{covg_{xy}}{\sqrt{V_{gx}.V_{gy}}}$$

Where: rgxy = Genotypic correlation coefficient between character x and y,

Covgxy = Genotypic covariance between character x and y,

Vgx= Genotypic variance for character x and

Vgy = Genotypic variance for character y.

Genotypic correlation coefficient was tested with the following formula suggested by Robertson (1959).

$$t = \frac{rg_{xy}}{SEg_{xy}}$$

The calculated 't' value was compared with the tabulated 't' value at g-2 degree of freedom at 1 and 5% level of significance, where, g = number of genotypes

3.5.3.2. Phenotypic and genotypic path coefficient analysis

Path coefficient analysis was computedusing the formula suggested by Dewey and Lu (1959);

$$Rij = p_{ij} + \sum r_{ik} pk_j$$

Where:

R_{ij} = Mutual association between the independent character (i) and dependent character,Grain yield (j) as measured by the correlation coefficients.

P_{ij} = Components of direct effects of the independent character (i) as measured by the Path coefficients and

$\Sigma R_{ik}P_{kj}$ = summation of components of indirect effect of a given independent character i on a given dependent character (j) via all other independent characters (k).

The residual effect $(h) = \sqrt{1 - R^2}$

Where:

$R^2 = \Sigma r_{ij} p_{ij}$

3.5.4. Multivariate analysis

Genetic divergence analysis was computed based on multivariate analysis using Mahalanobis's D^2 statistic (Mahalanobis, 1936). The D^2values obtained for pairs of clusters were considered as the calculated values of Chi square (X^2) and tested for significance both at 1% and 5% probability levels against the tabulated value of $X^2$for 'P' degree of freedom, where P is the number of characters considered (Singh and Chaudhary, 1985).

3.5.4.1. Clustering analysis

The analysis was estimated using SAS software version 9.3 (SAS institute, 2009), so as to group sets of genotype in to homogenous clusters. Genetic distances between clusters as standardized by Mahalanobis's D^2 statistics was calculated as:

$$D_{ij}^2 = (\mathbf{x_i} - \mathbf{x_j})\mathbf{cov}^{-1}(\mathbf{x_i} - \mathbf{x_j})$$

Where, D^2_{ij} = the squared distance between two genotypes i and j;

x_i and x_j = vectors of the values of the variables for the genotype i and j and

cov^{-1}= the pooled within groups variance-covariance matrix.

Clustering of genotypes were done using Average Linkage Cluster Analysis method as described by Singh and Chaudhary (2001).

3.5.4.2. Estimation of intra and inter cluster squared distance

Average Intra and Inter cluster distance was obtained by the formula $\frac{\sum Dij^2}{n}$, where $\sum Dij^2$ is the sum of distance between all possible combinations (n) of the genotypes included in a cluster. The correlation matrix is used to calculate the intra and inter cluster squared distances. Significance of the squared distances for each cluster was tested against the tabulated χ^2 values at p degree of freedom at 1% and 5% probability level, where p = number of traits used for clustering genotypes.

3.5.4.3. Principal component analysis

Principal component analysis (PCA) was used to find out the traits, which accounted more to the total variation. Principal components based on correlation matrix were calculated using SAS software.

4. RESULTS AND DISCUSSION

4.1. Analysis of Variance (ANOVA)

The analysis of variance revealedhighlysignificant differences among accessions for all traits except second leaf picking, indicating the existence of variationamong the collected accessions to make selection for further improvement (Table 3).The block sum of square were non-significant for all traits,except days to second leaf picking.

Table 3. Mean squares for 14 traits of 49 Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Traits	MSB (df=12)	MSG (df =48)	MSE (df=36)	CV	RE
PH	32.28^{ns}	167.2^{**}	51.63	10.86	90.63
PCW	30.69^{ns}	91.61^{*}	48.79	11.88	90.72
NLP	14.22^{ns}	2678.36^{**}	35.87	10.68	84.91
LWT	3405.5^{ns}	109211^{**}	2510.17	7.99	102.2
DM	98.83^{ns}	2222.42^{**}	54.99	8.28	107.96
LL	3.59^{ns}	12.79^{*}	7.17	11.76	87.53
LW	2.12^{ns}	21.39^{**}	2.52	10.2	96.03
LPL	0.62^{ns}	2.92^{**}	0.63	10.64	99.71
LPTH	0.99^{ns}	14.76^{**}	1.8	11.67	88.85
LA	1626.7^{ns}	6118.13^{**}	1821.89	18.16	97.32
DFLP	16.83^{ns}	47.26^{**}	11.39	6.5	103.57
DSLP	197.29^{**}	54.51^{ns}	27.37	6.35	210.01
BM	0.0004^{ns}	0.02^{**}	0.0004	7.47	100.43
LY	3.1^{ns}	93.2^{**}	3.05	8.67	100.01

Where, *= significant at (P≤0.05), and ** = significant at (P≤ 0.01), ns=non-significantMSG= mean squares of genotypes, MSE = mean squares of error, MSB = mean squares of block, CV = coefficient of variation DF = degree of freedom, PH=plant height, PCW=plant canopy width, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM=leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare

4.2. Mean and RangePerformance of Accessions

Means of the 14 traits of the accessions is presented in Appendix Table 1.Relatively wide range of variations were observed for traits such as number of leaves per plant, leaf fresh weight, leaf dry matter content, leaf area and days to second leaf picking.Thus,there is an opportunity for genetic improvement of Ethiopian kale through selection,using these traits.Varalakshmi, (2016)reportedwide range of variation in Indian Spinach for leaf number (15.33-40.56),which is in agreement with this study.However, relatively narrow range were observed for leaf fresh weight, leaf petiole length, leaf petiole thickness and days to first leaf picking, indicating that there is little opportunity to make selection using these traits.

Maximum plant height was recorded from accession Ek-70 (122.04 cm) which was statistically similar with accessions Ek-75 (78.05 cm), Ek-62 (76.2 cm), Ek-60 (75.9 cm), Ek-3 (75.33 cm), Ek-59 (74.65 cm) and Ek-33 (72.1 cm).However, accessions Ek-51 (60.92 cm), Ek-43 (60.65 cm), Ek-12 (59.35 cm), Ek-27 (59.25 cm), Ek-41 (59.15 cm), Ek-35 (59.01 cm), Ek-44 (58.65 cm), Ek-48 (58.13 cm), Ek-4 (56.55 cm) and Ek-67(53.99cm)displayed the shortest plant height. Mandal*et al*. (2012) studied seventeen genotypes of Amaranthus and reprted significant differences among genotypes for plant height.Thenumber of leaves per plantproduced varied from 11.5 to 185.92 among accessions. The highest number of leaves per plant was produced by the accession Ek – 59(185.92) and the lowest number of leaves per plant were obtained from accession Ek – 76 (11.5).

Accessions showed highly significant variation in days to first leaf picking that varied from 64 to 44 days.Twenty four accessions had days to first leaf picking less than the grand mean, and also sixteen genotypes had days to first leaf picking less than the local check. Maximum days to first leaf picking was recorded from accession Ek-60 (63.5 days); while minimum number of days for first leaf picking were recorded from accessions Ek-76, Ek-48, Ek-47, Ek-46, Ek-41 and Ek-18 (44 days). Gorka*et al.* (2017) reported significant differences in kale (*Brassica oleracea*L.) genotypes for days to first leaf picking. Therefore, selection ofaccessions with low number of days to first pickingmight indicate the possibility of improving picking day for first round.In general, accessions that displayed short time to

harvest are suitable for reducing some of pests' damages and having enough time for second round harvest.

Similarly thirty three accessions had days to second leaf picking less than the grand mean and also seventeen accessions had days to second leaf picking less than thelocalcheck, which indicate that there is the possibility of improving the accession for early leaf picking. Accession EK-5 (176 days) require maximum days to second leaf picking, taking long time to harvest may give unmarketable yield by yellowing of leaf and defoliation. AccessionsEk-48, Ek-47, Ek-46, Ek-41 and Ek-18(75days) require minimum days to second leaf picking. Early harvestable is an ideotype trait for breeding *Brassica carinata*L. and other related *Brassica* species.

In this study, leaf yield ranged from 7.81 to 34.14 ton ha^{-1} and exhibited highly significant ($P \leq 0.01$) variation. Highest leaf yield (34.14 ton ha^{-1}) was harvested from the Accessions Ek-24, followed by accession Ek-53(33.77 ton ha^{-1}) and accession Ek-39 (31.55 ton ha^{-1}). Wide variability displayed by leaf yield might be due to diverse genetic variation of tested materials.Esiyok *et al*. (2011) studied fifty-four Swiss chard accessions and observed highly significant variations among accessions for all traits.Earler studies on Kale and Amaranthus genotypes relived significant difference among genotypes for leaf yield, which is in agreement with this study (Gorka *et al*., 2017; Mandal *et al*., 2012).

4.3. Estimate of genetic parameters

4.3.1. Estimation of phenotypic and genotypic coefficient of variation

There was minimum differencesbetween PCV and GCV values for all traits studied proving low environmental influence and greater role of genetic factors onthe expression of traits (Table 4).In addition, it may facilitate the success of selection process in Ethiopian kale accessions. Therefore, selection based on phenotypic performance of these traits would be effective to bring considerable improvement in leaf yield of Ethiopian kale accessions. Similarly, study onEthiopian kale genotypesfor oilseed showed little differences betweenPCV

and GCV for most of the characters studied (Tesfaye *et al*., 2013). Again Ghosh and Gulati (2001); Patel *et al*. (2006) study in Indian mustard relvealed that the PCV and GCV were high and their difference were narrow for all the characters studied.

Table 4. Estimates of range mean and variance components for different traits in Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Traits	Range	Mean	σp^2	σg^2	PCV	GCV	h^2_b(%)	GA	GAM (%)
PH	53.99-122.04	66.17	109.42	57.79	15.81	11.49	52.81	11.36	17.16
PCW	48.35-75.45	58.82	70.20	21.41	14.25	7.87	30.50	5.25	8.93
NLP	11.5-185.92	59.5	1357.12	1321.25	65.65	64.80	97.36	73.72	131.41
LWT	261.37-1179	620.04	55860.59	53350.42	37.70	36.84	95.51	464.10	74.02
DM	32.09-60.75	89.56	1138.71	1083.72	37.67	36.76	95.17	66.02	73.72
LL	14.88-49.13	23.27	9.98	2.81	13.88	7.38	28.16	1.83	8.03
LW	8.97-23.99	15.55	11.96	9.44	22.24	19.73	78.92	5.61	36.08
LPL	4.43-10.1	7.47	1.78	1.15	17.83	14.34	64.51	1.76	23.65
LPTH	4.74-18.41	11.34	8.28	6.48	25.09	22.21	78.26	4.63	40.37
LA	106.58-367	235.02	3970.02	2148.12	26.81	19.72	54.11	70.10	29.83
DFLP	44-63.5	51.89	29.33	17.94	10.45	8.17	61.16	6.82	13.13
DSLP	75-176	84.12	40.94	13.57	7.77	4.47	33.15	4.36	5.30
BM	0.05-0.5	0.25	0.01	0.01	40.00	40.00	96.56	0.20	79.41
LY	7.81-34.14	20.12	48.13	45.08	34.54	33.35	93.66	13.38	66.52

Where, PH=plant height, PCW=plant canopy width, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM= leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare

Generally, for all the studied traits, the results revealed a little higher phenotypic variance and phenotypic coefficient of variation than that of their corresponding genotypic variance and genotypic coefficient of variation, respectively, indicating the expression of these characters was influenced by environment. Esiyok*et al*. (2011) studied the variability amongfifty-four Swiss chard accessions and reported higher phenotypic coefficient of variation (PCV) than genotypic coefficient of variation (GCV) for all traits studied which is similar to the present study.

According to Sivasubramanian and Menon(1973), the PCV and GCV values are classified as low (0-10%), medium (10-20%) and high (>20%). High phenotypic coefficient of variation

(PCV) values were obtained for number of leaves per plant (65.65 %), biomass (40.00%), leaf fresh weight per plant (37.70%),leaf dry matter (37.67%), leaf yield (34.54%), leaf area (26.81%), leaf petiole thickness (25.09%) and leaf width (22.24%).Whereas low PCV value was obtained for days to second leaf picking (7.77%).This indicates that, if environmental variance is low compared to genetic difference, phenotypic selection will be efficient because the selected character will beeasly transferred to its progeny. This result is in agreement with Hasan*et al*. (2013)who reported highPCV in leaf weight/plant (80.14 %) and dry weight/plant(74.47 %) respectively in Amaranthus.

Higher genotypic coefficient of variation(GCV) were obtained for number of leaves per plant (64.80%), biomass (40.00%), leaf fresh weight per plant (36.84%), leaf dry matter content (36.76%), leaf yield (33.35%) and leaf petiole thickness (22.21%).The high values of GCV for these traits suggested the possibility of improvement through selection of these traits. Similar high magnitude of genotypic as well as phenotypic coefficients of variation for fresh weight leaves (46.18 and 48.15), leaf yield (43.45 and 46.93), leaf width (29.36 and 33.71), dry weight of leaves (23.15 and 27.40) and petiole length (22.51 and 27.99) was reported byChauhan (2016) on Water Spinach. However plant canopy width (7.87%), leaf length(7.38%), days to first leaf picking (8.17%) and days to second leaf picking (4.47%) showed low percentage of GCV.

4.3.2. Estimates of broad sense heritability

According to Stansfield, (1988) the estimates of broad sense heritability were classified as low (<20%), medium (20-50%) and high (>50%).Broad sense heritability estimates varied from 28.16% for leaf length to97.36% for number of leaves per plant (Table 4.). Thus, high broad sense heritability estimates were recorded for number of leaves per plant (97.36%), biomass (96.56%), leaf fresh weight per plant (95.51%), leaf dry matter content (95.17), leaf yield (93.66%), leaf width (78.92%),leaf petiole thickness (78.26%), petiole length (64.51), leaf days for first leaf picking(61.16%),leaf area (54.11%) and plant height (52.81).

Traits with high broad sense heritability estimates indicates, variation is manily due to genetic and also less role of environmental factors; and these traits were identified as the most

important direct selection criteria for developing high yielding Ethiopian kale variety. These results agree with the findings of Ahammed*et al.* (2013), who reported high heritability estimates in broad sense for leaf weight per plant (91.10%) followed by number of leaves per plant (86.83%) and yield/ha (78.70%) in Amaranthus.Abe*et al*. (2015) evaluated thirty two Amaranthus genotypes and revealed that the heritability estimates in broad-sense ranged from 2.21 to 99.78.Chauhan (2016) conducted a study on Water Spinach genotypes andreported highest heritability for fresh weight of leaves (90.6%), followed by foliage yield (85.7%), leaf length (77.1%), leaf width (75.9%), dry matter percent of foliage (75.6%) and dry weight of leaves (71.4%).

4.3.3.Estimates of genetic advance(GA) and genetic advance as percentage of mean (GAM)

According to Johnson *et al.* (1955) estimation of genetic advance as the percentage of mean at 5% selection intensity were classified as high (>20), medium (10-20%) and low (<10). The highest value of genetic advance as the percent of mean was obtained for number of leaves per plant (131.41%) and the lowest with days for second leaf picking (5.30%)(Table 4). Estimate of GAM for number of leaves per plant recorded 131.41%, indicating that whenever we select the best, 5% high number of leaves per plant as parents, mean of number of leaves per plant in the next progenies could be improved by 131.41% of 59.5, which is 78.19 and mean value of the new population for number of leaves per plant will be increased from 59.5 to 137.69.

Thus, the estimation of genetic advance as the percentage of mean was high for number of leaves per plant (131.41%), biomass (79.1%), leaf fresh weight per plant (74.02%), leaf dry matter content (73.72%), leaf yield (66.52%), leaf petiole thickness (40.37%), leaf width (36.08%), leaf area (29.83%) andleaf petiole length (23.65%). However, the estimation of genetic advance as the percentage of mean was low for plant canopy width (8.93%), leaf length (8.03%) and days for second leaf picking (5.30%),which explains the predominantroleof non-additive gene action for this trait, which is non-fixable and selection may be difficult for this trait due to the masking effect of the environment.

The coefficient of variation doesnot offer the full scope of heritable variation. It can be determined with greater degree of accuracy, when heritability in conjunction with genetic advance is studied. In this study, high heritability with high genetic advance as percent of mean was recorded for number of leaves per plant, leaf fresh weight per plant, leaf dry matter content, leaf width, leaf petiole length,leaf petiole thickness, leaf area, biomassand leaf yield. These indicates that variation for these traits is manily, due to genetic and moderate role of environmental factors and selection in the next generation could lead to considerable improvement in the Ethiopian kale production.This result is in line with the finding of Shukla*et al*. (2006) who studied twenty nine strains of vegetable Amaranthus (*Amaranthus tricolor* L.) genotypes revealed that high heritability with highest expected genetic advance as percent of mean for leaf yield (48.30%) and leaf size (29.51%).According to Eşiyok*et al.* (2011) high genetic advance accompanied with high heritability was obtainedinSwisschardfor petiole thickness and leaf dry matter. High heritability coupled with high genetic advance was also reported for leaf width in Spinach (Srivastava*et al.,* 1977).Also,high heritability values coupled with high genetic advance were recorded for leaf yield in Cabbage, which is in agreement with the present study (Soni*et al*., 2011).

4.3.4. Association among traits

In the present study, the genotypic (Table 6.) and phenotypic (Table 7.)correlation coefficient between all possible pairs of the traits were estimated, then partitioned into direct and indirect effect using path coefficient analysis.

4.3.4.1.Correlation of yield with other characters atphenotypicandgenotypic level

The genotypic and phenotypic correlations among the fourteen characters are presented in Table5. At phenotypic level, number of leaves per plant, leaf fresh weight, leaf dry matter content, leaf petiole length, days to first leaf picking and second leaf pickingexhibited positive and significant association with leaf yield ha^{-1}. Leaf fresh weight and leaf dry matter content displayed highly significant and positive correlation with leaf yield ha^{-1} (0.70).The present study is consistent with the results reported by Hasan*et al*. (2013), who evaluated seventeen

genotypes of Amaranthus (*Amaranthus tricolor* L.) and revealed that green yield was positively correlated with leaf weight and dry weight. Abe *et al.* (2015)evaluatedAmaranthus and revealed thatyield per plant showed moderateand positive correlation with leaf width.

Highly significant and negative associations were obtained for leaf petiole thickness (-0.34) and leaf yield with leaf width (-0.27). These results indicated that any increase in these traits could result in decrease in leaf yield ha^{-1}. Presence of thick leaf petiole accessions is important to overcome mechanical damage. However, too much thickness leads to high accumulation of photosynthates in the petiole and finally ends up with low leaf yield. Therefore, selection for thin to medium petiole thickness in Ethiopian kale accessions could be effective in increasing leaf yield in the study area. Negative correlation coefficient of leaf width with leaf yield indicates that the widest leaf in Ethiopian kale reduces the leaf yield, due to decrease in number of leaf per plant.

Table 5. Estimation of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficient between yields, and yield component traits in 49 Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Var	PH	PCW	NLP	LWT	DM	LL	LW	LPL	LPTH	LA	DFLP	DSLP	BM	LY
PH		-0.13	0.17	-0.12	-0.04	-0.21	0.13	-0.25	0.02	0.05	-0.08	0.01	0.26	-0.20
PCW	0.08		-0.03	0.38**	0.21	0.58**	-0.23	0.48**	0.07	0.01	-0.06	-0.18	-0.10	0.09
NLP	0.17	0.00		0.43**	0.62**	-0.54*	-0.78**	0.41**	-0.82**	-0.70**	0.09	-0.05	-0.38**	0.39**
LWT	-0.07	0.35**	0.44**		0.85**	0.29**	-0.37**	0.55**	-0.23	-0.05	0.60**	0.42**	-0.03	0.72**
DM	-0.01	0.22*	0.61**	0.85**		0.00	-0.50**	0.53**	-0.46**	-0.32**	0.49**	0.31**	-0.16	0.72**
LL	0.00	0.62**	-0.43*	0.28**	0.03		0.43**	0.17	0.65**	0.64**	0.20	0.16	0.27*	0.11
LW	0.19	-0.08	-0.72**	-0.33*	-0.45*	0.49**		-0.50**	0.88**	0.85**	0.02	0.22	0.66**	-0.29**
LPL	-0.12	0.47**	0.38**	0.51**	0.49**	0.19*	-0.43*		-0.32**	-0.33**	0.10	-0.04	-0.26	0.27*
LPTH	0.07	0.11	-0.77*	-0.21*	-0.42**	0.61**	0.87**	-0.25**		0.82**	-0.02	0.17	0.60**	-0.37**
LA	0.14	0.15	-0.62*	-0.01	-0.25**	0.63**	0.81**	-0.22*	0.76**		0.21	0.35**	0.57**	-0.07
DFLP	-0.03	-0.04	0.09	0.54**	0.43**	0.18	0.06	0.05	0.00	0.22*		0.81**	0.22	0.65**
DSLP	0.03	-0.13	-0.04	0.27**	0.20*	0.11	0.17	-0.03	0.16	0.20*	0.56**		0.30**	0.40**
BM	0.25**	-0.07	-0.37*	-0.02	-0.15	0.23*	0.64**	-0.23*	0.57**	0.56**	0.21*	0.21*		-0.19
LY	-0.17	0.07	0.38**	0.70**	0.70**	0.08	-0.27**	0.25**	-0.34**	-0.07	0.56**	0.24**	-0.19	

Where, * = significant at P<0.05;** = significant at P<0.01;PH=plant height, PCW=plant canopy width, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM= leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare

A positive and significant genotypic association was found between leaf yield per hectare andleaf weight per plant (0.72**), leaf dry matter content (0.72**), days to first leaf picking (0.65**), days to second leaf picking (0.40**), number of leaves per plant (0.39**) and leaf petiole length (0.27*), which indicates that considering those trait as a selection criteria could be an effective way to increase yield. The positive genotypic correlation of yield with other component traits indicated that increase in one of the trait will result in increasing of the correlated trait. This result of such genotypic correlation could possibly from pleiotropic effect or linkage of gene governing inheritance of these traits. Therefore, priority should be given to these traits together, for leaf yield improvement. Similar results were reported by Tejaswini*et al*. (2017) on Amaranthusfoliage yield per plant which recorded positive and significant correlation with leaf weight per plant and leaf width. According to Dolma *et al*. (2011), leaf yield per plant exhibited significant positive correlation with number of leaves per plant and leaf weight. Eşiyok*et al*. (2011) conducted experiment on Swiss chard genotypes and reported positive correlation of leaf weight, petiole length and petiole thickness with leaf yield.

Negative and highly significant correlation of yield were found with leaf petiole thickness (-0.37) and leaf width (-0.29). It indicated that increase in one of the trait will result in decrease the negatively correlated trait. Therefore, the improvement through breeding could be made successfully, by selecting the genetic material after determining the exact contribution of various components towards yield.

4.3.4.2.Correlation among yield related traits at phenotypic and genotypic levels

Plant height displayed non-significant phenotypic correlation with all other component traits, except with biomass (0.25) which shows highly significant and positive association (Table 5). These result emphasized that as plant height increases, biomass also ultimately increases. Number of leaves per plant had highly significant and positive correlation with leaf dry matter content (0.61), leaf fresh weight (0.44) and leaf petiole length (0.38) at phenotypic level, revealing that with the increase in number of leaves per plantwill also increase leaf fresh weight, leaf dry matter content and leaf petiole length proportionately. Negative and significant phenotypic correlation with petiole thickness (-0.77**), width (-0.72**), leaf leaf and leaf area (-

0.62*) and leaf length (-0.43*).At genotypic level number of leaves per plant exhibited highly significant and positive correlation with leaf dry matter content (0.62), leaf fresh weight (0.44) and leaf petiole length (0.41), and highly significant and negative association with leaf petiole thickness (-0.82), leaf width (-0.78), leaf area (-0.70), leaf length (-0.54)and biomass (-0.38).

Leaf fresh weight displayed highly significant and positive phenotypic association with leaf dry matter content (0.85), days to first leaf picking (0.54), leaf petiole length (0.51), leaf length (0.28)and days to second leaf picking (0.27), and negative association with leaf width (-0.33**) and leaf petiole thickness (-0.21*). Leaf fresh weight showed significant and positive genotypic association with leaf dry matter content (0.85**), days to first leaf picking (0.60**), leaf petiole length (0.55**), days to second leaf picking (0.42**), and leaf length (0.29*), and significant and negative association with leaf width (-0.37**). Days to first leaf picking had significant and positive phenotypic correlation with days to second leaf picking (0.56**). Association between days to first leaf picking and days to second leaf picking (0.81**) was highly significant and positive. Days to second leaf picking had significant and positive phenotypic and genotypic correlation with biomass (0.21**) and (0.3*), respectively.

5.3.3.Path coefficient analysis

5.3.3.1 Path coefficient analysis at phenotypic level

Traits that showed significant correlation with leaf yield ha^{-1} were advanced to path coefficient analysis at both phenotypic and genotypic levels. phenotypic path coefficient analysis for yield and yield component revealed (Table 6), positive direct effect ofleaf dry matter content (0.39), days to first leaf picking (0.29), leaf fresh weight (0.28) andnumber of leaves per plant (0.03). Positive direct effects of these traits indicated true relationship between this trait and importance in determining this complex character and should be given prior attention in practicing selection aimed at the improvement of leaf yield of Ethiopian kale, because of major influence on leaf yield.Tejaswini *et al.* (2017) reported that leaf weight per plant had the highest positive direct effect on yield which is in agreement with the present study.

Leaf petiole length (-0.12) and days to second leaf picking (-0.08) exerted negative direct effect on leaf yield ha^{-1}. In such situations, direct selection for accessions that tallest leaf petiole length and took long time to second leaf harvest might be ineffective for leaf yield improvement in Ethiopian kaleaccessions. Similar finding was reported in Indian Spinachpetiole lengththat exhibited negativedirect effect on total plant vegetable yield(Varalakshmi, 2016).

Table 6. Phenotypic direct and indirect effect of six component characters on yield in Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Character	phenotypic direct effect	NLP	LWT	DM	LPL	DFLP	DSLP	r^{ph}
NLP	0.03		0.12	0.24	-0.05	0.03	0.003	0.38^{**}
LWT	0.28	0.01		0.33	-0.06	0.16	-0.02	0.7^{**}
DM	0.39	0.02	0.23		-0.06	0.13	-0.02	0.7^{**}
LPL	-0.12	0.01	0.14	0.19		0.02	0.003	0.25^{**}
DFLP	0.29	0.003	0.15	0.17	-0.01		-0.05	0.56^{**}
DSLP	-0.08	-0.001	0.08	0.08	0.004	0.16		0.24^{**}
Residual effect = 0.64								

Where, Nlp= number of leaf per plant, Lwt=leaf fresh weight per plant, Dm= leaf dry matter content, LPL=leaf petiole length, Dflp= days to first leaf picking, Dslp=days to second leaf picking, r^{ph}= phenotypic correlation with grain yield

The indirect exertion of number of leaves per plant on leaf yield was positive for leaf dry matter content (0.24), leaf fresh weight (0.12), days to first leaf harvest (0.03) and days to second leaf harvest(0.003). while negative for leaf petiole length (-0.05). Therefore, along with number of leaves per plant, indirect selection for high leaf fresh weight, high leaf dry matter content, long time to first and second leaf harvest and also short leaf petiole length might be considered simultaneously, during in the process of selection for leaf yield improvement program in Ethiopian kale accessions. The current findings suggested that improvement of leaf yield of Ethiopian kale through selection could be achieved through direct selection for positively contributed component traits to leaf yield.

5.3.3.2 Path coefficient analysis at genotypic level

Genotypic path coefficient analysis indicated that days to first leaf picking showed the maximum positive direct effect (0.58) and significant genotypic correlation (0.65^{**}) with leaf yield (Table 7). High direct effects of these traits give the impression to be the main factor for their strong relationship with yield and should be considered as important trait improvement via direct selection. The least but positive and direct effect of number of leaves per plant (0.04) on yield could be compensated via the high and positive indirect effect of leaf dry matter content (0.22), leaf fresh weight (0.07), days to first leaf picking (0.05) and days to second leaf picking (0.01). Thus, considering number of leaves per plant alone as the most important direct yield component might be ineffective in improvement program. Therefore, from the present genotypic path coefficient analysis, traits like,number of leaves per plant,leaf fresh weight, leaf dry matter content and days to first leaf picking had positive direct effect on yield, which indicate considering of this trait during selection of genotype would be more rewarding to evolve potential varieties of Ethiopian kale. Similarly Dolma*et al*. (2011)reportedmaximum positive direct effectof number of leaf per plant (0.72) followed by average leaf weight (0.67) and days to first picking (0.44) on leaf yield per plant.

Days to second leaf picking exerted negative direct effect on yield. This indicates that, selection for early to medium days to second harvest accessions might lead to high leaf yield in Ethiopian kale accessions that helps to minimize pest damage.It has negative direct effect and it also expressed negative indirect effect on leaf yield through leaf weight (-0.10), leaf dry matter content (-0.08) and days to first leaf picking (-0.20).

Table 7. Genotypic direct and indirect effect of five component characters on yield in Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Character	Genotypic direct effect	NLP	LWT	DM	DFLP	DSLP	r^g
NLP	0.04		0.07	0.22	0.05	0.01	0.39**
LWT	0.15	0.02		0.30	0.35	-0.10	0.72**
DM	0.35	0.02	0.13		0.28	-0.08	0.72**
DFLP	0.58	0.003	0.09	0.17		-0.20	0.65**
DSLP	-0.25	-0.002	0.06	0.11	0.47		0.4**
Residual effect = 0.58							

Where, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM= Leaf dry matter content, DFLP= days to first leaf picking, DSLP=days to second leaf picking, r^g = genotypic correlation with leaf yield

5.4. Multivariate Analysis

5.4.1.Clustering of Genotypes

Clustering based on the traits produced a clear grouping of 49 accessions in to three clusters, (Appendix Figure 1) whereby the individuals within any one cluster are more closely related than individuals in different cluster. The accessions were grouped in such a way that cluster I had the largest member of all cluster, include 24 (48.98%) accessions followed by 22(44.9%) in C2 and 3 (6.12%) in C3. In the present study, accession gained from different source center clustered in the same category together, for instance, in cluster I accessions collected from Gurage, Sidama, Gedeo and East shoa grouped together (Table 8).The possible reason could be common ancestor of these accessions, due to free exchange of accessions among the breeders of different regions. Moreover, accessions collected from the same source of center were clustered in to different clusters, suggesting the existence of genetic diversity within each collection source.The grouping of accessions indicated that geographical distribution need not necessarily be the indicator of genetic divergence.

Table 8. Cluster of 49 Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Cluster	No. of Acc.	Accessions	Proportion (%)
C1	24	EK-69,Ek-58, Ek-51, Ek-18, Ek-66, Ek-74, Ek-64, Ek-81, Ek-75, Ek-48, Ek-46, Ek-62, Ek-76, Ek-56, Ek-57, Ek-20, Ek-41, Ek-63, Ek-44, Ek-39, Ek-47, Ek-70, Ek-59, Ek-60	48.98
C2	22	EK-7, EK-40, EK-28,Ek-61,Ek-52,Ek-38,Ek-43, Ek-21,Ek-33,Ek-35,Ek-67,Ek-54,Ek-12,Ek-42, Ek-36,Ek-2,Ek-34,Ek-4,Ek-53,Ek-6,Ek-27,Ek-5	44.90
C3	3	Ek-24,Ek-3,Ek-22	6.12

5.4.2. Comparison of accession performances among clusters

The results of cluster analysis for 14 studied traits in 49 accessions are presented in Table 9. All the accessions were classified in three groups with different mean values ofthetraits.Cluster I was characterized by the lowest cluster mean estimate for days to first leaf picking, days to second leaf picking,low in number of leaves per plant, leaf weight per plant, leaf dry matter content and leaf yield; and the highest cluster mean value for leaf fresh weight and leaf petiole thickness. Cluster II had a characteristic feature of low value in terms of plant height, leaf width, leaf petiole thickness, biomass and leaf areaon the other hand had high value in terms of days to second leaf picking as compared to the other. Cluster III showed high value in terms of leaf weight per plant, leaf dry matter content , leaf length, leaf area, biomass and leaf yieldand the lowest cluster mean value for leaf petiole thickness. The 49 genotypes of oil seed Ethiopian kale that were collected from 12 different Ethiopian agro ecological zones of the country were grouped in to four clusters (Belete *et al*., 2011). Akther *et al*. (2013) studied seventeen genotypes of Amaranthus. The genotypes were grouped into four clusters regardless of their origin.

Table 9. Cluster mean value of three clusters for 14 characters of 49 Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Traits	Cluster mean		
	C1± SD	C2±SD	C3±SD
PH	68.84± 12.44	62.87±5.44	69.04±4.81
PCW	57.44±7.58	59.64±6.26	63.86±1.52
NLP	44.87±16.00	73.19±32.91	76.09±12.42
LWT	412.00±87.77	777.96±82.64	1126.30±46.20
DM	63.07±19.30	111.70±20.45	139.07±8.58
LL	22.52±2.33	22.65±2.77	33.83±10.83
LW	17.19±4.07	13.81±1.64	15.30±0.51
LPL	6.87±1.35	7.98±0.84	8.61±0.83
LPTH	12.57±3.09	9.87±1.81	12.23±0.78
LA	244.85±68.94	220.19±47.80	265.12±26.42
DFLP	49.06±4.45	54.27±3.46	57.00+1.00
DSLP	80.67±6.00	87.59±19.61	86.33±0.47
BM	0.27±0.14	0.22±0.08	0.34±0.09
LY	15.11±4.74	24.66±4.21	26.82±6.28

Where, PH=plant height, PCW=plant canopy width, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM= leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare

5.4.3.Distance among clusters (genetic divergence analysis)

The pair wise generalized squared distance (D^2) between and within clusters are presented in table 11. The standardized Mahalanobis D^2stastics showed highly significant difference between all clusters, and the genetic divergence between all pairs were highly significant ($p \leq 0.01$). Regarding the inter cluster distance, the highest genetic distance was recorded between CI and CIII ($D^2 = 147.84$) followed by the cluster CIII and CI ($D^2 = 143.68$), indicating wider genetic divergence among clusters.The higher inter cluster distance values in this study might be larger

due to the inclusion of accessions which have wider genetic diversity. The extent of diversity present in the studied accessions implied the opportunity of Ethiopian kale improvement through hybridization followed by selection. The maximum inters cluster distance, the large magnitude of genetic variability among accessions and thus the better probability to create wider genetic bases through hybridization. The more diversity of parents the greater chance of obtaining high heterosis(Zaman*et al.*, 2005). In this study, a cross which involves accessions from cluster one and three might be rewarding for the improvement of Ethiopian kale through heterosis breeding and will help to develop superior inbred lines.

Higher inter cluster distance was obtained from CIII (5.59) followed by CII (1.60) and CI (1.43). Genetic divergence study reported by earlier worker showed high diversity among genotypes (Alemayehu and Becker 2002;Mekonnen*et al.*, 2014).The minimum distance was obtained between CII and CI (D^2 = 40.38) followed by the genetic distance CI and CII with (D^2 = 40.56) indicating that accessions of these two clusters were relatively less diverse. Thus, crossing of accessions from these two clusters will produce progenies with less amount of hetrotic expression in the F1's and narrow range of variability in the subsequent segregation (F2) population.

Table 10. Inter and intra (bold) cluster D^2 values among three clusters in 49 Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

Cluster	I	II	III
I	**1.43**	40.56**	147.84**
II	40.38**	**1.60**	47.82**
III	143.68**	43.84**	**5.59**

**= significant, X^2= 27.69 and 22.36 at 1% and 5% probability level, respectively.

5.4.4.Principal component analyses

In order to assess the patterns of variation, principal component analysis (PCA) scores might be used to summarizethe original 14 traits simultaneously for further analysis of the data (Table11).

The first four Principal components which have eigen value greater than one accounted75.8% of the total variation among Ethiopian kale accessions for fourteen traits.

Table 11. Eigenvectors, eigenvalues and percentage of total variance explained by the first four principal components (PC) for 14 traits in 49 Ethiopian kale accessions evaluated in 2017/18 main cropping season at DZARC

	PCA 1	PCA 2	PCA 3	PCA 4
PH	-0.07	-0.05	0.39	0.66
PCW	0.12	0.15	-0.57	0.36
NLP	0.31	-0.09	0.32	0.28
LWT	0.31	0.38	0.00	0.07
DM	0.37	0.24	0.12	0.07
LL	-0.03	0.38	-0.31	0.18
LW	-0.40	0.22	0.08	-0.03
LPL	0.30	0.08	-0.32	0.18
LPTH	-0.37	0.24	-0.09	0.00
LA	-0.31	0.35	-0.01	-0.02
DFLP	0.13	0.41	0.26	-0.29
DSLP	0.05	0.19	0.28	0.09
BM	-0.25	0.30	0.18	0.30
LY	0.29	0.29	0.12	-0.32
Eigenvalue	4.75	3.00	1.69	1.16
Difference	1.75	1.31	0.53	0.20
Total variance explained (%)	33.94	21.45	12.11	8.30
Cumulative total variance explained (%)	33.94	55.40	67.51	75.80

Where, PH=plant height, PCW=plant canopy width, NLP= number of leaves per plant, LWT=leaf fresh weight per plant, DM= leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare

The first principal component had high positive loading for eight characters out of fourteen. Number of leaves per plant, leaf fresh weight per plant, leaf dry matter content and leaf petiole length which contributed more to the variation. It has high negative weights for leaf width, leaf petiole thickness and leaf area. Additional 21.45% variation in the second principal component

was mainly observed in leaf fresh weight per plant, leaf length, leaf area, days to first leaf picking and biomass. The third principal component accounted for another additional 12.11% of the variation in which plant height and number of leaves per plant are the major positive contributors.plant canopy width, leaf length and leaf petiole length expressed highest negative loads in principal component three (PCA_3).

The major contributing traits for the variation in the four principal components (PC_2) were chiefly obtained from variations of plant height, plant canopy width and biomass. It has high negative weights forleafyield.The positive and negative weight shows the presence of positive and negative correlation trends between the components and the variables. Therefore, the above mentioned characters with high positive or negative loads contributed more to the diversity and they were the ones that most differentiated the clusters.

In general, it is assumed that traits with larger absolute values closer to unity with in the first principal component influence the clustering more than those with lower absolute values closer to zero (Chahaal and Gosal, 2002). In this study, most of the traits individually contributed small effects ($\pm$ 0.03-0.37) to the total variation. Plant canopy width had the highest negative weight. Principal of accessions was mainly attributed by the cumulative effect of the individual trait.Saleem*et al*. (2017) carried out PCA based on twenty quantitative morphological characters. The seven principal components accounted for 73.92% of the overall variability among the studied Indian mustardaccessions for the total phenotypic variations. According to Bozokalfa*et al.* (2016) PCA explained over 77% of the total variation for 27 quantitative and qualitative agromorphological characters in Swiss chard.

6. SUMMARY AND CONCLUSION

The experiment was carried out with an aim of estimating the amount of genetic variability and trait association with yield and yield related trait, this study evaluated Forty nine Ethiopian kale accessions including the local check in 2017/18 main cropping season. The experiment was carried out in simple lattice design. ANOVA showed significant variation among accession in most traits indicating existence of genetic variability.

In this study number of leaves per plant, leaf fresh weight per plant, leaf dry matter content, leaf petiole thickness, biomass and leaf yield have showed highest estimation of both genotypic and phenotypic coefficient of variation for which selection based on their phenotype could be effective for yield improvement. High heritability together with high genetic advance was obtained for number of leaves per plant, leaf fresh weight per plant, leaf dry matter content, leaf width, leaf petiole length, leaf petiole thickness, biomass and leaf yield, this indicate that selection for this trait lead considerable improvement.

A positive and significant genotypic character association was found between yield per hectare and number of leaves per plant, leaf fresh weight per plant, leaf dry matter content, days to first leaf picking and days to second leaf picking. Similarly number of leaves per plant, leaf fresh weight, leaf dry matter content, leaf petiole length, days to first leaf picking and days to second leaf picking showed significant and positive phenotypic correlation with yield. At genotypic level positive and direct effect of number of leaves per plant, leaf fresh weight per plant, leaf dry matter content and days to first leaf picking on yield were obtained. On the other hand, at phenotypic level traits, like number of leaves per plant, leaf fresh weight per pant, leaf dry matter content and days to first leaf picking revealed positive and direct effect on yield. Considering such traits would be effective in Ethiopian kale improvement program.

Multivariate analyses of genetic divergence among genotypes have resulted in the formation of three clusters, and have shown the presence variability for further selection and breeding. The largest and smallest numbers of genotypes were found under cluster one and three respectively.

75.8% of the variation was contributed by the fist four principal components. The first two principal components were responsible for about 45.39% of the total variation.

Besed on the result of the present study, it can be concluded that:

- The present study indicated that there is adequate genetic variability for most of yield and yield traits, including number of leaves per plant, leaf fresh weight, leaf dry matter content, leaf petiole thickness, biomass and leaf yield, which gives the opportunity to develop breeding lines and varieties.

- High heritability coupled with high GAM were recorded for for number of leaves per plant, leaf weight per plant, leaf dry matter content, leaf width, leaf length, leaf petiole length, leaf petiole thickness, days for first leaf picking, biomass and yield, which indicates higher contribution of genetic factor for the variability among the genotypes which in turn gives better chance of success in selection.

As future line of work, it can be suggested:

- The experiment should be repeated at more locations with more number of acessions to effectively predict genotypic performance across several locations and to validate the obtained current results.

- The present study only included fourteen quantitative traits; it is advisable if qualitative and additional number of quantitative traits should be considered to widen the scope of inference.

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APPENDIXES

Appendix Table 1. Climate data of Debre zeit agricultural research center in 2017/18

	Jun	Feb	Mra	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	average
Total rain fall (mm) 2017 year	0	36.3	22.2	14.6	106	67.8	262.3	200.2	115.2	0	0	0	824.6
Average Rain fall (mm) 2007-2016 year	5.69	11.69	50.66	52.06	66.78	84.15	183.47	205.59	101.2	13.24	7.56	6.41	788.5
Mean Max T (^{o}C) 2017 year	26.9	27.5	29.5	29.8	28.1	29.1	23.9	21.8	24.5	26.5	26.21	26.3	320.11
Mean Min T (^{o}C) 2017 year	7.5	11.7	12.5	13.5	14.8	13.4	14.6	14.3	14	11.1	8.3	7.5	143.2

Appendix Table 2. ANOVA summary for 49 Ethiopian kale accessions for 14 traits evaluated in 2017/18 main cropping season at DZARCfor accessions tested

	Mean of square					
Source of variation	**Rep**	**Treatment**	**Block**	**Error**	**Cv**	**R^2**
PH	31.5	167.2**	32.28	51.63	10.86	0.86
PCW	31.41	91.61*	30.69	48.79	11.88	0.75
NLP	12.79	2678.36**	14.22	35.87	10.68	0.99
LWT	5916.39	109211**	3405.5	2510.17	7.99	0.98
DM	127.27	2222.42**	98.83	54.99	8.28	0.98
LL	9.98	12.79ns	3.59	7.17	11.76	0.73
LW	3.48	21.39**	2.12	2.52	10.2	0.93
LPL	0.84	2.92**	0.62	0.63	10.64	0.88
LPTH	2.21	14.76**	0.99	1.8	11.67	0.92
LA	7468.52	6118.13**	1626.7	1821.89	18.16	0.85
DFLP	63.68	47.26**	16.83	11.39	6.5	0.86
DSLP	248.33	54.51**	197.29	27.37	6.35	0.84
BM	9.18	0.02**	0.0004	0.0004	7.47	0.99
LY	8.02	93.2**	3.1	3.05	8.67	0.98

Where, CV = coefficient of variation PH=plant height, PCW=plant canopy width, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM=leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare

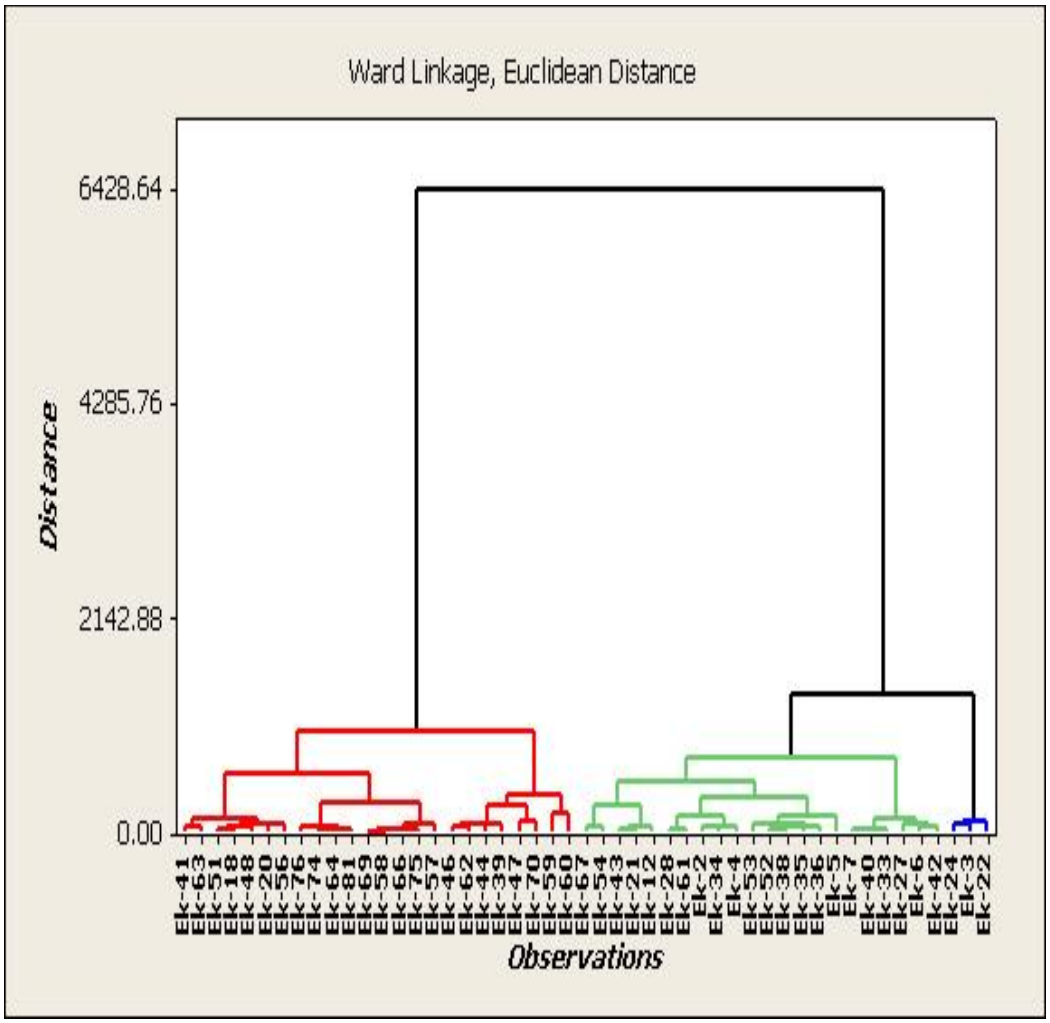
Appendix Table 3.Mean performance of 49 Ethiopian kale accessions for 14 traits evaluated in 2017/18 main cropping season at DZARC

Trt	PH	PCW	NLP	LWT	DM	LL	LW	LPL	LPTH	LA	DFLP	DSLP	BM	LY
Ek-41	59.15	69.8	22.6	450.97	48.22	25.70	14.72	8.06	13.85	204.20	44	75	0.11	7.81
Ek-51	60.92	65.68	46.3	391.12	48.60	22.37	12.94	8.33	10.63	186.17	45	76	0.13	9.88
Ek-18	62.92	68.73	34	392.76	57.51	23.00	14.24	9.33	12.41	187.95	44	75	0.30	7.83
Ek-48	58.13	64.65	60.2	358.22	48.67	21.66	12.17	8.08	10.49	166.69	44	75	0.20	11.44
Ek-46	65.57	74.63	35.5	520.44	79.57	26.07	15.59	8.21	14.52	234.01	44	75	0.23	14.16
Ek-47	68.13	66.07	124.4	506.58	64.07	19.38	11.86	7.12	7.68	171.75	44	75	0.11	15.72
Ek-67	53.99	50.15	128.2	665.60	140.12	18.60	11.33	8.14	7.28	125.53	48.5	77	0.14	28.66
Ek-76	66.66	47.2	11.5	261.37	32.09	21.99	18.76	5.70	13.73	263.21	44	76.5	0.18	10.13
Ek-74	71.5	51.25	16.1	297.00	44.81	24.25	18.87	6.15	15.04	252.13	48.5	78	0.37	11.16
Ek-7	66.45	57.66	76.55	859.00	112.58	24.46	15.72	8.92	10.57	241.36	57	79	0.33	28.32
Ek-28	61.5	66.05	44.4	686.25	91.87	27.02	16.12	6.90	11.34	281.13	55	79	0.15	26.31
Ek-69	70.75	54.5	18.6	365.90	45.49	24.47	21.73	6.84	15.58	311.35	50.5	78.5	0.49	17.64
Ek-20	62.05	60.45	41.6	340.40	80.21	24.34	14.20	8.83	11.46	210.17	47	78	0.11	17.70
Ek-54	69.95	51.8	149.3	682.90	118.22	17.08	11.58	8.24	7.07	138.90	48.5	77	0.21	22.50
Ek-75	78.05	53.1	15.1	345.35	54.27	23.75	20.66	5.28	13.14	310.52	46.5	80	0.33	16.46
Ek-2	55.95	53.06	38.1	662.40	70.95	20.84	12.79	6.58	9.12	195.43	56	86	0.18	24.05
Ek-39	62.18	63.75	70.8	486.00	90.95	24.13	15.06	7.88	9.98	238.03	55	84	0.14	31.55
Ek-53	71.4	66.09	35.8	815.10	116.65	24.78	15.35	7.35	11.71	284.09	50.5	82.5	0.11	33.77

Ek-24	63.65	62.15	60.6	1179.00	151.14	25.58	15.89	8.69	13.10	249.64	57	86	0.22	34.14
Ek-52	68.8	75.45	44.3	780.90	91.33	26.11	16.08	8.02	7.19	270.14	49	77	0.27	15.95
Ek-4	56.55	52.05	76.3	657.50	94.34	21.20	13.25	8.53	8.96	170.71	62.5	90.5	0.05	27.55
Ek-70	122.04	51.4	157.8	439.98	95.16	14.88	8.97	6.16	4.74	106.58	49	78	0.12	15.23
Ek-58	68.16	51.55	16.2	367.30	51.82	22.72	22.00	6.54	15.02	308.24	50	82	0.43	14.62
Ek-59	74.65	54.51	185.92	534.27	80.74	22.75	21.87	5.97	15.74	339.02	52	95	0.38	17.09
Ek-3	75.33	65.84	76.675	1133.40	134.02	26.77	15.37	9.59	12.38	302.31	57	87	0.41	18.80
Ek-27	59.25	66.35	55.125	927.90	108.40	26.01	15.48	7.46	10.71	281.42	54.5	84	0.20	27.70
Ek-6	70.75	62.9	72.5	925.00	160.75	25.28	16.10	8.63	12.52	218.81	57	88	0.21	24.30
Ek-57	69.3	54.26	12.4	380.10	52.83	22.55	23.27	7.15	15.73	367.00	49	79	0.37	14.15
Ek-34	54.05	59.4	51.4	697.80	99.06	21.03	12.98	6.86	10.09	212.55	57	86	0.11	24.38
Ek-66	65.2	47.6	11.9	370.80	59.29	22.18	20.87	5.12	15.62	305.41	50	82	0.26	13.73
Ek-40	63.8	61.83	78.7	865.80	124.52	21.16	13.02	10.10	8.83	222.60	52.5	83	0.22	20.93
Ek-38	62.61	64.15	44.8	764.90	110.55	24.98	14.76	7.47	11.36	268.54	55	84	0.35	18.48
Ek-22	68.15	63.6	91	1066.50	132.04	49.13	14.64	7.55	11.20	243.42	57	86	0.40	27.52
Ek-63	68	52.45	34.5	412.10	62.03	21.16	17.81	4.47	11.86	246.22	52.5	83.5	0.46	16.54
Ek-62	76.2	59	15.4	510.70	94.05	21.95	20.85	6.08	14.66	197.31	52.5	83	0.53	15.75
Ek-81	60.95	48.6	12	310.68	45.55	20.88	17.87	6.81	12.11	271.23	50	80	0.19	13.98
Ek-64	64.06	48.35	28.7	314.80	50.70	20.49	17.75	4.43	11.78	252.44	50	82	0.26	15.91
Ek-5	67.4	57.15	80.2	769.21	117.92	21.67	13.50	9.04	10.27	230.23	51	176	0.32	17.64
Ek-33	72.1	62.59	68.6	835.90	111.32	21.96	13.43	8.07	9.79	222.39	57	86	0.32	26.87
Ek-35	59.01	58.67	57.3	781.60	119.94	24.12	14.13	6.92	12.29	247.50	55	85	0.16	22.42
Ek-42	65.5	64.7	63.8	895.40	121.84	25.86	13.92	8.06	11.91	237.38	55	85	0.27	28.78
Ek-61	59.6	63	36.8	697.50	105.67	23.29	15.35	7.43	10.08	259.59	57	83	0.31	28.41

Ek-56	62.95	55.3	58.9	376.60	102.65	21.70	12.75	8.93	8.04	161.09	50	82	0.09	15.07
Ek-44	58.65	60.22	34.3	569.40	80.47	21.78	13.64	6.96	9.48	196.42	52.5	83	0.14	22.17
Ek-60	75.9	55.45	12.15	585.12	43.94	26.22	23.99	6.36	18.41	389.19	63.5	100.5	0.50	17.01
Ek-36	63.25	59.85	51.1	755.60	67.81	24.27	14.29	8.55	12.46	255.42	55	85	0.30	23.37
Ek-43	60.65	55.4	126	778.90	131.64	18.78	11.70	8.65	6.79	161.07	54.5	83	0.19	27.40
Ek-21	61.25	53.16	100	793.60	126.79	18.93	10.60	7.19	9.13	160.19	57	86	0.23	19.69
Ek-12	59.35	50.65	130.9	816.40	115.23	20.89	12.37	8.38	7.73	159.27	49.5	85	0.15	25.07
Mean	66.17	58.82	59.5	620.04	89.56	23.27	15.55	7.47	11.34	235.02	51.89	84.12	0.25	20.12
Min.value	22.04	48.35	11.5	261.37	32.09	14.88	8.97	4.43	4.74	106.58	44	75	0.05	7.81
Mx. Value	53.99	75.45	185.92	1179.00	160.75	49.13	23.99	10.10	18.41	367.00	63.5	176	0.50	34.14
Lsd(0.05%)	14.45	14.04	12.04	100.74	15.85	5.38	3.19	1.6	2.69	85.82	6.78	11.7	0.04	3.51

Where,PH=plant height, PCW=plant canopy width, NLP= number of leaf per plant, LWT=leaf fresh weight per plant, DM= leaf dry matter content, LL= leaf length, LW=leaf width, LPL=leaf petiole length, LPTH=leaf petiole thickness, LA=leaf area, DFLP= days to first leaf picking, DSLP=days to second leaf picking, BM=biomass, LY=leaf yield per hectare



Appendix Figure 1.Dendrogram showing relationship among 49 Ethiopian kale accessions using the mean of 14 traits evaluated in 2017/18 main cropping season at DZARC