AGRO-MORPHOLOGICAL DIVERSITY ANALYSIS OF ETHIOPIAN MUSTARD (*Brassica carinata)* LANDRACES IN SOUTHERN ETHIOPIA

MSc. THESIS

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Agro-morphological Diversity Analysis of Ethiopian Mustard (*Brassica carinata)* Landraces in Southern Ethiopia

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This is to certify that thesis entitled **"Agro-morphological Diversity Analysis of Ethiopian mustard (*Brassica carinata)* Landraces in Southern Ethiopia"** submitted in partial fulfillment of the requirements for the Degree of Master of Science with specialization in Horticulture the Graduate Program of School of Plant and Horticultural Sciences, College of Agriculture, and has been carried out by **IBRAHIM HASSEN GUYO ID. No GPHortR/0007/15,** under our supervision and no part of a thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore; we recommend that it be accepted as fulfilling the thesis requirements.

_____	_____	_____
Name of Major Advisor	Signature	Date

DEDICATION

It is my great pleasure to dedicate this work to my Family for their invaluable helps, morally and financially during all my phase of study.

DECLARATION

I hereby declare that this MSc equivalent thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: **Ibrahim Hassen Guyo**

Signature: _____

This MSc equivalent thesis has been submitted for examination with my approval as thesis advisor.

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ABBREVIATION

UNEP	United nation Environmental Program
MT	Million Tone
NARO	National Agriculture Research Organization
SIRARI	Sidama Region Agriculture Research Institution
rg	Genotypic correlation
SLA	Specific leaf area
J'	Pielou's evenness index
ANOVA	Analysis Of Variance
SAS	Statistical Analysis System
LSD	Least Significant Difference
CV	Coefficient of Variation
PVC	Phenotypic Variance Coefficient
GVC	Genotypic Variance Coefficient
$\bar{x}$	Mean
GAM	Genetic advanced of mean
GA	Genetic advance
rp	Phenotypic correlation
LAI	Leaf Area Index
PCA	Principal components
H'	Shannon diversity index

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ABSTRACT

Genetic diversity analysis of Ethiopian mustard landraces is an important step in selection and hybridization of plant with required traits to develop well adapted and farmers preferred high yielding varieties. The Field experiment was conducted at Hula district in Sidama region to study the genetic diversity of forty nine brassica carinata landraces collected from different agro-ecologies of southern Ethiopia. The experiment was carried out in a simple lattice design with the objective of assessing and estimating the genetic diversity of local landraces based on phenological and agro-morphological traits; estimating association and heritability of the study traits and to identify the best performances of landraces further breeding work for their leaf yield. The analysis of variance shows the significant differences among landraces for all leaf parameter as well as all phenological traits. The high degree of variability among the Ethiopian mustard landraces were observed for studied traits. The estimation of genotypic and phenotypic coefficient of variations was studied, the highest genotypic and phenotypic coefficient of variation suggested that the Brassica carinata landraces are highly diverse and provides a wide range of possibilities for selecting further breeding. The result heritability of broad sense (H2b) values in all traits was very high ranging from 90.99 to 99.975%; this implies that the genetic component of variation is substantial for all traits. To evaluate the pattern of variation, the principal component analysis was conducted for all quantitative traits. The first three principal components accounted for most of the variation observed and cumulatively explained 82.99% of the total variation among the all quantitative traits. Clustering produced a clear grouping of the forty nine landraces into four major groups of clusters Where, by the individuals within any one cluster are more closely related than individuals in different clusters. The landraces that early flowered are grouped in the same group, and the same is true for the late flowering landraces as well as the landraces with highest leaf yield was clustered in the same group. Overall, the study shows the wide variation and presences of high genetic variability among Brassica carinata landraces.

Keywords: *Brassica carinata,* Characterization, Correlation, Heritability, Leaf yield, Path analysis, Variability

1. INTRODUCTION

1.1 Background and justification

Brassica carinata is a species of flowering plant in the Brassicaceae family. *Brassica carinata* is commonly known as Abyssinian cabbage, Abyssinian mustard, African cabbage, Ethiopian kale, Ethiopian mustard, Ethiopian rape, mustard collard, chou Éthiopien, moutard d'Abyssinie (USDA ARS 2014). It is believed to be a hybrid between *Brassica nigra and Brassica oleracea*. *Brassica carinata* belongs to Brassicaceae family which comprises of many economically important species widely used as sources of oil and food, and as ornamental plants (Al-Shehbaz,et al 2006). *Brassica carinata* is a herbaceous annual with a determinate growth habit (Zanetti et al. 2013). *Brassica carinata* plants have an erect bearing, averaging 1.4 m in height and are highly branched, with a well-developed tap root and extensive rooting system (Barro and Martin 1999).

Brassica carinata is thought to have originated in the highland plateaus of Ethiopia and adjoining parts of East Africa and the Mediterranean coast. Evidence supporting this hypothesis involves the parental species, *B. nigra* and *B. oleracea*, being sympatric in these regions during the period that *B. carinata* was thought to have emerged (Alemayehu and Becker 2002). Cultivation of *B. carinata* is hypothesized to have started in Ethiopia near 4000 BC although precise information about its domestication is lacking, and cultivation may be more recent (Prakash et al. 2012). In Ethiopia, the crop is traditionally used for many purposes, such as greasing traditional bread-baking clay pans, curing certain ailments and preparing beverages (Alemayehu, 2001).

Brassica carinata production in Ethiopia is steadily increasing, as the country recognizes the economic potential of this crop. While exact production figures may vary from year to year, it is estimated that Ethiopia produces around 100,000-150,000 metric tons of *Brassica carinata* annually (Nega, 2018). Ethiopian mustard (*Brassica carinata A Braun*, BBCC, 2n=34) also known as Yehabesha Gomen originated from the highlands of Ethiopia, is cultivated as an oilseed and leafy vegetable crop (Getinet et al. 1994). It is partially amphidiploids. It is cultivated primarily as leafy vegetable and for oil in the seeds, annual, and grows up to 150 and

200 cm, branched, glabrous to slightly hairy at stem and petiole bases, leaves are alternate and simple.

Brassica carinata is the tropical as well as of the temperate zone crops and requires relatively cool temperature for satisfactory growth and yield. *Brassica*s grow well in areas receiving 350-550 mm rainfall. In tropics, brassicas grow well at higher elevation around 1000 m and prefer moderate temperature between 25° and 28°C with optimum around 20°C. Seed oil content is relatively high at ambient temperature of 10° to 15°C. Frost damage could be serious due to its adverse effect on flower and pollen production and pollen viability. About 10 brighter sunshine hrs are necessary for growth and development (Merga and Ahmed 2019).

Brassicas are commercially important species that provide human-use food dishes, industrial raw materials, fodder, and are grown as leafy vegetable. Ethiopian mustard is used to generate high quality vegetable oil for human consumption and as a high-protein meal to feed cattle, poultry and human food as vegetable, (Getinet et al. 1994). Ethiopian mustard varieties are being developed as biofuel feedstock as well. Ethiopian mustard, is commonly used as an oil crop and leafy vegetable (Leghari, et al, 2022). Ethiopian mustard is also protein-rich fodder for animals, and renewable materials for biodiesel and industrial applications (Raboanatahiry, et al., 2021).

Ethiopian mustard is an important vegetable crop in Ethiopia, the leaf has several uses and benefits in Ethiopia, including as a food source, Economic Value and livestock feed. Their cultivation contributes to food security, income generation, and agricultural sustainability in the country. As food Source: Ethiopian mustard leaves are edible and can be used in various traditional Ethiopian dishes (Hunde, N.F., 2017). It is one of the most important orphan leafy vegetable crops that have not received attention in research programs aimed at improving yield and nutrition (Rahiel et al. 2020). Despite this, Ethiopian mustard has been used as a leafy vegetable and oilseed crop for many decades (Yared 2011; Mistiru and Yared 2013).

Brassica carinata genetic diversity information is very important for developing new varieties of Brassica (Li et al., 2012). *Brassica carinata* is an allotetraploid species, which means that it has four sets of chromosomes, one inherited from each parent. The chromosome number of *Brassica carinata* is 2n = 4x = 38 (AACC), which means that it has 38 chromosomes in each of its cells.

Diversity in plant genetic resources provides opportunity for plant breeders to develop new and improved cultivars with desirable characteristics (Govindaraj et al. 2015).

Morphological evaluation is the primary step in description and categorization of the germplasm (Li et al., 2023). The importance of such information has been demonstrated in several genetic diversity studies of Ethiopian mustard. According to Diers and Osborn, 1994 and Becker, et al., 1995,the *Brassica carinata* classified into spring type, winter type and semi-winter type groups. Hybridization between winter, semi-winter, and spring mustard is an important approach to broaden the genetic base of these three types of *Brassica carinata* germplasm (Qian et al., 2009; Kebede et al., 2010). European rapeseed (Hu et al., 2007) and US rapeseed (Li et al., 2012) were discovered as important germplasm resource for enriching the genetic background of rapeseed.

Evaluation of phenotypic characters enhances the efficiency of germplasm collection management (Nisar et al., 2008). as well as the genetic improvement of crops leading to the higher genetic gain (Basheer et al., 2015).Morphological differences in plant species are the result of long-term selection/ adaptation in different parts of the world where the species were initially cultivated. Different techniques have been effectively used to find the pattern of phenotypic diversity in species indicating genetic differences of a variety of crops (Dias et al., 1993; Amurrio et al., 1995). To expand the existing genetic pool, breeders collect and evaluate the germplasm from all over the world for their genetic diversity (Alo et al., 2011). Plants growing under field conditions are subjected to various environmental stresses, such as high or low temperature, drought and salinity. Plants naturally face many unfavorable environmental conditions, such as organic and inorganic stresses.

1.2 Statement of the problem

Brassica carinata is being used as oil crop from its seed and as vegetable crop from its leaf yield (EARO, 2000). Morphological, molecular and oil characteristics of Ethiopian mustard has been done by some researchers in Ethiopia and other countries. These studies are piled with the objective for improvement of seeds for oil production. Characterization and evaluation to identify high-yielding, early mature types, and high glucosinolate content in the meal have been considered as prime importance in Ethiopian rapeseed breeding programs (Getinet et al., 1994). Despite the lack of solid statistical data on Ethiopian mustard distribution and leafy production in Ethiopia, with modest yields, the crop has been widely grown in various sections of the country

(Tesfaye et al., 2011). This could be because Ethiopian mustard production for leaf yield has received little attention from research and development initiatives (Jianchu et al., 2001), and its genetic resources are depleting due to physical and physicochemical factors (Mulualem and Ayenew, 2012).

Despite being an economically significant, there is a limitation of comprehensive research addressing the factors influencing *Brassica carinata* growth and leaf yield. It is one of the most important orphan leafy vegetable crops that have not received attention in research programs aimed at improving leaf yield and nutrition (Rahiel et al. 2020). Furthermore, there is limited investigation into the identification of growth-promoting factors and the understanding of genetic variability for growth and leaf yield traits in different mustard varieties (Fufa. 2020). Characterizing landraces for leaf yield is an important input for breeding programs for selection and hybridization and registration of new cultivars of Ethiopian mustard for vegetable production. To the best of our knowledge, there is no Ethiopian mustard variety released for leafy vegetable yield in Ethiopia.

Seed and foliage yields are complicated characters that can be determined by a genotypic factor which could have positive or negative impacts on these characters (Kayacetin, 2019; Saroj et al., 2021). Determination of genotypic and phenotypic coefficients is important to evaluate breeding programs for high yield, as well as to examine contributions to yield variables (Chandra et al., 2018; Parvin et al., 2020). This study will undertake to analyze the genotypic variability of rapeseed for growth, yield contributing characters and yield. Genetic variability is recognized to be the most important raw resource in every breeding operation (Zemede, 1992; Genet et al., 2005). Determining the level of variability and identifying variants within the gathered landraces is critical for genetic improvement and crop conservation (Mulualem and Weldemichael, 2013). Characterization of crops is a very essential first step in any crop improvement programme (De Vicente et al., 2005).

Therefore, this study is designed to characterize and analyze the agro-morphological characters of the Ethiopian mustard landraces collection Sidama region agriculture research institute. And to identify the landraces that have high leaf yield and heritability and making potential research problem to explore the genetic diversity of rape seed and its impacts on growth and leaf yield by comprehensive evaluating of the agro-morphological characteristic of Ethiopian mustard

landraces for vegetable use. In simple term the study aims to analyze the various phenological and agro-morphological traits of different local Ethiopian mustard landraces to determine the landraces suited for leafy vegetable production.

1.3 Objective

1.3.1 General objective

To characterize and analyze the diversity of Ethiopian mustard landraces collected from Southern Ethiopia

1.3.2 Specific objective

To assess and estimate the genetic diversity of Ethiopian mustard landraces based on the agro-phenological and morphological traits

To identify landraces best performances with desirable traits to enhance for leaf production and further breeding work.

To study the heritability of Ethiopian mustard landraces for high leaf yield production

2. LITERATURE REVIEW

2.1 Origin and distribution

Brassica Carinata is a member of the family Brassicaceae (formerly known as Cruciferae), order Capparales, tribe Brassiceae; genus Brassica, and species carinata (Edwards et al., 2000). *Brassica carinata* A. Braun, commonly referred to as "Ethiopian mustard," "Ethiopian rape," "Abyssinian mustard," or "brassica *carinata*," is being developed as a low carbon intensity, non-food oilseed feedstock to produce advanced drop-in renewable fuels, protein-rich meal, and bio-products. It exhibits a desirable oil profile and vegetables use, wide adaptability, and productivity under suboptimal conditions (Gesch et al., 2015). *Brassica Carinata,* an allotetraploid (BBCC-genome, 2n = 4x = 34, genome size ~1300 Mb) originated through spontaneous interspecific hybridization between wild B. nigra (BB-genome, 2n = 2x = 16, genome size ~630 Mb) and cultivated *B. oleracea* (CC-genome, 2n = 2x = 18, genome size ~700 Mb) in Northeastern Africa, probably in the Ethiopian Plateau and the Mediterranean coast (Warwick et al., 2006).

2.2 General description and agro-morphological characteristics

Ethiopian mustard (*Brassica carinata* A Braun, BBCC, 2n=34) also known as Yehabesha Gomen originated from the highlands of Ethiopia, is cultivated as an oilseed and leafy vegetable crop (Getinet et al. 1994). *Brassica carinata* is the most important cultivated type, which have the good agronomic traits, such as high-yield, wide-adaptability, strong-resistance and middle-growth-period (Liu. 2000). The original species of *Brassica carinata* was the heteropolyploid of natural crossing between *Brassica oleraceassp.oleracea* (CC, 2n=18) and the original species of *B. campestris L.*, cultivated for edible oil from the 16th century and introduced to Hukuoka and Hokkaido in Japan in the 19th century (Liu, 1985).

Brassica Carinata is an erect, annual grown as an oilseed or as a leafy vegetable. The seedling emerges epigeally, with heart-shaped cotyledons (2–3 cm) that are photosynthetically active to offset insufficient food reserves crop (Mnzava & Schippers, 2007). *Brassica Carinata* shows determinate growth with height averaging 1.4 m, high branching, and elongated taproots reaching up to 1 m (Zanetti et al., 2013). Inflorescences are racemes which form on the main and axillary branches. Flowering begins at the base of the raceme and the buds form above the open flowers. The pale yellow flowers have 4 sepals and 4 diagonally opposite obovate petals arranged in the form of a cross when viewed from above. The stamens are tetradynamous with

four long and two short stamens in each flower. The ovary is superior (Callihan et al. 2000; Gulden et al., 2008 and OECD 2012).

The seedlings grow to form a rosette of 5–6 leaves with the older leaves at the base and the smaller younger leaves in the center of the rosette (Gulden et al. 2008). The basal rosette leaves are short-petiolate, toothed, glaucous, ovate to elongate and entire to lobed with 1 to 5 pairs of small lateral lobes and a large terminal lobe. Bolting, stem extension, branching and upper leaf formation is the next stage of plant growth (Gulden et al. 2008).The leaves of *Brassica carinata* are hairless, smooth, fleshy and bluish-green in colour. The base of *Brassica carinata* leaves partially clasps the stem and the buds are borne above the open florets (Gulden et al. 2008).

2.3 Reproductive and pollination

Brassica carinata species reproduce sexually through cross-pollination, contributing to the great diversity within species. However, carinata sets seed efficiently through both self- and cross-pollination. *Brassica Carinata* was reported to self-pollinate 46%–88% of the time due to self-compatibility, and cross-pollinated 30% of the time due to its flower structure (Cheung et al., 2015). *Brassica carinata* pollen, like other Brassicaceae, is heavy, sticky, and is not dispersed well by the wind; dispersing only 10 m from the plant (Adeniji and Aloyce 2012). Following pollination, the petals are shed and the pistil elongates to form a silique (Misra 2010). While sporophytic self-incompatibility exists in Brassicaceae amphidiploid *Brassica carinata* species are self-compatible (Niemann et al. 2014).

2.4 Ecological requirement

Brassica Carinata is tolerant to a wide range of climatic conditions and can be fall-planted in the humid subtropical regions with mild winters and even rainfall throughout the year or spring planted in the humid continental climate with hot and humid summers (Seepaul et al., 2021). The winter, semi–winter, and spring types differ in their cold and drought tolerances; consequently, the growing conditions are also different. Winter-type *Brassica carinata* grows well in relatively high humidity and cooler temperatures (Seepaul et al., 2021)..

Brassica carinata cultivation needs well-drained soils with a pH ranging from 5.5 to 8.5 for optimal growth. Every part of Ethiopian mustard leaf and seed is used for food, remedies,

cosmetics, or industrial applications (Courtney et al., 2005). For use as leafy vegetables, the preferred traits are large leaf size, late flowering, many leaves per plant and tolerance to major diseases and pests. *Brassica carinata* produced the greatest number of leaves and in height clearly exceeded both parental species and others (Courtney et al., 2005).

Brassica carinata is the tropical as well as of the temperate zone crops and requires relatively cool temperature for satisfactory growth and yield. *Brassicas* grow well in areas receiving 350-550 mm rainfall. In tropics, brassicas grow well at higher elevation around 1000 m and prefer moderate temperature between 25° and 28°C with optimum around 20°C. Seed oil content is relatively high at ambient temperature of 10° to 15°C (Merga, B., & Ahmed, A. 2019). Frost damage could be serious due to its adverse effect on flower and pollen production and pollen viability. About 10 brighter sunshine hours are necessary for growth and development (Merga, B., & Ahmed, A. 2019).

2.5 *Brassica carinata* production

The cultivation of *Brassica* crops was believed to begin in the middle Ages in Europe (Kimber and McGregor 1995), and some researcher conjectured that in Holland in the 17th century the *Brassica carinata* has been grown as a source of oil, but other thought it should be earlier than that time (Schröder-Lembke 1989). Since the beginning of cultivation, with the improving of agronomic and processing technology, the utilization of both oil and meal of *Brassica carinata* is increasing gradually. As an important part of progress, the status of *Brassica carinata* oil has improved in recent decades. The new *Brassica carinata* cultivars with double low (low erucic acid and low glucosinolate) traits were widely cultivated.

Over the last ten years, the global production of *Brassica carinata* has increased by 12.5 million tones or 20.9% to about 72.3 million tone's and the production of *Brassica carinata* oil has risen by 15.3%–26.3 million tones, accounting for about 35.9% of the total mustard production (Oliveira and Yu, 2022). Oilseed is now the second-highest yielding oil crop worldwide and accounted for 12.1% of world major vegetable oil in 2021 (Faostat, 2022). As one of the world's largest rapeseed producers, China produced approximately one fifth (11.9 million tons) of the world *Brassica* species production and imported 2.5 million tons of *Brassica carinata* oil from other countries (Oliveira and Yu, 2022).

Next to soybean and oil palm, *Brassica carinata* is the third largest oil crop worldwide (Wang et al., 2010; Berrocoso et al., 2015 and Bouchet et al., 2016). Statistical data from the Food and Agriculture Organization of the United Nations have shown that the world production of *Brassica carinata* in 2016 was more than 68 million tons, mainly from Canada (19.5 million tons), China (13.1 million tons), and India (6.8 million tons) (Godfray et al., 2010). Increasing *Brassica carinata* yield is a major focus for *Brassica carinata* researchers and cultivators (Godfray et al., 2010). The crop stand count at early growth stages is one of the most important parameters for the prediction of yield, density, and growth status (Li et al., 2023).

Table 1.World production of edible vegetable oils, averages

Crop	1996-2000 (MMt)	2001-05 (MMt)	2006-10 (MMt)	2011-15 (MMt)
Soybean	22.4	29.8	36.8	46.2
Palm	18.3	28.2	40.8	58.5
Rape/mustard	11.8	13.7	19.1	25.7
Sunflower	8.9	8.4	11.0	14.7
Groundnut	4.3	4.9	4.8	5.5
Cottonseed	3.7	4.1	4.9	5.1
Others	7.9	9.5	11.2	13.1
Total	**77.3**	**98.6**	**128.6**	**168.7**

Sources: After USDA Foreign Agricultural Service (2015).

2.6 Ethiopian mustard production in Ethiopia

Brassica carinata grows in most part of Ethiopia at medium to high altitudes ranging from 2000 to 2600m asl, in areas of the country where rain fall and temperature amount ranges from 700–1000mm and 15-20^{o}C, respectively (Adefris Teklewold and Nigussie Alemayehu, 1996). The crop is often grown as a backyard crop on humus-rich soils by small holder farmers. In some potential areas where Ethiopian mustard is grown in large scale, the crop prefers moderately heavy and well drained soils with pH of 6.5- 7.6 (Nigussie Alemayehu et al., 1996)

Mustard production in Ethiopia is steadily increasing, as the country recognizes the economic potential of this crop. While exact production figures may vary from year to year, it is estimated that Ethiopia produces around 100,000-150,000 metric tons of *Brassica carinata* annually. Ethiopia mustard came quite recently in the country despite its importance as both a vegetable and an oil processing variety. It reached the country in the 1970s and now boasts four varieties.

These include Target and Tower. Ethiopia mustard produce from the central parts of the country (Nega, 2018)

The majority of *Brassica carinata* cultivation in Ethiopia is concentrated in the eastern and southern highlands of the country, where the climate and soil conditions are suitable for its growth. Farmers often grow it as a winter crop, taking advantage of the cool temperatures and ample rainfall during the season. Ethiopian mustard primarily grown in small-scale farmers which is cultivated both for leafy vegetable and oil production. The oil extracted from the seeds is used for cooking purposes, and the leftover seed cake is utilized as livestock feed (Nega, 2018)

2.7 Importance

Brassica carinata is used to generate high quality vegetable oil for human consumption and as a high-protein meal to feed cattle, poultry (Grubben and Oyen,. 2004). *Brassica carinata* was categorized as one of the most important traditional East African vegetables both in the amount of crop area and human nutrition and being developed as biofuel feedstock (Leghari, et al, 2022). Ethiopian mustard commonly known as oilseed , is one of the most important oil crops providing not only cooking oil for humans, but also protein-rich fodder for animals, and renewable materials for biodiesel and industrial applications (Raboanatahiry, et al., 2021). *Brassica carinata* vegetables are valuable sources of nutrients and health-promoting phytochemicals possessing nutraceutical and antioxidant activity such as vitamins, carotenoids, dietary fiber, phenolic, soluble sugars, minerals and glucosinolates (Wagner et al., 2013).

Seeds are the most important part, as they are used as oil and protein sources and *Brassica carinata* oil and protein contents vary in different lines of cultivars, and other components such as glucosinolates, phenols, phytic acid, cellulose, and sugars are also found in the seeds. Known for its production of high-quality vegetable oil, mustard competes with other crops (Merga, B., & Ahmed, A. 2019).

Brassica carinata is mainly known as a source of edible leaf and industrial oil, as well as protein and multiple extraction methods have been tested, and their variation affects oil and protein yield and quality, notably the usage of solvents, temperature, pressure, and the time of processing. However, some of these methods have not been tested at an industrial level (Unger, E.H. 2011). One of the most common oil extraction methods is with a solvent (mostly hexane). In brief, seeds

are heated for softening, flaked to burst cell walls, and cooked to promote cell disruption, before compression to release the oil, leaving the rest of the seeds to form a protein cake. Residual oil is then extracted using the solvent, which filters the cake and removes the oil. The solvent is removed from the cake and the oil, which undergo refining and processing stages before their release in the market (Unger, E.H. 2011).

The genus *Brassica* includes economically important species that provide oil for human consumption and raw materials for the industry, source as leaf and root vegetables and used for fodder and condiments (Getinet et al. 1991). Ethiopian mustard locally known as gomenzer is important as source of oil and as a leafy vegetable in mid altitude and highland areas, (1700 to 2800 meters a.s.l) and mainly small farmers grow the crop in more fertile and well- drained areas, often close to their houses. At its early stage of development the leaf is used as vegetable either by thinning or topping and seed can be also harvested from the same plant for oil extraction and other uses that include: greasing traditional bread baking clay pan (Mitad), curing certain ailments and preparing beverages (Alemayehu, 2001).

2.8 Genetic diversity

Brassica carinata is an allotetraploid species, which means that it has four sets of chromosomes, one inherited from each parent. The chromosome number of Ethiopian mustard is 2n = 4x = 38 (AACC), which means that it has 38 chromosomes in each of its cells. Definition of biological diversity could be written as the variation present in all species of plants and animals, their genetic material and the ecosystems in which they occur (Rao and Hodgkin 2002). The biological diversity can occur at three levels: genetic diversity (variation in genes and landraces), species diversity (species richness) and ecosystem diversity (communities of species and their environment). Diversity in plant genetic resources provides opportunity for plant breeders to develop new and improved cultivars with desirable characteristics (Govindaraj et al. 2015).

Genetic diversity information is very important for developing new varieties of *Brassica* (Li et al., 2012). The importance of such information has been demonstrated in several genetic diversity studies of Ethiopian mustard. On the basis of ecotypes, (Diers& Osborn 1994 and Becker et al. 1995), classified mustard into spring type, winter type and semi-winter type groups. Hybridization between winter, semi-winter, and spring mustard is an important approach to broaden the genetic base of these three types of rape mustard germplasm (Qian et al., 2009 and

Kebede et al., 2010). Genetic divergence is the statistical distance between the genotypes. It is determined by using cluster analysis, which assigns genotypes into different groups (Singh and Chaudhary, 1999). Crossing of genotypes belonging to the same cluster would not be expected to yield desirable recombinants. Consequently, a crossing program might be formulated in such a way that parents belong to different clusters. (Norden, 1980; Rao et al., 1981).

Any plant breeding activity focused on mainly creation of variability, selection of the best individual from the expanded resources and utilization of the best-selected individual to develop a new and superior variety (Kumar et al., 2021). There is plenty of scope to increase yield per unit of area through plant hybridization programs(Salah et al., 2022). The knowledge on heritability and genetic advance , genetic variability, and character association for starting a fruitful breeding program targeting to develop high yielding varieties (Parveen, et al., 2015). The genetic advance shows the progress for the choice of the best individuals, whereas high heritability value signifies the strategy for selection of suitable characters by the phenotypic performance of a corresponding genotype (Sarwar, et al.,, 2015).

Analysis of correlation coefficient between the characters has remarkable importance in selecting crop breeding materials. Path coefficient analysis splits the correlation coefficient into direct and indirect effects via pathways which allows an essential examination of components that greatly influenced a given correlation and can be useful in detailing an efficient selection technique (Sabaghnia, et al., 2010). By this way, the path coefficient analysis has proved to provide more particular data on the direct and indirect impact of each of the segment traits for seed yield (Kumar et al., 2021).

2.9 Genetic Variability Components

2.9.1 Genotypic and phenotypic variability

The components of variability include phenotypic variation, genotypic variation, environmental variation, heritability, genetic advance etc. It is a known fact that genotypes within the species exhibit variation in different metric traits and components of yield. The genetic variation can only be useful for crop improvement with the help of partitioning variances. Plant breeders should be able to determine the relative importance or magnitude of genetic and environmental variances. Genetic variability is the existence of differences among individuals due to differences

in their genetic composition and/or the environment in which they are raised(Falconer & Mackay 1996). Genetic variability is considered as important aspect which taken into account before planning for any breeding program. The success of any selection program depends largely upon the magnitude of genetic variability present in the landraces(Yadav et al. 2016).

A collection and evaluation of *Brassica carinata* landraces is the best means of obtaining genetic variability for further improvement of this crop (Nigussie, 2002 and Adefris, 2006). Genetic variability is found to be the principal raw materials of any breeding programme (Zemede, 1992; Tsige et al., 2005). Determining the level of variation and identifying the variants within the collected species is invaluable for genetic improvement and conservation of the crop (Tewodros and Biruk, 2012). *Brassica carinata* 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, et al, 2015).

In plant genetic and breeding sciences, correlated traits are of top significance due to genetic causes of correlations through pleiotropic action, or gene developmental interactions; as well as changes brought about by natural or artificial selection (Singh, 1993; Falconer and Mackay, 1996; Sharma, 1998). A clear delineation of direct and indirect effects of interaction among traits upon each other in some conditions was not realized using correlation alone; therefore, use of coefficient of path evaluation is better, particularly because it can observe the direct and indirect associations causes, and provide a measure of the relative importance of all (Sharma, 1998).

2.10 *Brassica carinata* genetic resources

Genetic resources are genetic material of plants, animals or micro-organisms of value as a resource for future generations of humanity (OECD 1997). FAO also give a similar definition about plant genetic resources for food and agriculture: It means any genetic material of plant origin of actual or potential value for food and agriculture (FAO 2009).Genetic resources are key to progress in breeding, contributing to sustainable agriculture and associated industries. More than 600 landraces, landraces and cultivars, are maintained at the Genetic Resources Center of the National Agriculture and Food Research Organization (FAO 2009).

2.11 Evaluation of germplasm

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 (Jatoi et al., 2010; Pervaiz et al., 2010; Turi et al. 2012). Germplasm resources are an important basis for biological research and genetic breeding of oilseed rape (Obermeier C, et al 2022). Varieties which are developed and evaluated in local conditions are often better suited to local natural or cultivation conditions than foreign varieties and have excellent traits or genes to adapt to the local environment (Jaradat A. 2018).

3. MATERIALS AND METHODS

3.1 Description of the study Area and Geographical location

The experiment was conducted in Sidama Regional State, at Hula district. Hula district is located at 6° 28′ N latitudes and 38° 318′E longitude and an elevation of 2,759m above sea level. The rainfall pattern is characterized by two rainy seasons (main and short rainy season). The main rainy season extends from June to October whereas the short rainy season extends from April to March (Abera, M, et al., 2022). The yearly rainfall ranged from 1,200 mm to 1,600 mm (Budusa, et, al., 2023). Hula is bordered on the south by the Oromia Region, on the west by Dara, on the northwest by Aleta-Wendo, on the north by Bursa, and on the east by Bona Zuria (Gelaw, et, al., 2023). The average annual temperature range from 12°C to 22.5°C, with the yearly lowest temperature around 10.5°C and the around 24.5°C (Yona, et, al., 2024)

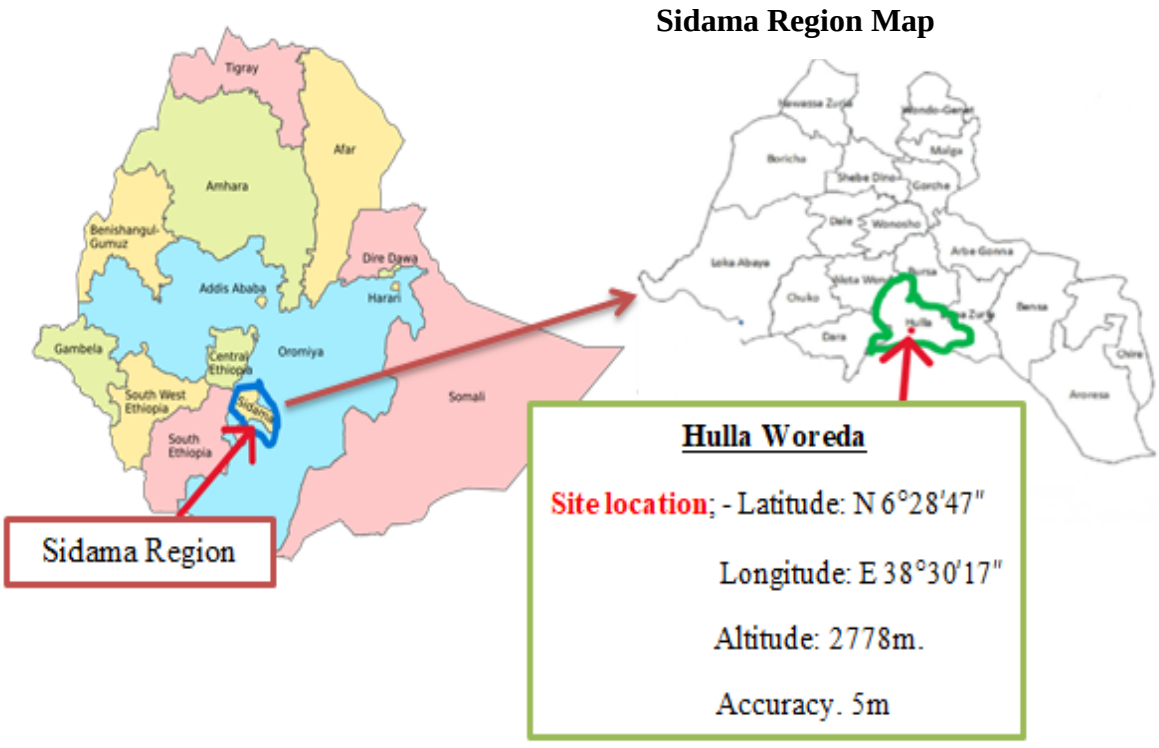

Figure 1.Geographical location of study site area

3.2 Experimental material

The experimental material used for this study was the forty nine landraces of Ethiopian mustard collected from Sidama Region Agriculture Research Institute and used as vegetable crop. The rape seed were plant in Hula.

Table 2.List of *Brassica carinata* landraces from Sidama Region Agriculture Research Institute (SRARI)

No.	Landraces location (collected)		Local name	Level
1		Dorebafeno	Adewalo (kale)	6
2		Wondogenet	Kale-3	3
3		Dorebafeno	Adewalo	4
4	Hawassa zuria	Dorebafeno	Adewalo	8
5	Doyogena	Sererabokata	Asossa (kale)	9
6	Agocha	Borchena	Asossa	2
7	Leva	Debella (1gna)	Denkale	6
8		Hulla	10-Addich	10
9	Wondogenet	Busa	Markale	6
10		Hulla woreda	Sidanch	13
11	Wondogenet	Yuwokebele	Kale (2)	2
12	Doyogena	Sererabokate	Asossa (6)	6
13	Sidama	Hulla	Darressich	8
14	Sidama	Hulla	15-sidancho	15
15		Dorebafeno	Sidancho(kale)	
16		Bonchera	Asossa (1)	1
17		Tulla	Shana-1	1
18		Hulla-kantich	14-darressich adewalo	14
19	Doyogena	Sererabokate	Asossa(kale)	8
20	Meskan	Ele–kebele	Denkale	4
21	West Arsi		1-sircho	1
22	Hulla	Gossa-kebele	9-addich	9
23	Gedeo zone		5-kale	5

24	Hulla	Chellelosa- kebele	11-sidancho	11
25	Chorso	Kuruma	2-kantic	2
26	Doyogena	Bongero	Chakefo(kale)	10
27	Chela	Dukuma	Fetira(kale)	6
28	Gedeo zone	Chorso(gash)	4-qalqo	4
29		Dorebafeno	Adewalo kale	1
30	Wondogenet	Huruma	Kale(4)	4
31	Hulla	Gossa	Kale-7(elalancho)	7
32	Meskan	Wezhaber	Denkale(kale) (fesho)	
33		Dorebafeno	Sidancho-3	3
34	Doyogena	Serera D1	Asossa(5)	5
35		Dorebefano	Adewalo(5)	5
36	Meskan	Ele	Nichile(yeguaroambir)	2
37	Doyogena	Sererabakate	Asossa(7)	7
38	Aletawando	Dobekabele	17-kale	17
39	Borcha	Korougoge	Adewalo(kale)	1
40	Angachu	Bonjrakebele	Asossa (4)	4
41		Dorebafeno	Sidama-2	2
42	Meskan	Elekebele	Denkale	1
43	Chorso	Kuruma	Diqala(1)	1
44	Meskan	Ele-kebale	Senafich species	
45	Argocha	Bonderakebele	Chekafo species	3
46	Aletawondo	Dobekebele	Kale-16/sidancho	16
47	sidama		Kale	46/46
48	sidama		Adwalo –kale	49/49
49	Hulla	Gocherakebele	Getere	12

Source, Sidama Region agricultural Research Institute (SARI)

3.3 Experimental procedure

To evaluate Ethiopian mustard landraces for growth and leaf yield, the following experimental procedures is described

3.3.1Treatments and Experimental design

The field experiment was conducted to assess and estimate the genetic diversity of Ethiopian mustard landraces. For this 49 *Brassica carinata* landraces from Sidama Region Agricultural Research Institute (SRARI) were used. The landraces were tested in simple lattice design with two replications. The designs consist of seven blocks.

7x7 Balanced simple lattices

v=49 block=7 r=2

Block	**Rep, II**							**Block**	**Rep, I**						
(1)	1	8	15	22	29	36	43	**(1)**	1	2	3	4	5	6	7
(2)	2	9	16	23	30	37	44	**(2)**	8	9	10	11	12	13	14
(3)	3	10	17	24	31	38	45	**(3)**	15	16	17	18	19	20	21
(4)	4	11	18	25	32	39	46	**(4)**	22	23	24	25	26	27	28
(5)	5	12	19	26	33	40	47	**(5)**	29	30	31	32	33	34	35
(6)	6	13	20	27	34	41	48	**(6)**	36	37	38	39	40	41	42
(7)	7	14	21	28	35	42	49	**(7)**	43	44	45	46	47	48	49

3.3.2 Planting and experimental plot establishment

First of all the seeds of the landraces were planted in nursery for growing and then transplanted after 30 days of sowing. The field was prepared for planting by plowing with oxen. The land was prepared to fine tilth to ensure proper growth of the seedlings. The soil were be prepared by removing weed, debris, and any unwanted material. Seedlings of landraces were transplanted in each plot using the proper planting methods, including depth and seed spacing. The seedlings were planted in spacing between plant 30cm and between row 50 cm, spacing between each plot 50cm.The number of rows in each plot was four (4). The space between replication 2m and the total area of the field was 36m length x 18m width.

3.4 Agro-morphologic data Collection

Data on growth and leaf yield were collected following appropriate procedure as presented below.

Growth: the growth of the landraces was assessed by the measure of plant height, leaf size and counted number of leaf per plant and number of branches in one week interval to assess their growth rate. This information help determine which landraces exhibit faster growth and development.

Leaf Yield (g): Quantify the leaf yield for each landrace by measuring the weight of leaves collected from the plants. This parameter is crucial as it directly reflects the productivity potential of the landrace.

Leaf Area (cm^2): Assess the leaf area of the plants was measured using digital imaging or leaf area meters. Leaf area is an essential parameter for understanding the photosynthetic capacity and nutrient assimilation potential of the landraces.

Leaf area index (LAI): LAI was measured as the leaf area of individual plant divided by the land cover (space) occupied by each plant.

Number of Leaf per plant: by counting the number of leaf per plant on each of selected plant within plot. Collecting the leaf number at regularly (e.g., weekly or biweekly) to track the rate of leaf production

Day to first flowering (days): The number of days from transplanting to when 50% days of the plants in a plot show flower. It's an essential parameter to collect as it indicates the onset of reproductive growth in rape seed plant. It is an important stage as it marks the time when the plant transitions from vegetative to reproductive growth. The time of flowering can vary among different rapeseed landraces, and this information can help in understanding the diversity and adaptability of landraces.

Day to pod formation (days): The number of days counted from transplanting to when 50% days of pod set of the plants in each plot. It is crucial parameter to collect as it signifies the initiation of seed development in rape seed plants. Time of pod formation is an important indicator of how efficiently the plants are progressing toward seed production.

2.4.1 Quantitative and qualitative data collection:

The totals of 19 agro-morphological traits were recorded for 5 qualitative characters on (Table 1) and 14 quantitative characters on (Table 2). The qualitative trait including leaf blade shape (LBS), leaf color (LC), stem color (SC), Flower shape (FS) and Flower color (FC) were measured as ordinal data class according to phenotypic descriptor (Table 1).

Similarly, the quantitative data set phonological trait including first flowering day (FFD), Pod formed day (DFD), maturity day (MD), harvested day (HD) were collected. Whereas, yield and yield related quantitative trait are plant height(PH), number of branch (NB), number of leaf (NL), leaf length (LL), leaf width (LW), leaf area (LA), lea fresh weight (LFW), leaf dry weight (LDW), leaf dry mater content (LDMC), and specific leaf area (SLA) were recorded.

Branch number per plants: number of branch is counted from ten (10) randomly select plants and averaged

Pant Height (cm): plant height were measured from the base to the top of the plants using ruler, ten randomly selected plants were measured and averaged.

Leaf fresh weight (g): It is measuring of the leaf weight of each individual select plant immediately after collection, without any drying or processing. The leaf weight were collected from each individual selected three plant from each plot and measured immediately after collected by sensitive balance.

Leaf dry weight (g): It is the weight of leaves from each individually select plant after being dried to remove any moisture content. The harvested leaves for yield were dried by oven dry for 48hrs using leaf samples and converted in to per hectare basis.

Number of leaf per plant: This refers to the total number of leaves collect from randomly select plant during data collection. The number of leaf were collected from ten individual select plant in each plot and counted.

Leaf Length (cm): It represents the measurement of the length of leaf of each individually select plant. The length of leaf is measured by using ruler from randomly selected plant.

Leaf width (cm: It represents the measurement of width of each individual leaf from ten randomly select plants. The leaf width is measured by using ruler.

Specific leaf area (m^2/g): The ratio of leaf area to leaf dry weight**.** It indicates the leaf thickness and density. It's an important trait to measure as it relates to the leaf structure and can affect the various physiological processes in the crop. The thicker leaf typically contains more mesophyll cell, which are responsible for photosynthesis and nutrient storage. Calculated using this formula, SLA = Leaf area/Leaf dry weight

Leaf yield (g/ha): The leaves of plants in the net plot was harvested in multiple times and calculated as per hectare basis.

Leaf dry matter content (%): is the proportion of dry matter in leaf, calculated as the ratio of dry weight to fresh weight. It indicates the amount of non-water biomass present in leaf and is an important indicator of leaf quality and productivity. The leaf with higher dry matter content generally has a higher nutrient concentration and energy content, which can contribute to increased photosynthesis and leaf yield. Evaluation of leaf dry matter content can help in assessing the nutritional value and potential productivity of the rape seed landraces. Calculated using this formula, LDMC =leaf dry weight/leaf fresh weight * 100

Table 3. Qualitative trait scored, their respective and descriptor used for *Brassica carinata* for leaf evaluation and characterization

Character	Code	Number of class	Phenotypic class and code
Leaf blade shape	LBS	8	3-linear slider narrow long, 9-ovate (oval), 7-cordate heart shaped, 6-reniform kedney shaped, 11-elliptical (ellipse shaped), 4-oblong rectangular, 5-orbicular (orbi-shaped), and 4-obovate
Stem color	SC	5	7-light green, 12 –green, 6 -red green, 8- purple green, and 18- dark green
Leaf color	LC	4	17-dark green, 18-green, 10-light green, and 4-yellow green
Flower color	FC	4	5-golden yellow, 11-yellow, 5-soft yellow, and 12-cream white
Flower shape	FS	3	12- central illustration, 14- rose day PNG, and 7-premiem vector

Table 4.Phenological and yield related quantitative trait scored, their respective and descriptor used for *Brassica carinata* leaf evaluation and characterization

Character	Code	Descriptor
Day to First flowering (days)	FFD	Number of day from emergences to first flowering
Day to Pod formation (days)	PFD	Number of days from emergences date to pod setting
Day to Maturity (days)	MD	Number of day from emergences date to mature
Day to harvest (days)	HD	Number of from emergences to harvested days
Plant height (cm)	PH	Measure from base to top of main stem by using ruler
Number of branch per plant	NB	Number of branch from ten randomly selected plant and averaged
Number of leaf per plant	LN	Number of leaf content per plat from ten randomly selected plant and averaged
Leaf length (cm)	LL	Measured by using ruler
Leaf width (cm)	LW	Measured by using ruler
Leaf area (cm^2)	LA	Measured using an automatic leaf area meter (model LI31000A Li-cor, Lincoln, USA)
Leaf fresh weight (g)	LFW	Measured by using sensitive balances
Leaf dry weight (g)	LDW	Measured by using sensitive balances
Leaf dry mater content (%)	LDMC	Calculated using leaf dry matter content formula, LDMC =leaf dry weight/leaf fresh weight (total weight) * 100
Specific leaf area (cm^2/g)	SLA	Calculated using specific leaf area formula, **SLA = LA/LDW**

3.5 Statistical Analysis

The descriptive summaries of quantitative morphoagronomic data were estimate using mean and dispersion parameter (range, standard deviation and coefficient of variation (CV). The levels of qualitative data were summarized using the Shannon-weaver diversity index (Shannon, 1948). The higher the indexes of a character entail its higher diversity.

$$Shannon\ Index = \sum_{i=1}^{s} -(\mathbf{Pi} * \mathbf{ln\ Pi})$$

Where,

Σ: A Greek symbol that means "sum"

ln: Natural log

i: species of index

s. total number of species

Pi: The proportion of the entire community made up of species *i*

The collected quantitative data were subject to analysis of variance (ANOVA) by using Statistical Analysis System (SAS) software and least significant difference (LSD) is used to separate at 0.05 probability levels of significance. The analyses of variances (ANOVA) were compute using a simple lattice design package to test the significant variation among *Brassica carinata* landrace quantitative variable. The *P-value*≤ 0.05 was used to indicate the significant difference between mean values determined by one – way analysis of variances (ANOVA). To perform analysis of various genetic parameters like genotypic and phenotypic coefficient of variance, heritability, genetic advance, and genetic advance as a percentage of mean the variability packages in Rstudio was used. The package also has been used for genotypic and phenotypic correlation and path analysis. To extract and visualize the Results of Multivariate Data Analyses, including 'PCA' (Principal Component Analysis) and 'HMFA' (Hierarchical Multiple Factor Analysis) functions from different R packages. It contains also functions for simplifying some clustering analysis steps and provides 'ggplot2' - based elegant data visualization.

3.5.1 Measures of Variability

Genotypic and phenotypic coefficient of variability: Genotypic and phenotypic coefficient of variability were computed according to Burton and Devane (1953).

a. Genotypic variance

$$\sigma^2 g = \frac{\text{MSt} - \text{MSe}}{r}$$

Whereas: MSt = Mean sum of squares for trait of genotype

MSe = Mean sum of squares for error of genotype

r = Number of replications

b. Phenotypic variance

$$\sigma^2 p = \sigma^2 g + \sigma^2 e$$

Whereas: $\sigma^2 p$ = Phenotypic variance for each trait of genotype

$\sigma^2 g$ = Genotypic variance for each trait of genotype

$\sigma^2 e$ = Environmental variation among the tested traits of genotype

Co-efficient of variability: Both phenotypic and genotypic co-efficient of variability for all characters was be estimated using the formula of Burton **(**1952**).**

Phenotypic Co efficient of Variability **(**PCV**%) =** $\frac{\sqrt{\text{Phenotypic variance}}}{\text{grand mean}} * 100$

Genotypic Co efficient of Variability **(**GCV **%) =** $\frac{\sqrt{\text{Genotypic variance}}}{\text{grand mean}} * 100$

According to Sivasubramanian and Madhamenon**(**1973**),** PCV and GCV are classified into three categories as suggested below:

Categories Low: Less than 10**%,** Moderate**:** 10-20% and High**:** More than 20**%**

c. Heritability: broad sense heritability was estimated based on the ratio of genotypic variance to the phenotypic variance and was expressed in percentage (Falconer and Mackay, 1996)

Heritability (broad sense) = $\frac{Genotipicvariance}{Phenotipic\ variance} X\ 100$

It was categorized according to Robinson et al. (1949) in to three classes: 0-30% (low), 31-60% (medium), and more than 60% (high)

d. Genetic advance:

The extent of genetic advance is expected by selecting certain proportion of the superior landraces was calculated by using the following formula (Robinson et al., 1949).

Genetic advance (GA) = k. σp.h2

Where: k=selection intensity at 5% (k=2.06)

σp = Phenotypic standard deviation

ĥ2 (BS) % = Heritability in broad sense.

Genetic advance expressed as percentage over Mean (GAM %):

$$\text{GAM (\%)} = \frac{GA}{mean} X\ 100$$

Where: GAM (%) = Genetic advance over mean

The extent of genetic advance expected by selecting a certain proportion of the superior landraces was calculated by using the following formula (Robinson et al., 1949). Meanwhile, GAM was categorized into three classes: less than 10 % (low), 10-20 % (moderate), and more than 20 % (high).

GA = genetic advance

Association of characters

Correlation analysis: To determine the degree of association of characters with yield and also among the yield components, the correlation coefficients were calculated**.** Both genotypic and

phenotypic coefficients of correlation between two characters were determined by using the variance and covariance components as suggested by Al-Jibouri*et al*. **(**1958**).**

$$\mathbf{r_g(xy)} = \frac{\mathbf{Cov_g xy}}{\sqrt{\sigma^2 x}\sqrt{\sigma^2 y}}, \mathbf{r_p(xy)} = \frac{\mathbf{Cov_p xy}}{\sqrt{\sigma^2 x}\sqrt{\sigma^2 y}}$$

Where, r_g**(**xy**)**, r_p**(**xy**)** are the genotypic and phenotypic correlation coefficients respectively**.** Cov_g, $Cov_p$are the genotypic and phenotypic covariance of xy, respectively**.**

$б^2_g$and $б^2_p$ are the genotypic and phenotypic variance of x and y, respectively**.**

The calculated value of **'**r**'** was compared with table **'**r**'** value with n-2 degrees of freedom at 5**%** and 1**%** level of significance, where, n refers to number of pairs of observation**.** Thus, the data obtained from various experimental objectives were subjected to pertinent statistical analysis to draw meaningful inference towards the genetic divergence of various snap bean landraces**.**

Path coefficient analysis: Based on genotypic and phenotypic correlations; path coefficient analysis, that refers to the direct and indirect estimation effects of leaf yield identified characters (independent character) on leaf yield (dependent character), was calculated based on the methods of Dewey and Lu (1959) as follows:

$$rij = Pij + \Sigma rik\ pkj$$

where, rij = mutual association among the independent character (i) and dependent character (j) as measured by the genotypic and phenotypic correlation coefficients; Pij = direct effects of the character of independent (i) on the dependent variable (j) as measured by the genotypic path coefficients; and Σrikpkj = components summation of indirect effects of a given character of independent (i) on a given character of dependent (j) through all other characters of independent (k).

4. RESULTAND DISCUSSION

4.1 Agro-morphologic qualitative trait

The qualitative traits were visually determined by comparing pictures and descriptions given for the crop in the descriptors for *Brassica carinata* (IBPGR, 1990). Ethiopia is believed to be the primary center of origin and diversity of *Brassica carinata* known as Ethiopian mustard. The diversity of 49 *Brassica carinata* landraces, were used to evaluate the qualitative characterization and scores were used as descriptors for *Brassica*. The qualitative trait diversity indices analyzed using Shannon -Weiner index, five qualitative traits include , Leaf shape (ovate, cordate heart-shaped, reniform kidney-shaped, orbicular, oblong rectangular, obovate, elliptical -ellipse shaped, and linear slender narrow long), Leaf color (green, dark green, light green, yellow-green), Stem color (dark green, green, purple-green, light green, red-green), Flower color (cream white, yellow, soft yellow, golden yellow), and Flower shape (rose day PNG, central illustration, premium vector) presented in Table.5.

The diversity of *Brassica carinata* landraces was assessed using five qualitative trait and diversity indices was analyzed using the Shannon-weaver index (table 5).The Table provides the information about the diversity of *Brassica carinata* distribution on the class size, observed phenotypic class percentage, Shannon's diversity index (H'), maximum diversity index (H'max), and Pielou's evenness index (J') to quantify the diversity and distribution of qualitative traits within the *Brassica carinata* samples. The leaf shape shows relatively high diversity, with multiple classes were observed and a Shannon's Diversity Index (H') close to the Maximum Diversity Index (H' max). In contrast, flower shape exhibits lower diversity, with fewer classes and a lower Shannon's Diversity Index

Leaf blade Shape

The diverse leaf shape refers to the wide variety of forms, size, and structure that leaf can take, which are adaptation to different environmental condition and evolutionary pressure. The major step in plant identification is recognizing the shapes and arrangement of leaves (Tsukaya, 2017). Under leaf blade shape the landraces grouped in to eight leaf blade shapes in which elliptical 22.45%, ovate 18.22%, cordate heart shaped 14.29%, reniform kedney 12.24%, orbicular 10.2%,

oblong rectangular 8.16%, obovate 8.16% and linear slinder narrowed 6.12%.The highest dominated leaf shape observed are elliptical (ellipse-shaped) by representing 22.45% of leaf shape, followed by ovate (oval-shaped) of 18.22%.The Shannon Diversity Index (H') of leaf shape calculated were 1.99, indicating the highest diversity index. The Maximum Possible Shannon Diversity Index (H'max) is 2.08, indicating a relatively even distribution of different leaf shapes among the samples.

The landraces exhibit the greatest diversity in leaf shape, and stem color, with the highest diversity index values and relatively high evenness. The broad leaves maximize surfaces area for photosynthesis in environments where light is abundant, while linear narrow slider reduce water loss in dry condition and the diversity in leaf shapes suggests high genetic diversity within the landraces collection (Tsukaya, 2017). Leaf shape is heritable traits, so the differences in leaf shape reflect underlying genetic differences among landraces. The highest diversity of leaf shapes in differences landraces suggest a rich pool of genetic resources that can be used for crop improvement and adaptation to changing environments (Tsukaya, 2017).

According to Thakur et al. 2019, reported the leaf blade and shape attributes had important roles in the agronomic traits of crops, such as yield, quality and response to stress conditions. In addition, Li and Wang 2021, reported that leaf morphological traits such as leaf shape, influences water and nutrient cycling, that reflects the response of communities to climate change, and can be scaled up to predict ecosystem primary productivity. The landraces also grouped in to four for leaf blade shape in which most of the landraces them fall 27.8, and55.6%, were under elliptic and ovate, respectively (Yimer, 2021).

Leaf and stem Color

The phenotypic classes of leaf color observed were grouped into four classes**:** green (36.73%), dark green (34.69%), light green (20.41%), and yellow green (8.16%). The dominated colors of leaves are green (36.73%) and dark green (34.69), which together account for over 70% of the observed classes. Leaf color shows diversity (H' = 1.26 and H_{max} = 1.39). The phenotypic classification of stem color was carefully observed and grouped into five distinct categories: dark green (36.73%), green (20.41%), purple green (16.33%), light green (14.29%), and red green (12.24%). The diversity index of stem color (H' = 1.52 and H_{max} = 1.61). Dark green is the most

dominant color observed, but other colors like purple green and light green also contribute significantly to the diversity (Table 5).

The diversity of leaf and stem color in different landraces implies that within a landraces, there wide range variation. Color in plants is influenced by pigment, primarily chlorophylls, carotenoid and anthocyanin's. Variation can range from different of green, green yellow, purple green, light green and purple green. This variation suggests that the different genetic diversity of landraces within collection exhibit a wide spectrum of leaf and stem color. The variation of color in stem and leaf implies the genetic variation, identification and characterization and photosynthesis efficiency of the landraces.

The previous studies of Characterization and evaluation of the morphological attributes of Ethiopian mustard (*Brassica carinata A. Braun)* landraces showed frequency distribution of leaf plant pigmentation attributes of Ethiopian mustard landraces and their respective frequencies leaf color (light green, green, dark green and purple green) and stem color (light green, green, purple and other) (Hagos et al., 2024). Similarly studies characterization of leafy Ethiopian mustard (*Brassica carinata A. Braun*) germplasm based on morphological descriptors results, a total of 20 (55.6%) and 16 (44.4%) of landraces had green and light-green leaf colors, respectively (Yimer, 2021). The highest diversity of color in different landraces suggest a wide valuable genetic resources of landraces potential for improving crops through breeding and providing diverse option for various application.

Gorka et al., 2018 reports, Leaf color at fully developed leaf stage revealed that 25 (83.34%) genotypes among 30 were found to be green while 4 (13.34%) genotypes were blue-green and only one genotype was found to be of purple color. Leaf shape showed variation from very narrow elliptic, narrow elliptic to elliptic with 11 (36.67%) genotypes very narrow elliptic and 4 (13.34%) was elliptic in kale genotypes. Similarly, Esawi, M. 2012, observed that most of accessions were of green leaf color (48%) also light green color of seedling leaf is represented by a high percentage (30%). Muthoni, J. 2010, also observed from 47 genotypes of Ethiopian mustard 31 genotypes were green and others light green leaf colour.

Flower Color and shape

The diversity of flower colors and shapes refers to the wide variety Ethiopian mustard, pattern and form that flower genetic and ecological variation (Hoyle et al., 2018). The flower shape of *Brassica carinata* is characteristic of many species in the Brassicaceae family, but there can be some variability across different landraces (local varieties cultivated and adapted to specific environments) (Hoyle et al., 2018). Under flower color, the landraces are grouped into four colors: cream white, yellow, soft yellow and golden yellow of landraces, in which 36.36%, 33.33%, 15.15%, and 15.15%, respectively**.** The diverse flower shape existences indicated that the genetic variation among landraces collected. The flower shape shows the lowest diversity in the study, but the distribution among the flower shapes is most even.

The flower color shows the diversity index of 1.31 and high evenness (J' = 0.94). The majority of flowers are cream white and yellow. The flower shape was grouped into three shapes rose day PNG, central illustration and premiem vector. The rose day PNG flower shape consist of 42.42% of flower shapes which dominated the over rest of flower shape. The central illustration group of flower shape was 36.36%, and the premiem vector flower shape was covered 21.21% of flower shapes (Table 5). The higher Shannon-weaver diversity index indicates greater genetic diversity in flower color and shapes among the landraces. The flower color leaf color shows the moderate levels of diversity distribution based on the study.

Table 5. Diversity of qualitative traits in forty-nine (49) Ethiopian mustard (*Brassica carinata*) landraces.

Qualitative trait	**Class Size**	**Observed phenotypic class**	**%**	**H'**	**H'max**	**J'**
Leaf shape	8	elliptical (ellipse shaped)	22.45	1.99	2.08	0.96
		ovate (oval)	18.37			
		cordate heart shaped	14.29			
		reniform kedney shaped	12.24			
		orbicular (orbi-shaped)	10.2			
		oblong rectangular	8.16			
		Obovate	8.16			
		linear slindernurrow long	6.12			
Stem color	5	dark green	36.73	1.52	1.61	0.95
		Green	20.41			
		purple green	16.33			
		light green	14.29			
		red green	12.24			
Flower color	4	cream white	36.36	1.31	1.39	0.94
		Yellow	33.33			
		soft yellow	15.15			
		golden yellow	15.15			
Leaf color	4	Green	36.73	1.26	1.39	0.91
		dark green	34.69			
		light green	20.41			
		yellow green	8.16			
Flower shape	3	rose day PNG	42.42	1.06	1.1	0.97
		central illustration	36.36			
		premiem vector	21.21			

4.2 Agro-morphological variation Variability of quantitative trait

The total of all 13 agro-morphological quantitative traits showed statistically significant variation among landraces (Table 6). The comparison of agronomic characters among 49 rape seed landraces collected from the southern part of Ethiopia was made. A significant difference was observed for the entire quantitative variable among Ethiopian mustard landraces. The C.V value shows the degree of precision with which the treatments are compared and it's a good indicator of reliability of the experiments.

The lower C.V value shows the results of the experiments are reliable (K.A. Gomez and A.A. Gomez, 1984). The high degree of variability among the Ethiopian mustard landraces were observed for studied traits. The largest variation in among the landraces is useful for selecting the landraces for breeding programs aims at improving genetic diversity in *Brassica carinata* landraces. The ANOVA analysis indicated that all the phenological, growth, and yield-related quantitative traits showed significant differences among the landraces (Table 6).

4.2.1 Phenological quantitative trait variation among landraces

Days to Flowering

The statistical results from the analysis of variances show, there is a statistically significant difference in the day to first flower across the different *Brassica carinata* landraces (Table 6). The distribution of flowering times among the *Brassica carinata* landraces shows that different percentage of flower timeframe (Figure 2). Early-flowered landrace segments representing between 30-41 days (24.5%) are early-flowered. The *Brassica carinata* landraces collected from the guarage zone (Denkale species) and 10 landraces species from the two landraces from the Silte zone, 1-kampata zone, 2-guarage zone, 1-oromia region (wondo-genet woreda), 2-dorebafano woreda, and 1-hula woreda are early flowered**.** The early flowered landraces was lower in terms of leaf yield where compared with mid and late flowered landraces. Moderate flowered landraces combine the largest 46.9% (64-75 days) represents the landraces that flowered in a moderate time frame.

The late flowered landraces were taken the timeframe between 170–210 days after transplanted and combined 28.6% of landraces were flowered at late stage. Potentially, the late-flowered landraces extended for their vegetative growth, resulting in greater biomass accumulation and potentially higher in leaf yield. Hagos et al., 2024, reports the previous study characterization and evaluation of the morphological attributes of 313 Ethiopian mustard (*Brassica carinata A.* Braun) landraces. The variation among flower set of the landraces was classified as early, intermediate and late flowering time. According to the descriptive statistics, the majority of the landraces (70.9%) had intermediate flowering time with average days of 81 days after sowing.

Day to Maturity

Day to first mature, the *Brassica carinata* landraces also show the highly significant difference. This implies that the time to maturities varies considerably among landraces. The maturity date distribution among the landraces indicates considerable diversity, which can be advantageous for adapting to various environmental conditions. The largest groups of landraces mature at mid-stages (Figure 2). Early matured landrace segments, which combined 24.5% (70 days), were matured at an early stage and the early matured landraces were flowered at early stage. Early maturity can help in avoiding late-season drought, frost, and pest pressures and allows for multiple cropping cycles within a single growing season.

The majority of landraces (61.2%) were matured at mid-stages of time frames. This maturity period can offer a good balance between vegetative growth and reproductive development, potentially leading to optimal yields. Late matured (14.35%) landrace segments for the duration of 95-110 days length. The late and moderate matured landraces were matured before the flower set. The moderate and late-matured day landraces have a high leaf yield compared to early-matured landraces.

Days to First Harvest

The mean square values for landraces for days to first harvest are highly significant differences between landraces (Table 6). The distribution of days to first harvesting among the landraces shows a diverse range of maturity periods (Figure 2). The actual days of first harvested landraces were taken three month or 90 day after transplanted. Early-harvested landraces represented

(24.5% combined) indicate a significant portion of the landraces are early-maturing. These landraces are beneficial for areas with shorter growing seasons or for farmers who prefer quicker harvest cycles. Moderate-harvested landraces are segments (69.4% combined) that show that the majority of landraces are matured in a moderate timeframe. The actual days of moderate harvested landraces were taken three month and half or 105 days after transplanted. The majority of landraces were harvested in moderated stages of harvesting timeframe. The late-harvested landraces represent 6.1% of percentages were taken the actual days of more than 115 days or three months (Figure 2).

Day to pod formation

The time frame differences among the rapeseed landraces pod setting variability were written in percentages. The landraces that emerged in those early flowered days are pod-formed at early stages. The majority of dankale genotype landraces that were collected from the Guarage and Silte zones were pod-formed in the early. The early pod-formed landraces observed accounted for 26.5%, and the landraces that have not pod-formed yet during the observation period account for 28.6%, the largest portion of landraces. A percentage of landraces (44.9%) formed pods in 100-115 days, suggesting that the largest portion of pods formed days.

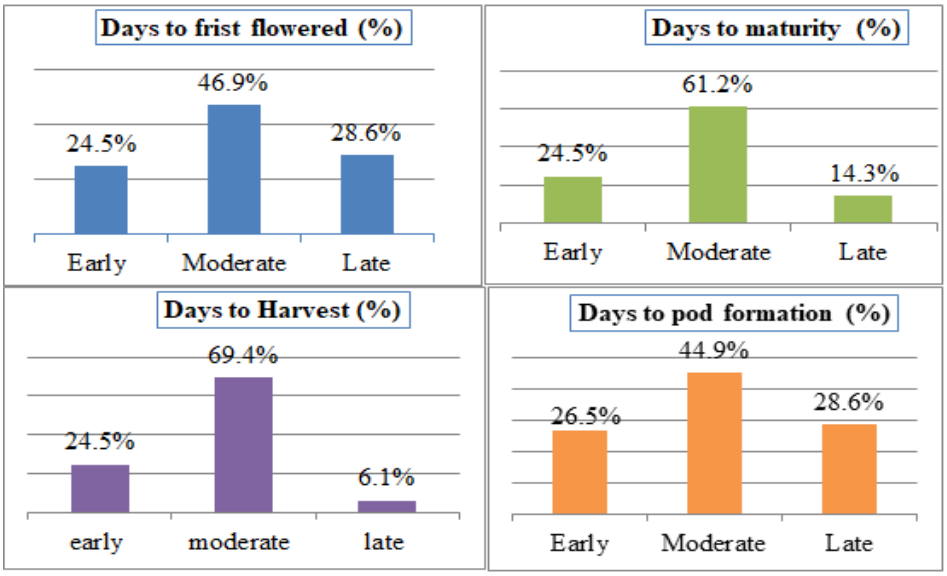

Figure 2. The percentages distribution of different phenological quantitative trait variation among *Brassica carinata* landraces

4.2.2 Growth, Yield and yield related quantitative trait variation among landraces

Analysis of variance among the different landraces revealed significant differences for each quantitative trait, showing different patterns of mean square values, indicating variability in these agro-morphological traits of the 49 *Brassica carinata* landraces from southern Ethiopia. The ANOVA result shows the significant genetic variation among the "*Brassica carinata*" landraces for all the measured traits (Table 6). The R-squared values (R2) are close to 1, suggesting that the variation in the data is well explained, highlighting the reliability of the measurements and the substantial genetic diversity present. The coefficients of variation (C.V.) are relatively low for most traits, indicating consistent measurement precision. The highest coefficient of variation was recorded in specific leaf area (SLA- 21.38%C.V). The lowest coefficient of variation was 0.997 % from leaf area (LA).

The analysis of variance showed that there were significant differences among landraces for all leaf parameter in their different plant parts of leaf traits. Among analyzed leaf traits highly significantly differences were observed in all leaf parameter (Table 6). The significant difference indicates the existence of genetic variability among the landraces which is important for leave agro morphological traits improvement. Walle et al. 2015, reported the analyzed data indicated the existence of variability within the collected landraces this provides for selection from landraces and the genetic improvement of Ethiopian mustard. Among 16 characters, seven (i.e. days to maturity, secondary branches /plant, harvest index,) showed highly significant ($P<0.05$) difference among the tested landraces. Similarly, day of flowering, plant height, primary branch, biomass revealed significance difference at $P<0.05$ among tested landraces (Table 6).

Brassica carinata landraces provides an important insight into the range of variability among the landraces to potentially for breeding purpose. The previous studies that characterized of *Brassica carinata* landraces from several regions from Ethiopia reported high quantitative diversity in characterizing in landraces of *Brassica carinata* observed the presences of wide variation for morphological and agronomic traits (Abebe et al., 1992).Alemayehu,2001, also evaluated 36 genotypes of Ethiopian mustard for agronomic important traits and reported the existence of an enormous amount of genetic variability.

All yield related traits such as leaf number, leaf area, leaf fresh weight, leaf dry weight, leaf length, leaf width, leaf dry matter content and specific leaf area were show the significant

variation among landraces. The highest number of leaves per plant was recorded from the Sidancho kale landraces (124.5 LN counted) that collected from the Sidama region, Aleta-Wondo zone, and the smallest leaf number per plant was recorded from the Assosa kale landraces (5.1 LN counted) from Kampata zone. The highest leaf fresh weight was recorded from Sidancho kale 740.5 LFW landraces from Sidama region Hula woreda, whereas the lowest leaf fresh weight was recorded for Senafich species 19.8LFW from Guarage zone. The high leaf dry matter content was recorded from the assosa-kale (5.6 LDMC) collected from the Kampata zone. The high leaf area was recorded from the landraces that collected from the Sidama region (Sidancho-kale species, 9917.11 LA), whereas the lowest leaf area was recorded from Dankale species 1029.63 LA, which was collected from the Guarage zone. The highest leaf dry weight was recorded from Sindancho kale (145.8 g of leaf dry weight) landraces from Sidama region Hula woreda, and the lowest lead dry weight was from Dankale species 2.5 g from Guarage zone.

Leaf width ranged from 4-30cm with 3.48% of coefficient of variations. The widest leaf was recorded from assosa kale landraces (30 cm leaf width) collected from Kampata zone Agocha Woreda, and the smallest leaf width was recorded from the dankale species (4 cm leaf width) from Guarage zone. The highest leaf length was recorded from the sidancho kale (29.2 cm leaf length) landraces collected from the sidama region of Hula Woreda. The smallest leaf length was recorded from dankale species (6.8 cm leaf length) landraces from Guarage Zones. The specific leaf area ranged from 17.4-835.6 with 21.38 coefficient of variation. The highest specific leaf area was recorded from the landraces called Chekafo kale (835.6 SLA) collected from Kampata zone Doyogeera woreda. The smallest specific leaf area was recorded from the assosa kale (17.4 SLA) landrace collected from Kampata zone.

The growth measure trait branch Number and plant height was shows the significant variation between the landraces. The number of leaf per plant ranged from 1-37.33 highly significant variation among landraces. Plant Height ranged from 17.2cm – 143.6cm indicates that a significant level of variation among *Brassica carinata* landraces. The statistically significant p-value confirms that the differences observed in plant height across the landraces

Similarly, Amsalu (2020) reported that forty-nine Ethiopian mustard landraces for date of flowering, plant height, leaf length, leaf width and leaf area trait found in the same results. The

analysis of variance for 12 agro-morphological traits showed the presence of significant (P ≤0.01) differences among Ethiopian mustard landraces (Yimer, et al. 2021). The coefficient of variation in percent was less than 20% for all traits except weight of leaf harvested per plant in gram indicated the degree of precision with which the treatments were compared was good (Yimer, et al. 2021).

Table 6.Mean squares for different sources of variations for thirteen leave agro morphological traits of *49 Brassica carinata* landraces from Ethiopian.

	Mean square						
Trait	**Replication (1)**	**Block (rep) (12)**	**Landraces (48)**	**Error (36)**	**Range**	**C.V (%)**	**R^2**
FFD	1.02	1.02	6436***	1.1	30-210	1.02	0.99
MD	82.7	2.3	156.83***	7.4	70-110	3.22	0.97
DFH	52.9	4.94	96.33***	3.8	90-120	1.9	0.98
LN	81.01	12.13	2316.47***	5.4	5.1-124.5	4.34	0.99
LFW	1396.79	886.6	47536.4***	1061.4	19.8-740.5	12.7	0.99
LDW	3.05	3.4	1898.04***	1.02	2.5-145.8	2.6	0.99
LDMC	0.00054	0.003	2.23***	0.002	0.12-5.6	3.7	0.99
LA	17092.7	2324.5	6791333.2***	1475.2	1029.63-9917.11	0.997	0.99
BN	0.163	2.5	122.33***	1.09	1-37.33	8.78	0.99
PH	9.74	6.33	2310.04***	2.89	16.1-144.1	2.31	0.99
LW	0.132	0.5	55.7***	0.34	4-30	3.48	0.99
LL	3.92	0.31	46.81***	0.66	6.8-29.2	4.23	0.99
SLA	2017.12	1410.91	45192.73***	1390.3	17.4-835.6	21.38	0.98

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), and specific leaf area (SLA). CV = coefficient of variation expressed in percentage; ***** = 0.01<p<0.05; ****** =0.001<p<0.01; ******* =p<0.001

4.3 Variance components and Heritability

Genotypic and phenotypic coefficients of variation and heritability are helpful in the prediction of the possible genetic advances by selection landraces for leaf yield. The estimates of various quantitative traits observed in *Brassica carinata* landraces, including genotypic variances (GV), phenotypic variances (PV), genotypic coefficient of variation (GCV%), phenotypic coefficient of variation (PCV%), heritability of broad sense (H2b%), genetic advances (GA%), and genetic advance as percentages of mean (GAM%) for yield and yield contributing traits of the Ethiopian mustard leaf evaluation, were presented (Table 7). The variances components (GV and PV) and variances coefficient (GCV and PCV) are similar and the heritability of broad sense as well as genetic advances as percentages of mean are very high (Table 7). In this case the phenotypic selection of landraces for these traits was being effective in improving the crop. Generally, the effect of variation in environmental factor was minimum.

Estimated genotypic variance ranged from 1.1 mg leaf dry matter content to 3394929.0 square meters (m^2) of leaf area (Table 7). Phenotypic variance ranged from 1.1 mg for leaf dry matter content to 3396404.2 square meters for leaf area, indicating the greater share of environmental variance in the total variability. The genotypic variances that relatively score higher total variances are leaf area (3394929), leaf fresh weight (23237.5), specific leaf area (21901.2), first flowering date (3217.45), leaf number (1155.5), plant height (1153.6), and leaf dry weight (948.5), and the same as true, the genotypic variances that score lower variance were maturity date (74.72), branch number (60.6), day to first harvest (46.27), leaf width (27.7), leaf length (23.1), and leaf dry matter content (1.1).

Phenotypic coefficient of variation (PCV) was found slightly superior to the genotypic coefficient of variation (GCV) for all traits, which suggested that presences of higher variability indicate possibilities of effective selection for character improvement. The lowest GCV and highest PCV are indicating as the traits are influenced by environments because of higher PCV than GCV. Environment had a significant role on the expression of those traits. High GCV along with high heritability and high genetic advance will be good information on a particular trait than mean of each parameter (Belete, 2011). Phenotypic and genotypic coefficient of variations

values are categorize low, moderate, and high values as indicated by Siva Subramanian and Menon, 1973 as follow 0-10% = Low, 10-20 Moderate, >20 - High.

Generally, the GCV values were slightly lower than those of PCV values for all traits studied. The GCV value ranged from 6.68% for maturity date to 87.4% for leaf dry matter content and PCV from 6.95 for days to maturity to 87.5% for specific leaf area. The highest genotypic coefficient of variation estimates were observed from leaf dry matter content (87.4%), specific leaf area (84.9%), leaf dry weight (80%), branch number (65.5%), leaf number (63.5%), first flowering date (60.11%), leaf fresh weight (59.3%), leaf area (47.9), plant height (46.2), leaf width (31.6), and leaf length (25%). The moderate genotypic coefficients of variation were recorded from maturity date (10.27%), and the lowest GCV were also from day to first harvest (6.68%). Similarly, Meaza, 2018, reported that high GCV estimates were observed for seed yield per plot, oil yield per plot and biomass per plot in Brassica carinata. Walle et al. 2015 reported that plant height, secondary branch and biomass showed high GCV of these traits and could be valuable phenotypic selection of landraces.

Similarly, the highest phenotypic coefficient of variation were observed from leaf dry matter content (87.4%), specific leaf area (87.5%), leaf dry weight (80%), branch number (66.1%), leaf number (63.6%), first flowering date (60.12%), leaf fresh weight (60.7%), leaf area (47.9%), plant height (46.3%), leaf width (31.7%), and leaf length (25.3%). The moderate phenotypic coefficient of variation was recorded from maturity date (10.76%), and the lowest phenotypic coefficient of variation was also from day to first harvest (6.95%). In this study, heritability values were found to be sufficiently high for all traits that come per plant, and it indicates that improvement in yield can be achieved through the selection of these traits. Dabholkar 1992, generally classified heritability estimates as low (5-10%), medium (10-30%) and high (30-60%). Based on this classification, the all traits recorded were high heritability estimates.

Similarly, Muthoni 2010, studied forty seven lines of Ethiopian mustard of vegetative agro morphological traits in order to identify with useful traits that can be used as genitors for active breeding and based on vegetative agro morphological traits. His results indicated as there is a wide variation in Ethiopian mustard.

H2b (%) (Heritability in the Broad Sense)

Heritability in the broad sense represents the proportion of total phenotypic variance that is due to genetic variance. It ranges from 0 to 100%, with higher values indicating a stronger genetic influence on the trait. Heritability was calculated for all traits. The result of broad sense heritability estimations shows that the highest broad sense heritability under the study conditions was observed for leaf area (LA) and day to first flowering (FFD) (99.96 and 99.97%, respectively), while maturity day (MD) had the lowest heritability estimates at 90.99% based on the present study (Table. 7).

The previous study, the result of heritability in the study suggests the occurrence of additive gene action with low environmental influence for the determination of these traits and could be valuable in phenotypic selection of *Brassica carinata* (Luo et al., 2020). This also indicates that phenotypic selection for these traits would be effective for the expression of these traits in the succeeding generations. Therefore, good improvement can be made if some of these traits are considered as selection criteria in future breeding program. In present study the high heritability values were recorded in all traits. All traits that recorded were score above 90% of heritability of broad sense (Table 7). Genetic advance indicates the degree of gain in a character obtained under a particular selection and helps the breeder to predict the degree of improvement that can be achieved in different characters.

High heritability together with high genetic advance is vital tool for selection of the best individuals and for successful genetic improvement (Moteva et al., 2018). Estimates of genetic advance ranged from 2.2 for leaf dry matter content to 3794.8 for leaf area (Table 8). The value of genetic advance as percentage of means varied from 13.23% for day to first harvest to 179.8% for leaf dry matter content.

Table 7. Estimates of phenotypic variances (PV), genotypic variances (GV), heritability of broad sense, genotypic coefficient of variation, phenotypic coefficient of variation, genetic advances and genetic advance as percentages of mean for quantitative trait of *Brassica carinata* landraces from Ethiopia

Quantitative Traits	**GV**	**PV**	**GCV (%)**	**PCV %**	**H2b (%)**	**GA (%)**	**GAM (%)**
First flowering date (FFD)	3217.45	3218.55	60.11	60.12	99.97	116.83	123.80
Maturity Date (MD)	74.72	82.12	10.27	10.76	90.99	16.98	20.18
Day to first harvest (DFH)	46.27	50.07	6.68	6.95	92.41	13.47	13.23
Leaf number (LN)	1155.5	1160.9	63.5	63.6	99.54	69.9	130.5
Leaf fresh weight (LFW)	23237.5	24298.9	59.3	60.7	95.63	307.1	119.6
Leaf dry weight (LDW)	948.5	949.5	80.0	80.0	99.89	63.4	164.7
Leaf dry matter content (LDMC)	1.1	1.1	87.4	87.4	99.82	2.2	179.8
Leaf area (LA)	3394929.0	3396404.2	47.9	47.9	99.96	3794.8	98.6
Branch number (BN)	60.6	61.7	65.5	66.1	98.23	15.9	133.7
Plant height (PH)	1153.6	1156.5	46.2	46.3	99.75	69.9	95.1
Leaf width (LW)	27.7	28.0	31.6	31.7	98.80	10.8	64.6
Leaf length (LL)	23.1	23.7	25.0	25.3	97.21	9.8	50.8
Specific leaf area (SLA)	21901.2	23291.5	84.9	87.5	94.03	295.6	169.6

Where, (GV) genotypic variation, (PV) phenotypic variation , (GCV) genotypic coefficient of variation, (PCV) phenotypic coefficient of variation, (H2b) heritability of broad sense, (GA) genetic advance, and (GAM) genetic advance of mean

4.4 Principal component analysis

To evaluate the pattern of variation, the principal component analysis was conducted for all quantitative traits. The first three principal components accounted for most of the variation observed and cumulatively explained 82.99% of the total variation among the 13 quantitative traits (Table 8). The first principal component (PC1) had an eigenvalue of 7.71 and explained 59.30% of the total variation. This partitioned landraces mainly based on day to first flowering, maturity day, day to first harvest, leaf length and leaf width. This component discriminated the landraces based on the growth and phenological variation of the landraces.

The second principal component (PC2) accounted for an eigenvalue of 1.67 and 12.88% of the total variation, with most of the variation being attributed to leaf area, leaf number, leaf fresh weight and leaf dry weight. This component was illustrated based on the leaf yield of genotype variation. The third principal component (PC3) had an eigenvalue of 1.41 and explained 10.81% of the total variation. The traits that contributed most to the third principal component (PC3) were leaf fresh weight, leaf dry weight, leaf dry matter content and branch number. The Eigen value associated with each principle out of the ten PCA decreased gradually and stopped at 0.7 and 0.0132 respectively (Table 8).

The first principal component (PC1) explains the maximum variation in the dataset, accounting for 59.30% of total variation. It captures differences mainly associated with phenological trait (day to first flowering, maturity day and day to first harvest) and leaf dimension (leaf width and leaf length) and also leaf yield (leaf fresh weight). This emphasis is importance of these traits for assessment of the characterization of Brassica carinata.

Similarly, Ungusari 2015 report the PCA was used to eliminate redundancy in the data set. The authors showed that, two principal components (PC 1) and (PC 2) accounted for most of the variability observed among the four mustard collections from India. They further indicated that, PC 1 accounted for 56.72% of the morphological variation and was loaded on petiole length (PL), plant height (PH), leaf length (LL), days to 50% flowering (D50%F), length of pod (LP), number of branches (NB), while PC2 accounted for 20.92% of the variation and was loaded on total number of 1000 seed weight (1000SW), number of branches (NB), number of seeds per pod (NSP) (Ungusari 2015).

Hagoset al. (2024) reported the PCA was used before the cluster analysis to determine the relative importance of the 18 classification traits. The first and second PCs accounted for 34.3% of the observed variability. PC1 explained 22.2% of the variability between the morphological attributes and most strongly accounted for the differences among the landraces. Most of the traits describing size were grouped together while the color-related traits were also grouped together.

Table 8. Eigenvalues of the 13 quantitative descriptor of *Brassica carinata* landraces collection from Ethiopia

Variables	**PC_1**	**PC_2**	**PC_3**
Eigenvalue	7.71	1.67	1.41
% of Variance	59.30%	12.88%	10.81%
Cumulative (%)	59.30%	72.18%	82.99%
	Eigenvectors		
Day to first flowering (days, FFD)	0.32	-0.05	-0.01
Maturity day (days, MD)	0.30	0.04	-0.31
Day to first harvest (days, DFH)	0.30	-0.01	-0.31
Leaf number (#, LN)	-0.31	0.30	0.07
Leaf fresh weight (g, LFW)	0.25	0.42	0.29
Leaf dry weight (g, LDW)	0.25	0.40	0.38
Leaf dry matter content (LDMC)	0.27	-0.01	0.47
Leaf area (m^2, LA)	-0.06	0.68	-0.30
Branch number (#, BN)	-0.31	0.17	0.22
Plant height (cm, PH)	-0.28	0.18	-0.15
Leaf width (cm, LW)	0.31	0.06	-0.25
Leaf length (cm, LL)	0.32	0.16	-0.23
Specific leaf area (SLA)	-0.25	0.11	-0.29

4.4.1. Principal component analysis biplot

The biplot provides results of a principal component analysis (PCA) on *Brassica carinata* landraces. PCA is a statistical method used to reduce the dimensionality of data, identifying the most significant features that explain the variance within the dataset. Each blue dot represents a *Brassica carinata* landrace distribution across the plot, showing how they relate to the variables. Landraces near the same region are more similar in terms of the traits being analyzed. The biplot method for principal component analysis was originally defined by Gabriel (1971, 1981). Gower and Hand (1996) give a more complete treatment. Greenacre 2015 is a practical user-oriented guide to biplot. Gower et al. (2011) is the most up to date exposition of biplot methodology.

The principal component analysis (PCA) biplot shows the relationship among the different variables and landraces with respect to the first two principal components (Figure 3). The geometrical distances among landraces in the biplot reflect the genetic distances among them. Smaller angles between dimension vectors in the same direction indicated a high correlation of the traits in relation to discrimination of landraces. Landraces SUND-21 and SID-14 excelled in leaf yield, which was contributed mostly by leaf fresh weight, leaf length, and leaf width.

Morphological characters of Ethiopian mustard landraces based on principal component and cluster analyses indicated that individual characters differed in their patterns of distribution and the amount of variation among the 313 landraces. Overall, a total of 18 morphological characters had been taken and were analyzed by principal component analysis (PCA) and clustering was done based on their relative similarities (Hagos et al., 2024). According to Salvador et al. (2009), the correlation of two or more parameters with one main component indicates that these parameters are related. The same correlation for parameters with the same main component represents a direct relationship between these variables, and a correlation in the opposite direction indicates an inverse relationship (da Silva et al. 2012).

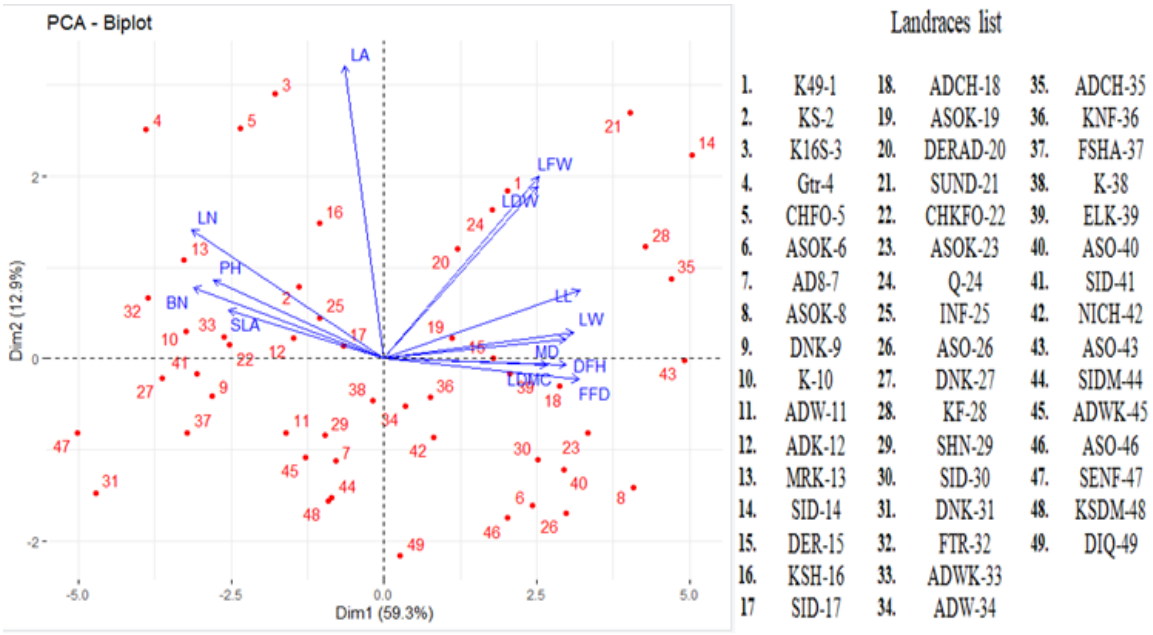

Figure 3.The biplot of the first two principal component factors scores for 13 variables across 49 landrace collections of *Brassica carinata* for landraces and variables correlation.

4.4.2. Principal component analysis Score plot

The score plot shows how different landraces are positioned based on these two components, reflecting their similarities and differences in yield-related traits. Landraces in the upper-right quadrant (positive PC1 and PC2) tend to have high values for the traits that positively influence both components. Most of the high-yield landraces (green dots), such as SID-14, SUND-21, KF-28, and ASO-43, are located in this region. This suggests that these landraces possess desirable characteristics related to yield. In the lower-left quadrant (negative PC1 and PC2), most of the low-yield landraces (red dots) are found, such as SIDM-44, KSDM-48, and ADW-34. These landraces likely perform poorly in terms of the traits associated with yield.

This score plot is a visual tool that effectively distinguishes between the *Brassica carinata* landraces based on their yield-related performance. The high-yield landraces cluster in the top-right side (positive PC1 value), showing that they possess the traits contributing the highest leaf yield, while the low-yield landraces are isolated in the bottom-left (negative PC1 values), reflecting their weaker leaf yield performance and sharing similar characteristics. The mid-yield landraces (yellow dots) are scattered in the center, showing moderate values for the traits. These

include landraces like KNF-36, ASOK-23, and K-38, which have balanced trait scores between the extremes of high and low yield (Figure 4).

This PCA plot offers valuable insights into the distribution of various landraces based on leaf yield. High yield landraces were the landraces in the upper right quadrant in the score plot indicates that landraces are particularly well-suited for high leaf yield, which is beneficial for selection to cultivation and vegetable breeding purposes. Medium yield landraces was the landraces exhibit variability, suggesting that some breeding might improve yield traits or that these varieties can serve as a bridge for genetic studies aiming at yield improvement. Low yield landraces the clustering of these landraces in the lower quadrant highlights a distinct group that potentially could benefit from selection or cross-breeding with higher yield counterparts (Figure 4).

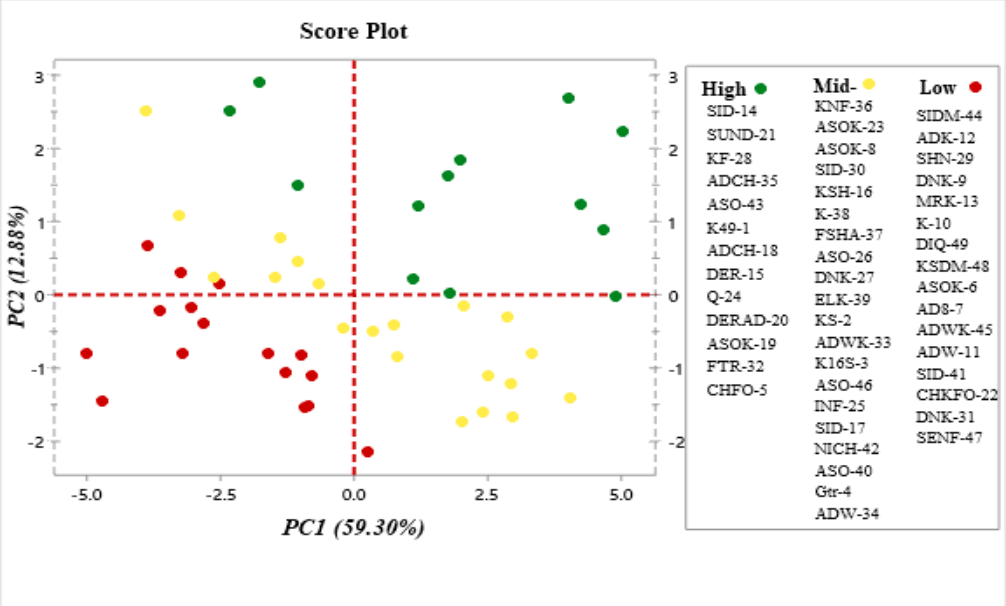

Figure 4.The score plot presented illustrates the distribution of various landraces based on leaf yield, analyzed through Principal Component Analysis (PCA). The axes indicate the variance captured by the first two principal components (PC1 and PC2)

4.5. Cluster Analysis

The cluster analysis was done for the landraces to categorize and group on the basis of 13 agro-morphologic quantitative trait of similarity to their distinct groups. In this present study, the cluster analysis classified the landraces to four major groups (Figure 5 and appendix table 6). These details give a compressive view of the cluster internal structure, revealing difference and similarity in compactness, spread and proportion of the observation. This analysis can be useful for understanding the distribution and characterization of the landraces within each cluster.

Clustering produced a clear grouping of the 49 landraces into four major groups of clusters, whereby the individuals within any one cluster are more closely related than are individuals in different clusters (Figure5). Some landraces with the same geographically collected were grouped in the same cluster and the landraces that flowered early are grouped in the same group. The same is true the late flowerings are grouped in one cluster. This phenomenon might have resulted from their similar genetic background. On the other hand, there are also landraces with same geographical origin but grouped in different clusters which might be due to difference in their genetic background. Similarly, Belete (2011) clustering produced a clear grouping of the 36 landraces into seven clusters, whereby the individuals within any one cluster are more closely related than are individuals in different clusters and landraces with the same geographic origin were grouped in the same cluster.

Cluster I has grouped 16.33% of all landraces which 62.5% from sidama region, 25% from Gedio Zone and 12.5% from kampata zone. Cluster II has grouped 26.53% of all landraces which is 38.46% from gurage zone, 15.38% from silte zone, 15.38% from sidama region and 7.69% from Oromia zone. Cluster III has grouped 28.57% of all landraces, which is 50% from sidama region, 42.86% from kampata zone and 7.14% from Oromia region. Cluster IV has grouped 28.57% of all landraces which are collected from 64.29% from sidama region, 14.29% from kampata zone, 14.29% from gedio zone and 7.14% from gurage zone.

The landraces in cluster III were recorded the highest leaf yield desirable trait that could be used for direct selection of landraces and used for further evaluation of the member of these cluster is possible to develop varieties. During observation the landraces member in cluster III are no pod formed yet. Cluster II were identified the most phenological (early flowered and pod formed landraces) desired trait that used for selection of landraces for early seed harvest and mature at

early stages. The landraces in cluster I and IV were most of them are identified for moderate leaf yield and characterized high seed yield, but for moderate flowered and pod formed at late stage. In this cluster I and IV the landraces was pod formed at late stages.

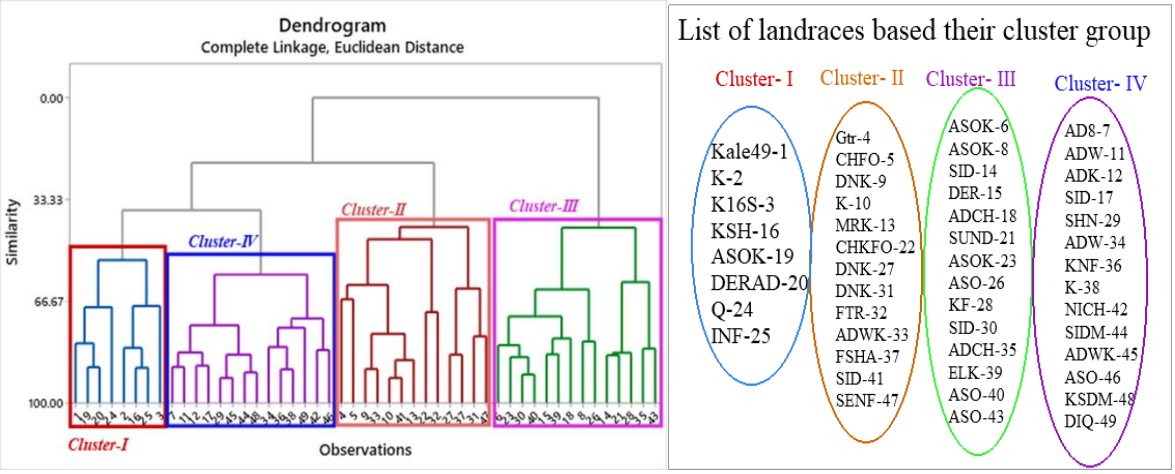

Figure 5.Wards minimum variance dendrogram which shows the distribution of the 49 *Brassica carinata* landraces based on agro-morphological traits.

The PCA ellipse plot is a valuable visualization that enhances understanding of the variation in leaf yield among *Brassica carinata* landraces. It helps in recognizing patterns that inform breeding efforts, and conservation of genetic diversity. Each ellipse on the plot typically represents a cluster of landraces that are similarity and variation in their leaf yield. The shape and size of the ellipse indicate the variability within that cluster. The center of each ellipse corresponds to the centroid of the landraces included in that cluster, indicating the average leaf yield for that group. Different colors and symbols help to differentiate between various groups of landraces. The landraces the moved from the outside of the ellipse cause the highest variation between landraces. This visual distinction allows you to identify how certain landraces cluster together based on their yield characteristics (Figure 6).

To visualize PCA results, especially in 2D, the plot data pointed along with an ellipse that represents the variations of the plot. This ellipse can help to understand the spread and orientation of plot in the principal component space. The plot reveal that certain landraces consistently achieve higher leaf yields (figure 6), the green ellipse and green dot were represented the highest leaf yields groups of *Brassica carinata*. The moderated leaf yielded

group of landraces was represented by the orange ellipse, which overlaps both high and low yield groups among PC1 and extend across a wider ranges on PC2. The low yield landraces are represented by the red ellipse, mostly on negative side ofPC1. The lower values along PC1 indicate the trait associated with reduced productivity. These specific groups are consistently performing better or worse in terms of yield; this information can guide researchers in identifying potential landraces for selection.

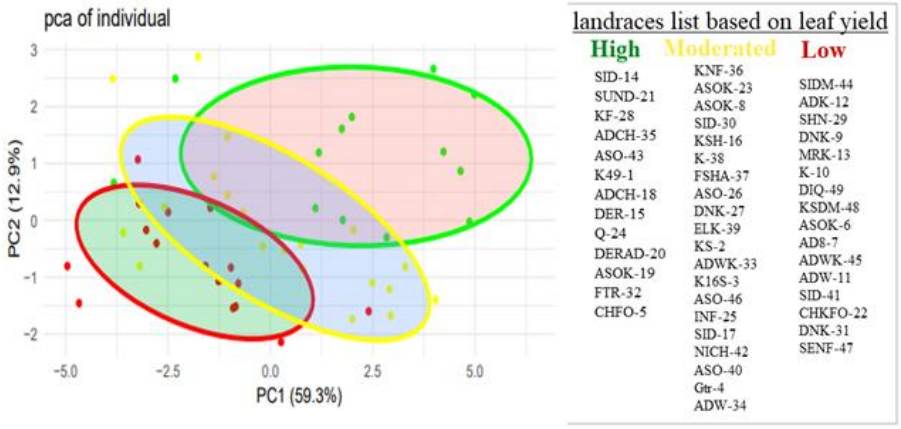

Figure 6. PCA ellipse plot displaying cluster of 49 *Brassica carinata* landraces categorized by leaf yield and landraces distribution each ellipse represents landraces with specific symbols and colors are assigned to display the grouping based on yield

4.6. Evaluation of Ethiopian mustard for leaf yield

The evaluation of Ethiopian mustard landraces for edible leaf use involves assessed the different tradition landraces to determine their potential as leafy vegetables. Certain landraces were having desirable trait for leaf production. The potential leaf yields were evaluated by the leaf fresh biomass per plants. The yield measurements were presented with the landraces alongside their corresponding leaf yields in kilograms (Table 9). The ANOVA showed significant difference among landraces of rapeseed for leaf yield.

The yield was presented as both actual yield values and percentages of their rank to highlight their relative performances compared to the highest-yielding landraces. Based on their leaf yield, the landraces were ranked from highest to lowest. Out of 49 *Brassica carinata* landraces collected, the leaf yield ranged from 20.675 to 739.97 g per plant. The landraces that ranked from 1 to 20 were the potential for leaf yields (Table 9). Hence, these landraces can be recommended for vegetable breeding programs in the country. The landraces that ranked from one to five SID-14 = 739.97 g, SUND-21 = 736.23 g, KF-28 = 674.88 g, ADCH-35 = 586.94 g, and ASO-43 = 503.1 g were evaluated as the top five highest landraces for their leaf yield.

Among the forty nine (49) *Brassica carinata* landraces evaluated in terms of leaf yields, twenty landraces were recorded above 60% based on the yield percentages (Table 9).The different leafy yield for vegetable use showed the existences of wide variation among the landraces. Vegetable breeders can determine the relative importance or magnitude of genetic and environmental variances along with the leaf yield.

The evaluation of *Brassica carinata* landraces for leaf yields offers a comprehensive overview of landraces potential for yield improvement in vegetable use by harnessing the strengths of high-yielding landraces while exploring the diverse traits found in lower-yielding ones. When considering future selection of landraces for yield improvement in vegetable breeding, it's essential to focus on those with the highest performance of leaf yields. The selection and development of adaptable cultivars for specific conditions is the first step in implementing cultivation practices to ensure stable, high-quality vegetables with superior nutritional value (Weiss and Gruda, 2025).

These top landraces which demonstrate high-yield potential, making them crucial for breeding programs aimed at boosting productivity and ensuring food security. The landraces with highest performance of leaf yield as promising for future vegetable leaf yield selection. By focusing on these varieties and considering their adaptability, genetic traits, and market potential, breeders can contribute significantly to improving food security and agricultural sustainability. Breeders can make informed decisions that lead to enhanced productivity and sustainability in vegetable production. Future studies should focus on integrating these findings into practical breeding programs that optimize yield without compromising other vital traits.

Table 9. *Brassica carinata* landraces leaf yield evaluation considering for future breeding for yield improvement in vegetable use.

No.	*Landraces Name*	Leaf Yield (g/plant)	*Percent (%)*	*Rank*	**No.**	*Landraces Name*	Leaf Yield (g/plant)	*Percent (%)*	*Rank*
1	SID-14	739.97	100.00	1	**26**	K16S-3	216.29	47.90	26
2	SUND-21	736.225	97.90	2	**27**	ASO-46	210.035	45.80	27
3	KF-28	674.88	95.80	3	**28**	INF-25	201.055	43.70	28
4	ADCH-35	586.935	93.70	4	**29**	SID-17	199.205	41.60	29
5	ASO-43	503.055	91.60	5	**30**	NICH-42	197.145	39.50	30
6	K49-1	467.53	89.50	6	**31**	ASO-40	196.98	37.50	31
7	ADCH-18	448.06	87.50	7	**32**	Gtr-4	176.635	35.40	32
8	DER-15	407.685	85.40	8	**33**	ADW-34	175.705	33.30	33
9	Q-24	397.34	83.30	9	**34**	SIDM-44	149.685	31.20	34
10	DERAD-20	378.105	81.20	10	**35**	ADK-12	147.715	29.10	35
11	ASOK-19	351.855	79.10	11	**36**	SHN-29	136.695	27.00	36
12	FTR-32	327.245	77.00	12	**37**	DNK-9	131.74	25.00	37
13	CHFO-5	324.955	75.00	13	**38**	MRK-13	123.765	22.90	38
14	KNF-36	299.035	72.90	14	**39**	K-10	107.145	20.80	39
15	ASOK-23	290.905	70.80	15	**40**	DIQ-49	106.375	18.70	40
16	ASOK-8	277.865	68.70	16	**41**	KSDM-48	103.68	16.60	41
17	SID-30	277.17	66.60	17	**42**	ASOK-6	101.025	14.50	42
18	KSH-16	277.025	64.50	18	**43**	AD8-7	92.805	12.50	43
19	K-38	275.74	62.50	19	**44**	ADWK-45	86.79	10.40	44
20	FSHA-37	257.88	60.40	20	**45**	ADW-11	79.955	8.30	45
21	ASO-26	242.75	58.30	21	**46**	SID-41	77.445	6.20	46
22	DNK-27	233.325	56.20	22	**47**	CHKFO-22	54.895	4.10	47
23	ELK-39	230.05	54.10	23	**48**	DNK-31	30.945	2.00	48
24	KS-2	228.5	52.00	24	**49**	SENF-47	20.675	0.01	49
25	ADWK-33	227.54	50.00	25					

4.7 Genotypic and phenotypic correlation coefficients

The correlation coefficients measure the strength and direction of the linear relationship between two variables. A positive correlation indicates that as one variable increases, the other variable tends to increase. A negative correlation indicates that as one variable increases, the other tends to decrease. A correlation close to 1 or -1 indicates a strong relationship, while a correlation close to 0 indicates a weak relationship. Significant correlations are denoted by asterisks (*), with different levels of significance represented by the number of asterisks. The analysis of the correlation coefficient of a quantitative trait to the interrelationships between the quantitative variables provides insights into how they are related to each other within the studied context.

Genotypic and phenotypic correlation coefficients of leaf yield are quantitative measures used to express the strength and direction of the relationship between edible vegetable leaf yields with other given variables. Correlation among different traits is of vital importance to know their association, as yield is an important outcome of many correlated characters. Thus it becomes necessary to study the association for effective selection. The estimates of both phenotypic and genotypic correlation coefficient for various characters are presented (Table 10).When considering edible yield significant positively correlated with other characters (traits), at both genotypic and phenotypic levels of correlations help researchers and breeders understand which traits are beneficial to select for improve overall yields.

Significant Positive Correlations**:** Days to First flowering (FFD), days to first harvest (DFH) and days to mature (MD) are strongly positively correlated each other suggesting that landraces that flower later also tend to mature later and expected early flowering is often associated with earlier maturity. Leaf length and leaf width are strongly positive correlated. A strong relationship between leaf width and leaf length, suggest that larger leaves are consistently wider and longer. Leaf dry weight and leaf fresh weight was strongly positively correlated each other. This shows that higher leaf fresh weight is linked to higher dry weight, indicating biomass accumulation. Leaf number and branch number was strongly positively correlated, indicating that plant associated with more branches had more number of leaf (Table 10).

Most of crop phenology and growth traits (viz. days to50% maturity, leaf petiole length, leaf length, leaf width, petiole width, plant height and canopy diameter) had positive and significant

correlations with edible vegetable leaf yield in ton ha^{-1} at both levels of genotypic and phenotypic. In addition, leaf number per plant had positive as well as significant correlations at phenotypic level. Among the growth parameters, leaf blade width ratio to length of leaf showed negative and significant correlations with leaf yield both at genotypic and phenotypic levels(Ousman et al., 2021).

Significant Negative Correlations: First flowering day and leaf number was strongly negatively correlated each other. Frist flowering day is negatively correlated with leaf number, indicating that earlier flowering plants tend to have fewer leaves. Leaf dry matter content and leaf number was strongly negatively correlation, leaf dry matter content has a negative relationship with leaf number, suggesting that higher dry matter content tends to appear in plants with fewer leaves. Both branch number and plant height are strongly negative correlation to leaf width (LW), this means the plant had more branches are associated with narrower leaves, and taller plants tend to have narrower leaves, which may indicate resource competition or specific adaptations.

The result reported by Ousman et al., (2021) showed that a positive as well as significant associations of leaf number per plant with the variables of leaf petiole length, leaf length, leaf width and petiole width, at both genotypic and phenotypic levels. There were positive and significant associations of plant height and canopy diameter with number of leaves per plant at both genotypic and phenotypic levels. The phenology and growth traits (days to 50% maturity, leaf petiole length, leaf length, leaf width, petiole width, plant height and canopy diameter) showed positive and significant associations among them; both at genotypic and phenotypic levels.

The magnitude of the genotypic correlation coefficient was higher than the traits of phenotypic correlation coefficient for all parameters. Phenotypic correlation (rp) measures the extent to which the two detected characters are linearly connected; although genotypic correlation (rg) measures the extent to which degree of the same genes, or closely related genes, cause covariation (simultaneous variations) in two characters that are different (Singh and Chaudhary, 1977; Falconer and Mackay, 1996; Sharma, 1998).

The more significant genotypic association between the different pairs of characters than the phenotypic correlation indicates the presence of strong association between those characters genetically, but the phenotypic value is lessened by the significant interaction of environment (Singh and Chaudhary, 1977; Falconer and Mackay, 1996; Sharma, 1998). Thus, the presence of significant correlation of phenology and most of the growth traits with edible vegetable leaf yield per hectare (both at genotypic and phenotypic levels) suggested the major significance of the traits in selecting program to identify Ethiopian mustard landraces with high leaf yield.

The edible vegetable leaf yield showed highly significant positive correlation with leaf width, leaf length, leaf dry weight, leaf dry matter content and phenological traits 50% of maturity day and day to first harvest at both genotypic and phenotypic levels (table 10). The edible vegetable leaf yield showed significant negatively correlation with branch number, leaf number, plant height and specific leaf area at both genotypic and phenotypic levels. The edible leaf yield was significantly positive correlation with 50% flowering day at phenotypic levels and negatively significant correlation at genotypic levels and also significant positive correlation with leaf area at phenotypic levels and non-significant correlations at genotypic levels.

The existence of negative correlation indicated the associated traits are in opposite direction; and thus, genotype selection for high performance of one trait leads to the reduction of performance in the other traits. Therefore, it is vital to give attention to the two crop traits in the selection process of landraces for high yield. Association of negative traits is difficult or virtually impossible to improve through concurrent selection of those traits (Akinyele and Osekita, 2006; Nwangburuka et al., 2012; Ahiakpa et al., 2013).

A similar result reported by (Buhroy et al. 2017) showed that total yield of the amaranth leaves had significantly and positive correlation with plant height, petiole length, leaf width and leaf length. Kumar et al. (2017) reported most of growth traits (leaf petiole length, leaf length, leaf width, petiole width, plant height and plant spread) had positive and significant correlations with curd yield quintal ha-^{1} of *Brassica oleracea L*. var. botrytis both at genotypic and phenotypic levels. (Kennaredet al, 1994) reports a highly significant correlation had been reported between leaf length and leaf width.

Table 10. The Genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficients among 13 quantitative traits of *49 Brassica carinata* landraces for leaf evaluation.

Traits	FFD	MD	DFH	BN	PH	LN	LA	LW	LL	LDW	LDMC	SLA	LFW
FFD	1	0.64**	0.61**	-0.75**	-0.74**	-0.74**	-0.21*	0.79**	0.79**	0.55**	0.64**	-0.47**	0.56**
MD	0.66**	1	0.96**	-0.69**	-0.53**	-0.67**	0.01NS	0.68**	0.72**	0.43**	0.41**	-0.48**	0.49**
DFH	0.63**	0.98**	1	-0.71**	-0.52**	-0.73**	-0.04NS	0.67**	0.71**	0.41**	0.39**	-0.53**	0.44**
BN	-0.76**	-0.71**	-0.74**	1	0.62**	0.86**	0.24*	-0.79**	-0.79**	-0.39**	-0.52**	0.45**	-0.39**
PH	-0.74**	-0.55**	-0.54**	0.63**	1	0.68**	0.36**	-0.53**	-0.57**	-0.43**	-0.58**	0.53**	-0.51**
LN	-0.74**	-0.69**	-0.76**	0.87**	0.68**	1	0.44**	-0.72**	-0.70**	-0.38**	-0.58**	0.64**	-0.36**
LA	-0.21NS	0.01NS	-0.05NS	0.24NS	0.36*	0.44**	1	0.02NS	0.11NS	0.16NS	-0.34**	0.32**	0.21*
LW	0.80**	0.71**	0.70**	-0.81**	-0.54**	-0.73**	0.02NS	1	0.92**	0.48**	0.51**	-0.46**	0.48**
LL	0.80**	0.75**	0.74**	-0.80**	-0.58**	-0.71**	0.12NS	0.94**	1	0.59**	0.48**	-0.47**	0.60**
LDW	0.55**	0.44**	0.43**	-0.39**	-0.44**	-0.38**	0.16NS	0.48**	0.59**	1	0.75**	-0.54**	0.89**
LDMC	0.64**	0.42**	0.41**	-0.52**	-0.59**	-0.58**	-0.34*	0.51**	0.49**	0.75**	1	-0.61**	0.63**
SLA	-0.48**	-0.52**	-0.55**	0.46**	0.54**	0.66**	0.33*	-0.48**	-0.49**	-0.55**	-0.63**	1	-0.48**
LFW	0.57**	0.51**	0.46**	-0.39**	-0.52**	-0.37**	0.21NS	0.50**	0.61**	0.91**	0.64**	-0.50**	1

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), and specific leaf area (SLA). And "***" indicates a very highly significance (typically p< 0.001), "**" indicates highly significance (typically p < 0.01), "*" indicates moderate significance (typically p < 0.05), "Ns" stands for not significant, meaning the correlation is not statistically significant.

4.8. Genotypic and phenotypic Path coefficient of leaf yield with other characters

Path coefficient analysis is a technique used in plant breeding to determine the direct and indirect effects of variables on dependent variables. Path coefficients measure the relative strength and direction of the effect of a causal variable on an outcomes variable in a model. They are standardized versions of linier regression weight that are used in structural equation modeling (SEM) to examine the potential causal relationship between variables. The sign of positive coefficient means that an increase in one variable leads to a direct increase in other variable. A negative coefficient mean that an increase in one variable to a direct decrease in other variables.

Genotypic and phenotypic path analysis in relation to leaf yield involves examining the relationships between genetic factors (genotype) and observable characteristics (phenotype) to understand their direct and indirect effects on leaf yield. This analysis helps identify the traits that contribute most significantly to leaf yield and the pathways through which these traits influence each other. By utilizing statistical methods, researchers can assess how different traits, such as plant height, leaf area, and flowering time, interact and contribute to overall leaf yield.

Associated characters that determined by correlation coefficient may not provide an exact picture of the relative importance of the direct and indirect influence of each of yield contributing characters on seed yield. To get a clear picture of the inter-relationship between leaf yield and other yield attributes, direct and indirect effects using path analysis is very much important. Leaf yield per plant was considered as a resultant (dependent) variable, and all other characters were causal (independent) variables. Estimation of the direct and indirect effect of path coefficient analysis for *Brassica* species is presented in (Table 11 and 12).

Leaf petiole length, leaf length, leaf width, petiole width and plant height had positive and highly significant genotypic correlation with edible vegetable leaf yield, and also exerted a confident direct effect on crop yield. (Lenka and Mishra (1973) report the direct and indirect effects into five categories: negligible (0.00-0.09), low (0.10-0.19), moderate (0.20 -0.29), high (0.30-1.00) and very high (>1.00). Leaf width had high positive indirect effects (>0.3) via days to 50% maturity, leaf petiole length, leaf length, petiole width, leaves per plant, plant height, and canopy diameter. Petiole width via days to maturity, leaf petiole length, leaf length, leaf width, and plant height and canopy diameter exerted high indirect effect on leaf yield; and, via leaves per plant, exerted a moderate indirect effect on leaf yield.

Similarly, Kumar et al. (2017) reported negligible positive direct effect of plant height and days to maturity on marketable yield of *B. oleracea L.* var. botrytis; and also observed a moderate indirect effect on marketable yield by leaf width via petiole length and number of leaves per plant.

A total of 8 traits showed significant positive correlations with edible vegetable leaf yield at genotypic and phenotypic levels, respectively. Therefore, path coefficient analysis was conducted for these traits, taking edible vegetable leaf yield as the dependent variable and other traits as causal variables to understand the direct and indirect effects of the traits. The results of genotypic and phenotypic path coefficient analyses are presented in Tables 11 and 12, respectively. Information obtained from correlation coefficients can be enhanced by partitioning them into direct and indirect effects for a set of a priori cause-effect interrelationships; thus, providing a convenient method in selecting the characters that have direct and indirect effects, as has been demonstrated in various crops (Kang et al., 1983; Gravois and Helms, 1992; Gravois and McNew, 1993; Board et al., 1997; Murtadha et al., 2004).

Estimates of direct and indirect effects of traits on edible vegetable leaf yield at the genotypic level. The Leaf dry weight, leaf length, and leaf dry matter content and 50% of maturity and day to flower had highly positive significant genotypic correlation with edible vegetable leaf yield. 50% of Maturity day (1.9678) and leaf dry weight (1.0571) had strongly a positive direct effect on leaf yield (Table 11). Leaf area, branch number, and leaf width were also positive direct effect on leaf yield. Day to first harvest (0.4571), leaf width (0.495), and leaf area (0.2098) was also positively correlation coefficient with edible leaf yield. Branch number (-0.3923), plant height (-0.5168), leaf number (-0.3741) and specific leaf area (-0.4983) was negatively correlation coefficient with edible leaf yield (Table 11). This suggested that selection of landraces for leaf length, leaf width, and leaf area themselves, and through other traits, could be regarded as a reliable source of getting high leaf yield in *Brassica carinata*.

Estimates of direct and indirect effects of traits on edible vegetable leaf yield at the phenotypic level. Maturity day, branch number leaf area and leaf dry weight had positively direct effect on edible leaf yield. Leaf dry matter content, leaf length and leaf dry weight were strongly positive correlation coefficient with edible leaf yield and leaf width and leaf area, and maturity day, day to first harvest and day to first flower also positive correlation coefficient with edible vegetable

leaf yield. Specific leaf area, branch number, leaf number and plant height were negatively correlation coefficient with edible vegetable leaf yield (Table 12).

Ousman et al, (2021), reported Days to 50% maturity, plant height, canopy diameter and leaves per plant had positive significant phenotypic correlations with edible leaf yield per hectare; but had negative and negligible to high direct effect on the trait. Ratio of leaf blade width to leaf length showed highly significant negative phenotypic correlation with edible leaf yield per hectare, and exerted negative and low direct effect on the trait. Kumar et al. (2017) reported leaf width and petiole length had positive low direct effect on marketable yield. In addition, leaf width had positive indirect effect via leaf length, plant height and number of leaves per plant; and plant height had negligible indirect effect via leaf length, leaf width and number of leaves per plant.

Sabaghina et al. (2013) reported a positive direct effect on leaf yield of spinach that was categorized as high for leaf length, medium for leaf width and low for petiole length. Similarly, Tejaswini, N.,et al(2017), reported positive and significant phenotypic correlations among leaf length and leaf width, and had direct effect on leaf yield of vegetable. Kumar et al. (2017) reported leaf width and petiole length had positive low direct effect on marketable yield. In addition, leaf width had positive indirect effect via leaf length, plant height and number of leaves per plant; and plant height had negligible indirect effect via leaf length, leaf width and number of leaves per plant. Similarly, Hasan, M., et al (2013) found a positive direct effect of leaf width on marketable yield, and a low positive indirect effect of leaf width via plant height and number of leaves per plant on marketable yield.

Leaf width had high positive indirect effects (>0.3) via days to 50% maturity, leaf petiole length, leaf length, petiole width, leaves per plant, plant height, and canopy diameter. Petiole width via days to maturity, leaf petiole length, leaf length, leaf width, and plant height and canopy diameter exerted high indirect effect on leaf yield; and, via leaves per plant, exerted a moderate indirect effect on leaf yield (Ousman, Y. et al, (2021). Leaf petiole length and leaf length exerted positive and high-to-low indirect effect via each other along with low-to-negligible effect through days to maturity, petiole width, number of leaves per plant, plant height and canopy diameter.

Tables 11.Estimates of direct (bold and diagonal) and indirect (off diagonal) effects of traits on edible vegetable leaf yield at the genotypic level.

Traits	FFD	MD	DFH	BN	PH	LN	LA	LW	LL	LDW	LDMC	SLA	**rg**
FFD	**-0.214**	1.3017	-1.267	-0.0983	0.1536	0.4208	-0.0161	0.0229	-0.0912	0.5797	-0.1955	-0.0220	0.5748
MD	-0.1416	**1.9678**	-1.9810	-0.0924	0.1135	0.3942	0.0007	0.0205	-0.0860	0.4680	-0.1272	-0.0238	0.5127
DFH	-0.1344	1.9310	**-2.0187**	-0.0959	0.1125	0.4302	-0.0035	0.0200	-0.0847	0.4507	-0.1247	-0.0255	0.4571
BN	0.1618	-1.3988	1.4887	**0.1300**	-0.1313	-0.4941	0.0180	-0.0233	0.0919	-0.4159	0.1593	0.0213	-0.3923
PH	0.1585	-1.0763	1.0938	0.0822	**-0.2076**	-0.3885	0.0268	-0.0155	0.0667	-0.4601	0.1784	0.0248	-0.5168
LN	0.1588	-1.3673	1.5309	0.1133	-0.1422	**-0.5673**	0.0335	-0.0209	0.0809	-0.4014	0.1774	0.0302	-0.3741
LA	0.0457	0.0190	0.0941	0.0311	-0.0739	-0.2519	**0.0754**	0.0007	-0.0132	0.1639	0.1039	0.0151	0.2098
LW	-0.1709	1.3993	-1.4092	-0.1053	0.1116	0.4116	0.0017	**0.0288**	-0.107	0.5112	-0.1547	-0.0219	0.4950
LL	-0.1702	1.4772	-1.4922	-0.1042	0.1207	0.4003	0.0087	0.0269	**-0.1146**	0.6274	-0.1482	-0.0224	0.6094
LDW	-0.1174	0.8712	-0.8608	-0.0511	0.0903	0.2154	0.0117	0.0139	-0.0680	**1.0571**	-0.2291	-0.0252	0.9080
LDMC	-0.1375	0.8222	-0.8270	-0.0680	0.1216	0.3306	-0.0257	0.0146	-0.0558	0.7957	**-0.3044**	-0.0288	0.6376
SLA	0.1028	-1.0198	1.1202	0.0603	-0.1123	-0.3735	0.0248	-0.0137	0.0559	-0.5799	0.1909	**0.0459**	-0.4983

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), specific leaf area (SLA) And (rg) Genotypic correlation.

Tables 12.Estimates of direct (bold and diagonal) and indirect (off diagonal) effects of traits on edible vegetable leaf yield at the phenotypic level.

Traits	FFD	MD	DFH	BN	PH	LN	LA	LW	LL	LDW	LDMC	SLA	**rp**
FFD	**0.0172**	0.3554	-0.3083	-0.0180	0.1603	0.0648	-0.0213	-0.0046	-0.0618	0.4961	-0.1188	0.0035	0.5646
MD	0.0110	**0.5561**	-0.4895	-0.0166	0.1144	0.0585	0.0010	-0.0040	-0.0568	0.3894	-0.0751	0.0037	0.4922
DFH	0.0104	0.5346	**-0.5092**	-0.0172	0.1133	0.0639	-0.0045	-0.0039	-0.0554	0.3724	-0.0730	0.0040	0.4355
BN	-0.0128	-0.3822	0.3629	**0.0241**	-0.1355	-0.075	0.0236	0.0046	0.0618	-0.3528	0.0958	-0.0034	-0.3894
PH	-0.0127	-0.2933	0.2660	0.0151	**-0.2169**	-0.059	0.0355	0.0031	0.0451	-0.3929	0.1083	-0.0040	-0.5066
LN	-0.0127	-0.3713	0.3714	0.0208	-0.1482	**-0.088**	0.0442	0.0042	0.0546	-0.3429	0.1076	-0.0048	-0.3648
LA	-0.0037	0.0055	0.0229	0.0057	-0.0772	-0.039	**0.0999**	-0.0001	-0.0090	0.1404	0.0632	-0.0024	0.2062
LW	0.0136	0.3793	-0.3392	-0.0191	0.1155	0.0629	0.0024	**-0.0058**	-0.0725	0.4365	-0.0936	0.0035	0.4835
LL	0.0135	0.4021	-0.3590	-0.0190	0.1245	0.0609	0.0114	-0.0054	**-0.0785**	0.5327	-0.0890	0.0036	0.5979
LDW	0.0094	0.2391	-0.2094	-0.0094	0.0941	0.0332	0.0155	-0.0028	-0.0462	**0.9057**	-0.1393	0.0041	0.8939
LDMC	0.0110	0.2255	-0.2007	-0.0125	0.1268	0.0509	-0.0341	-0.0029	-0.0378	0.6816	**-0.1852**	0.0046	0.6273
SLA	-0.0080	-0.2697	0.2686	0.0108	-0.1141	-0.056	0.0320	0.0027	0.0371	-0.4860	0.1134	**-0.0076**	-0.4768

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), specific leaf area (SLA) and phenotypic correlation (rp).

5. SUMMARY AND CONCLUSION

Ethiopian mustard is an eminent vegetable and oil-seed crop worldwide. However, the crop is nowadays more used in bio-industrial production in developed countries and as a leafy vegetable for food as obtained in developing countries, particularly in east African countries. In this study, we conducted agro-morphological diversity analysis and evaluated Ethiopian mustard landraces for leaf yield. It was observed that future breeding and morphological characterization of Brassica carinata could be effectively and cheaply done using fewer leaf parameters and traits.

These study results shows a wide variation in *Brassica carinata* landraces based on morphological attributes. 49 *Brassica carinata* landraces acquired from Sidama Region Agricultural Research Institute were evaluated in simple lattice design with two replications at Hula district in Sidama region, with the objectives of to analyze the agro-morphological diversity and evaluation of leaf variability, heritability, for leaf yield per plant and leaf agro-morphological related characters and to estimate the extent of genetic correlation. The analysis of variance showed the presence of significant differences among the tested landraces for leaf yield per plant, leaf length, leaf width, leaf number and leaf area traits. The significant difference indicates the existence of genetic variability among the landraces which is important for leaf agro morphological traits improvement.

High phenotypic coefficient of variation (PCV) was recorded from leaf dry matter content (87.4%), specific leaf area (87.5%), leaf dry weight (80%), branch number (66.1%), leaf number (63.6%), first flowering date (60.12%), leaf fresh weight (60.7%), leaf area (47.9), plant height (46.3), leaf width (31.7%), leaf length (25.3%). The moderate phenotypic coefficients of variation were recorded from maturity date (10.76%) and the lowest phenotypic coefficients of variation were also from day to first harvest (6.95%). The estimation of genotypic and phenotypic coefficient of variations in the study, the highest genotypic and phenotypic coefficient of variation suggested that the Brassica carinata landraces are highly diverse and provides a wide range of possibilities for selecting further breeding. The result heritability of broad sense (H2b) values in all traits was very high ranging from 90.99 to 99.975%; this implies that the genetic component of variation is substantial for all traits.

The first three principal components accounted for most of the variation observed and cumulatively explained 82.99% of the total variation among the 13 quantitative traits. The first principal component (PC1) explained 59.30% of the total variation was partitioned landraces mainly based the growth and phenological variation. The second principal component (PC2) explained 12.88% of the total variation, this component discriminated the landraces based on the leaf yield. The score plot is a visual tool that effectively distinguishes between the *Brassica carinata* landraces based on their yield-related performance. The high-yield landraces cluster in the top-right side (PC1), showing that they possess the traits contributing the highest leaf yield, while the low-yield landraces are isolated in the bottom-left (PC1), reflecting their weaker leaf yield performance and sharing similar characteristics.

All 49 *Brassica carinata* landraces were clustered into four major groups of clusters whereby, the individuals within any one cluster are more closely related than are individuals in different clusters. The landraces grouped in cluster III have the highest leaf yield desirable trait that can be used for selection of landraces further breeding. During observation the landraces member in cluster III are no pod formed yet. The landraces that flowered early are grouped in the same group. The same is true the late flowerings are grouped in one cluster. The landraces in cluster I and IV were most of them are identified for moderate leaf yield and characterized high seed yield, but for moderate flowered and pod formed at late stage.

Overall, the present study showed the presences of high variability in *Brassica carinata* landraces. The possibility for further improvement using these variations is wide. Therefore the economical leaf traits of plants (e.g. leaf yield, leaf number and leaf area) can be possibly to improve for their yield quality and quantity through selection. The breeder should use the generate information from different studies for increasing the leaf yield and quality of *Brassica carinata* landraces and to upgrade from under-utilized crop to a commercially important crops.

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APPENDIX

Appendix table 1.This test controls the comparison wise error rate, not the experiment wise error rate. The phenological quantitative trait Means with the same letter are not significantly different.

Landraces name and codes	FFD	DM	DFH	Landraces name and codes	FFD	DM	DFH
K49-1	75_{e}	90_{bc}	107_{bc}	ASO-26	180_{c}	90_{bc}	107_{bc}
KaleSidancho-2	64_{f}	85_{cd}	102.5_{cd}	DNK-27	30_{h}	70_{e}	90_{e}
K16S-3	64_{f}	95_{b}	107_{bc}	KF-28	175_{d}	90_{bc}	108.5_{b}
Getere-4	41_{g}	70_{e}	90_{e}	SHN-29	64_{f}	82.5_{d}	100_{d}
CHiFO-5	41_{g}	70_{e}	90_{e}	SID-30	180_{c}	$90b_{c}$	107_{bc}
AsossaK-6	190_{b}	90_{bc}	108.5_{b}	DNK-31	41_{g}	70_{e}	90_{e}
ADich8-7	64_{f}	85_{cd}	107_{bc}	FTR-32	41_{g}	70_{e}	90_{e}
ASOK-8	190_{b}	95_{b}	107_{bc}	ADWK-33	41_{g}	70_{e}	90_{e}
DNK-9	41_{g}	70_{e}	90_{e}	ADW-34	75_{e}	90_{bc}	108.5_{b}
K-10	41_{g}	70_{e}	90_{e}	ADCH-35	210_{a}	90_{bc}	108.5_{b}
ADW-11	64_{f}	85_{cd}	102.5_{cd}	KNF-36	75_{e}	90_{bc}	107_{bc}
ADK-12	64_{f}	85_{cd}	102.5_{cd}	FSHA-37	30_{h}	70_{e}	90_{e}
MRK-13	41_{g}	70_{e}	90_{e}	K-38	64_{f}	85_{cd}	102.5_{cd}
SID-14	180_{c}	95_{b}	108.5_{b}	ELK-39	190_{b}	90_{bc}	107_{bc}
DER-15	180c	95_{b}	107_{bc}	ASO-40	190_{b}	90_{bc}	108.5_{b}
KSH-16	64_{f}	82.5_{d}	102.5_{cd}	SID-41	41_{g}	70_{e}	90_{e}
SID-17	64_{f}	82.5_{d}	102.5_{cd}	NICH-42	64_{f}	82.5_{d}	102.5_{cd}
ADCH-18	180_{c}	95_{b}	107_{bc}	ASO-43	190_{b}	90_{b}c	107_{bc}

ASOK-19	75_{e}	90_{bc}	107_{bc}	SIDM-44	64_{f}	82.5_{d}	102.5_{cd}
DERAD-20	75_{e}	90_{bc}	108.5_{b}	ADWK-45	64_{f}	82.5_{d}	102.5_{cd}
SUND-21	180_{c}	95_{b}	108.5_{b}	ASO-46	75_{e}	90_{bc}	$107b_{c}$
CHKFO-22	64_{f}	82.5_{d}	100_{d}	SENF-47	41_{g}	70_{e}	90_{e}
ASOK-23	190_{b}	90_{bc}	107_{bc}	KSDM-48	64_{f}	82.5_{d}	102.5_{cd}
Q-24	75_{e}	110_{a}	120_{a}	DIQ-49	64_{f}	87.5_{cd}	108.5_{b}
INF-25	64_{f}	82.5_{d}	102.5_{cd}				

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH),

Appendix table 2. This test controls the comparison-wise error rate, not the experiment-wise error rate. The growth, yield and yield related quantitative trait Means with the same letter are not significantly different.

Landraces Code	LN	LFW	LDW	LDMC	LA	BN	PH	LW	LL	SLA
1	32.05_{op}	467.53_{cd}	79.6_{g}	1.19_{k}	6687.61_{d}	8_{n-p}	59.5_{o}	20.3_{e-g}	26.5_{bc}	84.11_{j-r}
2	81.4_{f}	228.5_{j-n}	29.5_{o}	0.61_{s-t}	4833.6_{j}	25.5_{c}	101.2_{h}	15.6_{k-m}	18.9_{m-p}	164.4_{d-k}
3	116.5_{a}	216.3_{k-o}	26.1_{p}	0.27_{xy}	9908.4_{a}	21_{e}	126.5_{d}	17.5_{ij}	18.8_{n-p}	380.7_{c}
4	106.4_{c}	176.6_{n-r}	23.3_{qr}	0.24_{x-z}	9841.4_{a}	25.34_{c}	116_{e}	13.7_{n-p}	15.1_{u-x}	424.2_{c}
5	106.6_{c}	325_{g-i}	89.9_{f}	1.3_{ij}	6878.4_{c}	21.8_{de}	143.6_{a}	13.4_{pq}	15.8_{t-v}	76.6_{k-r}
6	6.0_{u}	101_{r-u}	15.3_{xy}	0.64_{q-s}	2398.6_{xy}	1_{u}	49.2_{pq}	27.1_{b}	25.5_{b-e}	156.8_{e-l}
7	49.1_{jk}	92.8_{s-v}	16.1_{v-y}	0.84_{no}	1908.66_{z}	10.7_{k-m}	133.6_{c}	16.6_{jk}	18_{o-r}	119.1_{p}
8	5.4_{u}	277.9_{h-l}	39.2_{m}	3.43_{c}	1143.39_{z}	1.0_{u}	40.8_{st}	29.8_{a}	25.9_{b-d}	29.2_{p-r}
9	81.85_{f}	131.7_{q-t}	16_{w-y}	0.47_{vw}	3403.8_{r}	16.5_{fg}	96.8_{i}	12.1_{r}	15.6_{t-w}	213.4_{d-g}
10	96.2_{d}	107.2_{r-u}	14_{yz}	0.27_{xy}	5217.6_{i}	16.34_{fg}	87.8_{jk}	12.3_{qr}	15.9_{t-v}	374.1_{c}
11	44.7_{kl}	80_{s-v}	11.65_{z}	0.41_{w}	2898.9_{u}	13_{h-k}	140.2_{b}	14.4_{m-p}	16.3_{r-v}	249_{d}
12	73.15_{g}	147.7_{o-s}	19_{tu}	0.44_{vw}	4304.1_{m}	15.17_{gh}	133.1_{c}	15.7_{k-m}	19_{m-p}	227.5_{d-f}
13	111.55_{bc}	123.8_{q-t}	17.6_{u-x}	0.29_{x}	6081.99_{f}	20.84_{e}	109.6_{f}	15.8_{kl}	18.5_{n-q}	346.6_{c}
14	21.5rs	739.97_{a}	145.8_{a}	3.36_{c}	4340.1_{m}	5.84_{p-t}	30.8_{wx}	23.7_{c}	29_{a}	29.8_{p-r}
15	42.6_{lm}	407.7_{d-f}	20.2_{st}	0.51_{u-w}	4024.9_{o}	7.33_{n-p}	37.9_{tu}	19.6_{e-g}	23.1_{f-i}	199.3_{d-h}

16	74.55$_{g}$	277$_{h-l}$	37.9$_{m}$	0.52$_{t-v}$	7357.1$_{b}$	14.17$_{g-j}$	95.8$_{i}$	15.5$_{k-m}$	17.5$_{p-t}$	194.4$_{d-i}$
17	54.8$_{i}$	199.2$_{m-q}$	37$_{m}$	0.94$_{lm}$	3955.5$_{op}$	12$_{j-l}$	129.1$_{d}$	15.8$_{kl}$	19.9$_{l-o}$	106.9$_{i-r}$
18	16.6$_{st}$	448.1$_{c-e}$	46.5$_{j}$	1.44$_{h}$	3237$_{s}$	4.67$_{r-t}$	21$_{z}$	19.7$_{e-g}$	22.7$_{g-j}$	69.63$_{l-r}$
19	29.3$_{mn}$	351.9$_{f-h}$	42.4$_{kl}$	0.93$_{mn}$	4560.6$_{l}$	7.67$_{n-p}$	42.8$_{rs}$	18.1$_{hi}$	20.9$_{j-l}$	107.7i-r
20	50.6$_{ij}$	378.1$_{e-g}$	47.4$_{ij}$	0.72$_{pq}$	6545.9$_{e}$	7.5$_{n-p}$	50.85$_{p}$	20.6$_{ef}$	22.2$_{i-k}$	138.3$_{g-n}$
21	36.45$_{no}$	736.23$_{a}$	128.8$_{c}$	2.2$_{f}$	5983.6$_{g}$	6.34$_{p-s}$	46.9$_{q}$	22.3$_{d}$	25.9$_{b-d}$	46.5$_{o-r}$
22	97.55$_{d}$	54.9$_{t-v}$	7.05$_{z}$	0.16$_{z}$	4512.1$_{l}$	8$_{n-p}$	110.2$_{f}$	15.4$_{k-m}$	17.9$_{p-s}$	677.12$_{a}$
23	6.85$_{u}$	290.9$_{h-k}$	42.7$_{kl}$	1.6$_{g}$	2715.11$_{v}$	1$_{u}$	38.1$_{tu}$	28.7$_{a}$	25,7$_{b-e}$	63.71$_{m-r}$
24	69.9$_{g}$	397.3$_{d-g}$	57.5$_{h}$	0.86$_{m-o}$	6694.9$_{d}$	9.67$_{l-n}$	60.8o	15.8$_{kl}$	20.7$_{k-m}$	116.6$_{h-p}$
25	61.85$_{h}$	201.1 $_{l-q}$	23.9$_{pq}$	0.44$_{vw}$	5446.9$_{h}$	15.17$_{gh}$	87.2$_{jk}$	15.9$_{kl}$	18.7$_{n-p}$	227.9$_{d-f}$
26	6u	242.8$_{j-n}$	44.4$_{k}$	3.13$_{d}$	1423$_{z}$	1.0$_{u}$	27.2$_{x-z}$	20.6$_{ef}$	20$_{l-n}$	32.03$_{p-r}$
27	108.4$_{bc}$	233.3$_{j-n}$	25.6$_{p}$	1.22$_{kl}$	2099.7$_{z}$	36.67$_{a}$	82.8$_{l}$	7.6$_{t}$	10.7$_{z}$	82.33$_{k-r}$
28	16.25t	674.88$_{a}$	100.4$_{e}$	2.8$_{e}$	3905.6$_{pq}$	3.67$_{t}$	26.9$_{yz}$	24.1$_{c}$	26.6$_{b}$	38.93$_{o-r}$
29	34.85$_{no}$	136.7$_{p-s}$	17.7$_{u-w}$	0.58$_{s-u}$	3071.3$_{t}$	12.17$_{jk}$	100.7$_{h}$	14.4$_{m-p}$	18.2$_{o-r}$	173.7$_{d-j}$
30	16t	277.2h-l	32.8$_{n}$	1.35$_{i}$	2431.24$_{x}$	4.2$_{st}$	23.8$_{z}$	20.e	24.2$_{d-h}$	74.21$_{k-r}$
31	112.0$_{ab}$	31$_{uv}$	3.2$_{z}$	0.31$_{x}$	1046.7$_{z}$	31.84$_{b}$	58.7$_{o}$	4.1$_{v}$	6.9$_{z}$	342.3$_{c}$
32	81.45$_{f}$	327.6$_{g-i}$	7.55$_{z}$	0.16$_{z}$	4702.6$_{k}$	17.83$_{f}$	113.8$_{e}$	9.7$_{s}$	12.2$_{yz}$	626.2$_{ab}$
33	92.0$_{e}$	227.5$_{j-n}$	32.4$_{n}$	0.78$_{op}$	4159.8$_{n}$	14.67$_{g-i}$	107.3$_{fg}$	11.1$_{r}$	13.9$_{w-y}$	128.4$_{h-o}$

34	33.8_{op}	175.7_{n-r}	29_{o}	0.89_{mn}	3251.6_{s}	14.67_{g-i}	85.7_{j-l}	19.1_{gh}	19.9_{l-o}	112.2_{h-q}
35	15.6_{t}	586.94_{b}	131.5_{b}	4.3_{b}	3048.5_{t}	4_{st}	17.2_{z}	19.2_{gh}	24.7_{c-f}	23.2_{qr}
36	53.9_{ij}	299_{h-j}	48.9_{i}	2.1_{f}	2343.3_{y}	10.8_{k-m}	67.7_{n}	15_{l-n}	18.1_{o-r}	47.92_{n-r}
37	108.95_{bc}	257.9_{i-m}	19.4_{tu}	1.26_{i-j}	1542_{z}	23.83_{cd}	67.8_{n}	6.5_{tu}	8.6_{z}	79.6_{k-r}
38	51.85_{ij}	275.7_{h-l}	37.9_{m}	1.46_{h}	2599.97_{w}	12.67_{i-k}	85.4_{kl}	14.8_{l-o}	16.6_{r-u}	68.8_{l-r}
39	36.5_{no}	230.1_{j-n}	28.6_{o}	0.62_{sr}	4653.1_{k}	5_{q-t}	26.85_{yz}	19.5_{fg}	28.5_{a}	163_{d-k}
40	7.2_{u}	197_{m-q}	41.6_{l}	1.57_{g}	2652.6_{vw}	1_{u}	32.4_{vw}	23.6_{c}	23.9_{e-i}	63.9_{m-r}
41	100.7_{d}	77.5_{s-v}	10.25_{z}	0.27_{xy}	3841.7_{q}	15.33_{gh}	89.3_{j}	14.6_{l-p}	17.4_{p-t}	375.98_{c}
42	28.9_{pq}	197.2_{m-q}	30.2_{o}	1.03_{l}	2943.4_{u}	6.83_{o-r}	45.8_{qr}	20.9_{e}	22.7_{g-j}	97.6_{j-r}
43	5.45_{u}	503.1c	109.3_{d}	5.8_{a}	1900.9_{z}	1_{u}	27.2_{x-z}	23.4_{cd}	24.4_{d-g}	17.42_{r}
44	32.4_{op}	149.7_{o-s}	21.6_{rs}	1.3_{ij}	1666.6_{z}	12_{j-l}	95.2_{i}	11.3_{r}	13.4_{xy}	77.2_{k-r}
45	36.15_{no}	86.8_{s-v}	12.6_{z}	0.42_{vw}	3030.8_{z}	13.84_{h-j}	88.1_{jk}	13.6_{op}	16.1_{s-v}	241.8_{de}
46	5.75_{u}	210_{l-p}	29.3_{o}	2.08_{f}	1404_{z}	1_{u}	32.3_{uv}	19.5_{fg}	22.5_{h-j}	48.1_{n-r}
47	110.3_{bc}	20.7_{v}	3.85_{z}	0.18_{yz}	2233.8_{z}	23.34_{cd}	105.6_{g}	5.5_{u}	8.7_{z}	580.5_{b}
48	25.8_{qr}	103.7_{r-u}	16.6_{v-x}	0.7_{p-r}	2403.8_{xy}	11_{k-m}	72.9_{m}	11.2_{r}	14.4_{v-x}	145.9_{g-m}
49	20.5_{st}	106.4_{r-u}	18.3_{t-v}	1.27_{i-k}	1440.1_{z}	9_{m-o}	28.8_{xy}	11.4_{r}	15.2_{u-x}	79_{k-r}

Where, leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), specific leaf area (SLA)

Appendix Table 3.Phenological, growth and yield related quantitative trait comparison wise error rate, means with the same landraces name are not significantly different.

Replication	N	Trait	Mean	Duncan Grouping		Mean	Trait	N	Replication
1	(49)	FFD	94.3	A	A	94.5	FFD	(49)	2
1	(49)	MD	83.3	B	A	85.1	MD	(49)	2
1	(49)	DFH	101.1	B	A	102.6	DFH	(49)	2
1	(49)	LN	54.463	A	B	52.645	LN	(49)	2
1	(49)	LFW	260.63	A	A	253.08	LFW	(49)	2
1	(49)	LDW	38.673	A	A	38.32	LDW	(49)	2
1	(49)	LDMC	1.2106	A	A	1.2059	LDMC	(49)	2
1	(49)	LA	3863.7	A	B	3837.3	LA	(49)	2
1	(49)	BN	11.85	A	A	11.932	BN	(49)	2
1	(49)	PH	73.802	A	A	73.171	PH	(49)	2
1	(49)	LW	16.71	A	A	16.637	LW	(49)	2
1	(49)	LL	19.42	A	B	19.02	LL	(49)	2
1	(49)	SLA	169.81	A	A	178.89	SLA	(49)	2

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), specific leaf area (SLA) and number of landraces (N)

Appendix table 4. Mean of block with replication

Rep	block	N	FFD	DM	DFH	LN	LFW	LDW	LDMC	LA	BN	PH	LW	LL	SLA
1	1	7	77.0	82.1	100.1	70.5	250.9	40.1	0.7	6080.5	15.2	104.4	17.7	20.3	203.4
1	2	7	88.7	80.0	97.7	63.6	229.8	37.5	1.2	3942.1	12.6	92.0	17.8	20.2	214.7
1	3	7	116.9	89.3	105.0	47.1	399.9	51.4	1.0	5105.7	8.6	60.3	18.9	21.9	123.9
1	4	7	110.4	87.1	104.4	54.0	302.9	43.3	1.4	3831.7	10.9	62.4	18.3	20.3	154.9
1	5	7	93.1	80.0	98.7	56.0	253.6	37.1	1.2	3110.1	13.7	72.7	14.1	17.4	193.9
1	6	7	93.4	81.4	100.1	55.9	218.4	30.8	1.2	2951.7	11.6	60.3	16.5	19.5	126.1
1	7	7	80.3	82.9	101.6	34.2	169.1	30.5	1.7	2024.4	10.4	64.5	13.8	16.5	171.9
2	1	7	119.7	90.0	104.4	37.9	302.9	45.2	2.0	3368.6	6.9	62.6	19.6	21.6	199.3
2	2	7	90.4	82.9	100.7	56.6	229.5	28.2	1.0	3392.7	13.8	73.6	15.6	17.6	122.9
2	3	7	59.0	86.4	102.9	77.9	189.3	27.1	0.7	4614.9	17.0	92.1	13.6	16.2	241.2
2	4	7	93.6	84.3	100.7	48.9	242.7	25.1	0.8	4610.8	11.9	76.7	16.3	19.5	258.7
2	5	7	90.3	81.4	99.3	60.6	195.7	39.3	1.2	3743.9	12.4	84.9	15.7	17.3	169.3
2	6	7	73.7	80.7	100.7	61.0	170.6	22.9	0.7	3770.0	15.2	76.4	16.3	18.1	197.0
2	7	7	134.6	90.0	109.3	25.7	441.0	80.4	2.2	3360.4	6.3	45.9	19.5	22.8	63.8

Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), specific leaf area (SLA) and number of block (N)

Appendix table 5. Landraces total treatment mean

Acc. code	Rep	FFD	MD	DFH	LN	LFW	LDW	LDMC	LA	BN	PH	LW	LL	SLA
1	2	75	90	107	32.1	467.5	79.6	1.2	6687.6	8.0	59.5	20.3	26.5	84.1
2	2	64	85	102.5	81.4	228.5	29.5	0.6	4833.6	25.5	101.2	15.6	18.9	164.4
3	2	64	95	106	116.5	216.3	26.1	0.3	9908.4	21.0	126.5	17.5	18.8	380.7
4	2	41	70	90	106.4	176.6	23.3	0.2	9841.4	25.3	116.0	13.7	15.1	424.1
5	2	41	70	90	106.6	325.0	89.9	1.3	6878.4	21.7	143.6	13.4	15.8	76.6
6	2	190	90	108.5	6.0	101.0	15.3	0.6	2398.6	1.0	49.2	27.1	25.5	156.8
7	2	64	85	105	49.1	92.8	16.1	0.8	1908.7	10.7	133.6	16.6	18.0	119.1
8	2	190	95	107	5.4	277.9	39.2	3.4	1143.4	1.0	40.8	29.8	25.9	29.2
9	2	41	70	90	81.9	131.7	16.0	0.5	3403.8	16.5	96.8	12.1	15.6	213.4
10	2	41	70	90	96.2	107.1	14.0	0.3	5217.6	16.3	87.8	12.3	15.9	374.1
11	2	64	85	102.5	44.7	80.0	11.7	0.4	2898.9	13.0	140.2	14.4	16.3	249.0
12	2	64	85	102.5	73.2	147.7	19.0	0.4	4304.1	15.2	133.1	15.7	19.0	227.5
13	2	41	70	90	111.6	123.8	17.6	0.3	6082.0	20.8	109.6	15.8	18.5	346.6
14	2	180	95	108.5	21.5	740.0	145.8	3.4	4340.1	5.8	30.8	23.7	29.0	29.8
15	2	180	95	107	42.6	407.7	20.2	0.5	4024.9	7.3	37.9	19.6	23.1	199.3
16	2	64	82.5	102.5	74.6	277.0	37.9	0.5	7357.1	14.2	95.8	15.5	17.5	194.4
17	2	64	82.5	102.5	54.8	199.2	37.0	0.9	3955.5	12.0	129.1	15.8	19.9	106.9
18	2	180	95	106	16.6	448.1	46.5	1.4	3237.0	4.7	21.0	19.7	22.7	69.6
19	2	75	90	106	39.3	351.9	42.4	0.9	4560.6	7.7	42.8	18.1	20.9	107.7
20	2	75	90	108.5	50.6	378.1	47.4	0.7	6545.9	7.5	50.9	20.6	22.2	138.3
21	2	180	95	108.5	36.5	736.2	128.8	2.2	5983.3	6.3	46.9	22.3	25.9	46.5

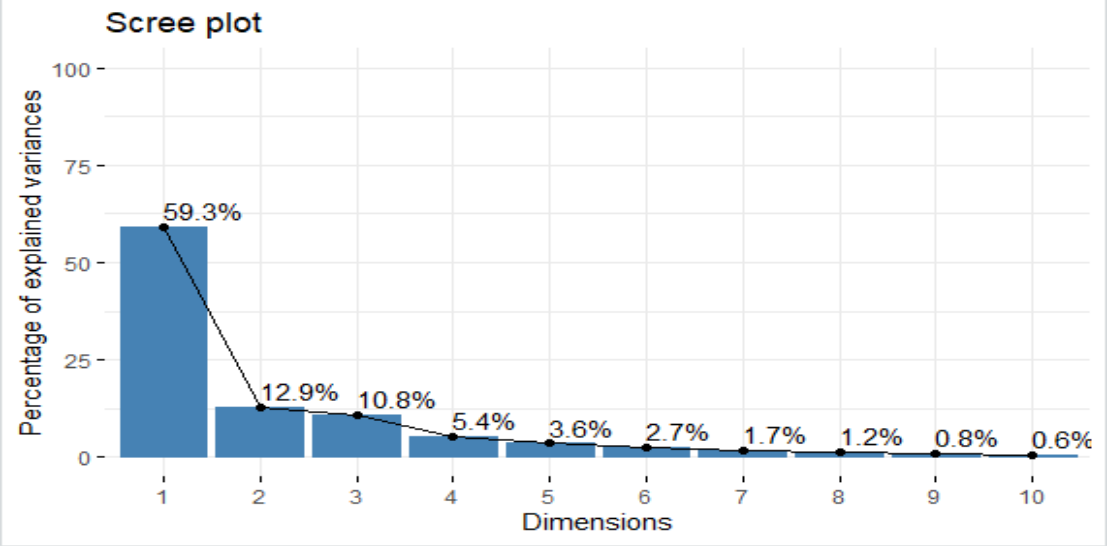
22	2	64	82.5	100	97.6	54.9	7.1	0.2	4512.1	8.0	110.2	15.4	17.9	677.1
23	2	190	90	106	6.9	290.9	42.7	1.6	2715.1	1.0	38.1	28.7	25.7	63.7
24	2	75	110	120	69.9	397.3	57.5	0.9	6694.9	9.7	60.8	15.8	20.7	116.6
25	2	64	82.5	102.5	61.9	201.1	23.9	0.4	5446.9	15.2	87.2	15.9	18.7	227.9
26	2	180	90	106	6.0	242.8	44.5	3.1	1423.1	1.0	27.2	20.6	20.0	32.0
27	2	30	70	90	108.4	233.3	25.6	1.2	2099.7	36.7	82.8	7.6	10.7	82.3
28	2	175	90	108.5	16.3	674.9	100.4	2.6	3905.6	3.7	26.9	24.1	26.6	38.9
29	2	64	82.5	100	34.9	136.7	17.7	0.6	3071.3	12.2	100.7	14.4	18.2	173.6
30	2	180	90	106	16.0	277.2	32.8	1.3	2431.2	4.2	23.8	20.9	24.2	74.2
31	2	41	70	90	112.0	30.9	3.2	0.3	1046.7	31.8	58.7	4.1	6.9	342.3
32	2	41	70	90	81.5	327.2	7.6	0.2	4702.6	17.8	113.8	9.7	12.2	626.2
33	2	41	70	90	92.0	227.5	32.4	0.8	4159.8	14.7	107.3	11.1	13.9	128.4
34	2	75	90	108.5	33.8	175.7	29.0	0.9	3251.6	14.7	85.7	19.1	19.9	112.1
35	2	210	90	108.5	15.6	586.9	131.5	4.3	3048.5	4.0	17.2	19.2	24.7	23.2
36	2	75	90	106	53.9	299.0	48.9	2.1	2343.3	10.8	67.7	15.0	18.1	47.9
37	2	30	70	90	109.0	257.9	19.4	1.3	1542.0	23.8	67.8	6.5	8.6	79.6
38	2	64	85	102.5	51.9	275.7	37.9	1.5	2600.0	12.7	85.4	14.8	16.6	68.7
39	2	190	90	106	36.5	230.1	28.6	0.6	4653.1	5.0	26.9	19.5	28.5	163.0
40	2	190	90	108.5	7.2	197.0	41.6	1.6	2652.6	1.0	32.4	23.6	23.9	63.9
41	2	41	70	90	100.7	77.4	10.3	0.3	3841.7	15.3	89.3	14.6	17.4	376.0
42	2	64	82.5	102.5	28.9	197.1	30.2	1.0	2943.4	6.8	45.8	20.9	22.7	97.6
43	2	190	90	106	5.5	503.1	109.3	5.8	1900.9	1.0	27.2	23.4	24.4	17.4
44	2	64	82.5	102.5	32.4	149.7	21.6	1.3	1666.6	12.0	95.2	11.3	13.4	77.2
45	2	64	82.5	102.5	36.2	86.8	12.6	0.4	3030.8	13.8	88.1	13.6	16.1	241.8

46	2	75	90	106	5.8	210.0	29.3	2.1	1404.0	1.0	35.3	19.5	22.5	48.1
47	2	41	70	90	110.3	20.7	3.9	0.2	2233.8	23.3	105.6	5.5	8.7	580.5
48	2	64	82.5	102.5	25.8	103.7	16.6	0.7	2403.8	11.0	72.9	11.2	14.4	145.9
49	2	64	87.5	108.5	20.5	106.4	18.3	1.3	1440.1	9.0	28.8	11.4	15.2	79.0

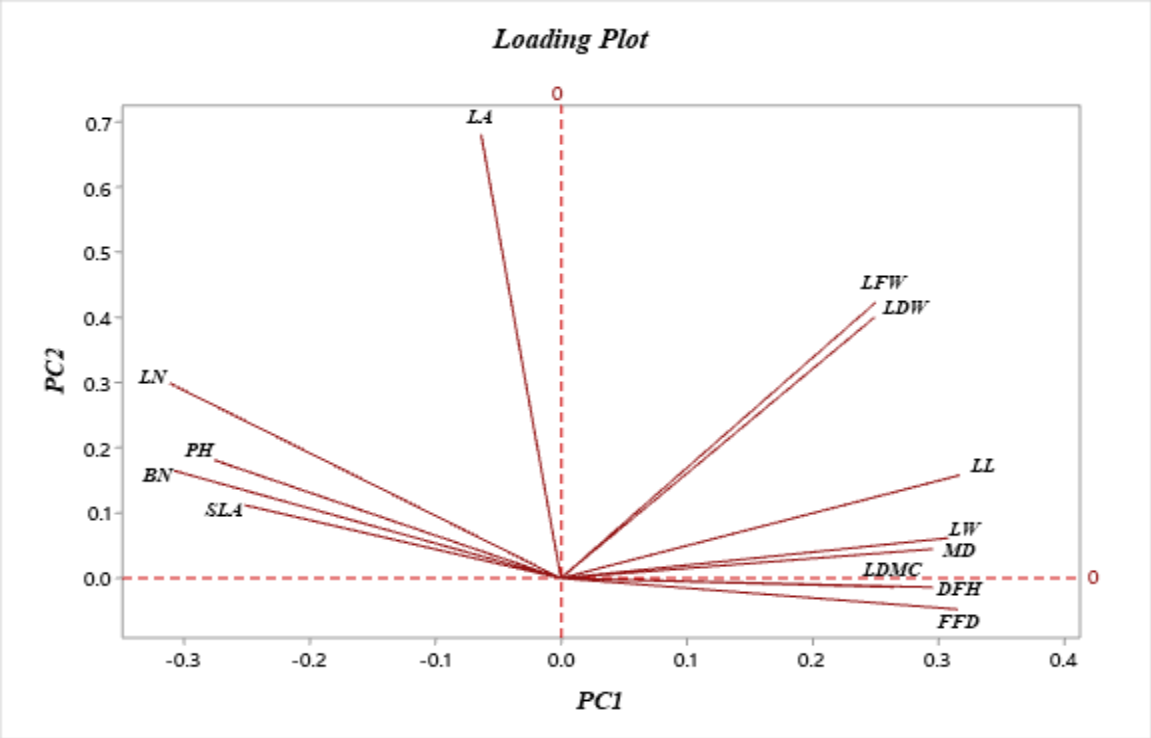
Where, first flowering date (FFD), maturity date (MD), day to first harvest (DFH), leaf number (LN), leaf fresh weight (LFW), leaf dry weight (LDW), leaf dry matter content (LDMC), leaf area (LA), branch number (BN), plant height (PH), leaf width (LW), leaf length (LL), specific leaf area (SLA)

Appendix table 6. Estimates of phenotypic variances, genotypic variances, heritability of broad sense, genotypic coefficient of variation, phenotypic coefficient of variation, genetic advances and genetic advance as percentages of mean for quantitative trait of *Brassica carinata* landraces from Ethiopia

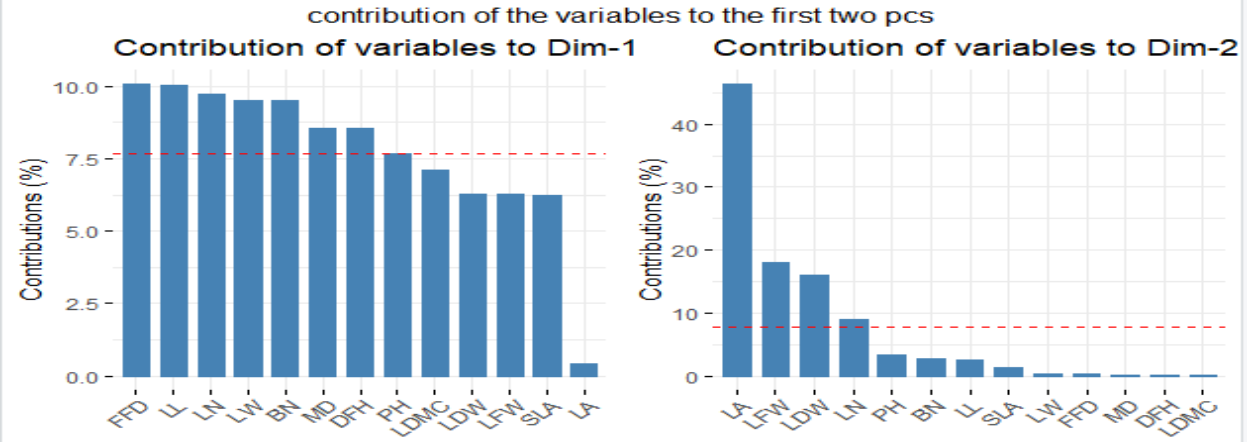
Quantitative Traits	X-mean	Landraces MS	σ2g	σ2p	σ2e	GCV (%)	PCV %	H2b (%)	GA (%)	GAM (%)
First flowering date (FFD)	94.4	6436	3217.45	3218.55	1.1	60.11	60.12	99.97	116.83	123.80
Maturity Date (MD)	84.2	156.83	74.72	82.12	7.4	10.27	10.76	90.99	16.98	20.18
Day to first harvest (DFH)	101.8	96.33	46.27	50.07	3.8	6.68	6.95	92.41	13.47	13.23
Leaf number (LN)	53.6	2316.5	1155.5	1160.9	5.4	63.5	63.6	99.54	69.9	130.5
Leaf fresh weight (LFW)	256.9	47536.4	23237.5	24298.9	1061.4	59.3	60.7	95.63	307.1	119.6
Leaf dry weight (LDW)	38.5	1898.0	948.5	949.5	1.0	80.0	80.0	99.89	63.4	164.7
Leaf dry matter content (LDMC)	1.2	2.2	1.1	1.1	0.00198	87.4	87.4	99.82	2.2	179.8
Leaf area (LA)	3850.5	6791333.2	3394929.0	3396404.2	1475.2	47.9	47.9	99.96	3794.8	98.6
Branch number (BN)	11.9	122.3	60.6	61.7	1.1	65.5	66.1	98.23	15.9	133.7
Plant height (PH)	73.5	2310.0	1153.6	1156.5	2.9	46.2	46.3	99.75	69.9	95.1
Leaf width (LW)	16.7	55.7	27.7	28.0	0.3	31.6	31.7	98.80	10.8	64.6
Leaf length (LL)	19.2	46.8	23.1	23.7	0.7	25.0	25.3	97.21	9.8	50.8
Specific leaf area (SLA)	174.4	45192.7	21901.2	23291.5	1390.3	84.9	87.5	94.03	295.6	169.6



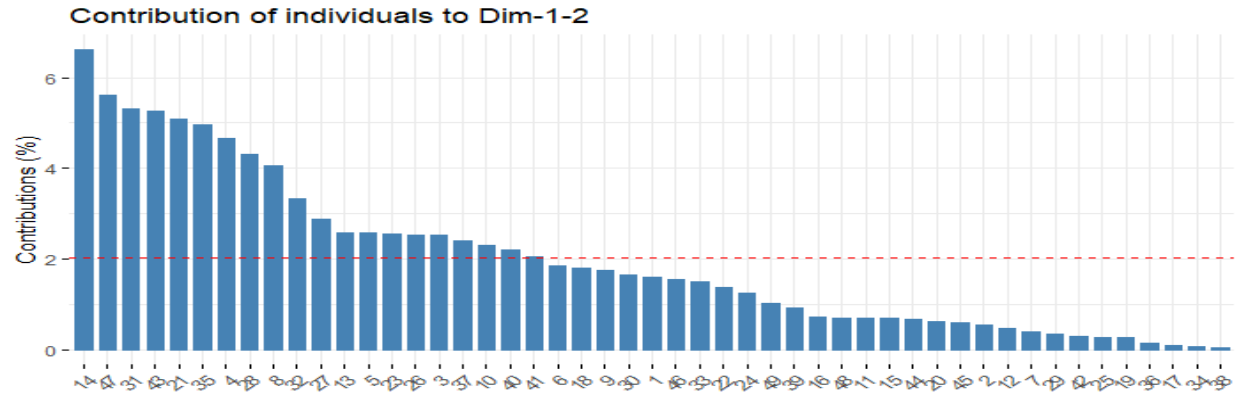
Appendix figure 1. The scree plot of 13 quantitative traits analyzed by PCA



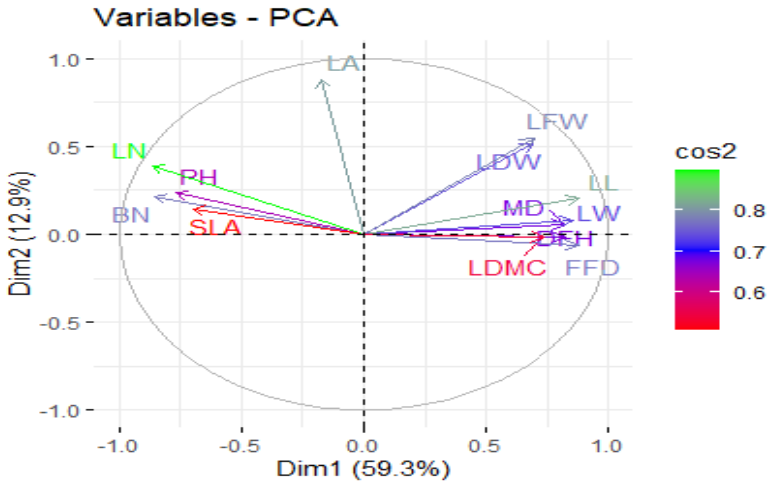
Appendix figure 2. The loading plot visualize the relationship between the original variables and the principal components (PC1 and PC2)



Appendix figure 3. The chart visualize the contribution of variables to dimension one and two of the first two principal components



Appendix figure 4. The chart visualize the contribution of individual to dimension-1 to dimension-2



Appendix figure 5. The biplot visualize the relationship between variables and the principal components (PC1 and PC2)

Appendix table 7. Cluster Centroids

Variable	Cluster1	Cluster2	Cluster3	Cluster4	Grand centroid
First flowering date (FFD)	-0.41	-0.89	1.53	-0.47	0
Maturity day (MD)	0.68	-1.39	0.80	0.10	0
Day to first harvest (DFH)	0.67	-1.48	0.72	0.27	0
Leaf number (LN)	0.33	1.30	-1.00	-0.40	0
Leaf fresh weight (LFW)	0.33	-0.55	0.88	-0.55	0
Leaf dry weight (LDW)	0.13	-0.52	0.82	-0.41	0
Leaf dry matter content (LDMC)	-0.45	-0.59	0.96	-0.16	0
Leaf area (LA)	1.27	0.20	-0.34	-0.57	0
Branch number (BN)	0.20	1.08	-1.02	-0.10	0
Plant heght (PH)	0.12	0.69	-1.12	0.41	0
Leaf width (LW)	0.13	-1.03	1.13	-0.25	0
Leaf length (LL)	0.25	-1.07	1.10	-0.26	0
Specific leaf area (SLA)	0.02	1.00	-0.65	-0.29	0

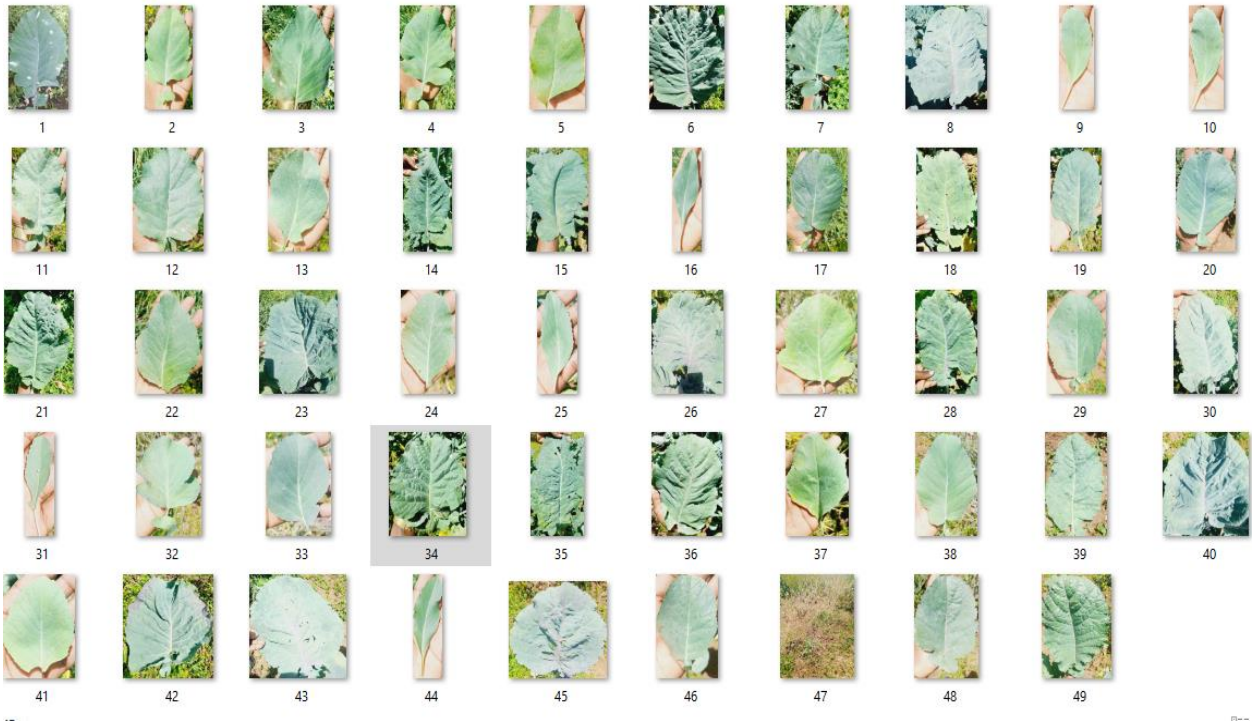
Appendix table 8. Distances between Cluster Centroids

	Cluster1	Cluster2	Cluster3	Cluster4
Cluster1	**0**	4.19	4.01	2.50
Cluster2	4.19	**0**	6.86	3.68
Cluster3	4.01	6.86	**0**	4.11
Cluster4	2.50	3.68	4.11	**0**

Appendix table 9. Final Partition of cluster

Cluster number	Number of observations	Within cluster sum of squares	Average distances from centroid	Maximum distances from centroid	Landraces percentages %
Cluster1	8	37.97	2.09	3.13	16.33
Cluster2	13	79.55	2.34	3.51	26.3
Cluster3	14	85.98	2.38	3.41	28.57
Cluster4	14	39.38	1.61	2.75	28.57

Appendix figure 6. The *Brassica carinata* landraces descriptions characterized and evaluated in Hulla



Appendix figure 7. The leaf blade shape of 49 *Brassica carinata* landraces leaf characterization and evaluated in Hulla

Appendix figure 8. Different data collection for leaf evaluation of *Brassica carinata* landraces

SKETCH OF BIOGRAPHY

The was born in Ethiopia, Somali Regional State, Dawa zone, Hudet Woreda on 1997 G.C, From his Mother AbibaAdan and Hassen Guyo. He attended his elementary, secondary and preparatory Education in Hudet primary school and Hudet secondary and preparatory school, respectively. He joined University of Kabridaharin 2017G.C academic year and graduated with BSc. Degree in Plant Sciences. He joined Hawassa University to pursue a master of science Degree in plant and Horticultural sciences in 2015 E.C.