GROWTH, REPRODUCTIVE AND YIELD RESPONSES AND OIL CONTENT OF ETHIOPIAN MUSTARD (*Brassica carinata* A. Braun) GENOTYPES AT DIFFERENT ALTITUDES

MSc. THESIS

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ADVISORS' APPROVAL SHEET

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This is to certify that thesis entitled "**Growth, Reproductive and Yield Responses and Oil content of Ethiopian mustard (*Brassica carinata* A. Braun) Genotypes at Different Altitudes**" 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 **Yenenesh Tefera Wolde** ID. No SGS/Hort/019/10, 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.

.....	.....	.....
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We, the undersigned, members of the Board of Examiners of the final open defense by **Yenenesh Tefera Wolde** have read and evaluated her thesis entitled "**Growth, Reproductive and Yield Responses and Oil Content of Ethiopian Mustard (*Brassica carinata* A. Braun) Genotypes at Different Altitudes**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree **Masters of Science** in Plant Science with specialization in **Horticulture.**

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Final approval and acceptance of the thesis is contingent up on the submission of the final copy of the thesis to the School of Graduate Studies (SGS) through the Department/School of Graduate Committee (DGC/SGC) of the candidate's School.

DEDICATION

I would like to dedicate this thesis to my mother Masresha Alemu for nursing me with affection and devoted her life above all to educate me and for her dedication in shaping me from early school age and paving the way for the success of my life.

DECLARATION

First, I declare that this thesis is my bonafide work and that all sources of materials used for the thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an MSc degree in Horticulture at Hawassa University and is deposited at the University Library to be made available for borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOCS	American Oil Chemists Society
℃	Degree centigrade
Cm	centimeter
CRD	Completely Randomized Design
CSA	Central Stastical Agency
E.C	Ethiopian Calender
EBI	Ethiopian biodiversity institute
gm	gram
HARC	Holleta Agricultural research Center
Kg/ha	Kilogram gram per hectar
Km	Killometer
KOH	Potassium Hydroxide
LSD	Least Significant Difference
m	meter
m.a.s.l	meter above sea level
mm	millimeter
N	Nitrogen
P2O5	phosphorous pentaoxide
PH	power of Hydrogen
SNNPR	Southern Nations Nationalities and People's Region
tons/ha	tones per hectar
U.S.A	United States of America

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GROWTH, REPRODUCTIVE AND YIELD RESPONSES AND OIL CONTENT OF ETHIOPIAN MUSTARD (*Brassica carinata* A. Braun) GENOTYPES AT DIFFERENT ALTITUDES

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Abstract

*Ethiopian mustard (Brassica carinata A. Braun) is an important vegetable and oil seed crop in the highlands of Ethiopia. The crop has attracted a lot of interests in recent years due to its potential as a feedstock and as a biofuel crop. However, there are little research effort towards the crop in terms of productivity and optimized agronomic requirements. The seed and oil yield of the crop is constrained by a number of factors among which the growing climate is the paramount factor. Therefore, a pot experiment was conducted at three locations with varying altitudes to investigate the impact of altitude on phenology, reproduction, growth, yield and oil content of 11 Brassica carinata genotypes. The study was conducted from January 2011 to June 2011, at three altitudes i.e. high (Bale Goba, 2743 masl), mid (Arsi Negele, 2043 masl) and low (Dilla, 1416 masl)) under irrigated condition using 11genotyp of Brassica carinata which resulted in 33 treatments. The factorial experiment was laid out in a completely randomized (CRD) design with three replications as pot experiment in a controlled edaphic condition. Data were collected on phenological and reproductive traits, growth parameters, yield and yield related traits and oil content. The result of the study revealed that interactions between altitude and genotype very highly significantly ($p<0.0001$) influenced all characters, except number of leaves per plant and pod length which were only influenced by the main factors. Increasing the altitude from low to high delayed the time for all the studied phenological traits. As a result, the number of days for 50% emergence, 50% flowering and 90% maturity were increased from 6.33 to 17.67, 50 to 107.33 and 92.67 to 147 respectively and the earliest genotypes to attain days to 50% emergence and days to50% flowering were 23601 respectively. The genotype to attain shortest days to maturity (92.67 days) was genotype 21338 at lower altitude. Reproductive traits showed an increase with increasing altitude. Hence the highest flower number per plant (218.6) was attained from genotype 23601 at higher altitude. Similarly Yield and yield components are also increased with increasing altitude. The maximum seed yield per hectare (194556Kg) was recorded from genotype 23601 at high altitude followed by the genotypes 202488(*1538.89*Kg) and 215187(1503.33Kg) at mid altitude. The highest oil percentage (41.79%) was recorded from genotype yellow dodolla at the same altitude. Hence, from the result it can be concluded that, high and mid altitudes respectively were appropriate to maximize Brassica carinata seed and oil yield. However, since the experiment was done only for one season and with limited number of genotypes repeating the experiment over different seasons with more number of genotypes at field condition will be demanding to come up with plausible recommendation.*

Keywords: *Brassica carinata*, Reproductive and Yield response, Oil content, Genotype, Altitude

1. INTRODUCTION

The Ethiopian Mustard (*Brassica carinata* A.Braun), locally known as "Gomenzer" or *"*Yabesha gomen" is among the oldest crops cultivated in Ethiopia (Zemede, 1997). It is a native herbaceous plant species of Eastern Africa and one of the most interesting oilseed crops for energy purposes in the Mediterranean region (Licata *et al.,* 2017). *Brassica carinata* is an amphidiploid species (BBCC, n = 17) containing the BB genome of *B. nigra* (n = 8) and CC genome of *B. oleracea* (n = 9) (UN,1935). It is believed that the crop is originated in the highlands of Ethiopia and adjoining portion of East Africa and the Mediterranean coast and has been cultivated there as an oilseed and vegetable crop since ancient times (Copani *et al*., 2009; Gomez-Campo and Prakash, 1999; Hemingway, 1995)

In Ethiopia, *Brassica carinata* is mainly grown in Arsi, Bale, Sidama, Gonder, Gojam, Wollo, Shewa and Wellega (Getinet and Nigussie, 1997). It grows well in either a heavy sandy loam or light clay soils with a good drainage system. *Brassica carinata* is well adapted to cool, long growing season and high rainfall areas at elevation between 2200 and 2800 meters above sea level. In these areas, the temperature and rainfall range is from 12 to 18 ^{0}C and 500 to 1200 mm, respectively during the growing season (i.e., June to December) (Getinet and Nigussie, 1997).

In Ethiopia, among the highland oilseeds, *Brassica carinata* stands third next to Noug (*Guizotia abyssinca* Casa) and Linseed (*Linumum statismum* L) in total production and area cultivated (CSA, 2013/2014). Traditionally, the crop is used for many purposes such as greasing tradition al bread-baking clay pan, curing certain diseases (treating certain ailments and stomach upset) and as a source of vegetable relish (Nigussie, 2003). As a vegetable, it has special nutritional components like vitamins, minerals, trace elements, dietary fiber and protein. It also gives zest

and flavor of diets (Tsige *et al*., 2005; Zemede, 1992). Additional advantage of Ethiopian mustard is also immense in the farming systems as a potential rotational-crop with cereals and pulses. Broad statures of the leaves make canopy and suppress weeds, making the crop tolerant to weed infestation. It is also known to improve soil structure and aeration due to the deep rooting nature of the crop (Doweny and Robbelen, 1989).

In addition to the above uses genetically diverse species of *Brassica carinata* have considerable potential as an oilseed crop (Nigussie and Becker, 2002). Due to the current interest in biofuels and bio industrial feed stocks, *Brassica carinata* is considered as a suitable crop for the production of oils enriched in the specialty fatty acids required for these applications (Gonzalez-Garcia *et al*., 2009 ;Cardone *et al.*, 2003; Getinet *et al*., 1994).

Brassica carinata is mostly cultivated at different agro-ecologies including temperate, tropical and subtropical regions as a cold weather crop. The crop has shown better adaptability and productivity than *Brassica napus* under unfavorable environmental conditions and low cropping systems, for its flowering earliness, resistance to lodging, large seed size and good shattering resistance, as well as both drought and heat tolerance (Sharma *et al.*, 2017;Pan *et al.*, 2012; Stamigna *et al.*, 2012). Nigussie and Becker (2002) identified *Brassica carinata* accessions with potential genes for early maturity, higher yield components and oil and protein content. Pan *et al.* (2012) also indicated the presence of higher degree difference of the performances of the genotypes of *Brassica carinata* in terms of seed yield and oil quality under contrasting environments. Hence, evaluation of genotypes' performance and studying the trait characters is as essential to recommend site specific genotypes and agronomic practices. Moreover, there is a need to identify the key production practices, agro ecology and genotype screening for achieving optimum seed and oil yield (Pan *et al.*, 2012).

It is well known that environmental and soil factors such as; rainfall, altitude, day length, light intensity, temperature, humidity, wind speed and soil factors such as soil type, soil nutrient content and soil pH affect the growth, development and yield of a crop and crop adaptation to a particular environment (Breda, 2008). More importantly, phenological events and developments are very important determinants of yield and yield attributes of crops. Temperature and to lesser extent photoperiod have been reported to be the major environmental factors that determine the timing and duration of each of the phenological phases of crops in general and *Brassica carinata* specifically (Roberts *et al*., 1993). But, since Ethiopia is located between 3^0 24' and 14^0 53' North Latitude and 32^0 42' and 48^0 12' East Longitude from equator (Yalden, 1983; Breitenbatch, 1963) and has almost equal day length throughout the year, fluctuation in temperature and range of growing temperature has more significance than the photoperiodic responses in determining time of flowering and other growth traits.

The varying altitude (agro-ecology) affects crop growth, morphology, yield and oil content in terms of varying temperature. As the altitude increases temperature decreases and vice versa, such that many crop simulation models correlated the rate of growth during most of the phenophases to temperature (Ritchie, 1991; Summerfield *et al.*, 1991). Plants require certain temperature conditions at different stages of growth and reproduction. *Brassica carinata* behaves differently under different environmental conditions that are based on prevailing temperature during the crop life cycle. Variation in maximum and minimum temperature largely alters the growth pattern of the crop by affecting the duration as well as the onset of different phenophases (Dutta *et al.*, 2011).

Temperature controls the duration starting from germination to the end of vegetative phase and from stem elongation to mid flowering stages (Gabrielle *et al.*, 1998). The rate of growth in each of these stages is hastened by increasing temperature at lower altitudes (Morrison *et al.*, 1989). Mills (1993) indicated that, temperature affects the number of days from seed sowing to germination in Canola plant (*Brassica napus* L.).

Previous research on rapeseed indicates that at lower altitudes with increasing temperature the growth stages, duration between germination, emergence to the end of vegetative phase and from stem elongation to mid flowering stages the rate of growth is hastened (Gabrielle *et al.*, 1998). However lower seed and oil yield is attained due to the reduction of the crop growing period at lower altitudes due to low degree days accumulated affecting the dry matter accumulation and partitioning (Tubiello *et al.*, 2007).

Furthermore, previous reports by Dar *et al.*(2017) and Barker *et al*.(2007) indicated that the oil content of *Brassica carinata* is also influenced by genotype and environmental conditions. Considering the diversity of agro-ecological conditions in the areas where the plants are grown, the oil content of Brassica species is largely influenced by temperature fluctuations at different altitudes. Longer reproductive phase and cooler temperature at higher altitudes at the time of seed development stage of the crop is favorable for high seed yield and good quality oil (Fayyaz-ul-Hasan *et al.*, 2005).

However, as most studies/experiments plants are grown under constant temperature conditions, in controlled environments, the effect of temperature at different altitudes on flowering, growth and yield of the plant is less understood. Therefore, understanding the role of fluctuating and difference in temperature at different altitudes on growth and flower development of *Brassica carinata* genotypes is paramount to utilize and recommend genotypes at different growing

conditions especially in Ethiopia. In addition to this, even if *Brassica Carinata* has wider adaptability and comparative tolerance to biotic and abiotic stresses as compared to other Brassica species grown as oilseeds its production is far below the national average (Fekadu, 2020). Under such a situation, it becomes very important to identify genotypes which perform better and give higher production and quality of seed and oil across different environments or locations with varying altitudes.

1.1. General Objective

- To assess the growth, Reproductive and yield responses as well the oil content of eleven *Brassica carinata* A. Braun genotypes at three different altitudes with varying temperature ranges in Bale Goba, Arsi Negele and Dilla.

1.2. Specific Objectives

- To investigate the growth, Reproductive and morphological responses of *Brassica carinata* genotypes at different altitudes.
- To investigate yield and yield attributes of *Brassica carinata* genotypes at different altitudes
- To study oil content of *Brassica carinata* genotypes at different altitudes.

2. LITERATURE REVIEW

2.1. Origin and Distribution of Brassica *carinata* A .Braun

Ethiopian Mustard (*Brassica. carinata* A. Braun) is believed to have originated in the highlands of the Ethiopian plateau and the adjoining portion of East Africa and the Mediterranean coast (Gomez-Campo and Prakash, 1999).It is distributed and has been cultivated in different parts of the world, including Southern Africa (Zambia), West Africa (Sierra Leon and Guinea) and in Asia (India, China, Bangladesh and Indonesia) as a vegetable crop along with other members of the genus (Gomez-Campo and Prakash, 1999). This crop is also extensively cultivated in Eastern Europe and U.S.A as animal and fish fodder ((IENICA, 2004) .

It has also a potential as an oilseed crop in other countries like Canada (Rakow, 1995), Spain (Velasco *et al*., 1997), India (Singh *et al*., 2018)and U.S.A (Cardone *et al*., 2002). This is because the crop is better heat and drought tolerant than any other Brassica species. Therefore, it is well adapted to oilseed production under semi-arid conditions(BioMatnet, 2006).

2.2. Botanical Description of *Brassica Carinata*

Brassica carinata A.Braun belongs to the family Cruciferae (Brassicaceae) (Hatam and Abbasi, 1994 ;Williams,1989),which contains about 338 genera and 3709 species (Warwick *et al.*, 2006). About 159 species are included in the genus Brassica (Zhou *et al.*, 2006 ; Zhou,2001), of which six are economically important species namely; *Brassica rapa*, *Brassica oleracea*, *Brassica nigra*, *Brassica juncea*, *Brassica napus* and *Brassica carinata* (Doweny and Robbelen, 1989).

Cytotaxonomic evidences suggest that from these species *Brassica carinata* A. Braun (n=17) is an amphidiploid species evolved through natural hybridization between *Brassica nigra* (BB, n=8) and *Brassica oleracea* (CC, n=9), followed by chromosome doubling in the highlands of

Ethiopia and the adjoining regions of East Africa and the Mediterranean coast where both the parental species were sympatric (Simmond, 1999; Hemingway, 1995). The evolutionary relationship of *Brassica carinata* and other oilseed Brassicas is usually illustrated by U–triangle (Fig. 1), which had got this name from Japanese scientist Nicolas (1935) who developed the relationship triangle.

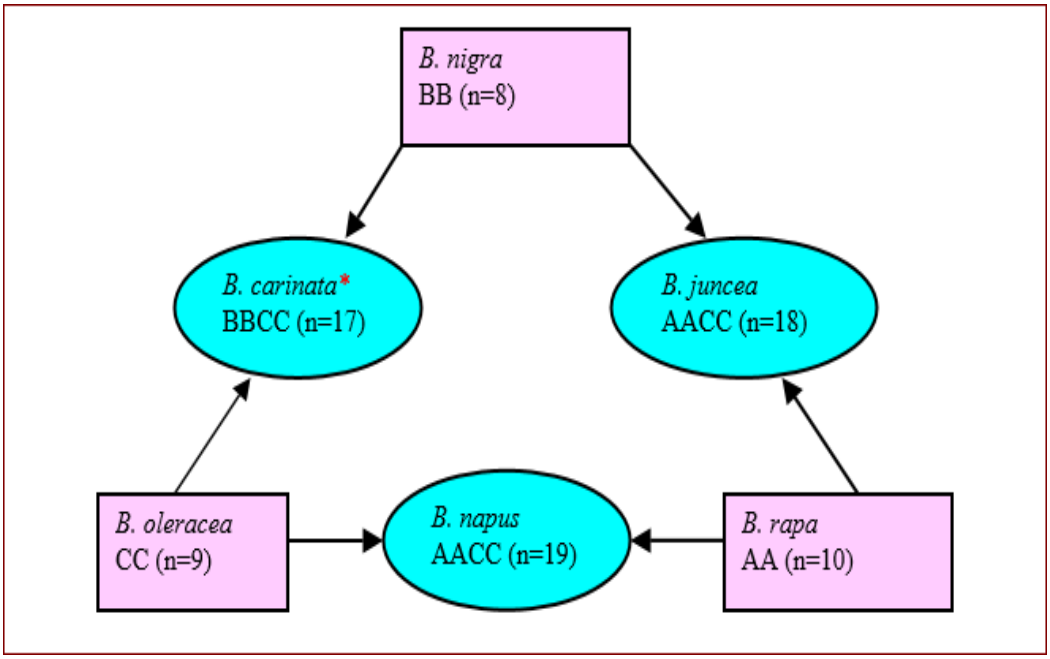

Figure1.Genomic relationships of the major oil seed Brassica spp. (after U, 1935)

In the figure (U's triangle), the three diploid species are represented at the tips of the triangle and their amphidiploids are found midway between the parental species. Letters with in parentheses denote haploid chromosome number of diploid and amphidiploid species.

Brassica carinata is an erect annual, occasionally biannual or perennial crop grown as oilseeds or as a leafy vegetable which is 0.9-1.8 m tall at flowering. The seedling of the crop emerges

with epigeal germination, whereby the cotyledons appear above the ground that enables them to be photosynthetically active to offset the negative consequences of insufficiency of the reserve food within the seed (Seepaul *et al.*, 2019). *Brassica carinata* develops a substantially elongated taproot reaching up to one meter or more with numerous laterals. The stem and leaves are green or deep green with many branches and short petiole respectively (Rakow, 2004).

Brassica carinata reproduces sexually, through both cross and self-pollination, sets seed and does not demonstrate potential for asexual reproduction (Mnzava and Schippers, 2007). Its pollen, like other Brassicaceae, is heavy, sticky and is dispersed by wind as much as 10 meters from its source and transfer via insects had been detected up to 3-4 km away (Adeniji and Aloyce, 2012). Due to its flower structure and delayed anthesis (Cheung *et al*., 2015), *Brassica carinata* has been reported to cross-pollinate only 30% of the time (Cheung *et al*.,2015; Velasco and Fernandez, 2009) and Self-pollination has been occurred from 46–88% of the time (Labana *et al*., 1987).

The inflorescence of *Brassica carinata* is an elongated raceme, born terminally on the main stem and branches. Flowers are ebracteate, pediculate, complete, hypogynous, actinomorphic and perfect attached on a short pedicel and are regular with four free sepals in one series and two sets of stamens. The fruit is a silique, usually less than 5 cm long and dehiscent. The seed is large and predominantly dark, often globular, 0.2 cm thick, filled with embryo (Andargie, 2006; Edwards *et al*., 2000). Flowering is indeterminate, beginning at the lowest end on the main shoot and continues upward (Mnzava and Schippers, 2007). The flowers are typically bright-yellow although flower color varies from orange to creamish white (Setia and Richa, 1989).

2.3. Importance of *Brassica carinata*

2.3.1. Nutritional importance of *Brassica carinata*

Brassica carinata has long been known to be one of the oldest crops in the plateaus of east Africa (Gomez-Campo & Prakash, 1999). Especially for the small-scale farmers, it is a security crop, because it is a source of vegetable and income at the time of acute food and income shortage that mostly occurs at the middle of the main rainy season (July to August).

According to Barker *et al.* (2007), *Brassica carinata* was categorized as one of the most important traditional East African vegetables both in the amount of crop area and human nutrition together with *Brassica juncea*, *Brassica napus* and *Brassica oleracea*. Unlike the nutritive value of white cabbage the nutrient composition of these green leaf cabbages is high. *Brassica carinata* cultivar TexSel greens, grown in northeast Africa are reported to be higher in protein content than spinach (Warwick *et al.*, 2006). Reports of *Brassica carinata* seed protein analysis revealed high content of amino acids like glutamic acid, arginine and proline (Malik,1990). Therefore, Ethiopian Mustard can be an alternate choice by improving the oil and protein contents of already adapted high yielding oilseed varieties (Nigussie, 2003).

2.3.2. Economic importance of *Brassica carinata*

Brassica carinata is traditionally used for many purposes, such as greasing traditional bread making clay pan, curing certain ailments and preparing beverages (Nigussie, 2003). The oil is also used for cooking in the country, usually adulterated with oils from Niger seed or Linseed. The crop has several industrial uses; according to (Gonzalez-Garcia *et al*., 2009) bioethanol can be synthesized from *Brassica carinata* oil using KOH (Potassium hydroxide) as catalyst. *Brassica carinata* can also be used for arsenic intoxicated soil treatment as a biofumignt; the

plant has the ability to tolerate arsenic toxicity by accumulating the substance in its leaves like its parents *Brassica oleracea* and *Brassica nigra* (Artus, 2002).

Brassica carinata could also be used in pharmaceuticals, hirudin a pharmaceutical protein commonly used as anticoagulants to prevent thrombosis has been successfully expressed and purified in seeds of *Brassica napus* and *Brassica carinata* (Miao *et al*., 2008). Nervonic oils extracted from *Brassica carinata* can be used as chemical feedstock in a number of industrial applications including polymers and polymer blends like Nylon, polyurethane plastics and foams, coatings and adhesives including modified epoxide resins and glues, composite materials and cosmetic formulations (Stymne, 2008).

2.3.3. Agronomic importance of *Brassica carinata*

Brassica carinata is known for its agronomic qualities which are rare or absent in other oilseed Brassica species. These include relatively large seed size (Getinet *et al*., 1996), high heat and drought tolerance, good resistance to blackleg disease and reduced amount of pod shattering problem providing more time, easier to complete mechanical harvesting and variability in seed oil content (Gugel *et al*., 1990). It is also resistant to insect pests like aphids and flea beetles and some accessions have high levels of resistance to alternaria black spot. Moreover, *Brassica carinata* is a promising oilseed crop for semi-arid areas where it has better agronomic performance than its close relative *Brassica napus* L. (DeHaro *et al*., 1998).

For use as a leafy vegetable, the preferred traits are large leaf size, late flowering, many leaves per plant and tolerance to major diseases and pests. *Brassica carinata* produces the greatest number of leaves and in height clearly exceeded both parental species and others. In the case of

stem biomass also, *Brassica carinata* was much larger than any other Brassica species(Courtney *et al*., 2005).

2.3.4. Importance of *Brassica carinata* as oil crop

Brassica carinata is a promising oil crop that could offer the possibility of exploiting for industrial uses; from its oil several oleo chemicals can be derived for industrial application and after an industrial processing they can be used for bio-diesel (Seegeler *et al*., 1983). The oil is used in the production of cosmetics, detergents, lubricants and biodegradable material substitutes of plastics. This crop also produces a big quantity of biomass that can be used as burning materials for energy production (Seegeler *et al*., 1983). Apart from this, its oil is indeed of immense importance in leather tanning, manufacturing of varnishes, diesel fuel, in tannery, bio pesticide production, in textile and cosmetics industries, soap and lamps (Tesfaye *et al*., 2014 ;Nigussie and Becker, 1999).

Genetically diverse species of *Brassica carinata* have considerable potential as an oilseed crop (Nigussie and Becker, 2002). With the current interest in biofuels and bio industrial feed stocks, *Brassica carinata* is considered as a suitable crop for the production of oils enriched in the speciality fatty acids required for these applications. The oil content of *Brassica carinata* varies, ranging from 20-45% depending on the variety (Nigussie and Becker, 1999). *Brassica carinata* oil contains 30 to 40% erucic acid (22:1), which is indigestible for human and animal organisms; rather they are suitable for industrial applications such as cosmetics and biodiesel (Gonzalez-Garcia *et al*., 2009; Bouaid *et al.*, 2005; Cardone *et al.*, 2003; Getinet *et al*.,1994). With a growing population, dwindling petroleum supplies and the low carbon dioxide impact of biofuels, demands for plant oils is increasing (Durrett *et al*, 2008).

2.4. Agro-ecological requirement and production management of *Brassica carinata*

Brassica carinata grows in most parts of Ethiopia at medium to high altitudes ranging from 2200 to 2800 m.a.s.l, in areas of the country where rain fall and temperature amount ranges from 500–1200 mm and 12-18 ^{o}C, respectively during the growing season (i.e., June to December). *Brassica carinata* is rather versatile and can be found in highland regions up to 2800 m.a.s.l with a cool climate, but also in lowlands with relatively warm and dry seasons under irrigation when there are few pests and diseases (Zemede, 1997).

Brassica carinata is widely adapted and performs well in a range of soil conditions, providing that moisture and fertility levels are adequate. In some potential areas where *Brassica carinata* is grown in large scale, the crop prefers moderately heavy and well drained soils with pH of 6.5-7.6 (Nigussie *et al.*, 1996). It prefers light medium to heavy soils and grows better in well – drained moist soil (Hiruy, 1985). *Brassica carinata* is able to tolerate low levels of salinity, however, there are severe reductions in plant growth at high levels of salinity (Canam *et al.*, 2013). Its ability to tolerate salinity better than other Brassica species (Asharf and McNeilly *et al.*, 2008) is hypothesized to be due to improved water use efficiency (Asharf, 2001).

Drought tolerance in *Brassica carinata* is related to the better developed root system (Liang *et al.*, 1992). An excessively low relative humidity with high temperatures can result in failure of seed germination and fertilization. Moisture stress combined with higher temperature from flowering to maturity significantly decreases the number of pods, number of seeds, seed weight and oil content (Singh *et al*., 2018).

Brassica carinata is long maturing species that gives an advantage of higher yield due to its long growing season in the areas where rain fall amount and distribution is optimum (Hiruy, 1985).

Field research in the central highlands of Ethiopia confirmed that higher yields for oil seed Brassica can be obtained when the crop is planted during the on-set of the main rainy season (Hiruy and Nigussie, 1986). For most localities, this time is expected to occur between late May and mid-June.

Previous research on *Brassica carinata* shows that, the length of time to reach flowering and maturity differs with in different accessions; there were accessions which flowered within 22 days and others 63 days after transplanting. This range of variation provided ample scope for selection of early, medium and late flowering accessions. Accessions that flowered on average of 22 days after transplanting are considered as early maturing group. At the other extreme, accessions that flowered between 53 and 63 days after transplanting constitute the late maturing group and the accessions that lie in between are considered as mid maturing (Adeniji and Aloyce, 2012).

According to the agronomic studies by Hiruy and Nigussie (1986), a seed rate of 10-15 kg/ha with a fertilizer rate of 46/69 Kg/ha of N/P2O5 is optimum depending on the season and planting techniques. In Ethiopia, among the highland oilseeds, *Brassica carinata* stands third next to Noug (*Guizotia abyssinica* cass.) and Linseed (*Linum usitatisimum* L.) in total production and area (CSA, 2013/2014). Its area and production are estimated to 44041.34 hectares and 62450.266 tons, respectively, at private peasants' holdings level, with an average productivity of 1.418 tons/ha (CSA, 2013/2014).

2.5. The Effect of different Agro-ecologies on plant growth and development

Environmental conditions influence crop growth and development which are the most vital factors to reduce crop productivity (Franklin *et al.,* 2010). Environmental factors during

flowering stage and grain development period affect quality and productivity of oilseed crops (Ali *et al.*, 2009; Monotti, 2003). In natural environments, plants must overcome many abiotic stresses, such as drought, salt, cold, ultraviolet radiation (UV) and altitude, to complete their life cycles (Ahmed *et al.*, 2016). Katsura *et al*.(2008) and Khush and Peng (19996), reported that the altitude of planting fields is an important environmental factor affecting plant growth, development and yield primarily through temperature effect. Altitudinal gradients cause the climate and environment to differ greatly within a short vertical distance by decreasing air temperature, total atmospheric pressure and partial pressure of all atmospheric gasses and by increasing radiation in the forms of incoming solar radiation, outgoing nighttime thermal radiation and UV radiation (Korner, 2007). Plants growing along high-altitudinal gradients experience interacting stresses, including weathering, dehydration and low temperature (Shepherd and Griffiths, 2006).

The relationship of altitude to temperature is like that of distance from the equator to the arctic poles. According to Miller (2001), temperature decreases by 1^0C for every 100 m increase in altitude in dry air. With the increase of altitude, air density decreases, air temperature decreases gradually, solar radiation intensity increases and ultraviolet rays' intensity becomes strong. In addition, precipitation and precipitation days are affected, consequently affecting growth and eventually affecting the yield and quality in rice plant (Li and Jichao, 2017).

2.5.1. The Effect of altitudes on Growth and morphology of *Brassica Carinata*

The growth of plants can be influenced by the environment for growth. The differences in altitude leads to different climate character elements such as temperature, light and moisture. The lowlands have a relatively high temperature with high light intensity, while the highlands have a

relatively low temperature with low light intensity as well. The physiological processes that govern the transition from one phenophase to another are strongly influenced by environmental factors. Temperature of a growing altitude is a major factor that affects and determines crop growth, development and productivity (Singh and Lallu Singh, 2014; Kaleem *et al.*, 2009; Qadir *et al*., 2007).

Previous research on rice by Wang *et al.* (1984) shows that, altitude affects the morphology of the rice plants in which the height of rice plants shortened with the increase of altitude. Nanda *et al.* (1995) reported that temperature affects the difference between the sowing date and first real leaf appearance and due to this the appearance of the first real leaf was delayed by 1.35 days for each $1^{o}C$ decrease in temperature at higher altitudes. Similarly, Morrison *et al.* (1992) reported that the leaf number of mustard plants is affected by altitude to such an extent that plants produce less leaves when exposed to low temperature at higher altitudes and produce more leaves at lower altitudes.

2.5.2. The Effect of altitudes on Reproductive traits of *Brassica Carinata*

Plant development, particularly the reproductive processes such as pollen development, pollen tube growth and fruit set and plant reproductive traits are highly vulnerable to environmental conditions, particularly temperature. As a cool season crop, both spring and winter canola are extremely sensitive to increasing temperature particularly during reproductive stage including gametogenesis, pollination, fertilization and early embryogenesis (Angadi *et al.*, 2000). One of the major effects of high temperatures is the reduction of reproductive success, which commonly translates into yield loss in agricultural settings (Asseng *et al.*, 2011). These effects have potentially serious impacts on crop yield and can determine the potential to drive adaptation of

reproductive traits to compensate for future temperature increase (Zinn *et al.*, 2010; Hedhly *et al*.,2009).

For example, the negative impact of higher temperatures on reproduction can lead to reduced pollen production, viability and pollen tube growth, with a resulting decrease in seed yield (Zinn *et al.*, 2010). High temperature can also induce flower abortion in Arabidopsis and *Brassica juncea* (Warner and Erwin, 2005; Gan *et al.*, 2004).

2.5.3. The effect of altitude on plant development, Yield and oil content of *Brassica carinata*

The impact of environmental events has already been documented on agricultural crop production, natural species diversity and distribution and other ecosystem services such as flowering time, pollination and etc. (Doney *et al*., 2012; Dale *et al.*, 2001). Many of the physiological processes affecting crop growth and development are also controlled by temperature (South worth *et al*., 2002; Wheeler *et al*., 2000).

Given that temperature at a given growing altitude is a major determinant of the timing and duration of key developmental phases, including flowering growing altitude has significant impacts on key flowering processes (Bahuguna and Jagadish, 2015). Flowering is a primary requirement for plant reproduction and one of the most important agronomic traits for crop production (Tasma *et al.*, 2001).

Flowering time is defined as the duration starting from seed germination till appearance of the first floral bud, open flower or anthesis (external appearance of anthers) which marks the visible transition from the vegetative to reproductive phase (Craufurd and Wheeler, 2009).

Temperature affects flowering time both by affecting the rate of development directly and influencing vernalization (Craufurd and Wheeler, 2009). Slafer (2003) and McMaster *et al.*

(2008) reported that, the phenological development rate and yield of plants are mainly determined by genetically prescribed responses to temperature.

Chmeilewski *et al.* (2004) reported that increased mean temperature and decreased photoperiod caused shortening of developmental phases of annual crops which in turn affects crop yield. With the increase of the altitude and the decrease of the average daily temperature, the whole growth period will be prolonged and takes more time to mature (GU, 1997). Research has indicated that the seed setting rate decreases with the increase of altitude **(**Yuan *et al*., 2005a). The reason is that the lower temperature restrains the transportation and content from the assimilate to grain which cannot be fully made used of (Li and Lin, 1990 and 1987). Rising of 1°C temperature to the normal reduce mustard yield by 450 kg/ha and shortened the maturity period (Anonymous, 2010)**.**

Kumar *et al.* (2010a) reported that increasing temperature at lower altitudes reduced the days to flowering and days to maturity in mustard thus shortening the seed formation period which in turn reduces seed yield. A higher temperature leads to higher respiration rates, reduces biomass production resulted in smaller and lighter grain therefore lower crop yield is obtained due to the reduction of the crop growing period **(**Tubiello *et al*., 2007). As it is indicated in Mendham *et al*. (1981) for each degree rise in temperature, the crop matures 8 days earlier. In addition to this, researches showed that, under high temperature conditions, the loss in crop productivity is mostly related to decreased assimilatory capacity as a result of reduced photosynthesis due to negative impact of above-optimum temperatures on membrane stability and enhanced respiration (Barnabas *et al.*, 2008; Hay and Porter, 2006; Sinsawt *et al*., 2004).

Both location and genotype contribute significantly to the variation in growth, yield and oil content of *Brassica carinata* **(**Johnson *et al*., 2003). The oil content of *Brassica carinata* varies

from 17 to 40% in wild relatives depending on genotype and growing location **(**Kumar *et al*., 1980). Areas receiving higher precipitation give considerably higher oil and protein than the low rainfall areas. Extended reproductive stage and lower temperature at higher altitudes at the time of seed development stage of the crop is promising for high seed yield and good quality oil in Canola (*Brassica napus* L.) **(**Hassan *et al*., 2005). Previous works by Singer *et al*. (2016) and Zhu *et al*.(2012) indicated that, higher temperatures at lower altitudes during the pod-filling stage have been reported to reduce seed oil concentration in oilseed rape.

3. MATERIALS AND METHODS

3.1. Description of the study area

The experiment was conducted from January 2011 to June 2011 E.C for six months at three different locations with different altitude ranges. The experimental sites were: Bale Goba (High altitude, 2743 m.a.s.l), Arsi Negele (Mid-altitude, 2043 m.a.s.l) and Dilla (Low altitude, 1416 m.a.s.l). Bale Goba is located at about 446 km south East of Addis Ababa, capital city of Ethiopia and found in the Bale zone of Oromia Region. Geographically, it is located at 7° 1' 0" North Latitude and 39° 58' 59" East longitude at an altitude of 2743 m.a.s.l. The mean annual rainfall and temperature of the area are 947-1272 mm and 13.3°C, respectively. The yearly average maximum and minimum temperature of the site is 14.4 ^{o}C and 12.3 ^{o}C, respectively.

Arsi Negele is located at about 231 km south of Addis Ababa, capital city of Ethiopia and found in the West Arsi zone of Oromia Region. Geographically, it is located at 7°21’ North Latitude and 38°42’East longitude at an altitude of 2043 m.a.s.l. The mean annual rainfall and temperature of the area are 915-1200 mm and 17.7°C, respectively. The yearly average maximum and minimum temperature of the site is 19.3^{o}C and 16.3^{o}C respectively.

Dilla is located at 360 km south of Addis Ababa, capital city of Ethiopia and found in the Gedeo zone of Southern Nations Nationalities and People’s Region (SNNPR). Geographically, it is located at 6°24’38’’North Latitude and 38°18’37’’East longitude at an altitude of 1416 m.a.s.l. The mean annual rainfall and temperature of the area are 1129 mm and 21.3 °C, respectively. The yearly average maximum and minimum temperature of the site is 30°C and 12.6°C, respectively.

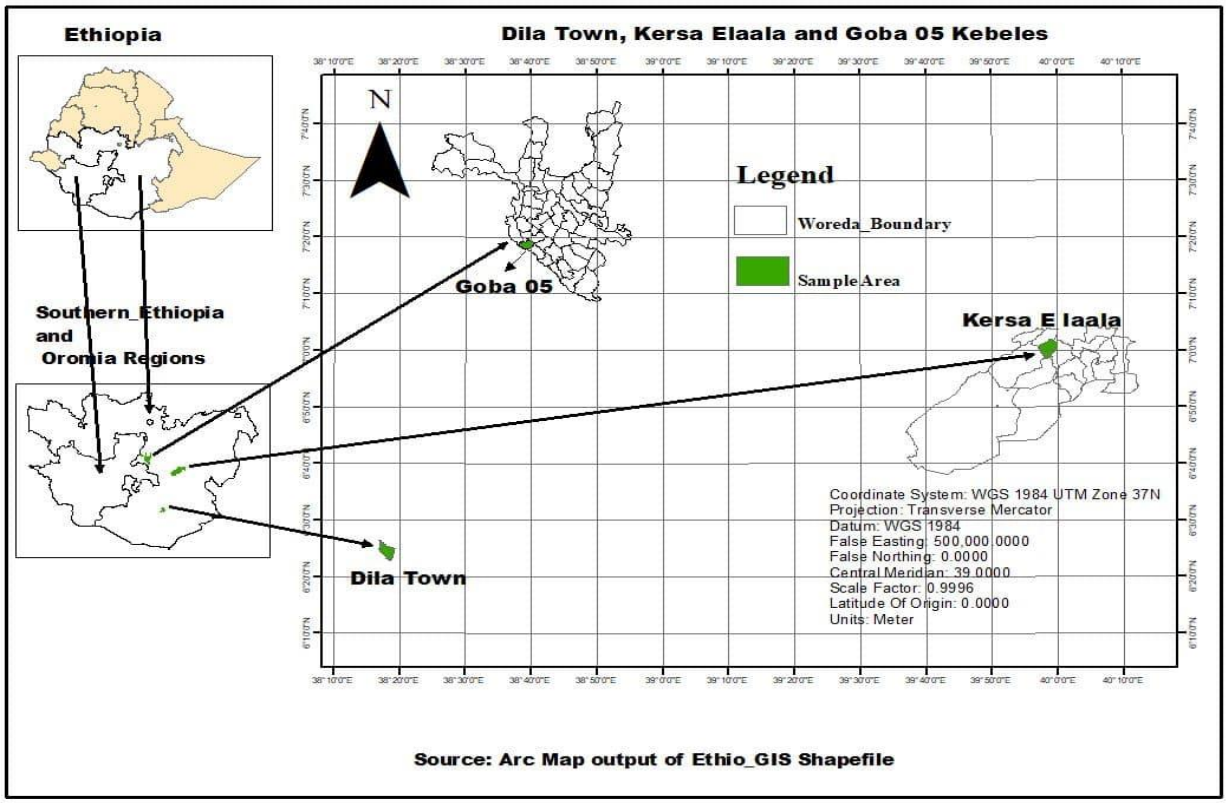

Figure 2.Geographical map of the study areas

3.2. Planting materials

For this study 11 genotypes (five varieties and six accessions) of *Brassica carinata* were used. The varieties were collected from Holleta Agricultural research Center (HARC) and the accessions were collected from the gene bank of Ethiopian biodiversity institute (EBI). The varieties were categorized as three late maturing and two mid maturing varieties (Table.1), among the collected accessions one accession is late maturing which was collected from the highland, one is mid maturing which was collected from mid altitude and four accessions were early maturing which were collected from low altitudes based on passport data and information from EBI. The list of the accessions used in the study is provided in Table 2. Due to the absence of early maturing released varieties of *Brassica carinata* in Ethiopia, accessions collected from

lower altitudes were used as early maturing genotypes to compare their growth and yield responses and oil content.

Table1.List of Ethiopian mustard Varieties used in the study

No	Varieties	Year of Release	Maturity date	Maturity group	Yield (Kg/ha)	Oil content (%)
1	S-67	1984	157	Late maturing	3030	40.5
2	Yellow dodolla	1986	156	Late maturing	3020	44.1
3	Holleta-1	2005	160	Late maturing	3030	39.1
4	Tesfa	2017	154	Mid maturing	2400	46.8
5	Derash	2017	153	Mid maturing	2300	46.8

Source: Highland Oil Crops Progress Report, EIAR, Holleta Center, 2007&2019

Table 2.List of Ethiopian mustard Accessions used in the study

No	Accession Colletion Number	Maturity group	Area of collection	Altitude(m.a.s.l)
1	26684	Late maturing	Amara -Misrak Gojam	2975
2	215187	Mid maturing	Amhara-Semen Wollo	1930
3	202488	Early maturing	Amhara-Semen Wollo	1440
4	17547	Early maturing	Oromiya -Misrak Wellega	1387
5	23601	Early maturing	Benishangul & Gumuz-Metekel	1483
6	21338	Early maturing	Oromiya-Mirab Wellega	1680

Source: Passport data information from EBI

3.3. Experimental Designs, Treatments, procedures and crop management

A pot experiment was conducted in a Completely Randomized Design (CRD) as pot experiment with three replications. The three pots were used as a treatment unit with three plants per pot for each genotype at three locations. The experiment consists a total of 33 treatment combinations, i.e. 11 genotypes of *Brassica carinata* and three locations with different altitudes. All the genotypes were planted in controlled edaphic environment by using growing media composition of 1:1:1 ratio in volume of Compost: Sand: Soil in order to reduce the impact of soil variability at

the different growing locations. The growing media was prepared at Hawassa University College of Agriculture experimental field and filled to the experimental pots before transporting to the experimental sites. Ten liter Plastic pots measuring a height of 25cm, 24 cm wide at the top and 7.5 cm wide at the base with five perforations at the bottom for drainage were used. After filling each pot with the mixture, six seeds of Ethiopian mustard were sown manually at a uniform depth of 2 cm. At 15 days after emergence, plants were thinned to three plants per pot. All Cultural practices required for raising the crop, hand weeding in two weeks interval, watering, thinning and cultivation were properly done.

3.4. Data Collection

3.4.1. Phenological parameters

Dates of 50% Emergence (DE): It was recorded as the number of days from the date of sowing to the date at which 50% of the plants cover the soil.

Days to first flowering (DFF): It was recorded as the number of days from the date of seedling emergence to the date at which the first flower appears in 5% of the plants.

Days to 50 % flowering (DF): It was recorded as the number of days from seedling emergence to a stage at which 50% of the plants are bloomed.

Days to flower completion (DFC): The number of days from seedling emergence until 95% of the plants stopped blooming.

Period of flowering (FP): Days from the beginning of flowering until the end of flowering. It was calculated by subtracting the number of days to first flowering from the number of days to flower completion.

Days to 90% maturity (DM): It was counted as the number of Days from the date of seedling emergence until 90% of the plants have dry or yellowish silique and mature seeds.

3.4.2. Reproductive traits

Flower number/plant (FN): The number of flowers per plant at full bloom stage was counted from three pre sampled plants of each replication and the average was taken by dividing the total no by three.

Petal width (PW): At flowering, petals were removed from three randomly selected newly opened flowers from three pre-sampled plants of each replication to measure petal width and the average was taken by dividing the total sum by nine. It was measured in millimeter (mm).

Petal length (PL): At flowering, petals were removed from three randomly selected newly opened flowers from three pre-sampled plants of each replication to measure petal length and the average was taken by dividing the total sum by nine. It was measured in millimeter (mm).

Pistil height (PSH): At flowering stage, three randomly selected newly opened flowers were removed from three pre-sampled plants of each replication to measure pistil height and the average was taken by dividing the total sum by nine. It was measured in millimeter (mm).

Short Stamen height (SSH): At flowering, three randomly selected newly opened flowers were removed from three pre-sampled plants of each replication to measure Short Stamen height and the average was taken by dividing the total sum by nine. It was measured in millimeter (mm).

Long Stamen height (LSH): At flowering, three randomly selected newly opened flowers were removed from three pre-sampled plants of each replication to measure Long Stamen height and the average was taken by dividing the total sum by nine. It was measured in millimeter (mm).

3.4.3. Growth parameters

Leaf number/Plant (LN): The number of intact leaves or leaf scars per plant at flowering stage was counted from three pre sampled plants of each replication and the average was taken by dividing the total no by three.

Plant height (PH): The height of three pre sampled plants of each replication was measured in centimeter from the bases of or soil surface to the tips of the plant at flowering stage and the average was taken by dividing the total no by three.

Pedicle length (PDL): At harvest, three randomly selected pods were removed from the main stem of three pre sampled plants of each replication to measure pedicle length and the average was taken by dividing the total sum by nine. It was measured in millimeter (mm).

3.4.4. Yield and yield related datas

Number of pods per plant (PD/PL): Number of fully matured and seed filled pods were counted from three pre-sampled plants at 90% physiological maturity and the average was taken by dividing the total no by three.

Number of seeds per pod (SD/PD): The average number of seeds per pod obtained from three randomly sampled pods of each of the three pre-sampled plants from each replication.

Seed yield (SY): The aboveground dry biomass was threshed after sun drying for five days and their seed weight was recorded and expressed in grams.

Thousand Seed weight (TSW): The weight in grams of 1000 seeds sampled from each replication was measured using sensitive balance and multiplied by ten.

Oil content (%): The proportion of oil in the seed to the total oven dried seed weight was calculated manually using scientific calculator.

3.4.5. Oil Extraction and Determination of oil content

Oil extraction was carried out at Hawassa University College of Agriculture Plant Cell Laboratory. From each genotype grown at the three locations, matured seeds were collected and oven dried at 40°C for four hours to reduce the moisture level to 4-5%. The dried seeds were then thoroughly ground with an electric blender. Five grams of grounded seeds were used to extract the oil in the Soxlet apparatus, using petroleum ether as a solvent for six hours according to the AOCS method (AOCS, 1993) and then percentage of oil content was calculated for each sample from the weight of the oil and seeds using the formula,

$$Oil\ content\ (\%) = \frac{\text{Oil weight}}{\text{Seed weight}} \times 100$$

3.5. Data Analysis

Data were subjected to analysis of variance using the procedures outlined by Gomez and Gomez (1984). The ANOVA model used for the analysis was: Yij=μ+Vi+Lj+ (VL) ij+εij Where, Yij= the mean value of the response variable of the ith genotype at the jth altitude and the right hand side of the equation gives the grand mean value (μ) and the respective main and interaction effects of altitudes and genotypes, εij is a random error term due to those uncontrolled factors.

After fitting the ANOVA model for those significant interactions or main effects mean separation was carried out using least significant difference (LSD) test at 5% probability level. Simple correlation analysis between different characters was also computed to observe associations between characters. In order to assess the associations between those measured response variables a core plot correlation procedure was carried out using *corrplot* package (Wei *et al.*,2017). All the statistical analyses were carried out using R stastical software version 3.6.1) (Rcore Team,2019).

4. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) indicated highly significant difference between altitudes and among different tested *Brassica carinata* genotypes for parameters measured such as phenology, reproductive traits, growth and yield parameters and oil content. The details of result interpretation are presented and discussed in the following sections.

4.1. Phenological Parameters

4.1.1. Days to 50% emergence

Days to 50% emergence was very highly significantly (p<0.0001) affected by the interaction effects of altitude and genotypes (Table 3 and Appendix table 1).At the lower altitude (1416 m.a.s.l), genotypes needed less days (six days) for seedlings to emerge and accessions 26684 but 17547 took significantly more days (10.33 days) than all other genotypes (Table 3). At the middle altitude (2043 m.a.s.l), genotypes needed about eight days for seedlings to emerge but accession 26684 tooks significantly more days(14.87 days) than all other genotypes. At the higher altitude (2743 m.a.s.l), most of the genotypes needed about nine days for seedlings to emerge whilst accessions 17547,23601,202488 and 26684 took significantly more days(11 and 17.87 days, respectively) (Table 3). In general, the increase in altitude from low to mid then to high has increased the number of days to seedling emergence**.** Hence the earliest genotype to reach 50% emergence is yellow dodolla (6 days) at lower altitude. Number of days needed from sowing to emergence did not show any relationship with the maturity grouping of the genotypes. That means, genotypes classified based on their time of maturity responded similarly for days to emergence at different altitudes.

On average 8.17, 10.67and 11.24 days were needed for seedlings to emerge at the altitudes of low, mid and high respectively in this study. The results of this study are in agreement with the report of Mendham and Salisbury (1995), who concluded that lower altitudes with increased temperature reduced the duration of all growth stages of canola (*Brassica napus* .L) and vice versa. This may be due to temperature effects of the respective altitudes on the number of days it tooks for seeds to germinate. Seed germination is a biochemical process that involves water absorption, activation and synthesis of enzymes, oxidation of stored food and transport of oxidates within the embryo and initiation of embryonic growth (Mills, 1993). These biochemical processes are highly affected by the surrounding temperature. Thus the relatively higher temperature at lower altitude reduce the time required for the seedlings to emerge as shown by Vigil *et al.* (1997).

4.1.2. Days to first flowering

The interaction effects of the main factors altitude and genotypes were very highly significantly (p<0.0001) affected the days to first flowering (Table 3 and Appendix table 1). At the higher altitude, the genotypes required significantly more days from emergence to first flowering than at the mid and lower altitudes. At lower altitude all genotypes required less than 60 days (two months) to show the first flower except accession 26684 which required about 71 days to produce the first flower (Table 3).Meanwhile accessions 202488, 21338,215187 and 23601 required significantly less days from emergence to first flowering (Table 3).

At mid- altitude, almost all genotypes on average required more than 60 days spanning to 78 days to reach first flowering stage (Table 3). Genotypes 202488, 21338, 215187, yellow dodolla and 23601 required significantly less days from emergence to first flowering (Table 3). Similarly at higher altitude genotypes required over range of 62-86 days to reach first flowering stage

which is the longest as compared to the low and mid altitudes for all the genotypes. Accession 26684 required the longest days to flower across all the altitudes whilst accession 202488 required the shortest days (Table 3). The relatively higher temperature at lower altitude most probably increased the rate of biochemical processes that take place in the plants and thereby reduced the time required for the seedlings to emerge and to bear the first flowers as shown by Vigil *et al.* (1997).

4.1.3. Days to 50% flowering

All genotypes very highly significantly ($P<0.0001$) differ in the number of days needed for 50% of plants to flower across all the altitudes (Table 3 and Appendix table 1). At the higher altitude genotypes required significantly more days from emergence to 50% flowering than at the mid and lower altitudes. The plants required ranges of 43-71 days, 59-96 days and 73-107 days to reach 50% flowering stage at lower, mid and higher altitudes respectively. Genotypes 202488, 21338,215187 and 23601 required significantly less days from emergence to 50% flowering across all altitudes whilst the longest days were recorded for the accession 26684.This is corresponding to the days to emergence and fist day to flowering as discussed above.

The rate of biochemical reactions, including those involved in mechanisms of crops to flower are generally faster at lower altitudes due to the prevalence of higher temperature. Therefore, the reduction in number of days from emergence to 50% flowering at lower altitude as compared to the mid and higher altitudes could be as a result of this catalytic acceleration of biochemical processes involved as also shown in a number of previous studies (Kaesha, 2009; Hepper, 2003; Fitter and Fitter,2002)**.** In this study early maturing canola cultivars required in the range of 44-109 days to flowering, while mid maturing cultivars required between 44-118 days and late maturing cultivars required between 47-124 days to flower depending on environmental

conditions. Robertson (2002) also got an early maturing canola cultivars required in the range of 44-109 days to flowering, while mid maturing cultivars required between 44-118 days and late maturing cultivars required between 47-124 days to flower depending on environmental conditions. Similarly Slauenwhite and Qaderi (2013) reported that there were significant differences between four canola cultivars grown at different temperature with respect to number of days to flowering.

4.1.4. Days to flower completion

The number of, days to flower completion for all genotypes, was very highly significantly (p<0.0001) different across the altitudes (Table 3 and Appendix table 1). In line with days to first flowering and 50% flowering as discussed above, all the genotypes required 28 and 17 more days to complete their flowering at the higher altitude than at the mid and lower altitudes respectively (Table 3). Genotypes required from 66-92, 77-108 and 94-121 days to complete flowering at lower, mid and high altitudes respectively. While genotypes 202488, 21338,215187 and 23601 required significantly less days from emergence to flower completion across all altitudes.

The rate of biochemical reactions, including those involved in mechanisms of crops to flower are generally faster at lower altitudes due to the prevalence of higher temperature. Therefore, the reduction in number of days for flower completion at lower altitude as compared to the mid and higher altitudes could be as a result of this catalytic acceleration of biochemical processes. This result is inline with Robertson (2002) who reported that increased temperature at lower altitudes reduced number of days to flowering in 21 canola cultivars.

4.1.5. Flowering period

This parameter indicates the number of days needed from start of flowering to completion of flowering (period of flowering). All genotypes showed a very highly significant (p<0.0001) difference in flowering period across the different altitude (Table 3 and Appendix table 1). Less period of flowering was obtained from plants grown at the lower altitude than at the mid and higher altitudes (Table 3 and Appendix table 1). The plants needed 20-29 days at low altitude, 24-31 days at mid-altitude and 30-35 days at high altitude for all genotypes from starting of flowering to the end of flowering. The genotypes 202488, 21338,215187 and 23601 required significantly less period for flowering across all the altitudes while accession 26684 required more days as compared to other genotypes.

The rate of biochemical reactions, including those involved in mechanisms of crops to flower are generally faster at lower altitudes due to the prevalence of higher temperature. Therefore, the reduction in number of days for period of flowering at the lower altitude as compared to the mid and higher altitudes could be as a result of this catalytic acceleration of biochemical processes (Kaesha, 2009; Hepper, 2003)**.**

4.1.6. Days to 90% maturity

The analysis of variance revealed that the interaction effects of altitude and genotype very highly significantly (p<0.0001) affected days to 90% maturity (Table 3 and Appendix Table 1). Accordingly the highest days to 90% maturity (147 days) was scored from genotype 26684 at higher altitude while the least (92.67 days) was from genotype 21338 at lower altitude. Increasing altitude from low to mid increased the number of days to 90% maturity by 9.57 days on average, similarly increasing altitude from mid to high increase the number of days to 90% maturity by 17 days on average.

The result from this study showed that, genotypes required significantly more days from emergence to the 90% physiological maturity stage when grown at higher altitude than at mid and lower altitudes. On average about 135.64 days were required from emergence to 90% physiological maturity at higher altitude, 118.57 days at middle altitude and 109 days at lower altitude. This could be attributed due to lower temperatures and higher amount of precipitation at higher altitude which prevented early maturity of the genotypes by maintaining high moisture content and cooler temperature (Kumar *et al.*, 2020; Inamullah *et al*.,2013)**.**

Kumar *et al*. (2010a) also reported that the increase in temperature lowered the days to flowering and days to maturity, which in turn shortens the seed formation period and the total crop duration. A higher temperature leads to higher respiration rates and reduces biomass production resulting in smaller and lighter grain therefore lower crop yield. While plotting relationship of days to maturity against mean temperature it gave nearly a linear relationship, it indicates that each degree rise in temperature the crop mature 8 days earlier (Mendham *et al*.,1981).

Warmer temperatures accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set resulting in poor yield (Morrison, 1996; Rawson, 1992). Nanda *et al*. (1994) reported that reduction in seed yield of Brassica species under lower altitude might be attributed to increase in temperature at the time of pod growth and seed filling stages, which reduced the dry matter accumulation into the seed and shortened the seed-filling period. The crops sown at higher altitude gave higher seed yield due to exposure of higher growing degree-days and extended time to maturity which shows a positive relationship between accumulated growing degree-days with seed yield (Roy *et al*.,2005).

Table 3: Interaction effect of altitude and Brassica carinata genotypes on Phenological traits.

Source of variation		Days to 50% emergence (No)	Days to first flowering (No)	Days to 50% flowering (No)	Days to flower compl etion(No)	Flowering period (No)	Days to 90% Maturity (No)
Altitude	**Genotype**						
	S-67	9.33 ^{def}	63.67 ^{de}	78.33 ^{fg}	98.67 ^{fg}	35 ^{a}	132.67 ^{cd}
	Yellow Dodolla	8.33 ^{fghi}	63 ^{de}	75.33 ^{ghi}	96 ^{ghi}	33 ^{abc}	127.33 ^{ef}
	Holeta 1	8 ^{fghij}	62.67 ^{de}	74.67 ^{ghi}	94.33 ^{hij}	31.67 ^{bcd}	131 ^{de}
	26684	17.67 ^{a}	86 ^{a}	107.33 ^{a}	121.00 ^{a}	34.33 ^{a}	147 ^{a}
	Tesfa	9.00 ^{efg}	72.67 ^{c}	80.33 ^{d}	107 ^{cd}	34.33 ^{a}	141.67 ^{b}
High	Derashe	8.67 ^{fgh}	73 ^{c}	85.67 ^{de}	103.67 ^{de}	30.67 ^{cdef}	135.67 ^{c}
	215187	8.33 ^{fghi}	64.00 ^{d}	74.33 ^{hij}	94 ^{hij}	30 ^{defg}	124.67 ^{fgh}
	202488	10.67 ^{cd}	62.33 ^{de}	73 ^{ijk}	96.33 ^{ghi}	34 ^{ab}	133.33 ^{cd}
	17547	11.33 ^{c}	77 ^{b}	90.67 ^{c}	111.00 ^{bc}	34 ^{ab}	133.67 ^{cd}
	23601	11.33 ^{c}	70.33 ^{c}	85.67 ^{de}	101.67 ^{ef}	31.33 ^{cde}	140.67 ^{b}
	21338	9.00 ^{efg}	77.33 ^{b}	91.00 ^{c}	112 .00 ^{b}	34.67 ^{a}	144.33 ^{ab}
	S-67	7.67 ^{ghijk}	60.33 ^{efg}	76 ^{ghi}	92.67 ^{ij}	31.67 ^{bcd}	128 ^{ef}
	Yellow Dodolla	6.67 ^{jkl}	58.67 ^{fgh}	72.33 ^{ijk}	87.67 ^{k}	29 ^{efgh}	125.67 ^{fg}
	Holeta 1	7.33 ^{hijkl}	61.33 ^{def}	73 ^{ijk}	90.33 ^{jk}	30 ^{defg}	121 ^{hi}
	26684	14.67 ^{b}	78 ^{b}	96 ^{b}	108 ^{bc}	30 ^{defg}	135.33 ^{cd}
	Tesfa	7.67 ^{ghijk}	63 ^{de}	77 ^{gh}	94 ^{hij}	31 ^{cdef}	118.33 ^{ij}
Mid	Derashe	8.33 ^{fghi}	62 ^{def}	74.33 ^{hij}	90.33 ^{jk}	29.67 ^{defgh}	121.33 ^{ghi}
	215187	8.00 ^{fghij}	53.33 ^{jk}	65.00 ^{l}	77.33 ^{no}	24 ^{jk}	112.33 ^{kl}
	202488	8.67 ^{fgh}	48.33 ^{mn}	58.67 ^{mn}	78.33 ^{mno}	30 ^{defg}	107.33 ^{m}
	17547	8.33 ^{fghi}	62.67 ^{de}	74.00 ^{hijk}	93 ^{ij}	30.33 ^{defg}	118.33 ^{ij}
	23601	8.00 ^{fghij}	51.67 ^{klm}	64.67 ^{l}	82.67 ^{l}	30 ^{defg}	114 ^{jk}
	21338	7.67 ^{ghijk}	54.33 ^{ijk}	61.67 ^{lm}	81.67 ^{lm}	27.33 ^{hi}	102.67 ^{n}
	S-67	6.67 ^{jkl}	49.67 ^{lmn}	64.00 ^{l}	78.33 ^{mno}	28.67 ^{fghi}	102.67 ^{n}
	Yellow Dodolla	6.00 ^{l}	52.33 ^{kl}	65.00 ^{l}	80.33 ^{lmno}	28 ^{ghi}	108.67 ^{lm}
	Holeta 1	7.00 ^{ijkl}	54.33 ^{ijk}	63.33 ^{l}	81.67 ^{lm}	27.33 ^{hi}	118 ^{ij}
	26684	10.33 ^{cde}	71.33 ^{c}	82.00 ^{ef}	97.67 ^{fgh}	26.33 ^{ij}	124 ^{fgh}
	Tesfa	6.67 ^{jkl}	57.67 ^{ghi}	70.67 ^{jk}	81.67 ^{lm}	24 ^{jk}	119.67 ^{klm}
Low	Derashe	6.67 ^{jkl}	56.67 ^{hij}	70.33 ^{k}	81.33 ^{lmn}	24.67 ^{jk}	119.67 ^{klm}
	215187	6.67 ^{jkl}	47.33 ^{n}	56.00 ^{no}	70 ^{pq}	22.67 ^{k}	99.67 ^{no}
	202488	6.67 ^{jkl}	43.3 ^{o}	50.67 ^{p}	66.33 ^{q}	23 ^{k}	96.33 ^{op}
	17547	10.33 ^{cde}	51.67 ^{klm}	63.00 ^{l}	76.33 ^{o}	24.67 ^{jk}	107.67 ^{m}
	23601	6.33 ^{kl}	48.33 ^{mn}	57.00 ^{n}	72 ^{p}	23.67 ^{k}	99.67 ^{no}
	21338	7.00 ^{ijkl}	46.33 ^{no}	52.67 ^{op}	66 ^{q}	19.67 ^{l}	92.67 ^{p}
	LSD(0.05)	**1.43**	**3.59**	**3.98**	**4.09**	**2.57**	**4.62**
	CV (%)	**10.14**	**3.63**	**3.35**	**2.79**	**5.43**	**2.36**

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation

4.2. Reproductive Traits

4.2.1. Number of flowers per plant

Interaction effect of altitude and genotype showed very highly significant difference (p<0.001) on number of flowers per plant (Table 4 and appendix table 2). The highest number of flowers per plant was recorded from genotype 23601 (218.67) at high altitude, whereas the least number of flowers per plant was observed from genotype Tesfa (52.33) at lower altitude. Genotypes 23601, 202488, 17547, 21338 produce relatively more flowers at lower altitudes as compared to the remaining genotypes. Although all genotypes showed a decrease in the number of flowers when grown at lower altitude as compared to mid and higher altitude, but differences were only very highly significant when going from high to low altitudes for genotypes 23601, 202488, 17547, 21338 and 215187. The number of flowers produced by different genotypes did show relationship with their maturity grouping as early maturing genotypes produce relatively higher number of flowers per plant across all altitudes while mid maturing genotypes and late maturing genotypes produced lower number of flowers per plant and did not show much variability across altitudes. Hence early maturing genotypes 23601 and 202488 gave the highest flower number at higher altitude (Table 4).

These variations could be due to the flower inhibitory effect of high temperatures at lower altitude on flowering and lack of Optimum soil moisture at the time of flowering of the crop especiallyat loweraltitude.This result is in agreement with the works of Sreelanthakumary and Rajamony (2004); Durner *et al*. (2002);Geleta (1998) and Faby (1997) who indicated that , the inhibitory effect of high temperatureshould be considered during the flowering period. The reduction in number of flowers recorded at the lower altitude could be attributed to the fact that the higher temperature at the lower altitude reduced the duration of different growth stages, so

that plants had less time to develop many flowers. Similar results were reported by Kutcher *et al*.(2010) who found that high temperatures during vegetative growth reduced number of flowers produced per plant.

4.2.2. Petal width (mm)

Very Highly Significant difference was observed from the interaction effect of altitudes with genotypes at (p<0.0001) concerning petal width. Genotypes did differ with regard to petal width when grown at different altitudes (Table 4 and appendix table 2).Consequently, genotypes 215187 and Holleta-1 scored the highest values for petal width (8.9mm and 8.83mm) at higher altitude. Whereas the smallest width of petals was obtained from genotype 17547 (3.98 mm) at lower altitude (Table 4).

In general most of the genotypes tend to produce wide petals at higher and mid altitudes than at lower altitudes except for early maturing genotypes 21338 and 202488 which produced significantly wide petals at the lower altitude than mid and higher altitudes (Table 4). Results suggested that the width of petals may to a larger degree be related to the genetic character of the genotypes than maturity grouping. Thus the variations were most probably being attributed to their inherited traits or the growing altitude.

It is widely accepted that plant reproduction and reproductive organs are highly sensitive to environmental factors from which temperature of the growing altitude is the most important factor (Zinn *et al*., 2010; Hedhly *et al*., 2003). Petal width has direct relationship with altitude, in which as the altitude increases petal width also increased. This idea is supported by (Qin *et al*., 2016), who revealed that petal length and width decreased with increasing temperature at lower altitude in different plant species.

4.2.3. Petal length (mm)

Petal length was very highly significantly (p<0.0001) affected by interaction effects of altitude and genotypes (Table 4 and appendix table 2). Genotypes did differ with regard to petal length when grown at different altitudes (Table 4). In general most of the genotypes tend to produce longest petals at higher and mid altitudes than at lower altitudes. Consequently, the longest petals was recorded from genotype 215187 (18.17mm) followed by Holetta-1 (17.81mm) at higher altitude whereas the shortest petal was obtained from genotype 21338 (9.01) at middle altitude.

However early maturing genotype 21338 produced longest petals at the lower altitude than mid and higher altitudes. Results suggested that even if there exists difference in petal length between genotypes, the differences are not stastically significant except for genotypes 21338 and 17547.This indicated that length of petals may to a larger degree be related to the genetic character of the genotypes than maturity grouping. Thus the variations were most probably being attributed to their inherited traits or the growing altitude. Differences in temperature of different altitudes induce stress in plant tissues affecting the reproductive stage by delaying or accelerating flowering, affecting differently male and female structures or inducing defects and deformities 38 on the reproductive structures (Zinn *et al*., 2010). Petal length has direct relationship with altitude, in which as the altitude increases petal length also increased. This idea is supported by (Qin *et al*., 2016), who revealed that petal length decreased with increasing temperature at lower altitude in different plant species.

4.2.4. Pistil height (mm)

Interaction effect of altitude by genotype on pistil height showed very highly significant difference (p<0.0001) in this study (Table 4 and Appendix Table 2). Accordingly, the highest pistil height was recorded from genotype Derashe (9.86mm) at mid altitude, whereas, the least pistil height was observed from genotype 21338 (5.48mm) at mid altitude. Although in general most genotypes showed an increase in pistil height with an increase in altitude from low to high altitudes and genotypes S-67, 215187 and 21338 showed relatively higher Pistil height at lower altitude than mid and higher altitudes. Early maturing genotypes 17547 and 21338 showed relatively the least pistil height than the other genotypes across all altitudes. On the other hand, at the mid altitude, mid maturing genotypes Tesfa and Derashe and early maturing genotype 17547 produced significantly highest pistil height than the other genotypes. Higher temperature of lower altitudes also had a negative impact on pistil height in which as the temperature increase the height of pistils is reduced for most of the genotypes. Reduced length of stigmatic receptivity under higher temperature has been reported in other plant species also (Hedhly *et al*., 2003).

4.2.5. Short stamen height (mm)

Very highly significant difference was observed from the interaction effect of altitudes with genotypes at (p<0.0001) concerning short stamen height. Genotypes did differ with regard to short stamen height when grown at different Altitudes (Table 4 and appendix table 2). Most of the genotypes tend to produce longest short stamens at higher altitudes than at mid and lower altitudes. Consequently, the highest short stamen height was recorded from genotype 215187 (10.78mm) at higher altitude whereas the least short stamen height was obtained from genotype 21338 (4.67mm) at the mid altitude.

Mid maturing genotypes Tesfa and Derashe and early maturing genotype 17547 produced longest short stamens at the middle altitude than low and higher altitudes. On the other hand, at the higher altitude, early maturing genotypes 21338 and 17547 produced relatively the least short stamen height than the other genotypes.

Researchers investigated that reduced seed yield was a consequence of the reduced pollen viability resulting from temperature effect that has been shown to reduce seed yield in a number of crops such as *A. hypogaea* (Prasad *et al*., 2003), *Cicer arietinum* (Srinivasan *et al*., 1998), cowpea (*Vigna unguiculata*) (Hall, 2004) and *Capsicum* species (Reddy and Kakani, 2007). Higher temperature of lower altitudes had a negative impact on short stamen growth, in which as the temperature increase the height of both short and long stamens is reduced for most of the genotypes. This lack of filament growth resulted in anthers not extending above the stigma which in consequence limited the deposition of pollen on to the receptive pistil and resulted in reduced pollination (Zinn *et al*., 2010; Hedhly *et al*., 2003, 2009).

4.2.6. Long stamen height (mm)

Genotypes differ very highly significantly ($p<0.0001$) with regard to long stamen height when grown at different altitudes (Table 4 and appendix table 2). The highest long stamen height was recorded from genotype 215187 (12.77mm) at higher altitude whilst the shortest long stamen height was obtained from genotype 21338 (6.6mm) at the mid altitude.

Even though most of the genotypes tend to produce longest long stamens at higher altitudes ,mid maturing genotypes Tesfa and Derashe and early maturing genotype 17547 produced longest long stamens at the middle altitude.

Researchers investigated that reduced seed yield was a consequence of the reduced pollen viability resulting from temperature effect that has been shown to reduce seed yield in a number of crops such as *A. hypogaea* (Prasad *et al*., 2003), *Cicer arietinum* (Srinivasan *et al*., 1998), cowpea (*Vigna unguiculata*) (Hall, 2004) and *Capsicum* species (Reddy and Kakani, 2007). Higher temperature of lower altitudes also had a negative impact on long stamen height, in which as the temperature increase the height of long stamens is reduced for most of the genotypes. This lack of filament growth resulted in anthers not extending above the stigma which in consequence limited the deposition of pollen on to the receptive pistil and resulted in reduced pollination (Zinn *et al*., 2010; Hedhly *et al*., 2003,2009). In general the growing environment have impact on the growth and development of plants in which flowering is the most sensitive stage. Most of the time when plants grow at higher altitude they accumulate higher degree days which would help them to grow bigger in size and to produce bigger reproductive organs.

Table 4: Mean values of Reproductive traits of eleven *Brassica carinata genotypes* as affected by the interaction of altitude and genotype tested at different altitudinal locations.

Source of variation Altitude	Genotype	Flower no(No)	Petal width(mm)	Petal length(mm)	Pistil height(mm)	Short stamen height(mm)	Long stamen height(mm)
	S-67	90.67 ^{ijklmn}	7.99 ^{abcdef}	17.53 ^{abc}	9.03 ^{abcdefg}	9.6 ^{b}	10.77 ^{def}
	Yellow Dodolla	69.67 ^{jklmnop}	8.57 ^{abc}	16.73 ^{abcde}	9.80 ^{a}	9.3 ^{b}	12.1 ^{ab}
	Holeta 1	106.67 ^{hijk}	8.83 ^{ab}	17.81 ^{ab}	9.67 ^{ab}	9.8 ^{b}	12.67 ^{a}
	26684	104.33 ^{hijkl}	8.67 ^{abc}	17.6 ^{abc}	9.37 ^{abcde}	9.53 ^{b}	12.55 ^{a}
	Tesfa	62.33 ^{nop}	8.53 ^{abcd}	16.93 ^{abcde}	8.83 ^{abcdefghi}	8.88 ^{bcde}	10.67 ^{def}
High	Derashe	71.67 ^{lmnop}	7.7 ^{abcdefgh}	15.05 ^{efghij}	9.6 ^{abc}	8.89 ^{bcde}	10.63 ^{def}
	215187	152.67 ^{cde}	8.9 ^{a}	18.17 ^{a}	9.53 ^{abcd}	10.78 ^{a}	12.77 ^{a}
	202488	217.33 ^{a}	7.77 ^{abcdefgh}	15.63 ^{cdefgh}	8.6 ^{cdefghi}	8.97 ^{bcd}	11.88 ^{abc}
	17547	200.67 ^{ab}	5.03 ^{ml}	9.62 ^{mn}	5.87 ^{m}	5.57 ^{j}	6.05 ^{j}
	23601	218.67 ^{a}	7.52 ^{cdefghi}	16.03 ^{bcdefg}	9.07 ^{abcdefg}	9.73 ^{b}	11.43 ^{bcd}
	21338	181 ^{bc}	4.75 ^{lm}	9.13 ^{n}	5.81 ^{m}	5.21 ^{jk}	8.87 ^{j}
	S-67	82 ^{jklmnop}	7.61 ^{bcdefghi}	17.3 ^{abc}	8.35 ^{efghij}	9.27 ^{b}	10.63 ^{def}
	Yellow Dodolla	78 ^{jklmnop}	8.07 ^{abcdef}	15.25 ^{defghi}	9.29 ^{abcdef}	9 ^{bc}	11.02 ^{cde}
	Holeta 1	99 ^{ijklm}	8.39 ^{abcde}	16.12 ^{bcdef}	9.03 ^{abcdefg}	9.43 ^{b}	11.47 ^{bcd}
	26684	93.67 ^{ijklm}	8.15 ^{abcdef}	16.18 ^{abcdef}	8.65 ^{bcdefghi}	8.88 ^{bcde}	10.46 ^{def}
	Tesfa	58.33 ^{op}	7.6 ^{bcdefghi}	17.25 ^{abcd}	9.57 ^{abcd}	9.15 ^{b}	10.96 ^{cde}
Mid	Derashe	71 ^{lmnop}	7.98 ^{abcdef}	15.03 ^{efghij}	9.86 ^{a}	9.25 ^{b}	11.15 ^{bcde}
	215187	108.67 ^{ghij}	7.18 ^{efghi}	13.57 ^{ijk}	7.93 ^{hijk}	7.06 ^{ghi}	8.7 ^{i}
	202488	173.33 ^{bcd}	4.73 ^{lm}	13.4 ^{ijkl}	8.05 ^{ghijk}	6.67 ^{i}	8.87 ^{hi}
	17547	152 ^{cde}	6.7 ^{ghij}	9.59 ^{mn}	8.52 ^{defghij}	7.53 ^{fghi}	9.12 ^{hi}
	23601	143.67 ^{def}	5.7 ^{jkl}	13.1 ^{jkl}	8.17 ^{ghij}	7.43 ^{fghi}	9.39 ^{ghi}
	21338	134.33 ^{efgh}	4.11 ^{m}	9.01 ^{n}	5.48 ^{m}	4.67 ^{jk}	6.6 ^{j}
	S-67	70.33 ^{mnop}	7.13 ^{fghi}	15.05 ^{efghij}	9.33 ^{abcdef}	8.08 ^{cdef}	10.47 ^{def}
	Yellow Dodolla	69.67 ^{mnop}	7.93 ^{abcdefg}	13.98 ^{hijk}	7.95 ^{hijk}	7.58 ^{fghi}	9.39 ^{ghi}
	Holeta 1	83.33 ^{jklmnop}	6.6 ^{hij}	11.53 ^{lm}	7.5 ^{jk}	7.17 ^{fghi}	9.11 ^{hi}
	26684	74.33 ^{klmnop}	5.75 ^{jkl}	11.44 ^{lm}	7.8 ^{ijk}	7 ^{hi}	9.23 ^{ghi}
	Tesfa	52.33 ^{p}	6.45 ^{ij}	13.63 ^{hijk}	7.08 ^{kl}	7.98 ^{efgh}	9.77 ^{fgh}
Low	Derashe	63.33 ^{nop}	7.01 ^{fghi}	14.07 ^{ghijk}	9.23 ^{abcdef}	8.13 ^{cdef}	9.27 ^{ghi}
	215187	80.33 ^{jklmnop}	7.3 ^{defghi}	15.27 ^{defghi}	8.93 ^{abcdefgh}	8 ^{defg}	10.86 ^{cde}
	202488	141.67 ^{defg}	6.4 ^{ijk}	14.58 ^{fghijk}	8.3 ^{fghij}	7.53 ^{fghi}	10.23 ^{efg}
	17547	120.33 ^{efghi}	3.98 ^{m}	9.57 ^{mn}	5.91 ^{m}	5.57 ^{j}	6.93 ^{j}
	23601	120.67 ^{efghi}	5.7 ^{jkl}	12.5 ^{kl}	7.97 ^{hijk}	7.06 ^{ghi}	9.33 ^{ghi}
	21338	111.67 ^{fghij}	5.17 ^{klm}	9.27 ^{n}	6.33 ^{lm}	5.53 ^{j}	7.03 ^{j}
	LSD(0.05)	**33.89**	**1.25**	**2.02**	**1.06**	**0.98**	**1.05**
	CV (%)	**18.71**	**11.00**	**8.66**	**7.8**	**7.57**	**6.45**

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation

4.3. Growth Parameters

4.3.1. Leaf Number per plant

The main factors altitudes and genotypes caused very highly (p<0.0001) and highly (p<0.001) significant differences on leaf number per plant, but there was no interaction effect of altitudes with genotypes concerning leaf number per plant. Accordingly, the highest leaf number per plant (50.78) was recorded from genotype 23601 followed by 21338 (42.33), while the smallest leaf number per plant (22.89) was attained from genotype Yellow dodolla (Table 5 and Appendix table 3). With regard to the growing altitudes the highest leaf number per plant was recorded at the lower altitude and the smallest leaf number per plant was produced at higher altitude. This may be due to the prevalence of higher temperature at lower altitude which facilitates the vegetative growth of plants.

Previous research work by Cordell *et al*. (1998) showed that many plants have smaller number of leaves at high altitudes. These morphological adaptations are presumably associated with decrease in temperature as well as nutrient and water limitations (Kao and Chang, 2011; Cordell *et al*., 1998). It may also be an adaptive strategy against the hazardous impact of strong wind that normally blows at high altitude, thereby improving photosynthetic activities of plants (Kofids *et al*., 2003; Korner and Cochrane,1983). Another works by Heide *et al*. (2020) revealed that Shoot growth and leaf number per plant increased with increasing temperature in apple.

At the higher temperature, there is a smaller plastochrone interval (a regular time intervals in which new leaves are produced) between the initiations of successive leaves (Hunter *et al*., 1977) in maize.

Table 5: Main effects of genotype and altitude on leaf number per plant at flowering stage eleven Brassica *carinata* genotypes tested at different altitudinal locations.

Genotype	Leaf No per plant
S-67	36.56 [bc]
Yellow Dodolla	22.89 [d]
Holeta 1	27.11 [cd]
26684	39.11 [abc]
Tesfa	28.00 [cd]
Derashe	27.44 [cd]
215187	38.22 [abc]
202488	31.44 [bcd]
17547	31.78 [bcd]
23601	50.78 [a]
21338	42.33 [ab]
LSD(0.05)	**12.82**
CV (%)	**39.88**
Altitude	
High	20.94 [c]
Mid	34.54 [b]
Low	46.97 [a]
LSD(0.05)	**6.69**
CV (%)	**39.88**

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation

4.3.2. Plant height (cm)

Plant height was very highly significantly (p<0.0001) affected by interaction effect of altitude by genotype in the present study (Table 6 and Appendix Table 3). Accordingly, the highest plant height was recorded for genotype Holleta-1 (124.87cm) at lower altitude, whereas, the least plant height was recorded from genotype 17547 (34.37cm) at higher altitude. Nevertheless, genotypes Holleta-1, Derash and Tesfa showed relatively higher plant height at higher altitudes as compared to the remaining genotypes (Table 6). Although all genotypes showed a decrease in plant height with an increase in altitude from low to mid and high altitudes, highly significant differences in plant height were found with early and mid-maturing genotypes 23601,202488,17547,21338 and 215187 respectively but the remaining genotypes showed little

response to the different altitude treatments and these genotypes were characterized by rapid stem elongation. The result from this study showed that, early and mid-maturing genotypes showed a large response to altitude difference which reveals that they are more adaptable to lower altitudes.

The present study revealed that the plants growing at low altitudes are comparatively taller and produce more number of leaves. The results are supported by the observations of Bresson *et al*. (2011); Johnson and Cook (1968) and Hickman (1975) who observed a reduction in plant height, length, breadth and area of leaves with an increase in altitude. These results are also in agreement with the findings of Izumi *et al*. (2007);Qaderi *et al*. (2006) and Osada *et al*. (1973) who reported that lower altitudes increased the height of canola plants through temperature effects.

Korner (2007) and Willis and Hulme (2004) revealed that plant height is decreased with an increase in altitude which is an adaptive phenomenon to protect the plant against the severe conditions at higher altitudes. The harsh climatic conditions and longer growing period results in the overall slow growth rate, which in turn enables the plants to efficiently utilize the available resources (Benningto and McGraw, 1995). The reduced plant height at higher altitude prevents the damaging effects caused by the strong winds prevalent at high elevations and keeps the leaves closer to warmer soil to enhance its photosynthetic efficiency (Korner and Cochrane, 1983).

4.3.3. Pedicel Length

Significant difference was observed for pedicel length due to the interaction effect of altitudes with genotypes at (p<0.05). Genotypes did differ with regard to pedicel length when grown at different altitudes (Table 6 and appendix table 3). The longest pedicel was recorded from

genotype 215187 (17.12mm) at higher altitude while the shortest pedicel was obtained from genotype 21338(3.18mm) at lower altitude (Table 6).

In general most of the genotypes tend to produce longest pedicels at higher and mid altitudes than at lower altitudes. Nonetheless, early maturing genotypes 17547 and 21338 produced shortest pedicels than the other genotypes at all growing altitudes. On the other hand, at the lower altitude mid maturing genotype 215187 produced significantly shortest pedicels as compared to mid and high altitudes. Pedicel length and orientation (angle) contribute to the diversity of inflorescence architecture and is important for optimal positioning of the flowers. Results suggested that length of pedicels be related to the maturity grouping of the genotypes in which late and mid maturing genotypes give relatively longest pedicels across all altitudes.

Table 6: Mean values of Growth parameters of eleven *Brassica carinata genotypes* as affected by the interaction of altitude and genotype tested at different altitudinal locations.

	Plant height (cm)			**Pedicel length (mm)**		
Genotype	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**
S-67	89.27 ^{ijkl}	96.77^{fghijk}	98.60^{defghij}	12.13 ^{fghi}	10.87 ^{ghij}	8.77 ^{jk}
Yellow Dodolla	92.7 ^{hijk}	103.18 ^{defghij}	120.62 ^{ab}	17.07 ^{ab}	14.67 ^{abcde}	12.52 ^{efgh}
Holeta 1	114.27 ^{abcde}	121.31 ^{ab}	124.87^{a}	14.47 ^{cdef}	12.33 ^{efgh}	10.53 ^{ghij}
26684	99.21 ^{cdefghij}	112.67 ^{abcdefg}	123.16 ^{a}	14.33 ^{def}	12.8 ^{efg}	10.1 ^{hij}
Tesfa	95.98^{ghijk}	98.55 ^{ghijk}	110.63 ^{abcdefg}	14.6 ^{bcdef}	11.38 ^{ghi}	9.67 ^{ijk}
Derashe	106.27 ^{bcdefgh}	112.65^{abcdefg}	120.00 ^{ab}	16.93 ^{abc}	15.55 ^{abcd}	11.43 ^{ghi}
215187	109.47 ^{abcdefgh}	85.21 ^{jklm}	109.47 ^{abcdefg}	17.87 ^{a}	14.46 ^{cdef}	8.57 ^{jk}
202488	71.58 ^{mn}	81.1 ^{klmn}	98.2 ^{efghij}	10.87 ^{ghij}	10.38 ^{ghij}	7.18 ^{kl}
17547	34.37 ^{o}	75.89 ^{lmn}	106.93 ^{bcdefgh}	5.36 ^{ml}	4.18 ^{m}	3.67 ^{m}
23601	70.3 ^{mn}	88.93^{ijkl}	115.33 ^{abc}	16.67 ^{abcd}	15.43 ^{abcd}	9.77 ^{ij}
21338	44.5 ^{o}	83.85 ^{jklm}	114.6 ^{abcd}	3.93 ^{m}	3.65 ^{m}	3.18 ^{m}
LSD(0.05)		**16.21**			**2.52**	
CV (%)		**10.3**			**13.98**	

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation

4.4. Yield and Yield Related Parameters and Oil Content

4.4.1. Pod length (mm)

Very highly significant difference was observed between altitudes and genotypes at (p<0.0001) on pod length, but there was no interaction effect of altitudes with genotypes concerning pod length (Table 7 and appendix table 4). The length of pods was measured at a stage of 90% physiological maturity and ranged from 12 to 54 mm. Accordingly, the highest pod length was recorded from genotype S-67 (54.11 mm) followed by Yellow dodolla (50.6 mm). The shortest pod length was attained from genotype 17547 (11.94 mm). With regard to the growing altitudes highest pod length was produced at the higher altitude and the shortest pods were produced at lower altitude. The variations in pod length might be due to the temperature effect of the growing environments in which the higher temperature effect of lower altitudes specially on the reproductive development stage, which is more sensitive to high temperature (day and night temperature) than vegetative development .

This result is in line with Lemma (1998) and Marcelis and Baan Hofman-Eijer (1997), who pointed that seed number per pod is one factor that determine pod size. Furthermore, this report is consistent with that of Russo (2003) and Aleemulah *et al*. (2000), who observed positive relationship between seed number and pod size, where fruit weight increased linearly with seed number in sweet pepper.

Table 7: Main effect of genotype and altitude on pod length at 90% maturity of eleven *Brassica carinata* grown at different altitudes

Genotype	Pod length
S-67	54.11 [a]
Yellow Dodolla	50.6 [b]
Holeta 1	49.71 [bc]
26684	47.47 [c]
Tesfa	48.60 [bc]
Derashe	21.41 [d]
215187	48.64 [bc]
202488	40 [d]
17547	11.94 [f]
23601	42.87 [d]
21338	16.87 [e]
LSD(0.05)	**3.09**
CV (%)	**7.98**
Altitude	
High	45.77 [a]
Mid	40.46 [b]
Low	37.04 [c]
LSD(0.05)	**1.61**
CV (%)	**7.98**

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation

4.4.2. Number of pods per plant

Numbers of pods per plant is a major yield determining component of Brassica species and contribute substantially towards seed yield. Results from analysis of variance indicated a highly significant interaction (p<0.001) effects of altitudes and genotypes on number of pods per plant (Table 8 and Appendix Table 4). In general, the number of pods per plant has ranged from 31 to 194 pods per plant) at physiological maturity. The genotypes responded differently with respect to the number of pods per plant when grown at different altitudes. Genotype 202488 had the highest number of pods (194.33) at higher altitude while the least number of pods per plant was recorded from genotype Holleta -1 (31) at lower altitude. With the exception of genotypes 23601,202488 and 17547 all genotypes produced significantly less pods per plant at the lower

altitude as compared to the mid and high altitudes. Although all genotypes showed a reduction in number of pods per plant as altitude decrease from high to low, highly significant (p<0.001) differences in number of pods per plant were found with early maturing genotypes 23601,202488,17547 and 21338 (Table 8). However, differences between late and mid maturing genotypes were not significant at all altitudes (Table 8). With the exceptions of 26684 and 215187, late maturing and mid maturing released varieties showed less reduction in the number of pods per plant at lower altitude than early maturing genotypes.

The variations in number of pods per plant might also be due to the temperature effect of the growing environments and the capability of each genotype to with stand the higher temperature effect of lower altitudes especially on the reproductive development stage, which is more sensitive to high temperature (day and night temperature) than vegetative development. This outcome can be explained by the work of Sato (2005), who reported that, the reduction of fruit set under moderately elevated temperature was mostly due to a reduction in pollen release and viability in tomato plant (*Lycopersicum esculentum* Mill.).

The potential and final pod numbers are related to cumulative dry matter production of canola (*Brassica napus* L.) until the beginning of flowering and the end of flowering, respectively (Faraji, 2012; Habekotte, 1993). Hence, in this study a decrease in dry matter accumulation due to higher temperature could be one of the reasons behind the reduced pod numbers at lower altitude. In wheat, reproductive organ development in later tillers when coincided with higher temperature exposure resulted in less grain number per plant (Impa *et al*., 2019; Garcia *et al*.,2015).

On the other hand, number of pods can be affected by flower abortion due to higher temperature and predation have all been proposed as factors explaining low pod number in plants. This also is

in agreement with Schemske (1980) who reported that, Pollination can be the first factor limiting seed and fruit production. In general the relative earliness in flowering and maturity could also have enabled early maturing genotypes to produce relatively more pods per plant at higher altitudes, which contributed for higher productivity of the genotypes per unit area.

4.4.3. Number of seeds per pod

Interaction effect of altitude by genotype had a very highly significant effect (p<0.0001) on number of seeds per pod (Table 8 and Appendix table 5). The highest number of seeds per pod (18.67) was recorded from genotype 215187 at higher altitude. Whereas the least number of seeds per pod (6) were recorded from genotype 21338 at high and mid altitudes. Late maturing genotypes showed higher reductions in number of seeds per pod than mid and early maturing genotypes with a decrease in altitude. In general the result of this study showed, except 23601 and 21338, all genotypes showed a significant reduction in number of seeds per pod at lower altitude as compared to the mid and higher altitudes.

The number of seeds per pod significantly decreased with increases in temperatures at lower altitude in this study. The number of seeds per pod was reported to be one of the yield components affected by environmental conditions, including temperature of the growing altitude (Barker *et al*., 1989). The result of the study is in agreement with the works of Puteh *et al*. (2013); Whigam *et al*. (2013) and Tischner *et al*. (2003) who revealed that the number of seeds per pod is reduced by seed set failure, due to unfertilized ovules and the abortion of fertilized ovules from environmental stress, such as high temperatures during flowering and early seed developmental stages in soya bean.

The result is also supported by Kutcher *et al*. (2010) who reported that increased mean temperature during vegetative development reduced the number of seeds per pod and size of seed per flower and consequently resulted in seed yield reduction, the view is also shared by findings of Morrison and Stewart (2002).

4.4.4 Thousand seed weight (gm.)

Thousand seed weight was very highly significantly (p<0.0001) affected by interaction effects of altitude and genotype (Table 8 and Appendix Table4).The maximum thousand seed weight (6.36gm) was attained from genotype Tesfa at higher altitude and the least seed weight (1.1gm) was registered from genotype 21338 at lower altitude. The early maturing genotype 21338 produced significantly lower thousand seed weight than the other genotypes at higher altitude. On the other hand ,except genotypes 26684 and 215187 late and mid maturing genotypes gave the maximum thousand seed weight than the early maturing at all altitudes which might indicate wider adaptability of the late and mid maturing genotypes.

The result of the study shows that, at the higher altitude with extended growth period genotypes tend to produce the highest seed weight. This might be attributed to the genetic makeup of genotypes and/or the agro ecological factors especially temperature of the growing altitude. Moreover seeds with higher weight can be considered as those receiving higher percentage of assimilate, due to the extended growth period. In addition, the reduced duration of crop growth stages at lower altitudes, increased rate of respiratory breakdown of accumulated dry mass and accelerated leaf senescence due to the higher temperature might be the reason for the reduced seed weight at lower altitude. Final seed weight is determined by both rate and duration of grain growth. The result of this study is in line with the works of Prasad *et al*. (2008) who got that seed weight was highly sensitive to increasing temperature and it is decreased due to reduced grain-

filling duration in wheat. Other studies in rice have also observed that higher temperature is more detrimental to grain weight (Morita *et al*., 2005; Morita *et al*.,2002).The result of this study is also supported by Garica-Inza *et al*. (2018) who found that olive fruit dry weight showed a tendency to decrease with increasing mean temperature at lower altitudes. Bosland and Votava (2000) also indicated that, in some cultivars of Chili seed can contain up to 60% of the dry weight of the fruit which makes it an important economic part of the crop.

4.4.5. Seed yield (Kg/ha)

Interaction effects of altitude and genotype were very highly significant (p<0.0001) on total seed yield (Table 8 and Appendix Table 5). Accordingly, the early maturing genotype 23601 gave maximum seed yield (1945.56 kg) at higher altitude and 1944.24 kg at mid altitude followed by genotypes 202488 (1538.89 kg) and 215187(1503.33 kg) at mid altitude. While the least total seed yield was recorded from genotype Yellow dodolla (560 kg) at the lower altitude (Table 8). The result of this study shows that, at the higher altitude with extended growth period genotypes tend to give higher seed yield than mid and lower altitudes and this might be due to the higher temperature at lower altitudes (Table 8). And also temperatures higher than needed increase respiration, sometimes above the rate of photosynthesis thus, photosynthates are used faster than they are produced but for growth to occur, photosynthesis must be greater than respiration. The result of this study is supported by the finding of Hatfield *et al*. (2011) who describes that an increase in temperature may cause yield decline between 2.5% and 10% across a number of agronomic species throughout the 21st century. It is also in agreement with work showing that seed yield decreased when soybean, canola and *Arachis hypogaea* plants were exposed to high temperature (Gan *et al*., 2004; Prasad *et al*., 2003; Gibson and Mullen, 1996)

Decreased fruit- set at higher temperature was mainly due to poor pollen viability, reduce pollen production and poor pollen tube growth, all of which lead to poor fertilization of flowers (Prasad *et al*., 2003). Flower abortion also has been attributable to the decreased seeds per plant and seed yield in other crops such as *Brassica napus* (Angadi *et al*., 2000), *Brassica Rapa* (Morrison and Stewart, 2002) and *Brassica Juncea* (Gan *et al*., 2004).

Previous works by McGregor (1981) indicated that the seed yield of canola (*Brassica napus* L.) is primarily determined by the number of pods, seeds per pod and seed weight. Photo-assimilate supply during fertilization determines seeds per pod, whereas seed weight depends on the continued supply of photosynthates after fertilization until maturity. In addition, other studies have indicated that the number of flowers that translate into pods is a key determinant of seed yield. Therefore, flower numbers and pod/flower ratio are also important factors that determine canola seed yield (Gan *et al*., 2004; Morrison and Stewart, 2002; Angadi *et al*., 2000). Higher temperatures at lower altitudes increased the rate of senescence and decreased the ability of the plant to efficiently produce grain (Hatfield and Prueger, 2015). Reproductive organs of canola plants exposed to higher temperature are affected negatively, resulting in reduced male and female reproductive organ viability (Polowick and Sawhney, 1988), which affects pollen viability, fertilization and grain or fruit formation (Hatfield *et al*., 2011). The prevalence of higher temperatures at lower altitude decrease seed set, grain number, grain-filling duration, grain-filling rate and individual grain weight and ultimately result in reduced grain yield.

Other studies have also examined the impacts of increasing temperatures on soybean seed production. Higher temperatures caused lower net photosynthetic carbon assimilation and biomass production, which were attributed to declines in stomatal conductance and intercellular carbon dioxide and resulted in yield reduction (Ruiz-Vera *et al*., 2013).

4.4.6. Oil content

The analysis of variance with interaction effect of altitude and genotype showed very highly significant difference (p<0.0001) for Oil content (Table 8 and Appendix Table 4). Accordingly the highest oil content was scored from genotype Yellow dodolla (41.79) at higher altitude while the least was from genotype 215187(20.51) at lower altitude. The result from this study showed that, the oil content of all Genotypes was increased with Increasing altitude from low to mid and then to high. Genotypes gave significantly more percentage of oil when grown at higher altitude than at mid and lower altitudes. On average genotypes gave 34.89% oil at higher altitude, 30.59% at middle altitude and 22.63% at lower altitude. The result of this study showed that for all genotypes, oil content and seed yield parameters decreased significantly with decrease in altitude. This may be due to the higher temperatures at lower altitude which accelerates the time of seed maturity and hence hindered dry matter accumulation (Nissim *et al*.,2020).The rate of synthesis of oil during seed development was found to be affected by the temperature of the growing environment because high temperature environment can repress seed development which reduces oil yield and quality in olive plants (Nissim *et al*.,2020). Previous works by Singer *et al*. (2016) and Zhu *et al*. (2012), also corporates that higher temperatures during the pod-filling stage have been reported to reduce seed oil concentration in oilseed rape. This is partly due to the fact that higher temperature at lower altitude promotes vegetative growth but negatively affects oil concentrations Misrere *et al*. (2018) and Trentacoste *et al*.(2012).

Table 8: Yield and yield related parameters and oil content of eleven *Brassica carinata* as affected by the interaction of altitude with genotype tested at different altitudinal locations.

Source of variation		Number of pods per plant (No)	Number of seeds per pod(No)	1000 seed weight (gm.)	Seed yield (Kg/ha)	Oil content (%)
Altitude	Genotype					
	S-67	65 ^{ijklm}	12.67 ^{hij}	4.89 ^{e}	1240 ^{cd}	41.25 ^{ab}
	Yellow Dodolla	60 ^{ijklmn}	15.33 ^{defg}	5.34 ^{c}	1118.89 ^{de}	41.79 ^{a}
	Holeta 1	86.33 ^{hi}	15.33 ^{defg}	4.72 ^{f}	1307.78 ^{c}	40.24 ^{bc}
	26684	78.33 ^{hijk}	15.67 ^{cdefg}	3.89 ^{h}	1156.67 ^{de}	33.41 ^{f}
	Tesfa	43.33 ^{lmn}	12.67 ^{hij}	6.36 ^{a}	753.33 ^{hij}	37.21 ^{de}
High	Derashe	54 ^{jklmn}	14.33 ^{efgh}	5.65 ^{b}	1066.67 ^{ef}	39.27 ^{c}
	215187	122.67 ^{ef}	18.67 ^{a}	3.29 ^{k}	1220 ^{cd}	31.57 ^{gh}
	202488	194.33 ^{a}	16.33 ^{bcde}	3.57 ^{i}	1355.56 ^{c}	30.58 ^{hi}
	17547	183.33 ^{ab}	6.67 ^{n}	3.4 ^{jk}	723.33 ^{hijk}	31.98 ^{g}
	23601	176.67 ^{ab}	16.67 ^{abcd}	4.03 ^{h}	1945.56 ^{a}	29.12 ^{j}
	21338	159.67 ^{bcd}	6.00 ^{n}	2.6 ^{n}	773.33 ^{hi}	27.39 ^{k}
	S-67	60.33 ^{ijklmn}	11.67 ^{ijk}	4.75 ^{ef}	704.44 ^{hijkl}	37.97 ^{d}
	Yellow Dodolla	58.33 ^{ijklmn}	13.67 ^{ghi}	3.55 ^{ij}	634.44 ^{ijkl}	36.58 ^{e}
	Holeta 1	85.33 ^{hij}	14.33 ^{efgh}	4.31 ^{g}	642.22 ^{ijkl}	34.57 ^{l}
	26684	78.33 ^{hijk}	14 ^{fgh}	3.46 ^{ij}	635.56 ^{ijkl}	29.48 ^{ij}
	Tesfa	52.33 ^{klmn}	11.33 ^{jkl}	5.06 ^{d}	1073.33 ^{ef}	33.73 ^{f}
Mid	Derashe	66 ^{ijkl}	14.33 ^{efgh}	5.30 ^{c}	942.22 ^{fg}	34.48 ^{f}
	215187	102 ^{fgh}	17.67 ^{abc}	3.06 ^{l}	1503.33 ^{b}	26.77 ^{kl}
	202488	164.67 ^{abc}	17.67 ^{abc}	3.4 ^{jk}	1538.89 ^{b}	25.73 ^{lm}
	17547	138 ^{cde}	6.33 ^{n}	3.01 ^{lm}	797.78 ^{gh}	25.97 ^{lm}
	23601	128.67 ^{def}	14 ^{fgh}	3.41 ^{ijk}	1924.44 ^{a}	26.03 ^{lm}
	21338	119.33 ^{efg}	6 ^{n}	1.98 ^{o}	797.78 ^{gh}	25.19 ^{m}
	S-67	33.33 ^{mn}	9.67 ^{klm}	2.6 ^{n}	577.78 k ^{l}	26.45 ^{kl}
	Yellow Dodolla	32.67 ^{n}	11.67 ^{ijk}	2.99 ^{lm}	560 ^{l}	23.44 ^{n}
	Holeta 1	51 ^{klmn}	10 ^{klm}	3.42 ^{ijk}	654.44 ^{hijkl}	20.73 ^{pq}
	26684	40.33 ^{lmn}	9 ^{m}	2.48 ^{n}	560 ^{l}	23.95 ^{n}
	Tesfa	36.67 ^{lmn}	9.33 ^{lm}	3.87 ^{h}	607.78 ^{jkl}	21.92 ^{op}
Low	Derashe	35.67 ^{lmn}	10.33 ^{klm}	1.9 ^{o}	628.89 ^{ijkl}	23.75 ^{n}
	215187	61.67 ^{ijklmn}	16 ^{cdef}	2.86 ^{m}	645.56 ^{ijkl}	20.51 ^{q}
	202488	106 ^{efgh}	15.67 ^{cdefg}	2.97 ^{lm}	568.89 ^{ijkl}	20.61 ^{q}
	17547	98.67 ^{fgh}	9.67 ^{klm}	2.54 ^{n}	631.11 ^{ijkl}	20.88 ^{pq}
	23601	109 ^{efgh}	18.33 ^{ab}	2.91 ^{lm}	623.33 ^{jkl}	22.99 ^{no}
	21338	90.33 ^{ghi}	6.67 ^{n}	1.1 ^{n}	595.56 ^{kl}	23.77 ^{n}
	LSD(0.05)	**32.06**	**2.11**	**0.16**	**146.66**	**1.2**
	CV (%)	**21.98**	**10.19**	**2.67**	**9.71**	**2.52**

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation

4.5. Correlation

The correlation analysis was performed to determine simple correlation coefficient between phonological, reproductive, growth, yield and yield related parameters and oil content as affected by genotype and altitude interactions. The present study has indicated that phenological parameters were found to be strongly and positively associated with each other and with days to maturity. Date of emergence was highly and positively correlated with days to first flowering(r = 0.71***), days to 50% flowering (r = 0.72***), days to flower completion (r = 0.68**), flowering period (r = 0.43**) and days to maturity (r = 0.63**). Days to first flowering was highly and positively correlated with days to 50% flowering (r = 0.98***), days to flower completion (r = 0.97***), flowering period (r = 0.66**), days to maturity (r = 0.89***), plant height (r = 0.63**), oil content (r = 0.51**) and thousand seed weight (r = 0.42**). Many phenological parameters and plant height contributed to the length of days to maturity because days to maturity was found to be strongly and positively associated significantly with date of emergence (r = 0.62**), plant height (r = 0.69**), days to first flowering (r = 0.89**), days to 50% flowering (r = 0.89***), days to flower completion (r = 0.93***) and flowering period (r = 0.80***). Days to maturity contributed to the increment of oil percentage and thousand seed weight because it is highly and positively correlated with oil content (r = 0.66**) and thousand seed weight(r = 0.57**). Petal width was positively correlated with petal length (r = 0.85***), pistil height (r = 0.83***), short stamen height (r = 0.85***), pod length (r = 0.71**), pedicel length (r = 0.66**), oil content (r = 0.57**), thousand seed weight (r = 0.54**) and plant height (r = 0.54**). Number of flowers was highly and positively correlated with number of pods per plant (r = 0.96***) and positively correlated with seed yield (r = 0.46**) .The present finding also showed that number of seeds per pod was positively correlated with pod length (r = 0.60**),

thousand seed weight (r = 0.30**) and seed yield (r = 0.46**). Leaf number is inversely (negatively) correlated with plant height and days to maturity (r = -0.56**), thousand seed weight (r = -00.42**) and oil content (r = -0.48**) (Fig 3 and Appendix Table5).

Awal *et al*. (2015) and Khan *et al*.(2000) notified significant positive relationship between pod numbers per plant with seed yield in *Brassica napus*. Rameeh (2015) and Sabaghnia *et al*. (2010) also discussed and elaborated a positive correlation between seeds per pod and seed yield of plants. Thousand Seed weight possessed positive and significant relation with percentage of oil. This correlation is supported by Singh *et al*. (2016) who elaborated the positive significant correlation of weight of seeds and number of pods per plant and oil percentage.

Singh *et al*. (2016) and Golparvar (2011) also noticed the same results and identified the positive and significant correlation between oil content and seed yield. In general, Positive correlations recorded among the traits suggest that these traits can be used as selection criteria for genotypes with high seed yield and also selection of these parameters of yield could be fruitful for improvement of yield.

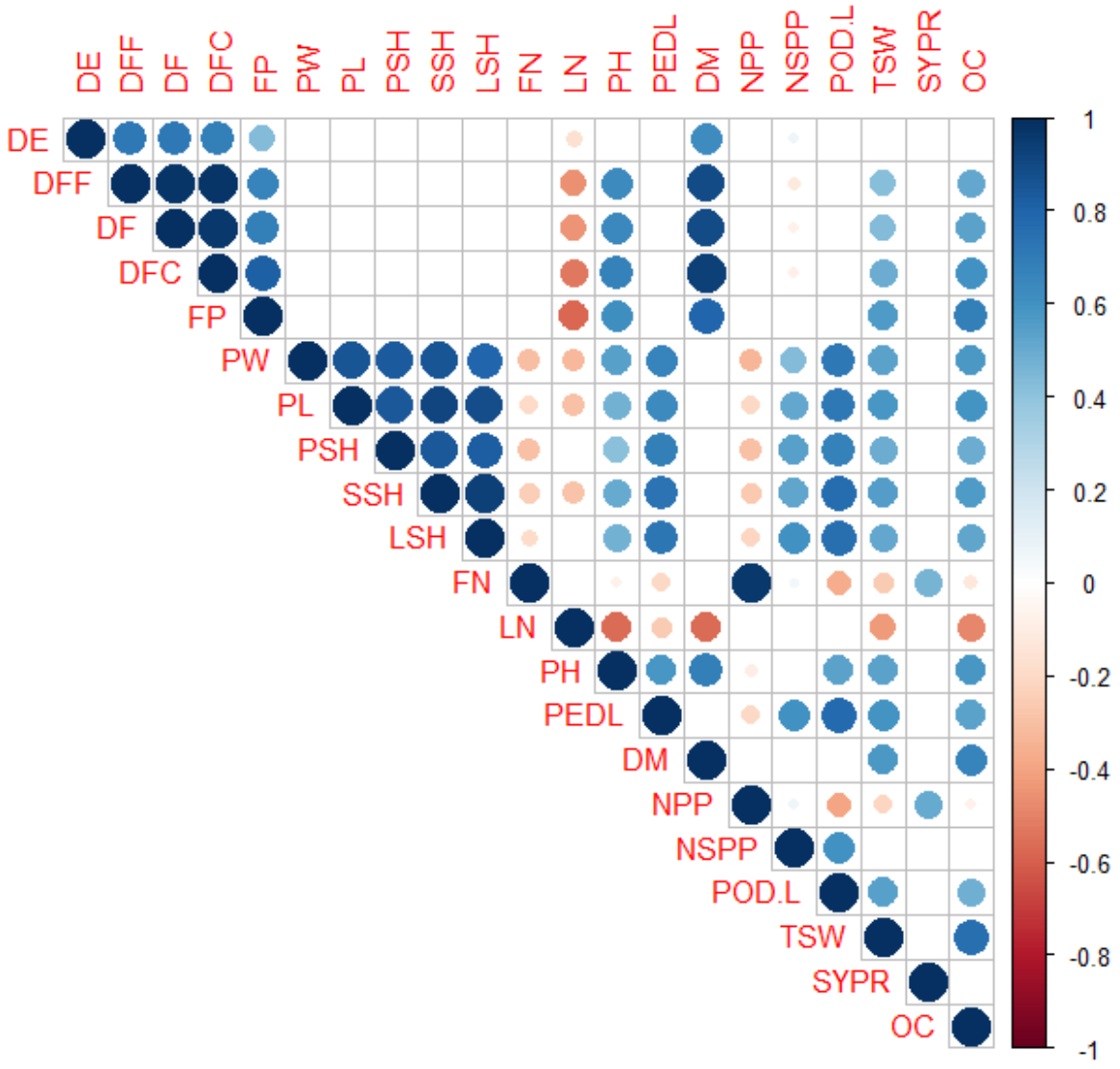

Fig 3: Correlation coefficients among parameters in *Brassica carinata* at high, mid and low altitudes. The size of circles and color intensity indicate the magnitude of statistically significant ($p < 0.05$) correlations and the cells with no circles indicate non-significant correlations; the red circles are for negative and blue are for positive correlations.

5. SUMMARY AND CONCLUSION

Ethiopian mustard (*Brassica carinata* A. Braun), locally known as "Gomenzer", is a native species to Ethiopia commonly cultivated for its leaves and oil seeds since ancient times. Recently, with increased interest to minimize the effects of greenhouse gas emission, utilization of green energy such as biofuels has been on the rise. *Brassica carinata* has become one of potentially exploited feedstock for biofuel production around the world especially in Europe, Australia and Canada. Besides, the crop is thought to have wider adaptability and comparative tolerance to biotic and abiotic stresses than other Brassica species grown as oilseeds. Nonetheless its production and productivity is still far below the national averages due to various factors. The yield of the crop is affected by many factors such as the growing environmental conditions (abiotic conditions), the genotype, pest and diseases (biotic conditions), agronomic practices and etc. Therefore, studies are needed to understand and compile comprehensive knowledge to increase the production potential. This particular study is therefore, mainly focused on the study of different genotypes under varying in growing altitude to see the crop responses. To this effect, the study was conducted to assess the phenological, reproductive, growth and yield responses as well as the oil content of 11 *Brassica carinata* A. Braun genotypes and the interaction effect of altitude with genotype on the responses at three different altitudes such as Bale Goba (2743 masl), Arsi Negele (2043 masl) and Dilla (1416 masl) during 2011 dry season. The study was comprised of factorial combinations of three altitudes and 11 *Brassica carinata* genotypes which resulted in 33 treatments. The experiment was laid out in a CRD design with three replications as a pot experiment in controlled edhaphic environment.

The results of the study revealed that the interaction effects of altitude and genotypes had considerable influence on phenological, reproductive, growth, yield and yield components as

well as oil content of *Brassica carinata* except for leaf number per plant and pod length. Phenological Parameters were very highly significantly affected by the interaction effects of altitude and genotype. Accordingly, the shortest days to 50% emergence (6.33days) was recorded from genotype 23601, shortest days to first flowering (43.3 days) and 50% flowering (50 days) were obtained from genotype 202488 and shortest days to flower completion (66 days) ,flowering period (19.67 days) and 90% maturity (92.67 days) were recorded from genotype 21338. The shortest days for all the phenological parameters were recorded at Lower altitude (1416 masl).

Reproductive traits also exhibited highly significant differences for interaction effects of altitudes and genotypes. Genotypes 215187 and Holleta-1 scored the highest values for petal width (8.9mm and 8.83mm) and petal length (18.17mm and 17.81mm) at higher altitude. The highest value for pistil height (9.86 mm) was exhibited from genotype Derashe at mid altitude. The highest records for short stamen height (10.78mm) and long stamen height (12.77mm) were obtained from genotype 215187 at high altitude. Similarly the highest number of flowers per plant was obtained from genotypes 23601 (218.67) and 202488 (217.33) at the same altitude.

The interaction effect of altitude and genotype very highly significantly ($P < 0.0001$) influenced the growth parameters of *Brassica carinata*. Thus the highest value for plant height (124.87 cm) was recorded from genotype Holleta-1 at lower altitude whereas higher record for pedicel length (17.87 mm) was recorded from genotype 215187 at higher altitude.

Yield and yield components of *Brassica carinata* were also affected with the interaction of genotype and altitude. Highest number of pods per plant (194.33), seeds per pod (18.67) and thousand seed weight (6.36 gm) were obtained at higher altitude from genotypes 202488, 215187 and tesfa respectively. Increasing the altitude from low to high strongly increased seed yield

from 1945.56 kg/ha to 560 kg/ha. The early maturing genotype 23601 gave maximum seed yield (1945.56 kg/ha) at higher altitude followed by genotypes 202488 (1538.89 kg/ha) and 215187 (1503.33kg/ha) at mid altitude. Similarly maximum oil percentage (41.79%) is also obtained from genotype yellow dodolla at high altitude.

Therefore, it can be concluded that different genotypes responded differently to different altitude ranges and their interaction have a significant impact on phenology, reproduction, growth and yield of *Brassica carinata*. Therefore from the result one can conclude that decrease in altitude from high to low reduces number of days from planting to all the studied phenological stages. In line with this early maturing genotypes required less days to reach all of the phenological stages as compared with late and mid maturing genotypes. Reproductive traits showed an increase with increasing altitude and early maturing genotypes gave the lowest values for those traits across all altitudes except for flower number per plant.

Increase in altitude reduces the number of leaves per plant and plant height. On average, early maturing genotypes produced more leaves per plant and shorter plants as compared to late and mid maturing genotypes. Even if they scored relatively the shortest plant height through all altitudes the highest values are scored at lower altitudes for both growth parameters.

Yield and yield components are also increased with increasing altitude. *Brassica carinata* grown at higher and mid altitudes produced higher seed and oil yields than when grown at lower altitudes. Hence, high and mid altitudes respectively were appropriate to maximize *Brassica carinata* seed and oil yield. In general, the result of the study in tells us using appropriate genotype and altitude interaction can be important for screening of genotypes for seed and oil yield based on the studied parameters. Besides, the study also showed the availability of *Brassica*

carinata accessions with comparable performance, i.e. Acc 23601,202488 and 215187 as the released varieties.

However, to come up with a plausible recommendation it requires repeating the experiment over different seasons with more number of genotypes intensively at field condition to verify the present results and the consistence performance of these parameters over different seasons and with more genotypes.

6. REFERENCES

Adeniji O. and Aloyce AA. 2012.'Floral and Seed Variability Patterns among Ethiopian Mustard (B. carinata A. Braun) of East Africa'. *Tropicultura* 30(3) pp. 133–140.

Ahmed J. *et al.* (2016) 'Growth and yield performance of various Brassica genotypes under the agro-ecological condition of Quetta'. pp. 25–29.

Aleemullah M., Haigh A.M. and Holford P. 2000. Anthesis, anther dehiscence, pistil receptivity and fruit development in the Longum group of Capsicum annum. *Australian Journal of Experimental Agriculture* 40:755-762.

Ali Q., Ashraf M. and Anwar F. 2009. Physicochemical attributes of seed oil from drought stressed sunflower (*Helianthus annuus* L.) plants. *Grasasy Aceites* 60 (5): 475-481.

Andargie A.2006. Genetic diversity within and among accessions of Ethiopian Mustard (*B. carinata* A. Braun) collections from south Gonder, Arsi and Tigray areas of Ethiopia using Allozyme analysis. PhD thesis, Addis Ababa University, Ethiopia.

Angadi S. V., Cutforth H.W., Miller P. R., McConkey B.G., Entz M.H., Brandt S. A. and Volkmar K.M. 2000. Response of three Brassica species to high temperature stress during reproductive growth. *Canadian Journal of Plant Science* 80(4): 693– 701.

Anonymous 2010. ICAR Network Project on Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change. *Annual Progress Report* (2009-2010) pp. 177-178.

AOCS.1993. Official Methods and Recommended Practices; The American Oil Chemists Society: Champaign, IL, pp 113–168.

Artus N.2002. Effect of arsenate treatment on growth and arsenic accumulation in four high biomass members of the Brassicaceae. In: The 9th New Phytologist Symposium. Biology Department, West Chester University, West Chester, USA. pp. 193 – 195.

Ashraf M. and McNeilly T.1990. Responses of four *Brassica* species to sodium chloride. *Environmental and Experimental Botany* 30(4):475–487.

Ashraf M. 2001. Relationships between growth and gas exchange characteristics in some salt-tolerant amphidiploid *Brassica* species in relation to their diploid parents. *Environmental and Experimental Botany* 45(2):155–163.

Asseng S., Foster I. and Turner NC.2011. The impact of temperature variability on wheat yields. *Global Change Biology* 17:997–1012.

Awal M. A., Uddin M.K., Uddin S.K.N., Jahan S.E. and Rahman L. 2015. Genetic diversity of morphological traits of *Brassica napus* parents and F7 family lines. *International Journal of Experimental Agriculture* 5: 24-29.

Bahuguna R.N.and Jagadish S.V.K.2015.Temperature regulation of plant phenological development. *Environ. Exp. Bot* 111, 83–90.

Baker JT., Allen LH., Boote KJ., Jones P. and Jones JW.1989.Response of soybean to air temperature and carbon dioxide concentration. *Crop Science* 29(1):98–105.

Barker G.C.,Larson T.R.,Graham I.A.,Lynn J.R. and King G.J. 2007.Novel insights into seed fatty acid synthesis and modification path ways from genetic diversity and quantitative trait loci analysis of the Brassica C genome. *Plant physiology* 144: 1827-1842

Barnabas B., Jager K. and Feher A. 2008. The effect drought and heat stress on reproductive processes in cereals. *Plant Cell Environment* 31: 491-543.

Bennington CC. and McGraw JB.1995. Natural-selection and ecotypic differentiation in Impatiens pallida. *Ecol Monogr* 65: 303-323.

BioMatnet .2006. Brassica carinata: The outset of a new crop for biomass and industrial non-food oil. Fair. CT96 - 1946. Updated by CPC press.

Bosland P.W. and Votava E.J. 2000. Peppers, Vegetables and Spices Capsicum.CABI Publishing. New York. p.198.

Bouaid A ., Diaz Y., Martinez M. and Aracil J. 2005 'Pilot plant studies of biodiesel production using Brassica carinata as raw material', 106, pp. 193–196. doi:10.1016/j.cattod.2005.07.163.

Breda NJJ. 2008. Leaf area index. *General Ecology* 2148-2154.

Breitenbatch V. 1963. The Indigenous Trees of Ethiopia 2nd ed. *Ethiopian Forest Association*, Addis Ababa, Ethiopia. pp.303.

Bresson CC., Vitasse Y., Kremer A. and Delzon S.2011. To what extent is altitudinal variation of functional traits driven by genetic adaptation in European oak and beech. *Tree Physiology* 31: 1164-1174.

Canam T., Li X., Holowachuk J., Yu M., Xis J., Mandal R., Krishnamurthy R., Bouatra S., Sinelnikov I., Yu B., Grenkow L., Wishart DS., Steppuhn H., Falk KC., Dumonceaux TJ. and Gruber MY. 2013. Differential metabolite profiles and salinity tolerance between two genetically related brown-seeded and yellow-seeded *Brassica carinata* lines. *Plant Science* 198:17–26.

Cardone M. Mazzoncini M., Menini S., Rocco V., Senatore A., Seggiani M. and Vitolo A. 2003 'Brassica carinata as an alternative oil crop for the production of biodiesel in Italy :

agronomic evaluation , fuel production by transesteriÿcation and characterization'. 25, pp. 623–636. doi: 10.1016/S0961-9534(03)00058-8.

Cardone, M., Prati, M. V. and Rocco, V. 2002. 'Brassica carinata as an Alternative Oil Crop for the Production of Biodiesel in Italy : Engine Performance and Regulated and Unregulated Exhaust Emissions'. 36(21): 4656–4662.

Cheung KW., Razeq FM., Sauder CA., James T. and Martin SL. 2015. Bi directional but asymmetrical sexual hybridization between *Brassica carinata* and Sinapis arvensis (Brassicaceae). *Journal of Plant Research* 128(2):1–12.

Chmielewski FM., Muller A. and Bruns E. 2004. Climate changes and trends in phenology of fruit trees and field crops in Germany 1961-2000. *Agriculture and Forest Meteorology* 121: 69-78.

Copani V.,Cosentino S.,Sortino O.,Terranova G., Mantineo M. and Virgillito S. 2009. Agronomic and energetic performance of *Brassica carinata* A. Braun in Southern Italy. Proc. 17th Eur. Biomass Conf. and Exhibition "From Research to Industry and Markets". Hamburg, Germany, pp. 166-170.

Cordell S., Goldstein G., Mueller-Dombois D., Webb D. and Vitousek PM .1998. Physiological and morphological variation in Metrosideros polymorpha, a dominant Hawaiian tree species, along an altitudinal gradient: the role of phenotypic plasticity. *Oecologia* 113: 188-196.

Courtney, Murren J. and Massimo P.2005. Morphological response to simulated wind in the genus Brassicaseae: allopolyploids and their parental species. *American Journal of Botany* 92: 810– 818.

Crawford P. Q. and Wheeler, T. R. 2009. Climate change and the flowering time of annual crops. *Journal of Experimental Botany* 60: 2529–2539.

CSA (Central Statistical Authority). 2013/14. Report on land utilization: Private peasant holdings, 'Meher' season. Statistical bulletin. Addis Ababa, Ethiopia.

Dale V. H., Joyce L. A., McNulty S., Neilson R. P., Ayres M. P., Flannigan M. D. *et al*. 2001. Climate change and forest disturbances. *Biological Science* 51: 723–734.

Dar A.A., Choudhury A.R., Kancharla P.K.and Arumugam N. 2017. The FAD2 gene in plants: Occurrence, Regulation, and Role. *Frontiers in Plant Science* 8: 1789.

De Haro A., Domınguez J., Garcıa-Ruız R., Velasco L., Del Rıo M., Munoz J. and Fernandez-Martınez J. 1998.Registration of six Ethiopian mustard germplasm lines. *Crop Science* 38: 558 - 561.

Doney S. C., Ruckelshaus M., Duffy J. E., Barry J. P., Chan F., English C. A. *et al*. 2012. Climate change impacts on marine ecosystems. *Ann. Rev. Mar. Sci.* 4: 11–37.

Doweny R.K. and G. Robbelen. 1989. Brassica Species. In: Robbelen G., Doweny R. K. and Ahri A. (eds). Oil crops of the world. McGraw-Hill New York. 339-359

Durner E.F., Poling E.B. and MAAS J.L.2002.Recent advances in strawberry plug transplant technology. *Hort Technology* 12:545-550.

Durrett TP., Benning C. and Ohlrogge J. 2008. Plant triacylglycerols as feedstocks for the production of biofuels. *Plant Journal* 54:593–607.

Dutta A., Dutta S K., Jena S., Nath R., Bandyopadhyay P. and Chakraborty K .2011. Effect of growing degree days on biological growth indices of wheat and mustard. *Journal of Crop and Weed* 7(1): 70-76

Edwards S., Tadesse M., Demissew S. and Hedberg I.2000. *Flora of Ethiopia and Eriterea.* Macnoliaceae to Flacourtiaceae. National Herbarium, Addis Ababa, Ethiopia and Uppsala, Sweden. pp.121-125.

Faby R. 1997. The productivity of graded "Elsanta" frigo plants from different origin. *Acta Horticulturae* 439:449-455.

Faraji A. 2012. Flower formation and pod/flower ratio in canola (*Brassica napus* L.) affected by assimilates supply around flowering. *International Journal of Plant Production* 4(4): 271– 280.

Fayyaz-ul-Hassan H.A., Cheema M.A. and Manaf A. 2005. Effects of environmental variation on oil content and fatty acid composition of canola cultivars. *J Res Sci* 16: 65-72.

Fekadu A.2020 'Stability Analysis for Seed Yield and Related Component Traits of Ethiopian Mustard Genotypes (Brasica Carinata A . Braun) in Central Highlands of Ethiopia'. 7(2): 1–6.

Fitter AH. and Fitter RSR.2002. Rapid changes in flowering time in British plants. *Science* 296:1689-1691.

Franklin P., Gardner R., Pearce B. and Mitchell RL. 2010. Physiology of crop plants. *Scientific Press* p.336.

Gabrielle B., Denoroy P., Gosse G.and Andersen MN. 1998. Development and evaluation of a CERES-type model for winter oilseed rape. *Field Crops Research* 57: 95-111.

Gan, Y. *et al.* (2004) 'Canola and mustard response to short periods of temperature and water stress at different developmental stages'. *Canadian Journal of Plant Science* 84(3): 697– 704.

Garcia G. A., Dreccer M.F., Miralles D.J. and Serrago R. A. 2015. High night temperatures during grain number determination reduce wheat and barley grain yield: A field study. *Global Change Biology* 21(11): 4153– 4164.

Garcia-Inza G., Hall AJ. and Rousseaux MC. 2018.Proportion of oleic acid in olive oil as influenced by the dimensions of the daily temperature oscillation. *Scientia Horticulturae* 227:305–12.

Geleta L.1998. Genetic variability and association study for yield, quality and other traits of yield of hot pepper (Capsicum species). MSc. thesis, Hramaya University.

Getinet A., Rakow G., Raney JP and Downey R.K.1994. Development of zero erucic acid Ethiopian mustard through an interspecific cross with zero erucic acid Oriental mustard. *Canadian Journal of Plant Science* 74: 793-795.

Getinet A., Rakow G. and Downey R. K. 1996 'Agronomic performance and seed quality of Ethiopian mustard in Saskatchewan', *Canadian Journal of Plant Science* 76(3): 387–392. doi: 10.4141/cjps96-069.

Getinet A. and Nigussie A. 1997. Highland Oil Crops: a two-decade research experience in Ethiopia. Research report No. 30. Institute of Agricultural Research, Addis Ababa, Ethiopia. p.30.

Gibson LR. and Mullen RE.1996.Soybean seed quality reductions by high day and night temperature. *Crop Science* 36:1615–1619.

Golparvar A.R.2011.Evaluation of genetic variation and indirect selection criteria for improvement of oil yield in canola cultivars (*Brassica napus*). J. Res. in Agric. Sci. 7(2):109- 113.

Gomez A.K and Gomez A. A. 1984. Statistical procedures for agricultural research.

Gómez-Campo C. and Prakash S. 1999. 'Biology of Brassica Coenospecies', *Developments in Plant Genetics and Breeding* 4, pp. 33–58. doi: 10.1016/S0168-7972(99)80003-6.

Gonzalez-Garcia S., Gasol C.M., Gabarrell X., Rieradevall J., Moreira M.T. and Feijoo G. 2009. "Environmental aspects of ethanol-based fuels from *Brassica carinata*: A case study of second generation ethanol". *Renewable and Sustainable Energy Reviews* 13: 2613-2620.

GU M.1997.The impact of altitude on the growth and development of rice. *Tillage and Cultivation* 5: 61-63.

Gugel R.K., Seguin-Swartz G. and Petrie A.1990.Pathogenicity of three isolates of Leptosphaeriamaculanson Brassica species and other crucifers. *Canadian Journal of Plant Pathology* 12: 75-82.

Habekotte B. 1993. Quantitative analysis of pod formation, seed set and seed filling in winter oilseed rape (*Brassica napus* L.) under field conditions. *Field Crops Research* 35(1): 21–33.

Hall AE.2004.Breeding for adaptation to drought and heat in cowpea. *European Journal of Agronomy* 21:447–454.

Hassan FU., Ali H., Cheema MA. and Manaf A. 2005. Effects of environmental variation on oil content and fatty acid composition of canola cultivars. *Journal of Research (Science),* Bahauddin Zakariya University, Multan, Pakistan. 16 (2): 65-72.

Hatam M. and Abbasi G.Q.1994. Oilseed Crops. In: E. Bashir and R. Bantel (Eds.) Crop production, National Book Foundation, Islamabad p.374.

Hatfield, J. L. and Prueger, J. H. (2015) 'Temperature extremes: Effect on plant growth and

development', *Weather and Climate Extremes*, 10(October), pp. 4–10. doi: 10.1016/j.wace.2015.08.001.

Hatfield J.L., Boote K.J., Kimball B.A., Ziska L.H., Izaurralde R.C., OrtD. Thomson A.M. and Wolfe D.W. 2011.Climate impacts on agriculture: implications for crop production. *Agronomy Journal* 103(2):351-370.

Hay RKM. and Porter JR. 2006. The physiology of crop yield. Blackwell publishing Ltd Oxford UK.

Hedhly A., Hormaza JI. and Herrero M. 2003.The effect of temperature on stigmatic receptivity in sweet cherry (*Prunus avium* L.). *Plant Cell and Environment* 26:1673–1680.

Hedhly A., Hormaza JI.and Herrero M. 2009.Global warming and sexual plant reproduction. *Trends in Plant Science* 14:30–36.

Heide O.M., Rivero R. and Sonsteby A. 2020.Temperature control of shoot growth and floral initiation in apple (*Malus* × *domestica* Borkh.). *CABI Agric Biosci* 1: 8

Hemingway J.S. 1995. Mustards: Brassica spp. and Sinapis alba (Cruciferae). *In: Smartt J. and Simmonds N.W. (Eds), Evolution of Crop Plants. Longman Scientific and Technical, Singapore*, 82–88.

Hepper FN. 2003. Phenological records of English garden plants in Leeds (Yorkshine) and Richmond (Surrey) from 1946 to 2002. An analysis relating to global warming. *Biodiversity and Conservation* 12: 2503-2520.

Hickman J.1975. Environmental unpredictability and plastic energy allocation strategies in the annual Polygonum cascadense (Polygonaceae). *Journal of Ecology* 63: 689-701.

Hiruy B. and Nigussie A. 1986. Progress in rapeseed or mustard research in Ethiopia. In: Omran Proceeding of The Third Oil Crops Network Workshop.IDRCMR,153e 3-5 December 1991, pp. 31-38, IAR, Addis Ababa, Ethiopia. IDRC Ottawa, Canada.

Hiruy B.1985. Review of rape seed mustard breeding and agronomy research in Ethiopia. Paper presented at the workshop on review of field Crops Research in Ethiopia, Addis Ababa, Ethiopia, 25 Feb.-1 March, 1985.

Hunter R. B., Tollenaar M. and Breuer C. M. 1977. Effects of photoperiod and temperature on vegetative and reproductive growth of a maize (*Zeamays*) hybrid. *Canadian Journal of Plant Science* 57: 1127-1133.

IENICA. 2004. Agronomy Guide: Generic guidelines on the agronomy of selected industrial crops. Retrieved from: http://www.ienica.net/agronomyguide/agronomyguide05.pdf on 21 June 2012.

Impa S.M., Sunoj V.J., Krassovskaya I., Bheemanahalli R., Obata T. and Jagadish S. K. 2019. Carbon balance and source-sink metabolic changes in winter wheat exposed to high night-time temperature. *Plant Cell & Environment* 42(4): 1233– 1246

Izumi O., Kuniyuki S. and Toshiro K.2007. Effects of High Temperature on Growth, Yield and Dry-Matter Production of Rice Grown in the Paddy Field, *Plant Production Science* 10(4):412-422.

Johnson B L., Zakaria A K M. and Hanson B K.2003. Row spacing interaction on spring canola performance in the North Great Plains. *Agronomy Journal* 95(3): 703- 708.

Johnson MP. and Cook SA .1968.Clutch size butter cups. *American Naturalist* 102: 405-411.

Kaleem S., Hassan FU. and Saleem A.2009. Influence of environmental variations on physiological attributes of sunflower. *African Journal of Biotechnology* 8: 3531-3539

Kao W. and Chang KW. 2001. Altitudinal trends in photosynthetic rate and leaf characteristics of Miscanthus populations from central Taiwan. *Australian Journal of Botany* 49: 509-514.

Katsura K., Maeda S., Lubis I., Horie T., Cao W. and Shiraiwa T.2008. The high yield of irrigated rice in Yunnan, China: 'A cross-location analysis. *Field crops research* 107:1-11.

Khan A M., Rahim A., Khan M., Khan I. and Riaz S. 2000. Correlation and path coefficient Analysis for yield contributing parameters in Brassica napus. *Pakistan Journal of Agriculture* 16(2): 127- 130.

Khush G. and Peng S. 1996. Breaking the yield frontier of rice. Increasing yield potential in wheat. *Breaking the barriers* 6:36-51.

Kofidis G., Bosabaldis AM. and Moustakas M.2003. Contemporary seasonal and altitudinal variations of structural features in Oregano (*Origanum vulgare* L.). *Annals of Botany* 92: 635-645.

Korner C. and Cochrane PM.1983.Stomatal responses and water rela-tions of Eucalyptus pauciflora in summer along an elevational gradient. *Oecologia* 66: 443-455

Korner C. 2007.The use of 'altitude' in ecological research. *Trends Ecological Evolution* 22(11):569–574.

Kumar G., Chakravarty N.V.K., Kurothe R.S., Sena D.R., Tripathi K.P., Adak T., Haldar D. and Anuranjan.2010a. Effect of projected climate change on mustard (Brassica juncea). *Journal of Agrometreology* 12(2): 168-173.

Kumar P.R.and Tsunoda S. 1980.Variation in Oil Content and Fatty Acid Composition among Seeds from the Cruciferae. In Brassica Crops and Wild Allies; Tsunoda S., Hinata K., Gomez-Campo C. Eds. *Japan Scientific Societies Press.* Tokyo, pp.235–252.

Kumar S., Seepaul R., Mulvaney M. J., *et al.* 2020. 'Brassica carinata genotypes demonstrate potential as a winter biofuel crop in South East United States'. *Industrial Crops and Products*. doi: 10.1016/j.indcrop.2020.112353.

Labana KS., Ahuja KL.and Banga SS. 1987. Evaluation of some Ethiopian mustard (Brassica carinata) genotypes under Indian conditions. Proceedings of the 7th International Rapeseed Congress, Poznan, Poland, May 11–14, 1987. p.115

Lemma D.1998. Seed production Guideline for tomatoes, onion, and hot pepper. Institute of Agricultural Research. Addis Ababa, Ethiopia.pp.11-27.

Liang Z. S., Ding Z. R. and Wang S. T. R. 1992. Study on type of water stress adaptation in both *Brassica napus* and *B. juncea* L. species. *Acta Botanika* 12: 38–45.

Li C. and Lin D. 1987. Dry-matter production and partitioning in the aerial part of rice grown at different altitude localities. *Acta Botanica Yunnanica* 9:89-95.

Li C. and Lin D. 1990. Final partitioning of the 14 Cfed before and after heading of paddy rice grown at different altitude localities. *Acta Botanica Yunnanica* 12:191-196.

Licata M. LaBella S., Lazzeri L., Matteo R., Leto C., Massaro F.and Tuttolomondo T. 2017 'Agronomic Evaluation of Ethiopian Mustard (Brassica carinata A . Braun) Germplasm

and Physical-energy Characterization of Crop Residues in a Semi-arid Area of Sicily (Italy)'. 58(2016), pp. 535–540. doi: 10.3303/CET1758090.

Li J. and Jichao Y. 2017. 'Research Progress in Effects of Different Altitude on Rice Yield and Quality in China'. 2(7), pp. 340–344. doi: 10.15580/GJAS.2012.7.110112203.

Malik R.S. 1990: Prospects for *Brassica carinata* as an oilseed crop in India. *Experimental Agriculture* 26: 125-129.

Marcelis I.F.M. and Baan I. R. and Hofman-Eijer 1997. Effect of seed number on competition and dominance among fruits in Capsicum annum L. *Annals of botany* 79:687-693.

McGregor D. I. 1981. Pattern of flower and pod development in rapeseed. *Canadian Journal of Plant Science* 61(2): 275– 282.

McMaster GG., White JW., Hunt LA., Jameson PD., Dillon SS.and Ortiz-Monasterio JI. 2008. Simulating the influence of vernalization, photoperiod and optimum temperature on wheat developmental rates. *Annals of Botany* 102: 561-569.

Mendham N.J., Shipway P.A. and Scott R.K. 1981. The effect of delayed sowing and weather on growth, development and yield of winter oil-seed rape (*Brassica napus*). *Journal of Agricultural Science* 96: 389-416.

Mendham NJ.and Salisbury PA. 1995. Physiology; crop development, growth and yield. In; D.S Kimber and D.I McGregor (Eds). Brassica oilseeds: production and utilization. Wallingford: CAB. pp.11-64.

Miao Y., Ding Y. U., Qiao-Y.S., Zeng- Fu X. U. and Liwen J.2008. Plant bioreactors for pharmaceuticals. *Biotechnology and Genetic Engineering* 25: 363-380.

Miller GT Jr. 2001. Environmental Science: Working With the Earth. 8th ed. Pacific Grove, CA, USA: Brooks/Cole. pp.135-167.

Mills P. 1993. The effects of low temperatures on the germination and emergence of canola. Alberta Agriculture Farming for the Future Project. pp. 83-86.

Miserere A., Searles PS., Garcia-Inza GP.and Rousseaux MC.2018. Elevated temperature affects vegetative growth and fruit oil concentration in olive trees (*Olea europaea*). *Acta Horticulture* pp. 523–533.

Mnzava NA, Schippers RR. 2007. *Brassica carinata* A. Braun. In: Grubben GJH, Denton OA (eds). Plant Resources of Tropical Africa 2: Vegetables. PROTA Foundation, Wageningen, Netherlands / Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. pp. 119–123.

Monotti M. 2003. Growing non-food sunflower in dryland conditions. *Italian Journal of Agronomy* 8: 3-8.

Morita S., Shiratsuchi H., Takanashi J. I. and Fujita K.2002. Effect of high temperature on ripening in rice plants: Comparison of the effects of high night temperatures and high day temperatures. *Japanese Journal of Crop Science* 71(1): 102– 109.

Morita S., Yonemaru J. I. and Takanashi J. I. 2005. Grain growth and endosperm cell size under high night temperatures in rice (*Oryza sativa* L.). *Annals of Botany* 95(4): 695– 701.

Morrison MJ., Stewart DW. and McVetty PBE. 1992. Maximum area expansion rate and duration of summer rape leaves. *Canadian Journal of plant Science* 72:117-126.

Morrison J.I.L.1996. Global environmental change impacts on crop growth and production in Europe. Implications of global environmental change for crops in Europe. Asp. Appl. Biol. 45: 62-74.

Morrison M. J.and Stewart D. W. 2002. Heat stress during flowering in summer Brassica. *Crop Science* 42(3):797– 803.

Morrison MJ., McVetty PBE and Shaykewich CF. 1989. The determination and verification of a baseline temperature for the growth of westar summer rape. *Canadian Journal Plant Science* 69: 455-464.

Nanda R., Bhargava SC.and Rawson HM. 1995. Effect of sowing date on rates of leaf appearance, final leaf numbers and areas in *Brassica campestris*, *B. juncea*, *B. napus* and *B. carinata*. *Field Crop Research* 42: 125-134.

Nanda R., Bhargava S.C. and Tomar D.P.S.1994. Rate and duration of siliqua and seed filling period and their relation to seed yield in Brassica spp. *Indian Journal of Agricultural Science* 64: 227-232.

Nigussie A. and Becker H. 2002. 'Genotypic diversity and patterns of variation in a germplasm material of Ethiopian mustard (Brassica carinata A. Braun)'. *Genetic Resources and Crop Evolution* pp. 573–582. doi: 10.1023/A:1021204412404.

Nigussie A. and Heiko B. 1999. Genetic variability in Ethiopian mustard (Brassica carinata Braun) for quality characteristics. In: Proc. Of the 10th Int. Rapeseed Conf. 26-29 Sep. Canberra, GCIRC, and Canberra, Australia. pp.1-4.

Nigussie A. 2003. 'Genotypic diversity and patterns of variation in a germplasm material of Ethiopian mustard (Brassica carinata A . Braun)'. pp. 573–582.

Nigussie A., Adefris T. and Tadele Z. 1996. Effect of agronomic practices on seed and oil yields of Ethiopian mustard (*Brassica carinata* A. Braun and rapeseed (*B. napus* L.). *Tropical Agriculture* 73:94-99.

Nissim Y., Shloberg M., Biton I., Many Y., Doron-Faigenboim A., Zemach H. *et al*. (2020) High temperature environment reduces olive oil yield and quality. PLoS ONE 15(4): e0231956.

Osada A., Takahashi H., Dhammanuvong S., Sasiprapa V. and Gunthararom S.1973. Seasonal changes in growth pattern of tropical rice. I. Environmental factors affecting plant height, tillering and leaf area. *Proc. Crop Sci. Soc. Jpn.* 42: 343-350.

Pan X., Caldwell C. D., Falk K. C. and Lada R. 2012. 'The effect of cultivar , seeding rate and applied nitrogen on Brassica carinata seed yield and quality in contrasting environments'. *Canadian Journal of Plant Science* 92: 961-971. doi: 10.4141/CJPS2011-169.

Polowick P. L. and Sawhney V. K. 1988. High temperature induced male and female sterility in canola (*Brassica napus* L.). *Annals of Botany* 62(1): 83– 86.

Prasad P.V.V.,Boote KJ.,Allen LH. and Thomas JMG.2003.Super-optimal temperatures are detrimental to peanut (*Arachis hypogaea* L.) reproductive processes and yield at both ambient and elevated carbon dioxide. *Global Change Biology* 9:1775–1787.

Prasad P. V. V., Pisipati S. R., Ristic Z., Bukovnik U. and Fritz A. K. 2008. Impact of nighttime temperature on physiology and growth of spring wheat. *Crop Science* 48(6):2372– 2380.

Puteh AB., Thuzar M., Mondal MMA., Abdulah APB.and Halim MRA. 2013. Soybean (*Glycine max* (L.) Merrill) seed yield response to high temperature stress during reproductive growth stages. *Australian Journal of Crop Science* 7(10): 1472–1479.

Qaderi MM., Kurepin LV. and Reid DM. 2006. Growth and physiological responses of canola (Bassica napus) to three component of global climate change temperature carbondioxide and drought. *Physiologia Plantarium* 128: 710-721.

Qadir G, Hassan F. and Malik M A .2007. Growing degree days and yield relationship in sunflower. *International Journal of Agriculture and Biology* 9(4):564-568.

Qin Y., Dong RJ., Bin T., Yong-PY. and Yuan WD. 2016.Changes of flowering phenology and flower size in rosaceous plants from a biodiversity hotspot in the past century. *Sci. Rep.* 6: 28302.

R Core Team .2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rakow, G. (2004). *Species Origin and Economic Importance of Brassica*. *54*, 3–11. https://doi.org/10.1007/978-3-662-06164-0_1

Rakow G.1995. Developments in the breeding of edible oil in other Brassica species. In: Proceedings of the 9th Int. Rapeseed Conf., Cambridge, Henry Ling Ltd. Dochester, UK pp.410 - 412 .

Rameeh V.2015.Genetic Variability and Interrelationships among Quantitative Traits in Rapeseed (*Brassica napus* I.) advanced Lines. *Journal of Agricultural Science* 3:158-167.

Reddy KR. and Kakani VG. 2007. Screening Capsicum species of different origins for high temperature tolerance by *in vitro* pollen germination and pollen tube length. *Scientia Horticulturae* 112:130–135.

Kaesha N. 2009. Flowering phenology: An activity to introduce human & environmental effects on plant reproduction. *The American Biology Teacher* 71(5).

Ritchie JT. 1991.Wheat Phasic development In: Hanks J, Ritchie JT (Eds) modeling plant and soil systems. Madison, Wisconsin. pp.31-54.

Roberts EH, Summerfield RJ, Ellis RH, Qi A. 1993. Adaptation of flowering in crops to climate. *Outlook Agriculture* 22: 105-110

Robertson MJ.2002. Understanding how environment and genotype determine time to flowering in canola and Indian mustard. *Australian Journal Agricultural Research* 52:345.352.

Roy S., Meena R.L., Sharma S.C., Vinod K., Chattopadhyay C. and Khan S.A.2005. Thermal requirement of oilseed Brassica cultivars at different phonological stages under varying environmental conditions. *Indian Journal Agricultural Sciences* 75(11): 717-721.

Ruiz–Vera UM., Siebers M., Gray S., Rosenthal D., Kimball BA., Ort DR. *et al*. 2013.Global warming can negate the expected CO2 stimulation in photosynthesis and productivity for soybean grown in the Midwest United States. *Plant Physiology* 162:410–23.

Russo V.M.2003. Planting date and plant density affect fruit seed of Jalapeno peppers. *Journal of Horticultural sciences* 38: 520-523.

Sabaghnia N., Dehghani H., Alizadeh B. and Mohghaddam M. 2010. Interrelationships between seed yield and 20 related traits of 49 canola (*Brassica napus* L.) genotypes in non-stressed and water-stressed environments. *Spanish Journal of Agricultural Research* 8(2):356-370.

Sato S. and Peel MM. 2005. The effect of moderately elevated temperature stress on the timing of pollen release and germination on tomato (*Lycopersicum esculentum* Mill). *Journal of Horticultural Science and Biotechnology* 80: 23-28.

Schemske D. W.1980. Evolution of floral display in the orchid Brassavola nodosa. *Evolution* 34: 489-493.

Seegler C.J.P. 1983. Oil plants in Ethiopia: their taxonomy and six-rowed barley. *Indian Journal Genetic Documentation*, PUDOC, Wageningen, Netherlands.

Seepaul, R., Small, I. M., Mulvaney, M. J., George, S., Leon, R. G., Paula-Moraes, S. V, Geller, D., Marois, J. J., & Wright, D. L. (2019). *Carinata, the Sustainable Crop for a Bio-based Economy: 2018-2019 Production Recommendations for the Southeastern United States 1*. 2018–2019. https://edis.ifas.ufl.edu

Setia R.C. and Richa. 1989. Anatomical studies on siliquae wall and seed coat development in Brassica juncea L. Czern and Coss. *Phytomonphology* 39: 371-377.

Sharma B. B., Kalia P., Singh D.and Sharma T. R. 2017. Introgression of black rot resistance from *Brassica carinata* to cauliflower (*Brassica oleracea* botrytis group)through embryo rescue. *Frontiers in Plant Science*. https://doi.org/10.3389/fpls.2017.01255

Shepherd T. and Griffiths DW. 2006. The effects of stress on plant cuticular waxes. *New Phytology* 171(3):469–99.

Simmonds N.W. 1999. Longman Principles of Crop Improvement Group, New York.

Singer S.D., Zou J.and Weselake R.J.2016. Abiotic factors influence plant storage lipid accumulation and composition. *Plant Science* 243: 1– 9.

Singh D. 2003. Genetic improvement in Ethiopian mustard (*Brassica carinata* A. Braun). Visa hvis Indian mustard (*Brassica juncea* L. Czern and Coss.). In: Proc.11th Int. Rapeseed Confr. Copenhagen, Denmark. p.513.

Singh M. J., Chaunhan S. K., Arvind and Singh N. B. 2003. Nitrogen assimilatory enzymes, chlorophyll content and yield as influenced by drought stress in Indian mustard (*B. juncea* L.): 42-47.

Singh M. P.and Lallu- Singh N. B. 2014. 'Thermal requirement of indian mustard (*Brassica juncea*) at different phonological stages under late sown condition'. *Indian Journal of Plant Physiology* pp. 238–243. doi: 10.1007/s40502-014-0072-0.

Singh V.V., Gujjar N., Ambawat S., Yadav S., Singh B.K.,Ram B., Meena M.L., Singh B.R., Singh S. and Singh D.2016. Morphological and molecular diversity among ful-sib progenies of Indian mustard (*Brassica juncea* L.). *Journal Breeding and Genetics* 48:180-188.

Sinsawat V., Leipner J., Stamp P. and Fracheboud Y.2004. Effects of heat stress on the photosynthetic apparatus in maize (*Zea mays* L.) grown at control or high temperature. *Environmental Experimental Botany* 52: 123-129.

Slafer GA. 2003. Genetic basis of yield as viewed from a crop physiologist's perspective. *Annal of Applied Biology* 142: 117-128.

Slauenwhite KLI, Qaderi MM. 2013. Single and interactive effects of temperature and light quality on four canola cultivars. *Journal of Agronomy and Crop Science* 199: 286-298

Southworth J., Pfeifer RA., Habeck M., Randolph JC., Doering OC. and Roa GD. 2002. Sensitivity of winter wheat yields in the Midwestern United States to future changes in climate, climate variability and Co2 fertilization. *Climate Research* 22: 73-86.

Sreelantha kumary I. and Rajamony L. 2004. Variability, heritability and genetic advance in chilli (*Capsicum annum* L.). *Journal of Tropical Agriculture* 42 (1-2): 35-37.

Srinivasan A., Johansen C. and Saxena NP. 1998. Cold tolerance during early reproductive growth of chickpea (*Cicer arietinum* L): characterization of stress and genetic variation in pod set. *Field Crops Research* 57:181–193.

Stamigna, C. *et al.* (2012) 'Oil and furfural recovery from Brassica carinata', *Biomass and Bioenergy*, 39, pp. 478–483. doi: 10.1016/j.biombioe.2011.12.024.

Stymne S. 2008. Genetic Engineered Vegetable Oils for Bio-materials and Bio-fuels. Swedish University of Agricultural Science. Sweden, Stockholm.pp.87-92.

Summerfield RJ., Roberts EH., Ellis RH.and Lawn RJ. 1991. Towards the reliable prediction of time to flowering in six annual crops In: The development of simple models for fluctuating field environments. *Experimental Agriculture* 27: 11-31.

Tasma I. M., Lorenzen L. L., Greenand D.E.and Shoemaker R. C.2001. Mapping genetic loci for flowering time, maturity, and photoperiod insensitivity in soybean. *Molecular Breeding* 8:25–35.

Tesfaye w., Adugna W. and Tewodros M. 2014. 'Analysis of Genetic Parameters on Ethiopian Mustard (Brassica carinata A . Braun) Genotypes in Northwestern Ethiopia'. 4(April), pp. 83–88.

Tischner T., Allphin L., Chase K., Orf JH. and Lark KG. 2003. Genetics of seed abortion and reproductive traits in soybean. *Crop Science* 43(2):464–73.

Trentacoste ER., Puertas CM. and Sadras VO. 2012.Modelling the intraspecific variation in the dynamics of fruit growth, oil and water concentration in olive (*Olea europaea* L.). *European Journal of Agronomy* 38:83–93.

Tsige G., Labuschagne M.T.and Hugo A.2005.Genetic relationships among Ethiopian Mustard genotypes on oil content and Fatty acid composition. *African Journal of Biotechnology* 4:1256-1268

Tubiello FN., Soussana JT. and Howden SM. 2007. Crop and pasture response to climate change. *Proceeding of the National Academy of sciences*, USA 104: 19686-19690.

U.N.1935.Genome Analysis in Brassica with special reference to the experimental formation of *B.Napus* and peculiar mode of fertilization. *Japanese Journal of Botany* 9:389-452.

Velasco L.and Fernandez-Martinez JM. 2009. Other Brassicas. In: Oil Crops, Handbook of Plant Breeding 4. Volkmann J. and Rajcan I (eds). *Springer* pp. 127–153.

Velasco L., Fernández-Martínez J. M. and De Haro A. 1997. 'Determination of the fatty acid composition of the oil in intact-seed mustard by near-infrared reflectance spectroscopy'. *JAOCS, Journal of the American Oil Chemists' Society* 74(12): 1595–1602. doi: 10.1007/s11746-997-0083-3.

Vigil MF., Anderson RL. and Beard WE. 1997. Base temperature and growing-degree-hour requirements for the emergence of canola. *Crop Science* 37: 844-849.

Wang T., Li J. and Yu X.1984. Regional effects of ecological environment in region of northwest Yunnan on rice growth and yield structure. *Tillage and Cultivation* 4:22-27.

Warner RM. and Erwin JE.2005. Naturally occurring variation in high temperature induced floral bud abortion across Arabidopsis thaliana accessions. *Plant Cell and Environment* 28:1255–1266.

Warwick S. I., Gugel R.K., McDonald T. and Falk K. C. 2006. 'Genetic variation of Ethiopian mustard (Brassica carinata A . Braun) germplasm in western Canada'. pp. 297–312. doi:

10.1007/s10722-004-6108-y.

Wei T. *et al.* (2017). 'Visualization of a Correlation Matrix'. *Statistician* 56, pp. 316–324.

Wheeler TR., Hong TD., Ellis RH., Porter JR. and Vara Prasad PV. 2000. Temperature variability and the annual yield of crops. *Agriculture, Ecosystem and Environment* 82: 159-167.

Whigam DK. 1983.Soybean. In: Smith WH, Banta SJ, editors. Potential Productivity of Field Crops under Different Environments. Los Banios: International Rice Research Institute pp.205–225.

Williams P.H.1989.Rapid-Cycling Brassicas (RCB's) in Hands-on Teaching of Plant Biology. Intested studies for laboratory teaching. Proceedings of the 10th Workshop/Conference of the Association for Biology Laboratory Education (ABLE), University of British Columbia, June 13-17, 1989.

Willis SG. and Hulme PE.2004. Environmental severity and variation in the reproductive traits of Impatiens glandulifera. *Funct Ecol*. 18: 887-898.

Yalden W.D.1983.The extent of high ground in Ethiopia compared to the rest of Africa. SINET. *Ethiopian Journal of science* 6: 35 - 38.

Yuan J., Ding Z., Cai G., Yang S., Zhu Q. and Yang J. 2005a. The Factors Influencing RVA Profile of Rice Starch and Their Changes with Altitudes in Panxi Region. *Acta Agronomica Sinica* 31:1611-1619.

Zemede A.1992.Conservation and use of traditional vegetables in Ethiopia. http:www. Biodiversity international.org/publications/Web version.

Zemede A. 1997. 'Conservation and use of traditional vegetables in Ethiopia', in *Traditional*

african vegetables: Proceedings of the IPGRI International Workshop on genetic resources of traditional vegetables in Africa Conservation and use. ICRAF-HQ, Nairobi, Kenya, pp. 57–65.

Zhou W.J., Zhang G.Q., Tuvesson S., Dayteg C. and Gertsson B. 2006. Genetic survey of Chinese and Swedish oilseed rape (*Brassica napus* L.) by simple sequence repeats (SSRs). Genetic Resource. Crop Yasir A. *et al*. *Heritability and correlation analysis for morphological*…370 Evol.53 (3):443-447.

Zhou W.J.2001.Oil seed rape.In:G.P.Zhang and W.J. Zhou Eds.Crop production, Zhejiang University Press, Hang Zhou pp.153-178.

Zhu Y., Cao Z., Xu F., Huang Y., Chen M., Guo W. and Jiang L. 2012. Analysis of gene expression profiles of two near-isogenic lines differing at a QTL region affecting oil content at high temperatures during seed maturation in oilseed rape (*Brassica napus* L.). *Theoretical and Applied Genetics* 124(3): 515– 531.

Zinn KE.,Tunc-Ozdemir M. and Harper JF. 2010. Temperature stress and plant sexual reproduction: uncovering the weakest links. *Journal of Experimental Botany* 61:1959–1968.

APPENDICES

Table 1. Mean square values of days to 50% emergence, Days to first flowering, Days to 50% flowering, Days to flower completion and Flowering period as affected by interaction of Altitude with Genotype tested at different altitudinal locations.

Source of Variation	Degrees of freedom	Date of 50% emergence (No)	Days to first flowering (No)	Days to 50% flowering (No)	Days to flower completion (No)	Flowering period (No)	Days to maturity (No)
Altitude	2	67.76***	2583***	3557***	5528***	558.8***	7189***
Genotype	10	36.47***	453.6***	716***	551***	24.8***	392***
Altitude*Genotype	20	3.50***	45.5***	76***	74***	9.3***	139***
Error	66	0.77	4.9	6	6	2.5	8

Ns =non-significant,*= significant, **= highly significant, ***= very highly significant

Table 2. Mean square values of petal width, petal length, pistil height, short stamen height and long stamen height as affected by interaction of Altitude with Genotype tested at different altitudinal locations.

Source of Variation	Degrees of freedom	Flower no (No)	Petal width (mm)	Petal length (mm)	Pistil height (mm)	Short stamen height(mm)	Long stamen height(mm)
Altitude	2	17054***	15.03***	66.15***	5.74***	16.21***	19.36***
Genotype	10	15735***	12.26***	40.67***	10.15***	15.05***	18.72***
Altitude*Genotype	20	946**	2.08***	7.80***	1.92***	3.16***	3.97***
Error	66	432	0.59	1.54	0.42	0.36	0.41

Ns =non-significant,*= significant, **= highly significant, ***= very highly significant

Table 3. Mean square values of Flower no, Leaf no, Plant height, Pedicel length and Days to maturity as affected by interaction of Altitude with Genotype tested at different altitudinal locations.

Source of Variation	Degrees of freedom	Leaf no (No)	Plant height (cm)	Pedice length (mm)
Altitude	2	5594***	8728***	161.29***
Genotype	10	596**	2048***	132.77***
Altitude*Genotype	20	258^{ns}	396***	4.45*
Error	66	4.9	99	2.39

Ns =non-significant,*= significant, **= highly significant, ***= very highly significant

Table 4. Mean square values of Number of pods per plant, Number of seeds per pod, Pod length, 1000 seed weight, Seed yield per block and Oil content as affected by interaction of Altitude with Genotype tested at different altitudinal locations.

Ns =non-significant,*= significant, **= highly significant, ***= very highly significant

Source of Variation	Degrees of freedom	Number of pods per plant(No)	Number of seeds per pod (No)	Pod length (mm)	1000 seed weight (gm)	Seed yield (gm)	Oil content (%)
Altitude	2	21480***	24.58***	639.5***	28.4***	210.39***	1276.4***
Genotype	10	15991***	110.78***	1736.1***	8.18***	42.61***	119.8***
Altitude*Genotype	20	705*	11.05***	18.1^{ns}	1.65***	17.39***	22.4***
Error	66	387	1.67	10.8	0.01	0.65	0.5

Table 5. Correlation coefficients among parameters in eleven *Brassica carinata* genotypes tested at different altitudinal locations.

	DE	**DFF**	**DF**	**DFC**	**FP**	**PW**	**PL**	**PSH**	**SSH**	**LSH**	**FN**	**LN**	**PH**	**PEDL**	**DM**	**NPP**	**NSPP**	**PODL**	**TSW**	**SY**	**OC**
DE																					
DFF	0.71***																				
DF	0.72***	**0.98*** **																			
DFC	0.68**	**0.97*** **	**0.96*** **																		
FP	0.43	0.66**	0.69	**0.81*** **																	
PW	0.09	0.28*	0.33*	0.31*	0.34*																
PL	0.13	0.24*	0.30*	0.31*	0.41*	**0.85*** **															
PSH	0.02	0.12	0.17	0.16	0.25*	**0.83*** **	**0.84*** **														
SSH	0.11	0.22*	0.28*	0.27*	0.34*	**0.85*** **	**0.92*** **	**0.84*** **													
LSH	0.15	0.20*	0.24*	0.25*	0.32*	0.8	**0.88** **	**0.83*** **	**0.94*** **												
FN	0.27*	0.10	0.05	0.15	0.22*	-0.31	-0.2	-0.29	-0.24	-0.19											
LN	-0.16	-0.45*	-0.44	-0.52	-0.58	-0.32	-0.29	-0.21	-0.29	-0.25	-0.8										
PH	0.26*	0.63**	0.64**	0.67**	0.62**	0.54**	0.48*	0.41*	0.50*	0.48*	-0.07	-0.56									
PEDL	0.11	0.25*	0.30*	0.29*	0.33*	0.66**	0.63**	0.68**	0.74**	0.72**	-0.2	-0.26	0.58**								
DM	0.62**	**0.89*** **	**0.89*** **	**0.93*** **	0.8	0.41*	0.38*	0.25*	0.38*	0.35*	0.16	-0.56	0.69**	0.42*							
NPP	0.26*	0.11	0.06	0.15	0.22*	-0.33	-0.2	-0.3	-0.26	-0.21	**0.96*** **	-0.05	-0.1	-0.2	0.15						
NSPP	0.08	-0.11	-0.08	-0.09	-0.01	0.43*	0.51*	0.55*	0.53**	0.6	0.05	-0.01	0.14	0.60**	0.05	0.07					
PODL	0.43*	0.16	0.23*	0.22*	0.29*	0.71**	0.72**	0.68**	0.76**	0.76**	-0.36	-0.26	0.53*	0.78**	0.35*	-0.39	0.6**				
TSW	0.12	0.42*	0.43*	0.49*	0.56**	0.54*	0.58*	0.49*	0.56**	0.52**	-0.26	-0.42	0.53*	0.6**	0.57**	-0.21	0.30*	0.55**			
SY	0.23*	0.10	0.12	0.20*	0.38*	0.14	0.29*	0.27*	0.28*	0.29*	0.46*	-0.19	0.23*	0.48*	0.29*	0.50*	0.46*	0.26*	0.28*		
OC	0.21*	0.51**	0.53**	0.60**	0.69**	0.57**	0.59**	0.49*	0.57**	0.52**	-0.12	-0.48	0.59**	0.54**	0.66**	-0.07	0.18	0.48*	0.75**	0.31*	

DE=Days to 50% emergence, DFF=Days to first flowering, DF=Days to 50% flowering, DFC=Days to flower completion, FP=Flowering period, PW=Petal width, PL=Petal length, PSH=Pistil height, SSH=Short stamen height, LSH=Long stamen height, FN=Flower Number, LN=Leaf number, PH= Plant height, PEDL=Pedicel length, DM=Days to maturity, NPP=Number of pods per plant, NSPP=Number of seed per pod, PODL=Pod length, TSW=Thousand seed weight, SY=Seed yield, OC=Oil content

BIOGRAPHICAL SKETCH

The author was born in January, 1991 in Goba town, Bale Zone, Oromia National Regional State. She attended her elementary education at the urgi barisa elementary school, her secondary educations at the Negade sefer Secondary School and her preparatory education at Batu Terara preparatory school in Bale Goba. After completing her preparatory school education and passing the Ethiopian university entrance examination, she joined Jimma University College of Agriculture and Veterinary Medicine in 2011 and graduated with BSc degree in Horticulture in June 2013.

After graduation, she was employed by Green Mark Herbs PLC as an Agronomist at Hawassa. In November, 2015 she was employed by Hawassa University College of Agriculture as a Graduate assistant. After serving for three consecutive years in the College, she joined Master's Program in school of Plant and Horticultural Sciences (Specialization: Horticulture) in Hawassa University in the year 2018.