The Open Biotechnology Journal

Content list available at: https://openbiotechnologyjournal.com

RESEARCH ARTICLE

Growth and Yield Response of Garlic (*Allium Sativum* L.) to Intra-row Spacing and Variety at Selekeleka, Northern Ethiopia

Mulu Teshale[1] and Negasi Tekeste[1,*]

[1]*Department of Plant Sciences, College of Agriculture, Aksum University, P.O.Box 314, Shire Campus, Shire, Ethiopia*

Abstract:

Background:

Garlic is an important condiment and cash crop in Ethiopia. Low yield and productivity of the crop are the major characteristics of the crop in the country. Many factors affect the productivity of the crop in the country, however poor agronomic practices, especially the use of low-yielding varieties and inappropriate spacing, are the major ones.

Objective:

The aim of this study is to evaluate the growth and yield response of garlic to intra-row spacing and variety, and to identify the optimum intra-row spacing and high-yielding variety.

Methods:

The field experiment was composed of three garlic varieties vis-a-vis Tsedey 92, Bishoftu Netch and Local and four levels of intra-row spacing with 5cm, 7.5cm, 10cm and 12.5 cm laid out in a Randomized Complete Block Design replicated three times. Data pertaining growth, yield and yield-related parameters were collected and analyzed using Genstat software.

Results:

Main effects of variety and intra-row spacing significantly($p \leq 0.05$) affected days to maturity, plant height, leaf number, leaf length, leaf width, bulb length, bulb diameter, clove number per bulb, mean bulb weight, and clove diameter. Interaction effects of variety and intra-row spacing significantly ($p \leq 0.05$) influenced clove length, fresh biomass yield, dry biomass yield, marketable cloves per bulb, marketable, unmarketable and total bulb yield. The highest total bulb yield of 8.98 tha^{-1} was obtained from treatment combination of variety Tsedey 92 and 5cm intra-row spacing although at par with treatment combinations of Bishoftu Netch variety and 5cm intra-row spacing which gave 8.70 tha^{-1} while the lowest (5.37 tha^{-1}) was obtained at treatment combinations of local variety and intra-spacing of 12.5cm. The highest (8.05 tha^{-1}) and lowest (4.94 tha^{-1}) marketable bulb yield of garlic were obtained at treatment combinations of variety Tsedey 92 planted with 5cm intra-row spacing and local variety planted with 12.5cm, respectively.

Conclusion:

Tsedey 92 variety together with an intra-row spacing of 5cm could be suggested for high total and marketable bulb yield in the study area.

Keywords: Bulb, Clove, Garlic, Growth, Marketable, Spacing.

Article History	Received: June 09, 2020	Revised: October 14, 2020	Accepted: October 23, 2020

1. INTRODUCTION

Garlic (*Allium sativum* L.) is the second most widely produced Allium crop next to onion [1]. It is produced for fresh market, dehydrated as an ingredient for food processing, and food supplement output like dehydrated powder, essential oil, oil macerate, powder and aged garlic extract [2, 3]. Moreover, it contains considerable amounts of Ca, P and K, and its leaves are sources of protein, vitamin A and contains antibiotics like garlicin and allistatin [4]. Many research data indicates that garlic has miraculous pharmaceutical effects and is used to cure a number of disease like blood pressure, cholesterol, cancer, chronic fever, anthelmintics, antioxidant, antifungal and wound healing, asthma, arthritis, malaria, diabetes, kidney stone and night blindness [5, 6].

* Address correspondence to this author at the Department of Plant Sciences, College of Agriculture, Aksum University, P.O.Box 314, Shire campus, Shire, Ethiopia; E-mail: negasite@gmail.com

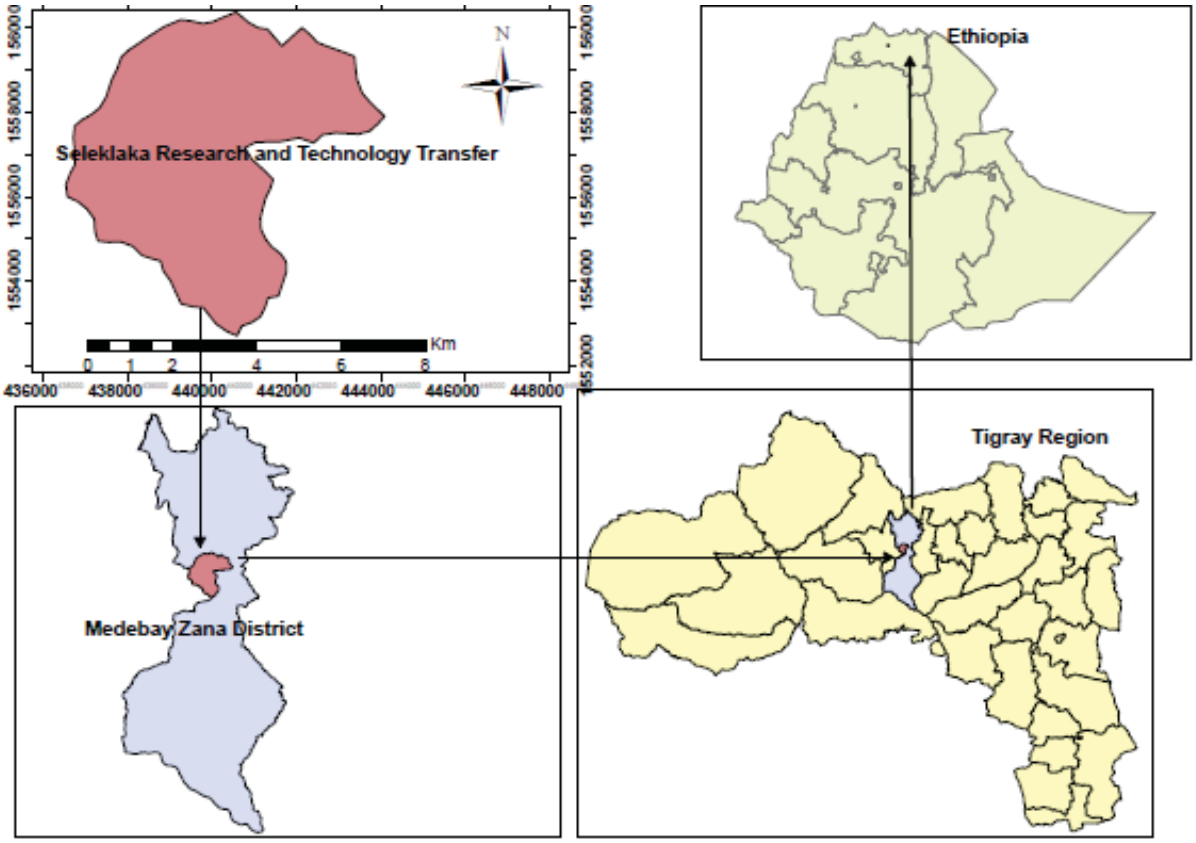

Fig. (1). Map of the study area.

In Ethiopia, the Alliums (onion, garlic, and shallot) are important bulb crops produced for home consumption as a spice, medicinal plant, and as a source of income for farmers [7]. It grows in a wide range of climatic and soil conditions, mainly in the mid-altitudes and highlands of the country. As a cash crop, it is a source of earning foreign currency by exporting to Europe, the Middle East, Africa and USA [8]. In the Tigray region of Ethiopia, the production and marketing of high-value vegetable crops are intensifying mainly due to market-oriented government policy. Garlic is one of the high-value vegetable crops produced in rotation with pulses during the cold season [9] (Fig. **1**). The region ranks 4th in garlic production next to Amhara, Oromia and S.N.N.P regional states of Ethiopia, covering an area of 540.97 ha with a production of 3912.826 tonnes [10]. According to Medebay Zana district office of agriculture and rural development, 2017 unpublished report, onion is one of the most important vegetable crops mostly cultivated under irrigation; during the 2017/18 cropping season, the irrigable area covered with alliums were about 226.62 hectares with a production of 10,656.25 quintals.

The average yield of garlic in Ethiopia was 9.34 t ha$^{-1,}$ which is far from the world average of 23.53 t ha^{-1}. Lack of improved and high yielding varieties, non-availability of quality seeds, low soil fertility, inappropriate agronomic practices, lack of proper pest and disease management and marketing facilities, and lack of improved post-harvest technologies are among the prominent factors for low productivity in the country [11, 12]. The optimum level of any agronomic practices, such as plant population density, varies with the environment, the purpose of the crop and variety. Bulb yield and days to maturity of garlic is disposed to environmental changes resulting in variable yield due to the significant effect of genotype-by-environment interaction [13]. Lack of appropriate variety and plant population greatly affects garlic growth, yield and quality. Many authors reported a detrimental effect of lack of optimum plant population on bulb production [14 - 17]. However, different garlic varieties might respond differently to different intra-row spacing, and to optimize crop yield and productivity, a full package of information is required for the specific growing system [7, 8]. The use of optimum plant population density has a dual advantage. It avoids strong competition between plants for growth factors such as water, nutrients, and light. Conversely, it enables the efficient use of available cropland without wastage [9].

In the study area, most farmers cultivate alliums according to their own choice due to the absence or unavailability of standard production techniques, which contributed to the low yield of the crop [18]. The national recommended intra-row spacing is not optimum under all growing conditions as well as crop or varietal characteristics. Moreover, there are local and improved garlic varieties under cultivation in the study area. Varieties of garlic may differ in root architecture, foliage and other growth characteristics, and even a cultivar performs differently under different agro-climatic conditions [11]. Furthermore, in the study area, there is a lack of information on

the growth and yield response of garlic to different intra-row spacing.

Therefore, the overall objective of the study is to evaluate the growth and yield response of garlic varieties to different intra-row spacing and to identify the optimum intra-row spacing and variety for high garlic yield in the study area.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The experiment was conducted at Aksum University Selekleka research and demonstration center, located at Medebay Zana district, Northwestern Zone of Tigray region, during the offseason of 2018/2019. The experimental area is situated at 14° 08' 57"N latitude and 38° 17' 02" E longitudes at an altitude of 1864 m.a.s.l. The study areas belong to the cool sub-humid agro-climatic zone [19]. It receives a mono-modal type of rainfall, which extends from June to September with an annual rainfall of 660 to 750 mm. The soil textural class is clay loam with a pH of 7.2. The average temperature for the past 15 years was 20.92°C with a mean maximum temperature of 30.97°C and a mean minimum of 11.4°C. The area is known for the mixed crop-livestock farming system in which cultivation of Teff (*Eragrostis tef*), Sorghum (*Sorghum bicolor*), Maize (*Zea mays*), Finger Millet (*Eleusine coracana*) and pea (*Pisum sativum*) are the major crops in the main season, and Garlic (*Allium sativum*) and onion (*Allium cepa*) are the leading root crops area during off-season [20].

2.2. Characteristics of Experimental Materials

Three garlic varieties, namely Bishoftu Netch and Tsedey 92, as improved varieties released by Ethiopia Institute of Agricultural Research, Debrezeit Agricultural Research Center, during 1999/2000 E.C and local garlic variety, were used for the study. The seed of the improved varieties was obtained from Aksum agricultural research center, and for the local, which is currently under production in the study area were collected from the local market. Tsedey 92 has white-colored bulbs, green leaves and takes about 110-130 days for its maturity and yields 7.5 to 8.13 t ha^{-1} with an average bulb weight of 41.59 g. The variety Beshoftu Netch has a white bulb color matures within 132 days, and yields 7.9 t ha^{-1} with a mean bulb weight is 42 g [21].

2.3. Treatments and Experimental Design

The experiment consisted of treatment combinations with four levels of intra-row spacing vis-a-vis 5cm, 7.5cm, 10cm and 12.5 cm and three garlic varieties vis-a-vis Bishoftu Netch, Tsedey92 and local variety. The experiment was set in a randomized complete block design (RCBD) with a factorial arrangement replicated three times. Bishoftu Netch and Tsedey 92 improved varieties released by Ethiopia Institute of Agricultural Research, Debre-Zeit Agricultural Research Center, during 2007. The local variety was collected from the local market in the area. For the experiment, a plot size of 3 m^2 (2 m x 1.5 m) having a distance of 0.5m, 0.3m and 1m between plots, rows and blocks, respectively, were used.

2.4. Experimental Procedure

Before planting the cloves, the experimental field was ploughed and harrowed by a tractor. Large clods were broken down to a fine tilth, and then a total of 36 plots, each with a size of 2 m x 1.5 m, were prepared, with 12 plots in each replication. On 23rd December 2018, cured and medium to large-sized cloves of 1.50-2.50 g of the three test varieties which are not diseased, damaged, soft and discolored, were planted on well prepared raised ridges at a depth of 3 cm. Urea at a rate of 150 kg ha^{-1} and DAP at 200 kg ha^{-1} were applied as a source of nitrogen and phosphorus respectively, where DAP fertilizers were applied at planting and urea fertilizer were side dressed in a split in two applications; with half was applied two weeks after emergence and the remaining half five weeks after emergence [22]. Gap filling (re-planting) was carried out within one week to replace those seedlings which were damaged and failed after transplanting. Irrigation was supplied through the furrow irrigation method at four days interval for the 1st month and then extended to seven days interval and stopped two weeks prior to harvesting [23]. All other management practices, including harvesting of bulbs, were carried out according to the procedure developed by [23].

2.5. Data Collection

Data on growth and yield and attributes yield were collected from ten randomly selected plants of three rows of each plot at physiological maturity and harvesting, respectively. The total, marketable and unmarketable bulb yield was recorded from three central rows of each plot. Phenological data such as days to maturity were recorded on a plot basis at maturity.

Days to maturity was recorded by counting the number of days from planting to the time when 70% of plants in a plot fall down their foliage and neck fall. Plant height was measured from the soil surface to the tip of matured leaf using a ruler in centimeters at the time of maturity; Leaf number was determined by counting the total number of leaves produced at physiological maturity; Leaf length was measured using ruler at physiological maturity; Leaf width was recorded as the average of the width of ten randomly selected leaves measured at their widest part at physiological maturity using meter scale; Bulb length was measured using digital caliper of ten randomly selected bulbs at the time of harvesting; Bulb diameter was measured at the widest point using digital caliper at the time harvesting; Clove number was recorded by counting the number of cloves per plant at harvesting; Clove length was recorded by measuring the length of cloves using digital caliper at the time of harvesting; Clove diameter was recorded by measuring the diameter of cloves at the widest point using digital caliper at the time of harvesting; Mean bulb weight was recorded by weighting the bulbs just after curing, using digital balance; Fresh and dry biomass were recorded as the sum of the fresh and dry weights of bulbs and above ground parts respectively at the time of harvesting using digital balance where the dry biomass was dried in an oven at 70 ^{o}c for 72 hours; Marketable clove number was recorded just after topping and curing by counting of cloves having greater 1 g weight and undamaged ones according to the procedure used

by Fikreyohannes (2005) [24]; Unmarketable clove numbers were recorded after topping and curing by counting the number of unmarketable cloves that are damaged and having less than 1.0 g weight [24]. Marketable bulb yield was expressed in ton per hectare and recorded from plants obtained from three rows in a plot just after curing that have a healthy and marketable bulb with a weight of 20 g - 160 g [25]. Unmarketable bulb yield was recorded as the weight of bulbs that are undersized (<20 g), diseased, decayed and bulbs having the physiological disorder as described by the study [25] from three central rows after curing and expressed in ton per hectare and thus total bulb yield was recorded as the sum weight of marketable and unmarketable bulbs after curing and the yield was converted into ton per hectare. Harvest index was computed by dividing the mean fresh weight of mature marketable bulb (economic yield) to mean fresh biomass yield (biological yield) and multiplied by 100.

2.6. Data Analysis

The collected data were subjected to analysis of variance (ANOVA) using Genstat 18th edition statistical software as per the procedure of Gomez (1984 [26]. Means were separated using Fisher's least significant difference (LSD) at a 5% probability level. Pearson's correlation was conducted to see the relationship between the recorded growth, yield and yield components.

3. RESULTS AND DISCUSSION

3.1. Effect of Variety and Intra-row Spacing on Days to Maturity and Growth of Garlic

3.1.1. Days to Maturity

The main effect of variety and intra-row spacing had significantly affected days to maturity of garlic while their interaction effect did not (Table **1**). Days to maturity ranges from 127.4 to 140.4 days. Tsedey 92 took a long time of 140.4 days to mature, while the local variety took shorter days of 127.4 to mature (Table **1**). The variation in maturity among the three varieties might be due to their genetic differences. Many research authors indicated that Tsedey 92 garlic variety matured late than Bishoftu Netch [27]. Intra row spacing of 12.5 cm took the longest time of 140.0 days to reach maturity, while the intra-row spacing of 5 cm reaches maturity earlier with 124.6 days (Table **1**). As the intra row spacing increases, days to maturity was delayed. The variation in maturity might be due to the fact that the growth rate is faster in closely spaced crops than widely spaced ones. This is because of high intraspecific competition for growth factors, where plants get stressed and strive to set the bulb as early as possible. Garlic planted closely mature earlier than those planted widely [28, 29].

3.1.2. Plant Height

Plant height was tallest (68.26 cm) with Variety Tsedey 92 while it was shortest (62.02 cm) with the local variety (Table **1**). Garlic displayed great variation for plant height and other morphological characters [30]. The difference among the varieties for plant height could be attributed to their genotypic variability. The tallest plant height of 69.74 cm was obtained from the wider intra-row spacing of 12.5 cm, whereas the shortest (60.5 cm) was obtained at 5cm intra-row spacing (Table **1**). The tallest plant height at a wider intra-row spacing of garlic was reported by [31]. Similarly, the study [32 - 34] reported maximum plant height at wider row spacing on the onion. This reduction in plant height at increased plant density might be due to the competition for growth factors such as soil moisture, nutrient, space and light [35, 36]. Interactions of intra-row spacing and variety did not significantly ($P \leq 0.05$) plant height of garlic (Table **1**).

3.1.3. Leaf Number

Tsedey 92 produced more leaf number of 16.53, while the local variety produced the lowest (14.01) number of leaves (Table **1**). Many scholars indicated significant varietal differences in the number of leaves produced by garlic plants [37, 38]. The results might be attributed due to the genetic variation and vegetative growth differences among the studied garlic cultivars. As intra-row spacing increased from 5 cm to 12.5 cm, the number of leaves per plant increased from 13.8 to 16.90. The highest leaf number of 16.9 was obtained from 12.5cm intra-row spacing while the lowest (13.80) was recorded at 5 cm intra-row spacing (Table **1**). This statement is in conformity with that of the study [31, 34, 39], which also reported a reduction in the number of leaves with an increased plant density of garlic plants. This could be due to the fact that widely spaced plants produce more axillary branching than closely spaced plants that resulted in fewer leaf numbers. It might also be attributed due to the closer the spacing, the more the competition among the plants for water, soil nutrients, space, light, *etc.*, hence making them not photosynthesizing very well. In the present study, however, interaction effects of intra-row spacing and variety did not significantly affect the number of leaves of garlic plants.

Table 1. Main effect of variety and intra-row spacing on days to maturity, plant height, leaf number, leaf length and leaf width of garlic.

Variety	DM	PH	LN	LL	LW
Tsedey 92	140.4^{a}	68.26^{a}	16.63^{a}	44.33^{a}	2.241^{a}
Bishoftu Netch	131.3^{b}	65.10^{b}	15.53^{b}	40.83^{b}	2.027^{b}
Local	127.4^{c}	62.02^{c}	14.01^{c}	35.92^{c}	2.084^{b}
LSD (5%)	3.254	1.60	0.579	1.428	0.066
Intra-row Spacing					
5	124.6^{c}	60.50^{d}	13.80^{d}	36.44^{d}	1.908^{d}

(Table 1) contd.....

Variety	DM	PH	LN	LL	LW
7.5	132.8[b]	63.80[c]	14.92[c]	38.67[c]	2.023[c]
10	134.9[b]	66.46[b]	15.80[b]	41.44[b]	2.197[b]
12.5	140.0[a]	69.74[a]	16.90[a]	44.89[a]	2.341[a]
LSD (5%)	3.757	1.847	0.669	1.649	0.076
CV (%)	**2.9**	**2.9**	**4.5**	**4.2**	**3.7**

Note: means with the same letter within a column are not statistically significant at 5% probability level, DM = days to maturity PH = plant height; LN=leaf number; LL=leaf length; LW=Leaf width

3.1.4. Leaf Length and Width

The results of the analysis of variance indicated that variety Tsedey 92 gave a longer leaf length of 44.33 cm while the local variety gave the shortest leaf length of 35.92 cm (Table **1**). Many research findings indicated a significant difference in leaf length among garlic varieties [38, 40]. Similarly, leaf width of Tsedey 92 variety gave highest (2.24 cm) while, Bishoftu Netch gave the lowest (2.02 cm) although statistically at par with the local variety of garlic (Table **1**). In accord, the study [39, 41] found a significant difference among garlic cultivars in their leaf width. This might be attributed due to inherent and genetic variation among garlic varieties in their growth habit like plant height, leaf length, leaf width, leaf number, leaf shape and vigour. There was a linear increase in leaf length of garlic from 44.89 cm to 36.44 cm with an increase in intra-row spacing from 5 cm to 12.5cm (Table **1**). The widest leaf width of 2.34 cm was obtained at intra-row spacing of 12.5 cm, while the narrowest leaf of 1.90 cm was obtained at 5 cm intra-row spacing (Table **1**). The highest leaf length of onion was obtained at wider intra-row spacing and the shortest at the narrow intra-row spacing [34, 40, 42]. The lowest plant densities can give wider leaf width of onion as reported by many scholars [34, 43 - 45]. This might be attributed due to the fact that wider plant spacing showed less competition for resources, and as a result, leaves develop to a larger size. However, the interaction effects of intra-row spacing and variety did not significantly affect leaf length and width of garlic plants (Table **1**).

3.2. Effect of Variety and Intra-row Spacing on Yield and Yield Components of Garlic

3.2.1. Bulb Length

There was a significant effect of variety and intra-row spacing on bulb length of garlic, but their interactions did not have any effect (Table **2**). Variety Tsedey 92 gave a maximum bulb length of 4.29 cm, although statistically at par with that of the local variety, which gave 4.22 cm. However, variety of Bishoftu Netch gave the shortest with 3.96 cm (Table **2**) [46, 47]. also found a significant difference in bulb length among garlic varieties. This variation might be due to the reality that varieties can have different characteristics in their bulb shape, bulb length and bulb color.

The wider intra-row spacing of 12.5cm gave the highest bulb length of 4.49cm, while the smaller intra-row spacing of 5cm gave the minimum of 3.78 cm. Bulb length obtained at 12.5 cm intra-row spacing exceeds that obtained at 5 cm intra-row spacing by 15.81% (Table **2**). Many researchers indicated bulb length of garlic was highest at wider intra-row spacing than 5cm intra-row spacing [47, 48]. The increment in bulb length at increased intra-row spacing probably might be attributed due to more nutrients, space and moisture availability so that there might be less competition for available growth resources.

3.2.2. Bulb Diameter

Tsedey 92 variety recorded the maximum bulb diameter of 4.71 cm and is at par with bulb diameter (4.62 cm) obtained with Bishoftu Netch while the minimum (4.36 cm) obtained at the local variety of garlic (Table **2**). Many researchers found a significant difference in bulb diameter among garlic varieties [49, 38, 46]. The possible reason for such a result could be due to variations among varieties in their bulb character, such as bulb size.

An increment in bulb diameter was observed with increasing intra-row spacing, and 12.5cm gave the highest (5.02cm) although statistically at par with that recorded at 10cm intra-row spacing. However, 5 cm intra-row spacing gave the minimum bulb diameter of 3.95cm (Table **2**). There was a bulb diameter increment of about 21.31% with an increase in intra-row spacing from 5cm to 12.5cm (Table **2**). The study [48, 24] reported a maximum bulb diameter at 15 cm intra-row spacing than the narrow intra-row spacing of 10 cm. In the study, interactions of variety and intra-row spacing did not significantly influence bulb diameter of garlic (Table **2**).

Table 2. Means for effect of variety and intra-row spacing on bulb length and diameter, mean bulb weight and clove number of garlic at seleklaka.

Variety	BL (cm)	BD (cm)	Mean Bulb Weight(gm)	Clove Number
Tsedey 92	4.29[a]	4.71[a]	41.58[a]	23.74[a]
Bishoftu Netch	3.96[b]	4.62[a]	36.88[b]	21.67[b]
Local	4.22[a]	4.36[b]	34.31[c]	20.29[c]
LSD (5%)	**0.214**	**0.243**	**1.369**	**1.195**
Intra-row spacing(cm)				
5	3.78[c]	3.95[c]	34.51[c]	19.96[b]

(Table 2) contd.....

Variety	BL (cm)	BD (cm)	Mean Bulb Weight(gm)	Clove Number
7.5	4.10[b]	4.52[b]	35.79[c]	20.97[b]
10	4.25[ab]	4.76[ab]	38.68[b]	22.64[a]
12.5	4.49[a]	5.02[a]	41.39[a]	24.03[a]
LSD (5%)	**0.247**	**0.281**	**1.581**	**1.38**
CV (%)	**6.1**	**6.3**	**7.4**	**3.8**

Note: means with the same letter within a column are not statistically significant at 5% probability level. BL = bulb length; BD = bulb diameter

3.2.3. Mean Bulb Weight

Mean bulb weight had significantly affected the main effect of variety and intra row spacing, while their interaction effect did not affect (Table **2**). Mean bulb weight ranged between 34.31 g to 41.58 g, where it was highest (41.58 g) with variety Tsedey 92 while it was lowest (34.31g) with the local variety (Table **2**). Garlic varieties show a significant variation in mean bulb weight [49, 50]. The difference in bulb weight among garlic varieties might be accounted for the vigorous growth (production of more leaves), which helped in the synthesis of more photosynthates, increased accumulation of carbohydrates, and other metabolites, which ultimately determined the weight of bulbs per plant.

Plots planted at a wider intra-row spacing of 12.5cm gave the highest mean bulb weight of 41.39 g, while those planted at a narrower intra-row spacing of 5cm gave the lowest (34.51 g) although statistically at par with that obtained at 7.5cm intra-row spacing (Table **2**). The result showed a linear increment of bulb weight per plant as plant density per square area decreased. The study [51] reported maximum bulb weight at 20 cm intra-row spacing on Huruta shallot variety than 10 cm. Moreover, an increased mean bulb weight of onion was observed with increasing intra-row spacing from 5 cm to 10 cm [52]. Production of heavier bulbs in the wider spacing might be due to the fact that widely spaced plants experienced little or no competition for limited environmental resources compared to closely spaced plants.

3.2.4. Clove Number

The highest clove number per bulb of 23.74 was obtained from Tsedey 92, while the lowest (20.29) was obtained at the local variety (Table **2**). A difference in the number of cloves per bulb with different garlic varieties was reported by many authors [49, 53]. The highest clove number per bulb of 24.03 was obtained from 12.5 cm intra-row spacing, while the lowest (19.96) was obtained at 5 cm intra-row spacing (Table **2**). The study [49] indicated the highest number of clove number per bulb at 20 cm intra-row spacing as compared to a plot planted with 10 cm intra-row spacing. Moreover, the highest clove number per bulb was at wider intra-row spacing [54]. These observations could be associated with garlic planted at wider spacing tend to establish better in individual bulb characteristics compared with those closely spaced plants because widely spaced plants are able to intercept more light and suffer less competition for nutrients, hence produced more yield per individual stands. Clove number per bulb of garlic did not significantly affect by the interactions of intra-row spacing and variety (Table **2**).

3.2.5. Clove Length and Diameter

Clove length was significantly affected by the main effect of variety and intra-row spacing as well as their interactions (Table **3**). The highest mean clove length of 3.34cm was obtained at the interactions of treatment combinations of variety Tsedey 92 and 12.5 cm intra-row spacing while the shortest clove length of 2.757 cm was obtained in the treatment combinations of local garlic variety with 5 cm intra-row spacing (Table **3**). The findings indicated that irrespective of variety, clove length was longer at wider (12.5 cm) intra-row spacing than at narrow spacing. Similarly, the study [55] confirmed an increased clove length of garlic at wider intra-row spacing.

Garlic variety significantly influenced clove diameter, and the highest clove diameter of 1.82 cm was obtained from Tsedey 92 variety, and the lowest (1.45 cm) was recorded from a local variety (Table **4**). The study [53] reported that garlic cultivars showed a significant difference in clove diameter. This might be due to variations in genetic character and genetic makeup among the evaluated garlic varieties. With regard to intra-row spacing, it has significantly affected the clove diameter of garlic with the maximum (1.74 cm) obtained at 12.5 cm intra-row spacing although at par with that obtained at 10cm intra-row spacing. However, the minimum (1.59 cm) clove diameter was obtained at 5 cm intra-row spacing, which was statistically similar to that obtained at 7.5 cm and 10 cm intra-row spacing (Table **4**). Many scholars indicated higher clove length and diameter among different varieties of garlic tested and onion at wider intra-row spacing [15, 38]. However, the interaction effects of variety and intra-row spacing did not significantly affect the clove diameter of garlic.

Table 3. Means for effect of variety and intra-row spacing on clove length of garlic at seleklaka.

Clove Length (cm)				
	Intra-row Spacing			
Variety	5cm	7.5cm	10cm	12.5cm
Tsedey 92	3.07[cd]	3.14[c]	3.26[ab]	3.34[a]
Bishoftu Netch	2.76[f]	2.93[e]	3.17[bc]	3.30[a]
Local	2.75[f]	2.82[f]	2.99[de]	3.08[cd]

(Table 3) contd.....

Clove Length (cm)	
LSD (5%)	**0.103**
CV (%)	**2.0**

Note: means with the same letter within a column are not statistically significant at 5% probability level.

Table 4. Main effect of variety and intra-row spacing on cloves diameter of garlic at Seleklaka.

Garlic Variety	Clove Diameter (cm)
Tsedey 92	1.82[a]
Bishoftu Netch	1.63[b]
Local	1.45[c]
LSD (5%)	0.102
Intra-row spacing (cm)	
5	1.59[b]
7.5	1.57[b]
10	1.65[ba]
12.5	1.74[a]
LSD (5%)	**0.150**
CV (%)	**5.8**

Note: means with the same letter within a column are not statistically significant at 5% probability level.

Table 5. Means for interaction effect of variety and intra-row spacing on fresh and dry biomass yield per plant of garlic.

Fresh Biomass Yield per Plant (gm)					Dry Biomass Yield per Plant(gm)				
	Intra- Row Spacing								
Variety	5cm	7.5cm	10cm	12.5cm	5cm	7.5cm	10cm		12.5cm
	Tsedey 92	73.6[g]	89.13[e]	112.9[c]	126.43[a]	46.8[f]	49.7[de]	59.23[b]	56.03[c]
	BishoftuNetch	67.53[hi]	81.13[f]	100.6[d]	118.7[b]	47.1[f]	51.33[d]	61.6[a]	58.13[b]
	Local	64.27[i]	70.5[gh]	91.77[e]	103.53[d]	39.0[h]	41.03[g]	48.13[ef]	47.53[f]
	LSD (5%)	**4.34**			**1.88**				
	CV (%)	**2.8**			**2.2**				

Note: means with the same letter within a column are not statistically significant at 5% probability level.

3.2.6. Biomass

Main effects of variety and intra-row spacing, as well as their interactions, had significantly affected the fresh and dry biomass yield of garlic (Table **5**). Variety Tsedey 92 interacted with 12.5 cm intra row spacing gave the highest fresh biomass yield of 126.43 g while local variety in combination with 5 cm intra-row spacing gave the lowest fresh biomass yield of 64.27 g although statistically at par with Bishoftu Netch in combination with 5 cm intra-row spacing which recorded 67.53 g (Table **5**). With regard to dry biomass yield of garlic observed at treatment combinations of varieties Bishoftu Netch and intra-row spacing at 10 cm gave the highest dry biomass yield of 61.6 g. However, local variety in a combination with intra-row spacing at 5 cm gave the lowest dry biomass yield of 39.0 gm (Table **5**). With all the tested garlic varieties, the fresh and dry biomass yield increased with increased intra-row spacing. The study [47] indicated lower dry biomass yield of Chelenko I and Tsedey 92 garlic varieties at a narrow intra-row spacing of 5 cm than at wider spacing. There were reports on increase in fresh and dry biomass yield of onion at wider intra-row spacing [56 - 58]. This might be due to the fact that closer spacing between plants resulted in competition for resources, thus reducing the assimilation rate stored in the plant.

3.2.7. Marketable Clove Per Bulb

The mean square analysis revealed that the main effect of variety and intra-row spacing, as well as their interaction effects, significantly influenced marketable clove numbers per bulb (Table **6**). The highest marketable clove numbers per bulb were highest (15.73) at combinations of Tsedey 92 variety and 12.5 cm intra-row spacing, while the lowest (9.67) was obtained at combinations of local variety planted at 5 cm intra-row spacing (Table **6**). Irrespective of the tested garlic variety, marketable cloves number per bulb was lowest with decreasing intra-row spacing. Garlic varieties showed a huge variability in clove number [1]. Larger clove size at a widely spaced planting might be due to greater accumulation of assimilates, which resulted in better utilization of nutrients, moisture and light among plants and an increase in the size of cloves per bulb.

3.2.8. Marketable Bulb Yield

Marketable bulb yield had been significantly affected by the main effect of variety and intra-row spacing as well as their interaction effects (Table **7**). Tsedey 92 variety in combination with 5 cm intra-row spacing gave the highest marketable bulb yield of 8.05 t ha^{-1} while the lowest marketable bulb yield of 4.944 t ha^{-1} was obtained from combinations of local garlic

variety interacted with 12.5 cm intra-row spacing (Table **7**).

In general, marketable bulb yield showed a decreasing trend with an increasing intra-row spacing in all tested garlic varieties. This variation might be due to the fact that with increased plant spacing, the population per area of land also decreases that accounts for reduced marketable bulb yield. There is an impact of plant density on marketable bulb size. With higher plant density, there is a smaller marketable bulb size [60]. Significant effect of variety and intra-row spacing combination on marketable bulb yield of garlic has also been observed [58, 59]. Similarly, increasing intra-row spacing from 5 to 10 cm gave a decrease in marketable bulb yield [52]. Moreover, Pearson's correlation indicated a significant and negative relationship between marketable bulb yield of garlic with many parameters such as leaf width (-0.35*), bulb diameter (-0.53***), bulb length (-0.39***) and fresh biomass yield (-0.39*) (Table **8**).

3.2.9. Total Bulb Yield

There was a significant main effect of variety and intra row spacing as well as their interaction effects on the total bulb yield of garlic (Table **7**). The highest total bulb yield of 8.98 t ha^{-1} was obtained at a combination of variety Tsedey 92 and 5 cm intra row spacing, although statistically at par with combinations of Bishoftu Netch interacted with 5 cm intra-row spacing which gave 8.81 tha^{-1}. However, the lowest total bulb yield of 5.37 tha^{-1} was obtained from combinations of local variety interacted with 12.5 cm intra row spacing (Table **7**).

As intra-row spacing increased from 5 to 12.5 cm, total bulb yield of garlic decreased from 8.98 t ha^{-1} to 7.0 t ha^{-1} in variety Tsedey 92, and from 8.815 t ha^{-1} to 5.704 t ha^{-1} in Bishoftu Netch as well as from 8.148 tha^{-1} to 5.370 tha^{-1} in local garlic variety (Table **7**). The highest total bulb yield observed at closer spacing could be due to increased plant population. Increased bulb yield of garlic at higher plant populations is confirmed by many authors [59, 60]. Moreover, total bulb yield showed a positive and significant correlation with unmarketable clove per bulb, marketable bulb yield (0.96***) and harvest index (Table **8**). Increased shallot total yield per hectare with an increase in plant density [51]. Many authors indicated that varieties could have different yield potential in different agro-ecologies due to their genetic and genetic environment interaction effects [43, 58].

3.2.10. Harvest Index

The main effect of intra row spacing significantly affected the harvest index of garlic plants, while the main effect of variety and its interaction with intra-row spacing did not (Table **9**). Intra row spacing at 5 cm gave the highest harvest index of 50.41% while, the lowest harvest index of 35.69% was obtained at the wider intra-row spacing of 12.5 (Table **9**). Higher harvest index recorded at narrow spacing's might be due to the presence of shortest leaf length, plant height and leaf diameter, which reduced above-ground biomass and resulted in a higher harvest index. On the other hand, the lowest harvest indices at the wider spacing could also be attributed to excessive vegetative growth that has a detrimental effect on the partitioning of assimilates towards the bulbs. Moreover, the lowest harvest index at a wider intra-row spacing of 12.5 might also be due to the existence of a higher number of leaves, wider leaf length and diameter at wider intra-row spacing. Similarly, harvest index positively and significantly influenced by plant height(0.63***), leaf number(0.67***), leaf length(0.54***), leaf width (0.66***), bulb diameter(0.50**), number of cloves per bulb(0.41*), mean bulb weight(0.47**), fresh bulb yield(0.88***), dry bulb yield(0.60***), marketable bulb yield(0.62***) and total bulb yield (Table **8**). Similar findings were reported for onion and shallot, respectively, in Ethiopia [52, 51].

Table 6. Means for Interaction effect of variety and intra-row spacing on marketable clove per bulb of garlic.

Marketable Clove Number				
	Intra- Row Spacing			
Garlic Variety	5cm	7.5cm	10cm	12.5 cm
Tsedey 92	11.90^{g}	12.80^{f}	14.27^{cd}	15.73^{a}
Bishoftu Netch	11.50^{gh}	12.70^{f}	14.50^{c}	15.10^{b}
Local	9.67^{i}	11.40^{h}	13.33^{e}	13.87^{d}
LSD(5%)	**0.410**			
CV (%)	**1.9**			

Note: means with the same letter within a column are not statistically significant at 5% probability level.

Table 7. Means for Interaction effect of variety and intra-row spacing on total and marketable bulb yield of garlic.

Total Bulb Yield (t ha^{-1})					**Marketable Bulb Yield (t ha^{-1})**			
Intra - Row Spacing(cm)								
Garlic Variety	5	7.5	10	12.5	5	7.5	10	12.5
Tsedey 92	8.98^{a}	8.38^{b}	7.55^{c}	7.00^{d}	8.05^{a}	7.50^{b}	6.98^{cd}	6.74^{d}
Bishoftu Netch	8.81^{a}	8.11^{b}	6.87^{d}	5.70^{f}	7.68^{b}	7.22^{c}	6.27^{e}	5.35^{g}
Local	8.14^{b}	6.96^{d}	6.09^{e}	5.37^{g}	6.87^{d}	5.79^{f}	5.37^{g}	4.94^{h}
LSD (5%)	0.28				0.25			

(Table 7) contd.....

Total Bulb Yield (t ha^{-1})		Marketable Bulb Yield (t ha^{-1})
CV (%)	**2.3**	**2.3**

Note: means with the same letter within a column are not statistically significant at 5% probability level.

Table 8. Pearson's correlation of phonological, growth, yield and yield components of garlic as affected by variety and intra-row spacing.

	DM	PH	LN	LL	LW	BD	BL	NCB	MBW	FBY	DBY	MBY	MC	UBY	TBY
PH	0.57***	1	-	-	-	-	-	-	-	-	-	-	-	-	-
LN	0.60***	0.78***	1	-	-	-	-	-	-	-	-	-	-	-	-
LL	0.47***	0.84***	0.73***	1	-	-	-	-	-	-	-	-	-	-	-
LW	0.43**	0.78***	0.64***	0.76***	1	-	-	-	-	-	-	-	-	-	-
BD	0.35*	0.47**	0.27ns	0.43***	0.62***	1	-	-	-	-	-	-	-	-	-
BL	0.26ns	0.49**	-0.13ns	0.63***	0.60***	0.85***	1	-	-	-	-	-	-	-	-
NCB	0.47**	0.79***	0.52***	0.71***	0.65***	0.49***	0.62***	1	-	-	-	-	-	-	-
MBW	0.47**	0.87***	0.78***	0.88***	0.78***	0.45**	0.51***	0.79***	1	-	-	-	-	-	-
FBY	0.63***	0.84***	0.84***	0.80***	0.83***	0.58***	0.42*	0.65***	0.82***	1	-	-	-	-	-
DBY	0.71***	0.72***	0.68***	0.72***	0.56***	0.39*	0.35*	0.60***	0.72***	0.75***	1	-	-	-	-
MBY	-0.27ns	-0.15ns	-0.04ns	-0.17ns	-0.35*	-0.53***	-0.39***	-0.08ns	0.01ns	-0.39*	-0.08ns	1	-	-	-
MC	0.70***	0.84***	0.74***	0.78***	0.77***	0.55***	0.50**	0.70***	0.81***	0.91***	0.84***	-0.37*	1	-	-
UBY	-0.64***	-0.83***	-0.81***	-0.77***	-0.8***	-0.82***	-0.39*	-0.65***	-0.75***	-0.94***	0.70***	0.43**	-0.87***	1	-
TBY	-0.41*	-0.39*	-0.26ns	-0.36*	-0.52***	-0.60***	-0.44***	-0.25ns	-0.20ns	-0.60***	0.27ns	0.96***	-0.56***	0.64***	1
HI	0.60***	0.63***	0.67***	0.54***	0.66***	0.50**	0.27ns	0.41*	0.47**	0.88***	0.60***	0.62***	-0.77***	0.85***	0.77***

DM = Days to maturity; PH = plant height; LN = leaf number; LL= leaf lenght; LW = leaf width ; BD = bulb diameter ; BL = bulb length; NCB = number of cloves per bulb ; MBW= mean bulb weight ; FBY = fresh biomass yield; DBY = dry biomass yield; MBY = marketable bulb yield; MC = marketable clov per bulb; UMB = unmarketable bulb yield; TBY = Total bulb yield; HI = harvest inde; ns = non-significant at $p<0.05$ probablity level

Table 9. Main effect of variety and intra-row spacing on harvest index of garlic at seleklaka.

Variety	Harvest Index
Tsedey 92	42.60[a]
Bishoftu Netch	41.45[a]
Local	42.60[a]
LSD (5%)	**ns**
Intra row spacing (cm)	
5	50.41[a]
7.5	44.71[b]
10	38.05[c]
12.5	35.69[d]
LSD (5%)	**1.66**
CV (%)	**4.0**

Note: means with the same letter within a column are not statistically significant at 5% probability level, ns=non-significant

CONCLUSION

The aim of this study was to evaluate the response garlic to intra-row spacing and variety, and to identify the optimum intra-row spacing and high-yielding variety. With this notion, a field experiment was conducted to assess the effect of intra-row spacing on the growth and yield response of garlic varieties. Accordingly, the highest total bulb yield of garlic was observed at the combinations of Tsedey 92 variety and 5 cm intra-row spacing, although statistically similar with the yield obtained at combinations of Bishoftu Netch at same intra-row spacing. Marketable bulb yield was highest at the combinations of variety Tsedey 92 and 5 cm intra row spacing, and the lowest was obtained at the local variety in combination with 5 cm intra-row spacing. Therefore, it can be concluded that Tsedey 92 variety of garlic in combination with 5cm intra-row spacing showed better yield performance, and thus, it can be recommended to the study area.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are the basis of the research.

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise

ACKNOWLEDGEMENTS

The authors would like to thank their families for their financial support to the research work which was part of the first author's MSc. Study in horticulture at Aksum University. The authors also would like to thank Aksum University for allowing their research site for conducting the research.

REFERENCES

[1] Rubatzky V, Yamaguchi M. World Vegetables, Principles, Production and Nutritive Values Chapman and Hall. 2nd ed. New York, USA: International Thomson publishing 1997; p. 843.

[2] Hector S, Espino F, San JH, Olivio HH. Agronomic and biotechnological strategies for breeding cultivated garlic in mexico. Genetic Diversity in Plants 2012.

[3] Nirman KS. Garlic and onion: Production, biochemistry, and processing.Handbook of Vegetables and Vegetable Processing. Blackwell publishing Ltd 2011; pp. 625-42.

[4] Maly I, Bartos J, Hlusek J, *et al.* Nutritional importance of garlic Polni zelina_stvi. Agrospoj Praha 1998; pp. 175-85.

[5] Agarwal KC. Therapeutic actions of garlic constituents. Med Res Rev 1996; 16: 114-24.

[6] Kilgori M, MagaJi M, Yakubu A. Productivity of two garlic (Allium sativum L.) cultivars as affected by different levels of nitrogenous and phosphorous fertilizers in Sokoto, Nigeria. American-Eurasian J of Agric & Environ Sci 2007; 2(2): 158-68.

[7] Getachew T, Asfaw Z. Achievements in shallot and garlic research. In: Ethiopia Agricultural Research Organization. Addis Ababa, Ethiopia. 2000.

[8] Kilgori M, MagaJi M, Yakubu A. Effect of plant spacing and date of planting on yield of two garlic (Allium Sativum L.) cultivars in Sokoto, Nigeria. American-Eurasian J of Agric & Environ Sci 2007; 2(2): 153-7.

[9] Gebremedhin W, Berhanu G, Kahsay B, Dirk H. Improving Livelihood of Small-scale Farmers through Market Led Irrigated Crops: Case Study from Tigray Northern Ethiopia Conference on International Research on Food Security. 1-4.

[10] CSA (central statistical agency). Report on area and production of major crops in the federal democratic republic of Ethiopia 2018; 1: 19-26.

[11] Getachew T, Asfaw Z. Achievements in shallot and garlic research. Report No36, Ethiopian Agricultural Research Organization 2010.

[12] Mohammed A, Shiberu T, Thangavel S. White rot (*Scelerotium cipivorum* Berk)-an aggressive pest of onion and garlic in Ethiopia: an overview. J Agric Biotechnol Sustain Dev 2014; 6(1): 6-15.

[13] Tewodros B, Fikreyohannes G, Nigussie D, Mulatua H. Registration of Chelenko I Garlic (Allium sativum L.) Variety Haramaya University, Ethiopia. East Afri J of Sci 2014; 8(1): 71-4.

[14] Singh RK, Shukla IN, Singh JP, Kumar S. Studies on effect on varying plant density, planting and irrigation time on growth and yield of garlic (Allium sativum L.). Progress Agric 2007; 7(1): 167-8.

[15] Khan MA, Hasan MK, Miah MAJ, Alam MM, Masum MH. Effect of plant spacing on the growth and yield of different varieties of onion. Pak J Biol Sci 2003; 6(18): 1582-5.

[16] Muhammad A, Gambo BA, Ibrahim ND. Response of onion (Allium cepa L.) to irrigation intervals and plant density in Zuru, Northern Guinea Savanna of Nigeria. Nigerian J of Basic and Appl Sci 2011; 19(2)

[17] Latif MA, Choudhury MSH, Rahim MA, Hasan MK, Pal BK. Effects of spacing and age of seedling on the growth and yield of summer onion. J of. Agrofo & Environ 2010; 3(2): 129-33.

[18] Kahsay Y. Enhancing onion production and productivity through introduction of seed production techniques in central zone of tigray region. Ethiopia 2017.

[19] Dejene A. Integrated natural resources management to enhance food security. The case for community-based approaches in Ethiopia Working paper, Environment and natural resources 2003; 16

[20] Yayneshet T. Feed resources available in Tigray region, northern Ethiopia for production of export quality meat and Livestock 2010.www.igaddata.org/livestock-production/doc/feed-resources

[21] Bezu T, Gedamu F, Dechassa N, Hailu M. Registration of 'Chelenko I'Garlic (Allium sativum L.) variety. East Afri J of Sci 2014; 8(1): 71-4.

[22] Mahmood N. Horticultural crops production. Effect of NPK and FYM on growth parameters of onion, garlic and coriander. Current Res 2000; 24(11): 212-3.

[23] Directory of released crop varieties and their recommended cultural practice. Addis Ababa, Ethiopia 2004.

[24] Fikreyohannes G. Effects of clove size and plant density on the bulb yield and yield components of garlic (Allium sativum L.) in Awabel woreda, Eastern Gojjam Zone. MSc Thesis, Alemaya University. 2005; 71.

[25] Lemma D, Shimelis A. Research Experience in Garlic Production. Research Report Number 55 2003.

[26] Gomez KA, Gomez AA. Statistical Procedures for Agricultural Research. Second Edition.. New York.: John and Sons 1984.

[27] Ayalew A, Tadesse D, Medhin ZG, Fantaw S. Evaluation of garlic (Allium sativum L.) varieties for bulb yield and growth at dabat, northwestern ethiopia. Open Access Libr J 2015; 2(01): 1.

[28] Brewster JL. Onion and other vegetable alliums. Cab. International Cambridge 1994; pp. 93-115.

[29] Rabinowitch HD, Kamenetsky R. Shallot (Allium cepa, Aggregatum Group). In: Allium crop science: recent advances. 2002; p. 409.

[30] Etoh T, Simon PW. Diversity, Fertility and Seed Production in Garlic.Allium crop science: recent advances. CABI 2002; pp. 101-18.

[31] Aliyu U, Dikko AU, Magaji MD, Singh A. Nitrogen and intra-row spacing effects on growth and yield of onion (Allium cepa L.). Plant Sci 2008; 3(3): 188-93.

[32] Ahmed I, Khan MA, Khan N, *et al.* Impact of plant spacing on garlic rust (Puccinia allii), bulb yield and yield component of garlic (Allium sativum). Pak J Agric Res 2017; 30(4): 380-5.

[33] Gebretsadik K, Dechassa N. Effect of nitrogen fertilizer rates and intra row spacing on bulb yield of onion (Allium cepa L.) at Shire, Northern Ethiopia. Int J Sci Res (Ahmedabad) 2016; 5(10): 1769-72.

[34] Martha M, Marie M. Intra row spacing effect on growth performance of garlic (Allium Sativum L.) at wolaita sodo southern ethiopia. J of Natural Sci Res 2019; 19(9): 2019.

[35] Bodnar JL, Schumacher B, Uyenaka S. Garlic production in Ontario. In: Omafra Factsheet. Canada 1998; pp. 1-8.

[36] Karaye AK, Yakubu AI. Influence of intra-row spacing and mulching on weed growth and bulb yield of garlic (Allium sativum L.) in Sokoto, Nigeria. Afr J Biotechnol 2006; 5(3): 260-4.

[37] Hassan AH. Improving growth and productivity of two garlic cultivars (Allium sativum L.) grown under sandy soil conditions. Middle East J of Agric Res 2015; 4(2): 332-46.

[38] Yeshiwas Y, Negash B, Walle T, Gelaye Y, Melke A, Yissa K. Collection and characterization of garlic (Allium sativm L.) germplasm for growth and bulb yield at Debre Markos, Ethiopia. J Hortic For 2018; 10(3): 17-26.

[39] Ahmed EN, Amgad M, Muatasim HS, Abdalla AE. Effect of intra-row spacing on growth and yield of three cowpea (Vigna unguiculata L. Walp.) varieties under rainfed. Res J Agric Biol Sci 2010; 6(5): 623-9.

[40] Baghalian K, Sanei MR, Naghavi MR, Khalighi A. Post-culture evaluation of morphological divergence in Iranian garlic ecotypes. IV International Symposium on Edible Alliaceae 688. 123-8.

[41] Singh Y, Chand R. Performance studies of some garlic (Allium sativum L clones. Himachal J of Agric Res 2003; 29(1&2): 35-42.

[42] Jilani MS, Ahmed P, Waseem K, Kiran M. Effect of plant spacing on growth and yield of two varieties of onion (Allium cepa L.) under the agro-climatic condition of DI Khan. Pak J Sci 2010; 62(1): 37-41.

[43] Jilani MS, Ghaffoor A. Screening of local varieties of onion for bulb formation. Int J Agric Biol 2003; 5(2): 129-33.

[44] Broome A. Biomass and photosynthetic efficiency of Allium species

grown in Elevated carbon dioxide levels, with differing plant densities and Harvest schemes 2009.https://ttu-ir.tdl.org/handle/2346/72272

[45] Om H, Srivastava RP. Influence of the planting material and spacing on the growth and yield of garlic. Indian J Hortic 1977; 34(2): 152-6.

[46] Espino HS, Hernández SJ, Hernández OH, *et al.* Agronomic and biotechnological strategies for breeding cultivated garlic in Mexico. Genetic Diversity in Plants 2012.

[47] Tewachew G. Growth and Yield of Garlic (Allium sativum L.) Varieties as Influenced by Intra and Inter Row Spacing at Agarfa, South- Eastern Ethiopia. Msc thesis, Haramaya university. 2016; 30.

[48] Alam MS, Rahim MA, Bhuyan AH, Simon PW, Malek MA. Effect of spacing on growth and yield of two lines of garlic under dry land condition. J. Agro-for. Environ 2010; 4: 151-4.

[49] Ibrahim M, Shafiullah MI, Shah FA, Abid SR, Haq IU. Comparison of different garlic (Allium Sativum) varieties for yield and yield components grown at agriculture research station, Buner. Int J Environ Sci Nat Res 2018; 13(5)555873

[50] Islam MJ, Hossain KM, Khanam F, Majumder UK, Rahman MM, Rahman MS. Effect of mulching and fertilization on growth and yield of garlic at Dinajpur in Bangladesh. Asian J Plt Sci 2007; 6(1): 98-101.

[51] Ademe D, Belew D, Tabor G. Influence of bulb topping and intra row spacing on yield and quality of some shallot (Allium Cepa Var. Aggregatum) varieties at Aneded woreda, western Amhara. Afri J of Plt Sci 2012; 6(6): 90-202.

[52] Kahsay Y, Belew D, Abay F. Effect of intra-row spacing on yield and quality of some onion varieties (Allium cepa L.) at Aksum, Northern Ethiopia. Afri J of plt sci 2013; 7(12): 613-22.

[53] Figliuolo G, Candido V, Logozzo G, Miccolis V, Zeuli PS. Genetic evaluation of cultivated garlic germplasm (Allium sativum L. and A. ampeloprasum L.). Euphytica 2001; 121(3): 325-34.

[54] Vidya G. Effect of planting time and plant densities on yield and yield contributing characters in garlic (Allium sativum L.) Cv. JAMNAGAR. Plant Arch 2015; 15(2): 947-52.

[55] Masoumi A, Rajabipoor A, Tabil L, Akram A. Physical attributes of garlic (Allium sativum L.). J Agric Sci Technol 2006; 8: 15-23.

[56] Khan H, Iqbal M, Ghaffoor A, Waseem K. Effect of Various Plant Spacing and Different Nitrogen Levels on the Growth and Yield of Onion (Allium cepa L.). Online J Biol Sci 2002; 2(8): 545-7.

[57] Sara B, Daniel M, Weldemariam S, Solomon G. Effect of intra-row spacing on growth and yield component of adama red onion (Allium cepa L.) cultivar under irrigation in Finch, North Shoa, Ethiopia. J of Harmonized Res in Appl Sci 2015; 3(4): 231-40.

[58] Jilani MS, Khan MQ, Rahman S. Planting densities effect on yield and yield components of onion (Allium cepa L.). J Agric Res (Lahore) 2009; 47(4): 397-404.

[59] Fikreyohannes G, Kebede W, Nigussie D, Akhilesh T. Effects of clove size and plant density on the bulb yield and yield components of Ethiopian garlic (Allium sativum L.). Pantnagar J of Res 2008; 6(2): 234-8.

[60] Castellanos JZ, Vargas-Tapia P, Ojodeagua JL, *et al.* Garlic productivity and profitability as affected by seed clove size, planting density and planting method. HortScience 2004; 39(6): 1272-7.