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Research Article

Effects of plant spacing and variety on growth bulb yield of garlic (Allium sativum L) at Koga Irrigation Scheme, Ethiopia

Tewachew Getahun*[1], Dessalegn Sinke[1]

[1]Department of Plant Sciences, College of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 5501, Bahir Dar, Ethiopia

***Corresponding author:** tewachewgd@yahoo.com

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Abstract: *Garlic (Allium sativum* L.*) is a widely cultivated and economically important crop, valued both as a condiment and a cash crop. However, its production and productivity is often low, which is obviously influenced with plant population and the variety used. A field study was therefore conducted to evaluate the growth and yield performance of garlic varieties under varying intra- and inter-row spacing during the main cropping season at the Koga Irrigation Scheme. The experiment followed a factorial arrangement of three inter-row spacing (20 cm, 30 cm, and 40 cm), three intra-row spacing (5 cm, 10 cm, and 15 cm), and three garlic varieties (Chelenko I, Tseday, local variety) laid out in a Randomized Complete Block Design (RCBD) with three replications. The results demonstrated that the length and diameter of bulbs were significantly affected by spacing and variety. Chelenko I exhibited superior agronomic performance, achieving the highest bulb length (3.737 cm) and bulb diameter (3.972 cm). The 10 cm × 30 cm spacing produced the largest bulb (4.232 cm in diameter and 3.908 cm in length). The highest fresh biomass yield (134.27 g plant^{-1}), dry biomass yield (61.40 g plant^{-1}), dry matter content (30.70%), and mean bulb weight (41.59 g) were obtained with Chelenko I at 10 cm x 30 cm spacing. The maximum total bulb yield (14.737 t ha^{-1}) was recorded with Chelenko I at 5 cm x 20 cm spacing. In conclusion, Chelenko I planted at 10 cm intra-row and 30 cm inter-row spacing is recommended for enhanced growth yield and bulb quality at Koga Irrigation Scheme. As the study was conducted in one location and season, it is also recommended to repeat the study in more locations and seasons*

Keywords: *Bulb weight, Clove number, Chelenko I variety, Intra row spacing, Tseday variety*
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1. Introduction

Garlic (*Allium sativum* L.) is the second most widely used Allium species in the world, following onion (Rubatzky and Yamaguchi, 1997). The global area under garlic cultivation was approximately 1,662,384 hectares, with a total production of about 29,149,437 metric tons (FAOSTAT, 2022).

Despite its wide adaptability and production across various regions, garlic productivity and production are often constrained by both genetic and environmental factors (Nonnecke, 1989). Major production limitations in the tropics include the lack of improved varieties and inappropriate agronomic practices (Getachew and Asfaw, 2000), as well as inadequate planting material, insufficient pest and disease management, and limited marketing infrastructure (Ayalew *et al*., 2015).

Crop production can be improved either by enhancing the genetic potential of the crop or through better agronomic practices, such as optimizing plant density. Efforts to increase garlic yield have focused on providing high-quality planting materials (cloves) of the best-adapted varieties available in production areas (Kedir U., 2025). However, in many tropical irrigation schemes, farmers still use suboptimal plant populations, and cloves are often planted without consideration for proper spacing, leading to low and unpredictable yields. Numerous studies on garlic have been conducted, but no single, universally accepted recommendation for optimal growing conditions has emerged due to variations in soil and climate conditions across regions.

Moreover, selecting the right variety plays a critical role in producing good bulbs and cloves. An ideal variety should not only be adapted to the local environment but also exhibit high yield potential, stress tolerance, and good marketability. To develop high-yielding and locally adapted varieties, joint experimentation involving farmers and researchers is essential, particularly in variable rain-fed environments. Conducting investigations under specific agroecologies is crucial for generating relevant recommendations on garlic varieties and agronomic practices. Given garlic's potential as both a staple food and a cash crop, enhancing its productivity through the evaluation of varieties and spacing is vital. This research was conducted to identify the best garlic varieties and determine appropriate plant spacing thereby enhancing its productivity in Koga irrigation schemes and other similar agroecology.

2. Materials and Methods

2.1. Description of the study area

The study was conducted at Bahir Dar University research site under Koga Irrigation Scheme, which is located at 11° 35' 19.644" N 37° 23' 17.2284" E with mean monthly minimum and maximum temperatures, rainfall and relative humidity during the growing period (Figure 1).

Prior to the establishment of the experiment, a representative composite soil sample was collected from the experimental field using a diagonal sampling method. Soil samples were taken from nine pits at a plow depth of 0–20 cm using an auger on April 26, 2022. The composite sample was submitted to the Soil Chemistry and Water Quality Laboratory Section of the Amhara Design and Supervision Works Enterprise for physicochemical analysis. The analyses included soil texture, pH, organic carbon (OC), organic matter (OM) and total nitrogen (TN), following standard laboratory procedures.

Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). Prior to analysis, soil samples were air-dried and ground to pass through a 2 mm sieve, while samples for total nitrogen determination were further ground to pass a 0.5 mm sieve. Soil pH was measured in a 1:2.5 soil-to-water suspension (Rhoades, 1982). Organic carbon and organic matter contents were determined using the wet combustion method of Walkley and Black (Walkley and Black, 1934). Total nitrogen was analysed using the Kjeldahl wet digestion method (Jackson, 1967).

The results of the soil analysis indicated that the soil pH was 6.22 (Table 1), classifying it as slightly acidic (Kanyanjua *et al.*, 2002). The organic carbon and organic matter contents were 2.57% and 4.43%, respectively, which are considered relatively good. The soil organic matter content was 4.43%. The total nitrogen content was 0.22%, indicating a good native nitrogen reserve.

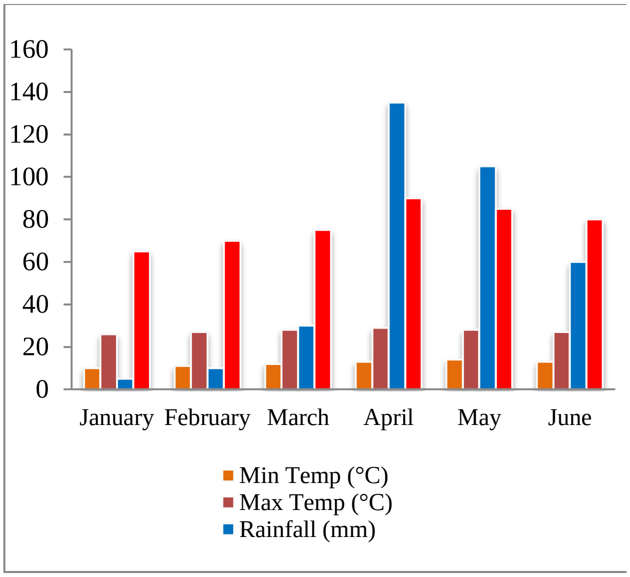

Figure 1: *Climatic description of the study area*

Table 1: Selected physicochemical properties of the experimental soil

Soil pH	Total N (%)	Organic Carbon (%)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (gcm^3)
6.2	0.22	2.57	51.08	17.84	31.08	1.45

2.2. Description of experimental materials

Two improved garlic varieties, G-147-2/94 (Chelenko I) and G-493 (Tseday) and one local variety were used in the study. The varieties were selected due to their wider adaptability and yield potentials. Chelenko I is characterized by deep green foliage, vigorous growth, and a medium maturation period. It is moderately susceptible to garlic rust but produces large-sized bulbs and cloves with white skins and creamy flesh. The variety matures in approximately 132 days, yielding an average of 9.33 t ha-1, with an average bulb weight of 49.15 g (Tewodros *et al*., 2014). Tseday, on the other hand, produces white bulbs with green leaves and matures in about 110-130 days. It yields an average of 8.13 t ha-1 and has an average bulb weight of 41.59 g (Tewodros *et al*., 2014).

2.3. Experimental treatments and design

The treatments consisted of three intra-row spacing (5, 10, and 15 cm), three inter-row spacing (20, 30, and 40 cm), and three varieties (Chelenko I, Tseday, and a local variety). The treatments were layout in Randomized Complete Block Design (RCBD) with 3x3xe factorial arrangement with three replicates. Each plot was 2.4 m x 1.8 m (4.32 m²) in size, with 12, 8, and 6 rows for inter-row spacing of 20, 30, and 40 cm, respectively. The number of plants per row was 36, 18, and 12 for intra-row spacing of 5, 10, and 15 cm, respectively. The plots were spaced 0.5 m apart, and blocks were separated by 1 m. All agronomic practices except spacing were uniformly applied as per the recommendation. Border plants, including the outer rows and plants at both ends of the rows, were not included in the data collection to prevent edge effects. Only the plants in the central rows were considered for yield and other growth parameters.

Table 2: Net plot areas for each spacing combinations

Inter row spacing (cm)	Intra row spacing (cm)		
	5	10	15
20	3.40	3.20	3.00
30	3.06	2.88	2.70

40	2.72	2.56	2.40

2.4. Experimental procedures

The bulbs of Chelenko I variety was sourced from Haramaya University, while those for the Tseday variety came from the Debre Zeit Agricultural Research Center (DZARC). The local variety was collected from the local market. Healthy cloves at the range of medium to large (1.50-2.50 g) in size were used as planting material. Cloves which were diseased, soft, damaged, or discolored were not used.

Prior to planting, the experimental field was ploughed and harrowed with a tractor, breaking up large clods to create a fine tilth. A total of 81 plots, each measuring 2.4 m x 1.8 m, were prepared and cured and stored bulbs were manually planted on 11 January 2022 at a depth of 3 cm on raised seedbeds. The plots were irrigated through furrow irrigation at seven days interval in March and twice every fortnight in late April. A fungicide (Ridomil gold 80 EC) was applied to control fungal diseases during the study period. All other standard agronomic practices, such as weeding, fertilizing, harrowing, and watering, were applied uniformly across all plots. Bulb harvesting took placed on 20 June 2022, when 70% of the plants exhibited neck fall (EARO, 2004).

2.5. Data collection and analysis

The growth and yield data were collected timely using the standard procedures of the respective parameters of garlic as described below.

Plant heights (cm) of 10 randomly taken plants grown in the net plot area were measured in centimeters from the soil surface to the tip of matured leaf at the time of maturity.

The leaf widths (cm) of 10 randomly taken plants grown at the net plot area were measured at the widest part at physiological maturity using caliper and the average was taken for analysis. Similarly, the lengths (cm) of longest leaves of these plants were also measured at maturity. The average leaf number was determined by counting the total number of leaves of ten plants grown at net plot area at physiological maturity. Days to maturity (Day) was recorded by counting the number of days elapsed from date of planting to the date at which about 70% of plants showed neck fall.

Bulb length (cm) was measured as the average length of the 10 matured bulbs randomly selected from bulbs harvested from the net plot area using. Bulb diameter (cm) was also determined by measuring the diameter of 10 bulbs harvested from the net plot area. It was measured at the middle of the bulb with a slide caliper and used for analysis.

Mean bulb weight (g) was recorded by measuring the weights of 10 randomly taken bulbs harvested from the net plot area. The average bulb weight was computed and used for analysis. Number of cloves per bulb was determined by counting the cloves of 10 bulbs and averaged.

Fresh biomass yield (g/plant): The total weight of above-ground parts and bulbs of 10 randomly selected plants was weighed using digital balance and averaged to the number of plants and used for analysis.

Dry biomass yield (g/plant) was obtained by oven-drying the fresh biomass yield at 70°C for 72 hours. The dry biomass yield was measured using a digital balance. Bulb dry matter content (%) was determined by peeling and chopping the cloves of five randomly selected bulbs. After weighing the fresh weight, they were oven dried at constant weight and weighed using sensitive balance.

Bulb dry matter content was calculated as the ratio of dry weight to fresh weight and expressed as a percentage using the following formula:

$$\text{Bulb dry matter } (\%) = \left(\frac{\text{Bulb dry weight}}{Bulb\ fresh\ weight}\right) * 100$$

Bulb yield (t ha^{-1}) was determined by weighing cured bulbs harvested from the net plot area and converted to hectare base.

The collected data were subjected to analysis of a variance (ANOVA) using Genstat (Genstat, 2012) version 15. Treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance.

3. Results and Discussion

3.1. Influence of plant population and variety on phonology and growth of garlic

Plant height was influenced (P<0.01) by the interaction effect of variety, intra row spacing, and inter row spacing significantly affected plant height. Variety Chelenko I produced the tallest plants when planted at 5x30 cm intra-row and inter-row spacing, respectively Local variety of garlic planted at the intra and inter row spacing of 5x30 cm, respectively produced the shortest plants (Table 1). The difference among the varieties for plant height could be attributed to the genotypic variability. The tallest plants with narrow spacing could also be due to competition for light. This result is in agreement with the findings of Kassahun (2006) who observed a wide range of variation in plant height among different garlic varieties. Similarly, Etoh and Simon (2002) and Jilani *et al*. (2009) reported that garlic displayed great variation for plant height and other morphological characters. Concurrent with this result, Brewster (1994) also reported a wide range of plant height in "California Late" cultivars of garlic.

In contrast with this result Kanton *et al*. (2003) reported that plant height decreased as population density increased and found plant height at the lowest density of 37 plants m^{-2} was 20% greater than those above 76 plants m^{-2}.

Table 1: Interaction effect of variety, intra row spacing, and inter row spacing on plant height of garlic

Variety	Inter row spacing (cm)	Intra row spacing (cm) 5	10	15
Chelenko I	20	77.77^{bcde}	79.67^{ab}	78.11^{bcde}
	30	82.07^{a}	79.51^{abc}	77.90^{bcde}
	40	76.17^{c-h}	77.10^{b-g}	79.33^{abc}
Local	20	78.35^{bcd}	74.93^{d-i}	71.60^{ijk}
	30	70.36^{k}	77.45^{b-f}	71.37^{jk}
	40	73.83^{ghij}	71.49^{ijk}	71.33^{jk}
Tseday	20	78.03^{bcde}	77.18^{b-g}	74.22^{f-j}
	30	77.83^{bcde}	73.21^{hijk}	76.40^{b-h}
	40	74.73^{e-j}	73.53^{hijk}	75.22^{d-h}
LSD (0.05)			3.457	
CV (%)			2.8	

Means in the table followed by the same letter(s) are not significantly different at 5% level of significance

The main effects of variety, intra-row spacing and inter-row spacing influenced (P < 0.05) the days to maturity where variety Chelenko I matured earlier (146.9 days) than that of variety Tseday (157.3 days) and local (155.2 days) varieties (Table 2). The variation among the three varieties in days to maturity might be due to the genetic differences. This extended growth period of late maturing variety Tseday may incur additional cost and make the land not to be ready for the next crop. In line to these results, scholars also reported significant variation in days to maturity for different accessions of garlic (Islam et al., 2004, Kassahun, 2006). The findings also align with Tewodros *et al.* (2014), who reported Chelenko I and Tseday matured in 132 and 133 days, respectively.

Intra-row spacing significantly affected days to maturity and leaf number but not plant height. Garlic at 5 cm spacing matured earliest (151.2 days), followed by 10 cm (153.4 days) and 15 cm (154.7 days). Closer spacing led to earlier maturity likely due to higher competition and stress that accelerate the development of the plants. The findings are supported by Gebre, (2024).

Wider spacing (15 cm) resulted in more leaves (11.55) than narrower spacing (10 cm = 11.41, 5 cm = 11.13). This may be attributed to reduced competition for resources. Similar observations were made by Amans (1989), Wadjito *et al.* (1988), and Singh and Singh (2002) for onion.

Leaf length differed significantly among varieties, with Chelenko I produced the longest leaves (55.61 cm), followed by Tseday (53.20 cm), and the local variety (51.29 cm), likely due to genotypic differences. The results are supported by earlier findings of Tewodros *et al.* (2014).

Table 2: Main effect of variety, intra row spacing and inter row spacing on growth and phenology of garlic

Treatment	Leaf length (cm)	Leaf width (cm)	Leaf number (no)	Days to maturity (days)
Variety				
Chelenko *I*	55.61^{a}	2.19	11.56	146.9^{c}
Local	51.29^{c}	2.15	11.17	155.2^{b}
Tseday	53.20^{b}	2.19	11.36	157.3^{a}
LSD (0.05)	1.872	NS	NS	0.683
Intra-row spacing (cm)				
5	53.27	2.09^{b}	11.13^{b}	151.2^{b}
10	53.97	2.22^{a}	11.41^{ab}	153.4^{ab}
15	52.86	2.22^{a}	11.55^{a}	154.7^{a}
LSD (0.05)	NS	0.0819	0.3232	2.700
Inter row spacing (cm)				
20	53.14	2.13^{b}	11.44	152.5
30	53.73	2.15^{b}	11.40	153.0
40	53.23	2.25^{a}	11.24	153.8
LSD (0.05)	NS	0.0819	NS	NS
CV (%)	7.2	6.9	5.2	0.8

Means followed by the same letter are not significantly different at 5% level of significance

The interaction effect of variety and intra row spacing influenced ($P < 0.05$) the leaf width of garlic. However, the three-way interaction, two-way interaction of intra and inter row spacing did not influence the leaf width.. Local variety at intra-row spacing of 10 cm had the highest leaf width (2.28 cm). The lowest leaf width (1.987 cm) was recorded when local variety was grown at 5 cm intra row spacing (Table 3). The results illustrated that varieties have got higher leaf width at wider intra row spacing. This may be attributed to the fact that wider plant spacing showed less competition for resources and as a result leaves develop to larger size. These results are in conformity with findings of various scholars where the lowest leaf width recorded at higher population while the highest leaf width at lowest population. Recent studies demonstrate that intra-row spacing and garlic variety both significantly influence leaf width in Allium sativum L. Legese (2023) found that wider plant spacings produced greater leaf width compared to closer spacings, indicating that reduced competition allows for greater leaf expansion.

Table 3: Interaction effect of variety and intra row spacing on leaf width (cm) of garlic

Variety	Intra row spacing (cm)		
	5	10	15
Chelenko I	2.12^{bc}	2.25^{ab}	2.20
Local	1.98^{c}	2.28^{a}	2.19
Tseday	2.17^{ab}	2.12^{b}	2.26
LSD (0.05)	0.1413		
CV (%)	6.9		

Means followed by the same letter within row and column are not significantly different at 5% level of significance

3.2. Yield and yield components of garlic as influenced by plant population and variety

3.2.1. Bulb length and bulb diameter

Variety, intra-row spacing, and inter-row spacing each significantly affected bulb length and diameter, though their interactions were not significant. Chelenko I variety produced the largest bulb sizes, while the local variety had the smallest bulb sizes. The highest bulb size was achieved at 10 cm intra-row spacing, and the best overall results (3.908 cm length, 4.232 cm diameter) were found at 30 cm × 10 cm spacing as indicated in Table 4 and 5. As spacing increased, bulb size improved due to reduced plant competition. These findings align with Lemma (2004), who reported varietal differences in onion yield traits, and Kanton *et al.* (2003), who observed reduced bulb weight at higher planting densities. Similarly, Castellanos *et al.* (2004) emphasized the role of quality planting material in enhancing garlic bulb development, while Llosas and Fernandez (1984) recommended optimal garlic densities for improved yield.

Table 4: Main effects of variety, intra row spacing and inter row spacing on bulb length and bulb diameter of garlic

Variety	Bulb length (cm)	Bulb diameter(cm)
Chelenko I	3.73[a]	3.97[a]
Local	3.42[c]	3.67[c]
Tseday	3.56[b]	3.79[b]
LSD (0.05)	0.0967	0.1099
Intra-row spacing (cm)		
5	3.41[b]	3.58[b]
10	3.69[a]	3.93[a]
15	3.62[a]	3.92[a]
LSD (0.05)	0.1048	0.1041
Inter-row spacing (cm)		
20	3.49[b]	3.72[b]
30	3.70[a]	3.95[a]
40	3.53[b]	3.76[b]
LSD (0.05)	0.1048	0.1041
CV (%)	5.4	5.3

Different letter indicates significant difference at $p < 0.05$

Table 5: The interaction effects of intra row spacing and inter row spacing on bulb length and bulb diameter of garlic

Row spacing (cm)	Plant spacing (cm)	Bulb length (cm)	Bulb diameter (cm)
20	5	3.45[cd]	3.60[ef]
	10	3.57[bc]	3.77[cde]
	15	3.47[cd]	3.79[cd]
30	5	3.50[c]	3.70[de]
	10	3.90[a]	4.23[a]
	15	3.69[b]	3.93[bc]
40	5	3.30[d]	3.46[f]
	10	3.59[bc]	3.78[cde]
	15	3.71[b]	4.03[b]
LSD (0.05)		0.18	0.18
CV (%)		5.4	5.0

Different letter indicates significant difference at $p < 0.05$

3.2.2. Bulb weight and clove number

The analysis of variance revealed that the interaction among garlic variety, intra-row spacing, and inter-row spacing significantly ($p < 0.05$) influenced both bulb weight and the number of cloves. This indicates that the response of garlic plants to spacing is highly dependent on the specific variety used. The highest bulb weight (41.59 g/plant) was recorded from the Chelenko I variety at a spacing of 10 cm x 30 cm. This was followed by Chelenko I at 15 cm × 40 cm (39.41

g/plant), and Tseday at 10 cm × 30 cm spacing. In contrast, the lowest bulb weight (34.53 g/plant) was observed in the local variety under the most crowded condition of 5 cm intra-row and 20 cm inter-row spacing. In terms of clove number, Chelenko I again outperformed the other varieties, producing the highest value (13.33 cloves) at 15 cm intra-row and 40 cm inter-row spacing. A comparable result (13.13 cloves) was also observed at 10 cm × 30 cm spacing. The lowest clove number (10.80) was recorded for the local variety at both 5 cm × 20 cm and 10 cm × 30 cm spacings (Table 6).

The general trend showed that increasing spacing between and within rows led to a consistent increase in both bulb weight and clove number. This improvement is likely due to reduced plant competition for essential growth resources such as nutrients, water, and light.

These findings are in agreement with earlier studies. Duranti and Cuocolo (1984) and Duranti and Barbicri (1986) reported that wider spacing significantly improves bulb weight by minimizing competition and enhancing nutrient uptake. Rahman and Talukdar (1986) similarly noted increased garlic yields under lower planting densities. Abubakar *et al.* (2008), Mohammad *et al.* (1996), and Kanton *et al*. (2003) also confirmed that appropriate spacing increases bulb size and weight in garlic. Furthermore, Rashid and Rashid (1978) and Llosas and Fernandez (1984) emphasized the role of optimized plant population density in achieving better bulb development and yield performance.

Table 6: Interaction effect of variety, intra-row spacing and inter-row spacing on yield parameters of garlic varieties

Variety	Intra row spacing (cm)	Inter row spacing (cm)	MBW (g)	CNPB	FBY (g/plant)
Chelenko I	5	20	35.00[efg]	11.20[f-j]	74.00[kl]
	10	30	41.59[a]	13.13[ab]	134.27[a]
	15	40	39.41[b]	13.33[a]	124.53[bc]
Local	5	20	34.53[e-h]	10.80[ij]	61.40[m]
	10	30	35.29[ef]	10.80[ij]	91.43[fg]
	15	40	37.33[d]	11.27[f-j]	117.80[c]
Tseday	5	20	34.85[e-h]	11.20[f-j]	63.47[m]
	10	30	39.05[bc]	12.27[cde]	127.67[ab]
	15	40	37.20[d]	11.87[def]	118.93[c]
LSD (0.05)			1.2709	0.7910	7.725
CV (%)			2.1	4.2	5.4

Different letter indicates significant differences at $p < 0.05$; MBW = Mean Bulb Weight; CNPB = Clove Number Per Bulb; FBY = Fresh Biomass Yield

3.2.3. Fresh and dry biomass yields

The interaction between variety, intra-row spacing, and inter-row spacing significantly influenced both fresh and dry biomass yields. The highest fresh biomass yield (134.27 g/plant) and dry biomass yield (61.40 g/plant) were achieved by the Chelenko I variety with 10 cm intra-row and 30 cm inter-row spacing. Chelenko I outperformed Tseday and the local variety in both yield categories (Table 7). These results reflect the genetic traits of each variety and their adaptability to specific soil and climatic conditions.

Previous studies support these findings. Figliuolo *et al.* (2001) observed high genetic advancement in garlic for traits like leaf diameter, leaf number per plant, bulb dry weight, and yield. Getachew and Asfaw (2000) reported significant yield differences among garlic cultivars, and Khan *et al*. (2003) found that wider spacing improved plant height, dry biomass yield, and other growth characteristics in onions. Moravčević *et al.* (2011) found that sparse planting led to larger bulbs but lower yields, while denser plantings resulted in higher yields with smaller bulbs.

Table 7: Interaction effect of variety, intra row spacing and inter row spacing on selected yield components of garlic

Variety	Intra-row spacing (cm)	Inter-row spacing (cm)	DBY (g/plant)	BDMC (%)	TBY (t ha^{-1})
Chelenko I	5	20	34.63^{ijk}	17.32^{hij}	14.73^{a}
	10	30	61.40^{a}	30.70^{a}	11.99^{b}
	15	40	58.00^{a}	29.00^{a}	5.86^{f-j}
Local	5	20	28.00^{l}	14.00^{k}	11.34^{b}
	10	30	42.47^{def}	21.23^{def}	6.98^{d-j}
	15	40	56.50ab	28.25^{ab}	5.05^{j}
Tseday	5	20	32.97^{jkl}	16.49^{ijk}	7.09^{d-j}
	10	30	59.53^{a}	29.77^{a}	8.56^{cd}
	15	40	47.27^{cde}	23.63^{cde}	5.47^{hij}
LSD (0.05)			6.094	3.066	2.079
CV (%)			8.9	9.0	16.7

Different letter indicates significant differences at $p < 0.05$; DBY = dry biomass yield; BDMC = Bulb dry matter content, Total bulb yield

3.2.1. Total bulb yield and bulb dry material content

The interaction between variety, intra-row spacing, and inter-row spacing significantly affected both total bulb yield and bulb dry matter content. The highest total bulb yield (14.737 t/ha) was achieved with the combination of Chelenko I variety, 5 cm intra-row spacing, and 20 cm inter-row spacing. In contrast, the lowest yield (5.05 t/ha) occurred with the local variety at 15 cm intra-row and 40 cm inter-row spacing. Similarly, Chelenko I produced the highest bulb dry matter content (30.70%) at 10 cm intra-row and 30 cm inter-row spacing, while the local variety had the lowest dry matter content (14.00%) at 5 cm intra-row and 20 cm inter-row spacing (Table 7).

These findings align with previous research. Jilani and Ghaffoor (2003) and Jilani et al. (2009) highlighted that variety performance can vary based on genetic and environmental factors. Mohamood et al. (2002) also reported significant yield differences among garlic cultivars, which is consistent with Chelenko I outperforming other varieties here. Islam et al. (2007) and Mohamed (2009) observed substantial differences in dry matter content among onion genotypes, matching the study's findings. Regarding spacing, Tendaj (2005) and Pandey et al. (1992) showed that closer intra-row spacing increases plant density, resulting in higher bulb yield per unit area. Rekowska and Skupien (2007) found that garlic grown at closer spacing produced higher yields and better green leaf growth, with similar results reported by Kanton et al. (2003) for onions. Bleasdale (1966), Frappel (1973), and Sam-Aggrey et al. (1986) all noted that closer plant spacing led to higher yields per hectare. However, Moravčević et al. (2011) and Karate and Yakubu (2005) cautioned that denser plantings could reduce bulb size and quality, particularly under irrigation conditions. Castillo et al. (1996) emphasized that narrower row and plant spacing increased dry matter content, while wider spacing produced larger bulbs suited for marketable yields.

3.2.2. Marketable clove and Unmarketable clove

Marketable clove yield in garlic was significantly influenced by the interaction of variety, intra-row spacing, and inter-row spacing. The highest number of marketable cloves per bulb (13.20) was observed for Chelenko I variety at 15 cm intra-row and 40 cm inter-row spacing, while the lowest (10.40) was recorded for the local variety at 5 cm intra-row and 20 cm inter-row spacing (Table 8). These results indicate that garlic planted at wider spacing tends to perform better, as it reduces competition for resources, leading to better growth and higher yields.

This aligns with findings from Panthee *et al.* (2004), who found a positive correlation between the number of marketable cloves and bulb yield. Sims *et al.* (1976) reported that the average number of marketable cloves per bulb could range from less than 8 to more than 15, depending on the variety. Rashid and Rashid (1978) also noted that onion bulb size and weight increased with increased spacing, although higher yields were observed at closer spacing, which can reduce bulb size due to increased plant density.

Further supporting these results, Rekowska and Skupien (2007) found that garlic grown with closer intra-row spacing resulted in higher bulb and green leaf yields. Lawande *et al.* (1994) observed that closer spacing led to higher marketable yields compared to wider spacing, while Rubatzky and Yamaguchi (1997) suggested that larger bulbs are achieved with 25-40 cloves per square meter, and higher densities (60-70 cloves per square meter) maximize total yields, but at the expense of bulb size.

Other studies emphasize that increased spacing improves marketable bulb size and quality. For example, Couto (1958), Genkov (1961), and Menezes *et al.* (1974) found that wider spacing resulted in larger and higher-quality garlic bulbs. Duranti and Cuocolo (1984) and Rahman and Talukdar (1986) confirmed that while higher plant spacing leads to higher yields, it often reduces bulb weight. Purewal and Daragan (1961) noted that a spacing of 15 x 7.5 cm is optimal for economic yield. Tendaj (2005) reported that wider intra-row spacing in shallots increased marketable yield. Castellanos et al. (2004) found that higher plant density increases yield but reduces bulb size and marketability, particularly for fresh market garlic. Finally, Darabi and Dehghani (2010) observed increased economic yield at higher plant densities, but with a reduction in the number of cloves per bulb and bulb weight at reduced inter-row spacing.

Table 8: Interaction effect of variety, intra row spacing and inter row spacing on the number of marketable clove of garlic

Variety	Intra row spacing (cm)	Inter row spacing (cm)	Marketable clove/bulb (no)
Chelenko I	5	20	11.00^{g-j}
	10	30	13.00^{ab}
	15	40	13.20^{a}
Local	5	20	10.40^{jk}
	10	30	10.53^{ijk}
	15	40	11.00^{g-j}
Tseday	5	20	10.93^{g-k}
	10	30	12.07^{def}
	15	40	11.67^{efg}
LSD (0.05)			0.8127
CV (%)			4.4

Different letter indicates significant differences at $p < 0.05$

High unmarketable yield was observed in closely spaced plants (Table 9). This could be due to inter-plant competition resulted in a fewer large sized bulbs than widely spaced plants that negatively affected the marketable yield and favored the production of small sized bulbs which are unmarketable. High plant density brings out certain modifications in the growth of plants such as increase in plant height, reduction in leaf thickness, alteration in leaf orientation, and leaves become erect, narrow and are arranged at longer vertical intervals to intercept more sun light. Similar observations were also reported by Abubakar *et al.* (2008); and Voigt (2004).

Table 9: Main effect of variety, intra row spacing and inter row spacing on unmarketable clove (UMC) of garlic

Treatments	Unmarketable clove/bulb (no)
Variety	
Chelenko *I*	1.44
Local	1.48
Tseday	1.55
LSD (0.05)	NS
Intra row spacing (cm)	
5	1.59
10	1.51
15	1.37
LSD (0.05)	NS
Inter row spacing (cm)	
20	1.70[a]
30	1.37[b]
40	1.40[b]
LSD (0.05)	0.2641
CV (%)	32.6

Different letter indicates significant differences at $p < 0.05$

4. Conclusion

Results showed that variety, intra-row, and inter-row spacing significantly affected the growth and yield parameters of garlic. Chelenko I matured earliest (146.9 days) and had the greatest leaf length (55.61 cm) and bulb size. Wider intra-row spacing (15 cm) leading to longer maturity and more leaves, while increased inter-row spacing improved leaf width. The best fresh and dry biomass, dry matter content, and mean bulb weight were achieved with Chelenko I at 10 cm x 30 cm intra and inter row spacing, respectively. However, the highest bulb yield (14.73 t/ha) was obtained from Chelenko I variety of garlic planted at 5 cm intra row and 20 cm inter row spacing. The lowest bulb yield (5.05 t/ha) was recorded from the local variety of garlic at 15 cm intra row and 40 cm inter row spacing. Generally, planting Chelenko I variety of garlic at 5 cm intra row and 20 cm inter row spacing enhanced the bulb yield of garlic at Koga Irrigation Scheme and areas with similar agro-ecology. As the study was conducted in one location and season, it is also recommended to repeat the study in more locations and seasons.

Conflict of Interest

The authors declared that there is no conflict of interest.

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Data Availability Statement

Data will be made available on request.

Reference

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