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ORIGINAL RESEARCH ARTICLE

Integrated Management of Garlic rust (*Puccinia allii*) disease using varieties and Fungicides at Gondar Zuria District in Central Gondar Administrative zone, North Western Ethiopia

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Abstract

Garlic (*Allium sativum* L.) is an important spice crop which is belonged to the family Alliaceous, and which is widely grown in Ethiopia. The crop is currently challenged by biotic and abiotic factors. One of the biotic factors which affect garlic is garlic rust disease that is caused by Pucciniaallii Rudolphi. This garlic disease is the most affective biotic factor in all garlic producing areas of Ethiopia. The objective of this study was to find out a solution for garlic rust disease by applying the integrated use of garlic varieties and fungicides. Field experiment was conducted at Teda horticultural experimental site during 2019/2020 main cropping season in the College of Agricultural and Environmental Sciences. The experiment was done in randomized complete block design in a factorial arrangement of nine (9) treatments with combinations of varieties and fungicides at three replications. Two improved varieties (Tseday and Kuriftu) and one local variety combined with two fungicides (Tilt 250EC and Ridomil Gold MZ 68 WG). Untreated plots were also used as treatments. The plot's size was 2.5m*1.8m (4.5m^2) with a spacing of 0.5m between plots, 0.3m, between rows and 0.1m between plants. Data on disease incidence, percentage severity index, yield and yield component parameters were collected and analyzed. The highest (99.2%) local untreated and the lowest (3.51%) Tseday variety treated with Tilt percentage severity index were recorded. The lowest (8.01 t ha-1) yield was found variety while the highest (12.04 t ha-1) total bulb yield and high marginal rate of return were recorded from Tseday variety treated with Tilt 250 EC fungicide. Therefore, according to our research result, Tseday variety treated with Tilt fungicide was recommended as best management method among treatments on garlic rust disease.

Keywords: Garlic rust, Variety, Fungicide, Disease incidence, Severity

INTRODUCTION

Garlic (*Allium sativum*L.) is an important spice crop which is belonged to the family *Alliaceae,* and which is the second most widely used *Allium* next to onion (Rubatzky and Yamaguchi, 1997). According to Etoh and Simon (2002), garlic was originally found on the north-western side of the Tien-Shan Mountains of Kirgizia in the arid and semi-arid areas of Kazakhstan, Central Asia. Garlic is produced in Ethiopia in 2,255,598 small scale farmers' field of 19,412.49 hectares of land. From these hectares of lands, 178,221.893 tones were produced in 2018 with anational average productivity of 9.181 tons per hectares. The production was carried out throughout the country both under irrigation and rain fed conditions in different agro - climatic conditions (CSA, 2018).

The composition of the bulbs was approximately 84.09% water, 13.38% organic matter, and 1.53% inorganic matter while the composition of the leaves were 87.14% water, 11.27% organic matter, and 1.59% inorganic matter (Etoh and Simon, 2002). Today, garlic is one of the twenty most important vegetables in the world which is produced within one Million hectares (2.5 million acres). About 10 million metric tons of garlic is produced globally each year, and the major growing countries are USA, China, Egypt, Korea, Russia and India (FAO, 2017). Garlic (*Allium sativum*L.) is the second most widely cultivated *Allium* species in Ethiopia next to onion (Worku and Mashila, 2012).

In Ethiopia, garlic is one of the most vital vegetable crops which is used as ingredients of local stew *wot (*sauce*)*. It has also a tremendous use in the preparation of local medicines (Tilahun and Hassen, 2008). It is one of the most important bulb crops produced by small scale and commercial farmers for both local use and export purpose respectively (Metasebia and Shimelis, 1998). Ambo, Debrework, Adiet, Sinnana and many other areas of Ethiopian highlands produced the most coverage of garlic production (Shege, 2015). The crop is produced mainly as a cash crop to earn foreign currency by exporting it to Europe, the Middle East and USA. It had been also under commercial production by Horticultural Development Corporation at DebreZeit, Guder and Tseday State Farms (Getachew and Asfaw, 2000).

Garlic production is challenged by several biotic and abiotic factors. Despite its multifaceted uses, garlic productivity is affected by many problems that caused to low production and to poor quality largely attributable to the use of unimproved local seeds (Dessie and Mulat, 2019). The productivity of this crop across the globe or in Ethiopia is generally low due to numerous and prominent production problems which encompass: lack of proper planting material, inappropriate agronomic practices, absence of proper pest and disease management practices, marketing facilities, a biotic and biotic factors. Yeshiwas *et al*., (2017) also indicated that lack of improved varieties and garlic rust are among the major factors responsible for low production and productivity of garlic in Ethiopia.

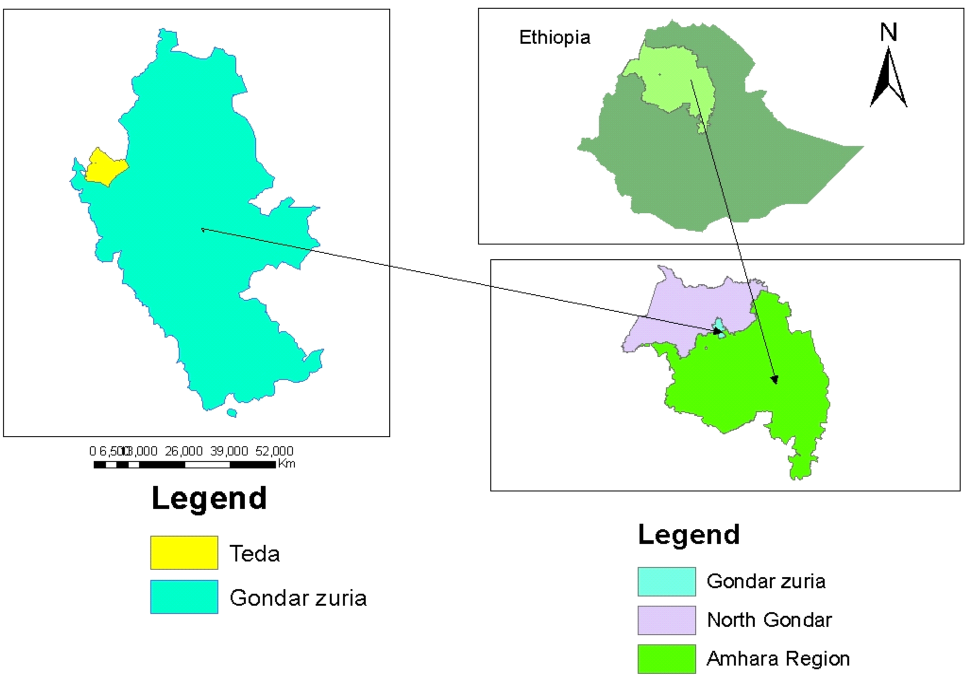
The production has been significantly reduced due to fungal diseases of which garlic rust that is caused by *Pucciniaallii* Rudolphi is the most affecting disease of the crop in all garlic producing areas of Ethiopia (Worku and Mashila, 2012;

2012; Azene, 2016). The genus *Puccinia* is the first in the order Uredinales. *Pucciniaallii* infects garlic at bulb formation stage (Koike *et al*., 2001). The fungus does not affect the garlic bulb directly, but its damage on the leaves has indirect effect of reducing the size and quality of the bulbs at harvesting time (Tahir *et al*., 2006). The disease is found in every areas of Ethiopia where garlic is cultivated (Worku, 2017).Therefore, this study was initiated to find out the integrated use of Garlic varieties and fungicides for the management of Garlic rust (*Pucciniaallii*) disease in Gondar Zuria district, Ethiopia.

Materials and Methods

Experimental Site

The experiment was conducted during 2019/20 main cropping season at Teda horticultural farming site, College of Agriculture and Environmental Sciences, University of Gondar. The experimental site is located at 12°45.76' N Latitude and 37°47.87' E Longitude with the elevation of 1965 m.a.s.l (Fig. 1).



Experimental Treatments and Design

Two improved varieties (Tsedey 92 and Kuriftu) which were distributed by DebreZeit Agricultural Research Center, under Ethiopian Institute of Agricultural Research (DZARC/EIAR), one local garlic cultivar produced locally in Teda area with two fungicides Tilt 250 EC (Propiconazole) and Ridomil Gold MZ 68 WG (metalaxyl-M+chlorothalonil) were used for this study. Untreated plots were used as a control.

The experiment was done in randomized complete block design in a factorial arrangement of nine treatment combinations with three replications. The plot size was 2.5*1.8 m (4.5 m^2) total area of 27.5*9.4(258.5m^2) from where this area calculated with a spacing of 1m between blocks, 0.5m between plots, 0.20 m height, 0.3m and 0.1m between rows and plants respectively. There were 6 rows in a plot and 25 plants in one row. The application of fungicides was done during the time of disease incidence. The sizes of both the clove and the bulb were important considerations when selecting planting stock and medium to large size (1.50-2.50 g) cloves were used. Both size and quality of cloves of the varieties were reasonably uniform. 0.22ml Tilt fungicide was applied for each plot (0.5L/ ha) and 45 ml Ridomil fungicide was applied for the experiment (2.5 kg/ha) according to manufacturer recommendation. Planting was done during main cropping season on June 10, 2019. However, the harvesting days were not the same days. This was due to the reason of garlic variety physiological maturity day varied from 124 to 140 days. The seed rate was 0.8 ton per hectare while fertilizer was applied at the rate of 200kg NPS/ha (applied at planting time) and UREA at 150 kg/ha (half at planting and half after one month of first application) were applied (Worku, 2017).

Method of data Collection

Disease Parameter

Disease Incidence: Disease incidence was calculated by using the percentage of plants showing disease symptoms divided by total observed plants. The number of infected and healthy plants was counted at seven days interval from the beginning of disease symptom appearance (Habtu and Abiye, 1997).

$$Disease\ Incidence\ (\%) = \frac{Infected\ plant}{Total\ assessed\ plant} x\ 100$$

Severity of garlic rust: Disease severity was estimated by calculating the percentage of the leaf surface covered with lesions? There is missed information. It is the degree of infestation of garlic rust per infested plant per plot on scale base after and before the application of treatments. It was assessed from all leaves of plants and the average was taken (recorded) for the respective plant.

Disease severity was estimated using 1 to 5 scale. The proportion among the 1 to 5 scales is as follow: 1 meant 1% to 10% was covered, 2 meant 11% to 25%, 3 meant 26% to 50%, 4 meant 51% to 75% and 5 meant 76% to 100%) (Koike *et al*., 2001). Average severity level of the 10 tagged plants per plot was changed into percentage severity index (PSI) for

$$PSI = \frac{\text{Sum of numerical rating}}{\text{No. of plants scored} \times \text{max score on scale}} \times 100$$

analysis using Wheeler's (1969) formula. Where, Snr = the sum of numerical ratings, Npr = the number of plants rated, MSc = the maximum score of the scale. Mean disease severity from each plot was used in data analysis.

Area under Disease Progress Curve (AUDPC)

The area under disease progress curve (AUDPC) was calculated for each treatment from the assessment of disease severity using the following formula by (Campbell and Madden, 1990).

$$AUDPC = \sum_{i-1}^{n-1} \left(\frac{X_i + X_{i+1}}{2}\right) (t_i + t_{i+1})$$

Where X_i is the severity index (SI) of disease at $_i{}^{th}$ assessment level, t_i was the time of the $_i{}^{th}$ assessment in days from the first assessment date and n was the total number of disease assessed. The reason is that severity should be expressed in percent and time in days. AUDPC was expressed in %-days.

Crop parameter

Assessment of Yield and Yield Components

Plant height was measured as the mean of 10 plants. Clove weight was calculated by dividing bulb weight to the number of cloves per bulb. Similarly, bulb weight was measured as the average weight of 10 bulbs taken from each plot after curing. In the same way, yield per plot was determined by harvesting plot yields of garlic from a 2.5 meter length. Finally, total bulb yield was computed as the total number of bulbs which were found from four middle rows taken in a plot.

Cost Benefit Analysis

To estimate the economic significance of the different treatments, partial budget analysis training manual (CIMMYT, 1988) was applied to calculate the marginal net benefit (MNB), and economic analysis was done on three garlic varieties treated with fungicide application in a factorial experiment.

i. Adjusted yield (AJY) = AVY- (AVY×0.1)
*ii. Sale revenue (SR) = AJY*farm gate unit price for the crop*
iii. Net benefit (NB) = Sale revenue – Variable Cost

Total costs that vary were calculated from the cost of fungicides, labor to apply fungicides, labor to haul water and rent of sprayers that were used for this experiment. The cost of other inputs and production practices such as fertilizer cost, labor for land preparation, planting, weeding and harvesting were assumed to remain the same.

Marginal rate of return (MRR) was calculated as follows:

MRR = DNI/DIC

Where, MRR = marginal rate of return, DNI = difference in net income compared with control and DIC = difference in input cost compared with control. Price of garlic per kg and total sale from each plot was also considered. On untreated plots, the inputs were clove and fertilizer and production practice cost was the same for all treatments. Net Profit was calculated by subtracting the total costs from the gross field benefit for each treatment.

Data Analysis

Analysis of variance (ANOVA) was done for disease parameters (incidence and severity) for each assessment date. Crop yield and yield component parameters (Days to emergence, Days to maturity, plant height, yield per plot, Stand Count at emergence and harvest) were recorded.

From field experiment, the main effects and their interactions were calculated as described by Gomez's (1984) formula using

SAS computer software. Least significant difference (LSD) value was used to identify differences among treatment means at 5% probability level to analyze the effect of treatments in disease assessment and yield components. Correlation analysis was carried out to determine the relationship of disease severity and yield related components of garlic which was done using General Linear Model (GLM) of SAS procedure (SAS, 2018).

Result and Discussion

Parameters

Garlic rust disease incidence

The highest (36.70%) initial disease incidence was recorded on the local variety; and this was significantly different from other varieties (Fig. 2, Table 1) whereas, the lowest initial disease incidence (32.23%) was documented on Tseday variety and this was significantly different from other varieties. This result indicated that improved Garlic varieties especially Tseday variety was relatively resistant than the rest varieties (Fig.2).

Results of ANOVA showed that variety difference was significantly highest (P < 0.001), but among fungicides, there was no significant difference on disease incidence at 90 days after planting (Table 1). In addition, there was high (p < 0.01) significant difference on the main effects of fungicides and varieties while there was no significant difference on the interaction effects at 97 DAP (Table 1).

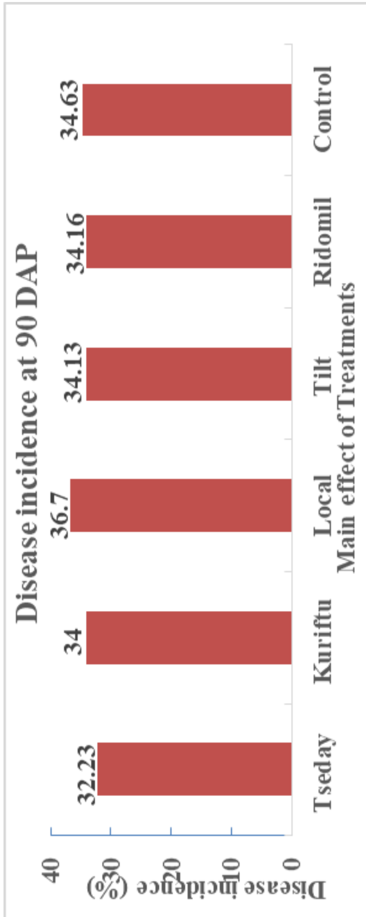


Figure 2. Main effects of varieties and fungicides on garlic rust disease incidence at 90 DAP

Table 1. Analysis of variance with mean square value for Disease incidence of days after planting

Source	DF	90 DAP	97 DAP	104 DAP
Rep	2	0.36	23.32	0.60
F	2	0.70^{ns}	4717.56**	4658.29**
V	2	45.54*	198.10*	373.33**
F*V	4	0.50^{ns}	19.84^{ns}	106.89**
Error	16	0.69	18.25	2.21
Total	26			
CV (%)		2.43	6.26	1.90

DF=Degree of freedom, F=Fungicides, V=Varieties, CV=Coefficient of variations, Rep= Replication, DAP=Days after Planting, DPR = Disease progress rate

The lowest disease incidence (63.36%) was recorded from Tseday variety which was significantly different from the local variety whose highest incidence was documented as (72.23%). However, there was no significant difference between the Local and Kuriftu varieties (Table 2).Tilt sprayed plot indicated less incidence (43.20%) and showed highly significant ($p < 0.01$) difference with Ridomil and control plots even though two times highest disease incidence (88.13%) was recorded from untreated plots compared to Tilt treated plot (Table 2). The different fungicide treatments had varying effects on disease incidence. Both Tilt and Ridomil fungicide treated plots significantly affect disease incidence regardless of the foliar application. In the fungicide trials, Tilt consistently provided the best control of rust incidence. This experimental result was consistent with Meseret Tadesse (2014) report which indicated that the less disease incidence was recorded on Tseday variety treated with Tilt treatment.

Table 2. Main effects of Varieties and Fungicides on garlic rust disease incidence at 97 DAP

Disease incidence (%) at 97 DAP			
Varieties	Inci	Fungicides	Inci (%)
Tseday	63.36b	Tilt	43.20c
Kuriftu	68.53a	Ridomil	73.30b
Local	72.23a	Control	88.13a
LSD (0.05)	4.26		
CV (%)	6.26		

Means within the same column show different letters significant difference at P<0.05 and Means within the same column followed by a common letter are not significantly different at P<0.05. DAP = days after planting, Inci = Incidence

Disease incidence on the 104th days after planting (DAP) was highly significant (P< 0.01), and there was difference in the interactions of fungicides and varieties. The incidence was increased from 90 to 104 DAP. The highest average incidence level (100%) of garlic rust was recorded from untreated plots while the lowest average disease incidence level of garlic rust (41.5%) was taken from Tilt treated Tseday variety on 104 DAP (Table 3).

There is significant difference between garlic varieties on disease incidence. The result indicated that Tseday variety is comparatively resistant to garlic rust than Kuriftu and Local varieties (Table 3). Tilt fungicide treated varieties significantly reduced the rust incidence compared to all other fungicide and the unsprayed check plots (Table 3). In general, Tseday variety that was treated by Tilt fungicide showed comparatively lower disease incidence than any of fungicide and variety tested. The result was similar to Worku *et al.,* (2015) who evaluated the efficacy of fungicides on the control of garlic rust, and he found that Tilt is effective fungicide than Ridomil and other fungicides at 107 DAP.

Table 3. Interaction effects of fungicides and garlic varieties on garlic rust disease incidence at 104 DAP

	Disease incidence (%) at 104 DAP		
Treatments	**Tilt**	**Ridomil**	**Control**
Tseday	41.5cf	71.20c	100a
Kuriftu	58.60de	80.30bc	100a
Local	63.00d	86.80b	100a
LSD (0.05)	1.48		
CV (%)	1.90		

LSD = Least Significance Difference, CV = Coefficient of Variation, DAP = days after planting. Means within the same column show different letters significant difference at P<0.05 and Means within the same column followed by a common letter are not significantly difference at P < 0.05.

Garlic rust Disease severity

During diseases development, a small reddish, and dull orange oval-shaped pustules were developed on leaf blades. The disease severity was recorded at 90, 97, 104, 111, and 118 days after planting, and there was 7 days interval to spray fungicides. The fungicides were applied starting from the onset of the disease according to the fungicides manufacturer recommendation.

At 90 days after planting, there was highly significant difference (P< 0.01) among the different garlic varieties with regard to disease severity (Table 4), and the disease progress was also slightly higher in plots which were local variety than the rest of two varieties. However, there was no significant difference between fungicides and their interactions. The highest disease severity level (7.05%) was recorded on local variety while the lowest level of disease severity (5.50%) was documented on Tseday variety (Fig. 3). Both Tseday and Kuriftu varieties were less susceptible to garlic rust with Tseday being the lowest (Fig. 3) and their interactions. The highest disease severity level (7.05%) was recorded on local variety while the lowest level of disease severity (5.50%) was documented on Tseday variety (Fig. 3).

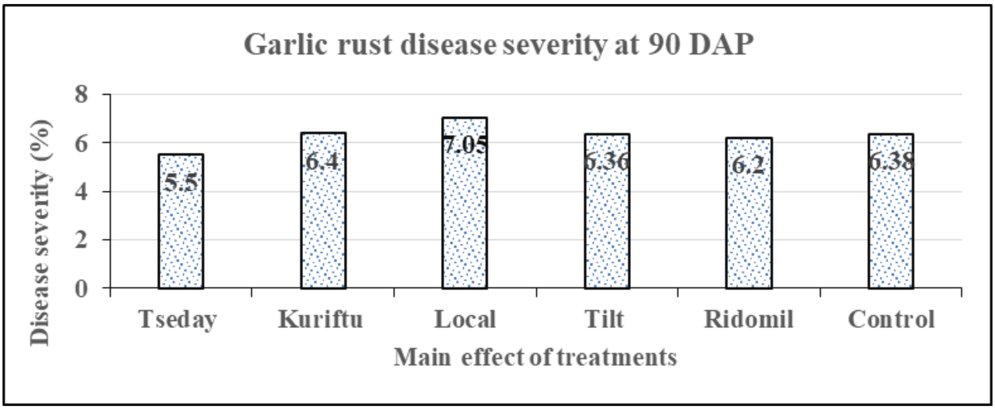


Figure 3. Main effects of Varieties and Fungicides on garlic rust disease severity at 90 DAP

There was highly significant difference (P<0.01) between interaction effect of fungicides and varieties on disease severity at 97 DAP (Table 4). Rust severity level on all fungicides treated plots was significantly lower than the unsprayed plots. At 97 DAP, the lowest disease severity level (11.60%) was recorded from Tseday variety treated with Tilt fungicide. In contrast, the highest disease severity level (51.10%) was noticed from Local variety with Untreated plots (Table 4). Similarly, this result was coincided with Mengesha's *et al.* (2016) previous research work which reported that plots treated with Tilt showed the lowest garlic rust disease severity (3.72%) compared to those which were untreated and which showed higher disease severity level (83.45%) at the 128 days.

Table 4. Interaction effects of fungicides and garlic varieties on garlic rust disease severity at different days of planting

Treatments		Disease severity (%) at different DAP			
		97 DAP	104 DAP	111 DAP	118 DAP
Tseday	Tilt	11.60i	7.00f	5.20h	3.51i
	Ridomil	27.40f	31.40e	45.00e	43.40e
	Control	31.40e	62.00a	76.40c	97.30c
Kuriftu	Tilt	21.40g	33.60de	28.80g	21.30h
	Ridomil	33.70d	46.10c	44.30ef	41.50f
	Control	36.20c	54.80bc	79.30b	98.30ab
Local	Tilt	18.30h	35.30d	32.30f	30.60g
	Ridomil	40.00b	56.40b	52.00d	50.80d
	Control	51.1a	61.60ab	91.00a	99.20a
LSD (0.05)		1.72	2.21	2.18	0.93
CV (%)		5.77	5.14	4.33	1.73

LSD = Least Significance Difference; CV = Coefficient of Variation, DAP = days after planting. Means within the same column show different letters significant difference at P<0.05 and Means within the same column followed by a common letter are not significantly different at P

The disease severity showed increment after 90 DAP, but from all treatments, Tilt treated plots indicated less disease severity than other interactions. Both fungicides had a reduction effect on disease severity level. On the other hand, there was significant difference within the different garlic varieties with regard to disease severity (Table 5), and the disease progress was also slightly higher in plots which were not sprayed than the rest which were treated plots. Both treated and untreated ones, however, had effects on the severity of the disease. The result indicated that the application of different fungicides showed decrement of the disease severity level. Similar findings have been reported by Gianessi and Reigner (2005); Negash *et al*. (2019) which indicated that fungicides Nativo and Tilt had adverse and antagonistic effects on garlic rust physiology since they suppressed and prohibited further lesion expansions.

Table 5. Analysis of variance with mean square value on different DAP of disease severity

Source	DF	90 DAP	97 DAP	104 DAP	111 DAP	118 DAP
Rep	2	0.26	3.68	4.32	15.01	0.44
F	2	0.09^{ns}	1222.09**	2641.75**	8213.05**	14844.44**
V	2	5.48**	380.90**	719.11**	593.62**	331.62**
F*V	4	0.01^{ns}	65.00**	279.63**	145.90**	155.96**
Error	16	0.07	3.02	4.92	4.79	0.87
Total	26					
CV (%)		4.39	5.77	5.14	4.33	1.73

DF=Degree of freedom, F=Fungicides, V=Varieties, CV=Coefficient of variations, rep= Replication, DAP=Days after Planting

Area Under Disease Progressive Curve (AUDPC)

Analysis of the area under disease progress curve (AUDPC), data revealed that there were very highly significant differences (P < 0.001) among treatments of combinations of the three garlic varieties with two types of fungicides and untreated plots (Fig. 4). The highest (1811.9 %-days) AUDPC value was taken on the untreated local variety, and the second highest (1565.2 %-days) AUDPC value was recorded on the untreated plots of Tseday variety. On the other hand, the lowest AUDPC 198.14 %- days was documented from Tseday variety which was treated with Tilt, and this variety was followed by Kuriftu variety which was treated with the same fungicide.

Tseday variety with Spraying Tilt in every 7 days significantly (P < 0.05) reduced the AUDPC values compared to all other fungicide and the unsprayed control (Fig. 4). Similarly, Ridomil fungicide also significantly reduced the area under disease progress curve on garlic crop. Hence, all fungicides reduced AUDPC compared to the unsprayed plots, but the difference between Tilt and Ridomil in AUDPC values was statistically significant (Fig. 4).

Generally, combinations of Tilt treated with varieties showed the lowest AUDPC value and had significant difference compared to other treatments while the highest AUDPC value was found from untreated local variety, and it had significant different with other treatments. The highest AUDPC value indicated that there was fast disease development on treatments whereas the lowest AUDPC value indicates that the use of fungicides had reduced the development of the disease. The result of the present study was similar to the report of Azene (2016) which indicated lowest AUDPC value recorded with Tilt treated plots, and the highest value of AUDPC showed the fast disease development on plots that were not treated with fungicides.

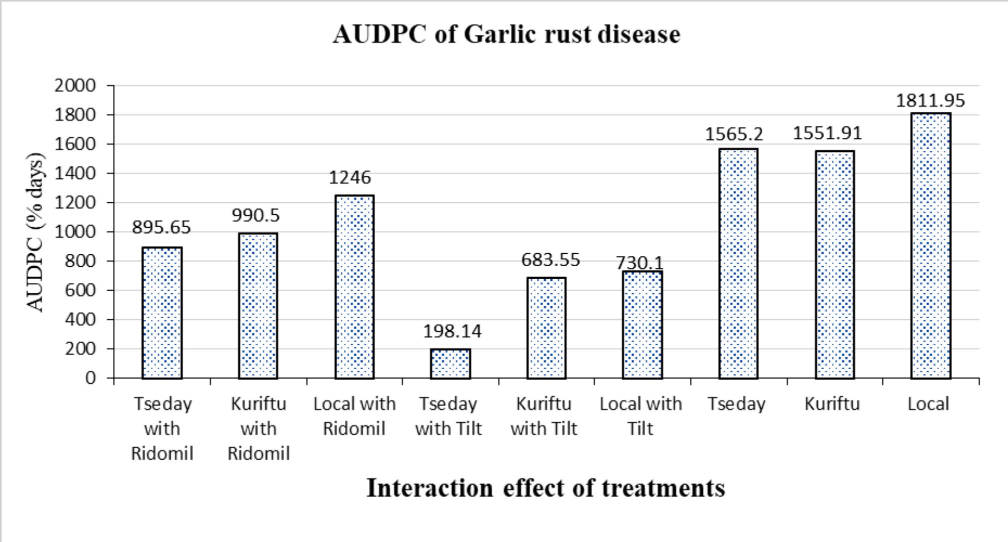


Figure 4. Interaction effects of fungicides and varieties on an Area Under Disease Progress Curve (AUDPC) value

Crop parameters

Clove weight

There was highly significant (P ≤ 0.01) difference in clove weight of interaction effect on garlic variety and fungicide treatments (Table 6). The maximum clove weight (3.06g) was found from Tseday variety treated with Tilt whereas the minimum values of clove weight (1.68g) were recorded from both Local treated with Ridomil and untreated Kuriftu variety treatments. Statistically, there was no significant difference between Tseday and Local untreated plots (Table 7). However, both untreated varieties had significantly higher clove weight compared to untreated Kuriftu variety.

Table 6. Analysis of variance with mean square value for yield and yield components

Source	Df	NLP	NCB	CW	BD	BW	TBW
Rep	2	1.62	1.08	0.06	0.00	0.87	0.03
F	2	0.00^{ns}	0.44^{ns}	1.99**	5.17**	514.22**	22.15**
V	2	0.46^{ns}	0.33^{ns}	1.25**	4.95**	127.31**	1.66**
F*V	4	0.78^{ns}	0.55^{ns}	0.39**	1.01*	37.90**	0.32*
Error	16	2.44	1.31	0.01	0.14	2.71	0.03
Total	26						
CV (%)		8.44	7.10	5.61	7.12	4.89	1.89

Df = Degree of freedom, F = Fungicides, V = Varieties, Rep = replication, CV = Coefficient of variations, NLP = Number of leaves per plant, NCB = Number of cloves per bulb, CW = Clove weight, BD = Bulb diameter, BW = Bulb weight, and TBW = Total bulb weight

The findings of this study indicated that clove weight of garlic was severely affected by varieties and different fungicides. Tseday variety and Tilt fungicide significantly increased clove weight compared to other interaction effects on varieties and fungicides. This finding is very consistent with research findings of Worku *et al*., (2015) who reported that the highest (2.39g) and the lowest (1.06g) clove weight were found from plots treated with Tilt fungicide and the control plots respectively. The reason for this might be due to the different disease severity levels created by spraying different fungicides which caused varying levels of clove weight losses.

Bulb diameter

Bulb diameter was highly affected by garlic rust. From the trial, there were significant differences ($p < 0.01$) among interaction effects of fungicides and varieties (Table 6). Improved varieties which were treated with both fungicides had wide bulb diameter than unsprayed plots (Table 7)

Table 7. Interaction effects of varieties and fungicides on clove weight, bulb diameter, bulb weight, and number of cloves per bulb parameters

Treatments		Yield and yield components			
		CW (gr)	BD (cm)	BW (gr)	NC (No.)
Tseday	Tilt	3.06a	7.60a	49.60a	16.20a
	Ridomil	2.93b	5.50c	34.26cd	15.40a
	Control	1.77ef	5.00cd	28.50e	16.10a
Kuriftu	Tilt	2.80c	5.60b	42.00b	15.60a
	Ridomil	1.88e	5.45cd	32.00d	16.30a
	Control	1.68g	4.80d	27.00efg	16.60a
Local	Tilt	2.14d	5.20c	35.00c	16.5a
	Ridomil	1.68g	4.25e	27.00efg	16.00a
	Control	1.73f	4.20ef	27.80ef	16.33a
LSD (0.05)		0.12	0.37	1.64	1.14
CV (%)		5.61	7.12	4.89	7.10

LSD = Least Significance Difference; CV = Coefficient of Variation, DAP = days after planting. Means within the same column show different letters significant difference at P<0.05 and Means within the same column followed by a common letter are not significantly different at P < 0.05

The widest (7.60cm) bulb diameter was recorded on bulbs harvested from Tseday variety with Tilt -sprayed plot while the narrowest diameter (4.20cm) was documented from unsprayed plots. The average bulb size (5.45 mm) harvested from Kuriftu variety treated with Ridomil plot was statistically different compared to Local varieties which were treated with Ridomil and untreated plots (Table 7). From the trial, there were significant differences among fungicide spray and unsprayed plots. Similar research results were reported by Worku *et al*., (2015) that showed the bulb diameter was increased with the application of Tilt fungicide than Ridomil and other fungicides. On varieties, Tewachew (2016) reported that Tseday variety had a wider bulb diameter than the Local variety. This implies that Tilt fungicide with Tseday variety reduced the disease severity, and it significantly affected the growth parameters per plant.

Bulb weight

Bulb weights were severely affected by rust disease and also there were highly significant differences ($p < 0.01$) among interaction effects of varieties and fungicide treatments (Table 6).The highest bulb weight was recorded from Tseday variety treated with Tilt fungicide (49.6g), and there was highly significant different with other treatments while the lowest bulb weight (27.00g) was found from Local treated varieties with Ridomil fungicide and kuriftu with untreated plots. Tilt was effective fungicide to reduce garlic rust disease than Ridomil fungicide sprayed plots.

The interaction effect of Tseday variety with Tilt fungicide produced the maximum bulb weight compared to other fungicide interaction effect treatments. This result is also similar to Habtewold (2019) and (Azene, 2016) results which reported that the bulb weight was increased with the application of Tilt fungicide than other fungicides. Similarly, the existence of significant variations among garlic varieties for fresh bulb weight were reported by Abraham and Esubalew (2015), and they indicated that Tseday variety with fresh bulb weight was higher than from Kuriftu and Local varieties.

Total bulb yield

The interaction effects of fungicides application on the experiments of three garlic variety plots reduced the garlic rust disease infestation and resulted highly significant difference ($p<0.01$) among treatments on total bulb yield (Table 6). Total bulb yield was increased with application of different fungicides with the exception of untreated plots. The highest (12.038 t ha-1) total bulb yield was obtained from Tseday variety plots sprayed with Tilt fungicide while the lowest (8.01 t ha-1) total bulb yield was found from the unsprayed Local garlic variety (Table 8). Application of Tilt fungicides on Tseday variety produced higher yields than other treatments. This result was coincided with Tadesse Abadi (2015) previous study that indicated Tseday garlic cultivar produced maximum total bulb yield. In the same way, Azene's (2016) result indicated that maximum yield was recorded on Tilt treated garlic plots.

Table 8: Interaction effects of garlic varieties and fungicides on Total bulb yield

	Total buld yield (t ha^{-1})		
Treatments	Tilt	Ridomil	Control
Tseday	12.038a	9.89d	8.21gh
Kuriftu	11.35b	9.67e	8.32g
Local	10.54c	9.06f	8.01h
LSD (0.05)	0.18		
CV (%)	1.89		

Means within the same column show different letters significant difference at P<0.05 and Means within the same column followed by a common letter are not significantly difference at P <0.05.

Correlation of disease parameters with yield and yield components

Correlation analysis showed that garlic rust disease incidence at 104 days after planting (DAP) and Total bulb yield of different garlic varieties had highly significant negative correlation (r = -0.99) (Table 9). This indicated that the observed value of the disease incidence had a considerable adverse effect on total garlic bulb yield. Similarly, this disease incidence at 104 days after planting (DAP) and bulb weight of different garlic varieties had highly significant and negative correlation (r = -0.94) (Table 9). In the same effect, disease severity index at 118 days after planting (DAP) and total bulb yield of different garlic varieties had highly significant and negative correlation (r = -0.95). Likewise, percent severity index at 118 days after planting (DAP) and bulb weight of different garlic varieties had significant and negative correlation (r = -0.83).

This study result is parallel with Yonas' finding of (2010) which showed the negative relationships among garlic rust ratings and yield and yield components pinpoint that rust is a negative factor in garlic productivity. Similarly, (Tilahun *et al.*, 2019) reported that the correlation analysis revealed significant and negative relationships among garlic rust disease parameters and total yield, and clove weight.

Table 9. Correlation coefficients (r) of treatments on garlic rust disease, with different Parameters

	Inci	PSI	AUDPC	CW	BD	BW	TBY
DI	1						
DS	0.95**	1					
AUDPC	0.98**	0.96**	1				
CW	-0.86*	-0.76*	-0.82*	1			
BD	-0.83*	-0.72*	-0.85**	0.79*	1		
BM	-0.94**	-0.83*	-0.90*	0.88*	0.91*	1	
TBY	-0.99**	-0.95**	-0.97**	0.84*	0.82*	0.94*	1

** = significant difference, ** =highly significant difference. Inci = Incidence, PSI = Percentage Severity Index, AUDPC = Area under Disease Progress Curve, CW = clove weight, BD = bulb diameter, BW = bulb weight and TBY = Total bulb Yield*

Cost benefit analysis

The maximum total gross yield benefits (812,565 and 766,565 ETB ha -1) were obtained from Tseday and Kuriftu varieties that were treated with Tilt fungicide respectively. The lowest (540,675 ETB ha-1) gross yield benefit was found from the Local untreated variety plots (Table 10). Variation in net profit was observed among combinations of the three garlic varieties. Among all combinations, the Tseday variety treated with the fungicide Tilt had the highest (808,565 ETB ha-1) net profit. The second and the third highest (762,125 and 707,450 ETB ha-1) net profits were found from the above fungicide that was used to treated Kuriftu and local plots respectively. On the other hand, the lowest (540, 675 ETB ha-1) net profit was obtained from the Local untreated variety plots (Table 10).

The highest (254,390 ETB ha-1) marginal net benefit (MNB) was recorded from the Tseday variety treated with Tilt fungicide (Table 10). However, the lowest (71,145 ETB ha-1) MNB was obtained from the local variety plots treated with Ridomil fungicide (Table 10). In general, higher marginal rate of return was recorded from Tilt application in all garlic varieties than with the application of Ridomil. In the same manner, Tilt spraying increased marginal rates of return increased significantly. Use of Tilt fungicide was more economical. Hence, higher marginal return was recorded in Tseday (98.45%) followed by Kuriftu (98.04%) and Local (97.65%) varieties compared to the rest fungicides. On the other hand, the lowest marginal rate of return (90.51 %) was obtained from the local variety treated with Ridomil fungicide (Table 10).

Table 10: Economic assessment of fungicide and Varieties on garlic rust

Treatments		AY ($kg.ha^{-1}$)	Pr/ kg	SR ($Br.ha^{-1}$)	VC ($Br.ha^{-1}$)	NP ($Br.ha^{-1}$)	MC ($Br.ha^{-1}$)	MNB ($Br.ha^{-1}$)	MRR (%)
Tse	Tilt	10,834.2	75	812,565	4,000	808,565	258,390	254,390	98.45
	Ridomil	8,901	75	667,575	6,750	660,825	113,400	106,650	94.04
	Control	7,389	75	554,175	0	554,175	0	0	-
Kur	Tilt	10,215	75	766,125	4,000	762,125	204,525	200,525	98.04
	Ridomil	8,703	75	652,725	6,750	645,975	91,125	84,375	92.59
	Control	7,488	75	561,600	0	561,600	0	0	-
Loc	Tilt	9,486	75	711,450	4,000	707,450	170,775	166,775	97.65
	Ridomil	8,157.6	75	611,820	6,750	605,070	71,145	64,395	90.51
	Control	7,209	75	540,675	0	540,675	0	0	—

Total variable costs are costs attributed to labor and fungicide, Gross benefits or revenue for garlic kg based on the local market price in Teda birr 75.00 for one kg garlic yield. Tse = Tseday, Kur = Kuriftu, Loc = Local, AY = Average yield, PR = Price VC = Variable cost, SR = Sale revenue NP = net Profit, MC = marginal cost, MNB = marginal net benefit, MRR = marginal rate of return

CONCLUSION AND RECOMMENDATION

The present study revealed that Tseday Garlic variety treated with Tilt Fungicide resulted in less disease incidence with higher yield of Garlic bulb. Furthermore, Tilt treatment showed best result in Garlic disease management with higher net profit. Hence, the present finding could provide basic information for further research and development efforts of combating Garlic rust disease management. However, to present more reliable information, similar experiments shall be carried out in several locations involving the farmers across many cropping seasons.

Statement of *Ethical considerations and conflict of interest*

We declare and confirm that this study is our work. We have followed all ethical and technical principles of scholarships in the preparation, data collection, data analysis and completion of this study. All sources of materials used have been duly acknowledged and given recognition through citation.

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