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Effect of *Trichoderma harzianum* (Bio Inoculants), Wheat Straw Mulching and Groundnut Genotypes on Groundnut Early Leaf Spot Disease (GELSD) Management at Rama Northern Ethiopia

Nahom Weldu [a++*] and Gebretsadkan Zereabruk [a#]

[a] Tigray Agricultural Research Institute, Axum Agricultural Research Center, P.O. Box 230, Axum, Ethiopia.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Groundnut (*Arachis hypogaea* L.) is the 13th and fourth most important food and oilseed crop of the world respectively. kernel contains 40-50% oil, 20-50% proteins and 10-20% carbohydrates. However, lack of appropriate management practices of early leaf spot diseases becomes extremely serious production problems in Rama. *Trichoderma harzianum* could suppress disease causal pathogenic species due to its antagonistic nature. Wheat straw mulches could increase the soil

[++] *Plant Pathology Researcher;*
[#] *Plant Entomology Researcher;*
**Corresponding author: E-mail: nahomweldu373@yahoo.com;*

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moisture retaining capacity to overcome terminal drought stress and decrease soil temperature. Therefore, a field experiment was conducted in Rama, Central Zone of Tigray, northern Ethiopia, from in 2016 G.C to evaluate the integrated management of groundnut early leaf spot diseases of groundnut of ICGV00308, ICIAR19BT, Werer-961 and Rama local. The treatments were arranged in a factorial randomized complete block design (RCBD) with three replications. The interaction effect of genotypes * T. harzianum at 56 DAP and genotypes * wheat straw mulching at 63 DAP showed significant ($p \leq 0.05$) difference on GELS incidence. At the final assessment date 63 DAP, the highest (96.90%) percentage mean incidence occurred in the treatment combination of Rama local without application of wheat straw mulching, followed by 96.10, 93.68 and 89.59% for the treatment combinations of ICIAR19BT*ML0, ICGV00308*ML0 and ICGV00308*ML1, respectively. The lowest values of 52.22 and 51.73% ELSD incidence at the final assessment were recorded for Werer-961 and Rama local genotypes treated by wheat straw mulching, respectively. Application of wheat straw mulching significantly reduced GELS incidence by 45.17 and 27.80% in Rama local and Werer-961, respectively, as compared to the non-mulched plots of the respective genotype. Mulch highly and significantly ($p \leq 0.01$) decreased ELSD severity during the final 77 DAP assessment as compared to the non-mulched plots with the highest disease severity of 21.91% as compared to the lowest severity of 18.15% in straw mulched plots. As a recommendation application of wheat straw mulch and T. harzianum on groundnut genotypes showed significant reduction at ($P \leq 0.05$) on ELSD diseases severity and incidence and producer have to use locally available mulching materials and bio inoculants having diseases suppression characteristics.

Keywords: Early leaf spot diseases; diseases incidence and severity assessment; T. harzianum; wheat straw mulch.

1. INTRODUCTION

"Groundnut (*Arachis hypogaea* L.), which is also known as peanut, earthnut, monkey nut and goober is an annual legume crop. The genus term *Arachis* is derived from the Greek word *Arachis* to mean a weed, and the species term *hypogaea* is also a botanical term that stands for a weed with fruits produced below the soil surface. The term groundnut refers to the pod with seeds that mature underground and the conceptual meaning of peanut is due to the crop belonging to the leguminous family" [1]. Groundnut is known and used as a pulse crop in most countries of Africa, Asia, Australia and Europe, while it is commonly known as peanut in North and South America. Groundnut has unique plant characters, flowers are formed and fertilized above the soil and subsequently fruit development takes place under the soil. According to Surendranatha et al. [2], the crop is the 13th most important food and the 4th most important crop of the world. Its kernel contains 40 - 50% oil, 20 - 50% protein and 10 - 20% carbohydrates and the seeds are also source of vitamin E, niacin, riboflavin, thiamine and minerals such as calcium, magnesium, phosphorus, potassium, iron and zinc.

According to Wiess [3], "groundnut is originated from South America and gradually become the most popular and universal crop cultivated over 107 countries in six continents of the world including Ethiopia. Groundnut covers an area of 25.34 million hectares in the world with a total production of 42.63 million metric tons with the highest production of 46.76% from Asia and 41.99% from Africa. The major groundnut growing countries of the world are India (20.92%), China (18.75%) Nigeria (18.7%) and Sudan (7.10%) [4]. Its cultivation is mostly confined to the tropical, sub-tropical and warm temperate regions of the world ranging from 40ºN to 40ºS". In Ethiopia, the crop was expanded from Eritrea to Hararghe in 1920's by Italian explorers and it is relatively new crop as compared to sorghum [*Sorghum bicolor* (L.) Moench], tef [*Eragrostis tef* (Zucc.) Trotter] and finger mille [*Eleusine coracana* (L.) Gaertn] [5]. Its production accounts about 75,255.73 ha with a corresponding gross annual production of 115,150.04 metric tons in 2015/2016 cropping season [6]. However, its productivity is limited to about 1.53 t ha^{-1}, which is lower than the average global yield of 1.68 t ha^{-1} but with good management practices, the potential of the crop can go up to 3.0 t ha^{-1}. According to Mastewal (2017) "groundnut is widely grow in the eastern part of the country, i.e. Hararghe and there are also other identified groundnut producing lowland areas in Ethiopia, like Beles, Didessa, Gambella, Gamu Gofa, Gojam, Illubabor, Pawe, Wellega, Werer and Wollo" [5]. In addition to these areas, groundnut is produced in Tanqua Abergelle and

Mereb Leke from Central Zone and some districts from North Western Zone of Tigray [7,8,9]. Its production is mainly constrained by several a biotic, biotic and socio-economic factors. Out of these several factors, lower productivities of cultivars currently in production and the loss of yields due to groundnut leaf spot are most commonly known production constraints observed in the study area Rama.

Rama, the study area, is one of the lowland areas of Tigray, agro-ecologically ideal for groundnut production, but the productivity of the crop is far below its potential which is about 0.7 t ha^{-1} much lower as compared to the national average productivity of 1.3 t ha^{-1}. This lower productivity is mainly due to biotic, a biotic and socio economic factors such as poor soil fertility, prevalence of soil borne fungal pathogens, drought stress, lack of appropriate agronomic management, lack of leaf spot resistant/tolerant and high yielder groundnut varieties in the area except the local cultivar. Despite the fact that groundnut is the major source of income and many farmers cultivated it as a major crop, limited researches have been conducted in relation to evaluation of groundnut varieties and management practices of groundnut leaf spot disease. Therefore, the present research work conducted focused on evaluating integrated management of groundnut leaf spot disease and yield related components for the selection of better adaptable and leaf spot resistant/tolerant groundnut varieties aiming at boosting its production in the study area. To Evaluate the Integrated management of Groundnut Early Leaf Spot (*Cercopora arachidicola)* Disease

2. MATHERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted at Rama, Mereb-Leke district, Central zone of Tigray, northern Ethiopia, in 2016, during main cropping season. Rama is located at 14°22'25" N latitude and 038°47'32" E longitude at an elevation of 1390 m above sea level (m.a.s.l.) (Fig. 1). Rama is 1041 km far from Addis Ababa towards the north. It lies in the low land agro-ecological zone and the soil type is sandy clay loam. The mean annual rainfall in the area ranges from 400 to 600 mm and the rainfall distribution is mono-modal with an erratic distribution beginning in late June and terminating in the last week of August. The mean maximum and minimum temperature of Rama during growing season in 2016 was 33.9 and 18.7°C, respectively, and the average temperature of the study area was 26.3°C in the season, while the total annual rainfall of Rama Experimental Site during main cropping season in 2016 was 586.9 mm National metrological Agency [10]. Commonly grown crops are finger millet, maize, sorghum, tef and groundnut. According to Mereb-Leke District Office of Agriculture and Rural Development (DOARD), citrus species and mango are also among the commonly grown fruit crops in the study area.

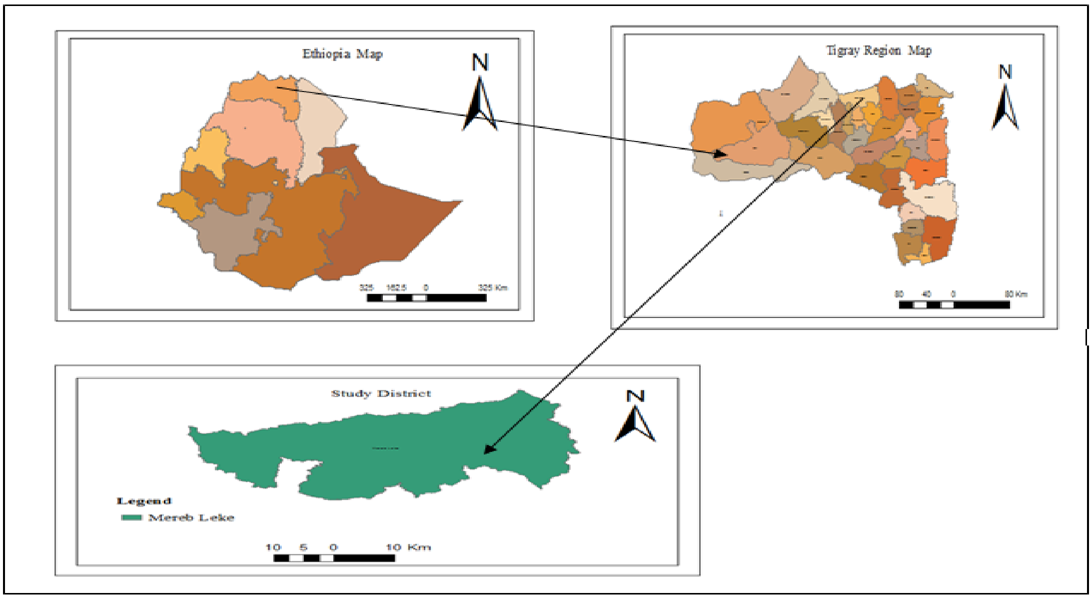


Fig. 1. Map of the study area

2.2 Experimental Materials

2.2.1 Planting materials

Four groundnut genotypes, namely ICGV00308, ICIAR19BT (introduced from ICRISAT as drought tolerant), Werer-961 and Rama local as drought susceptible were used as planting materials in the study. Seeds of these cultivars were obtained from Mekelle University which is one of the Ethiopian higher institutions RUFORUM Groundnut Project.Werer-961 was released from Werer Agricultural Research Center in Afar region Ethiopian in 2004 and the other two genotypes ICGV00308 and ICIAR19BT were introduced from ICRISAT.

2.2.2 *Tricoderma harzianum*

T. harzianum designated as BD-13 was used as biocontrol agent against groundnut seed infection of Aspergillus species that mainly cause seed infection and aflatoxin contamination at pre-harvest and post-harvest conditions and study the antagonistic effect on early leaf spot diseases (ELSD).

Preparation of *T. harzianum* Inoculums and Inoculation Techniques: "Culture of *T. harzianum* BD-13 was prepared on potato dextrose agar (PDA) plates that were incubated under fluorescent light at 25°C until sporulation was visible. The conidial inoculum was harvested by washing the plates with 10 ml distilled sterile water and the suspension was filtered through nylon mesh into a tube. The concentration of the spore suspension was standardized via haemacytometer count and the spore suspension was adjusted with distilled sterile water to produce a spore suspension of 10^6 spores per milliliter. Finally, a drop of Tween 20 was added to the adjusted spore suspension at a rate of 0.5% to disperse the spores and to increase the effectiveness of inoculation by attaching the spores with the seeds" [11]. 70 seeds of groundnut per plot were inoculated in 50 ml spores' suspension by seed priming techniques (soaking seeds in the spore's suspension) for 3 h just before planting. The inoculated seeds (Tr1) were air dried under shade for 40 min and, similarly, the remaining non-inoculated seeds (Tr0) were soaked with sterile distilled water for similar duration and air dried in the same manner to that of the *T. harzianum* inoculated seeds. Additionally, spore suspension of the *T. harzianum* BD-13 prepared as earlier described was sprayed on soils of groundnut seedling plots that were first planted with inoculated seeds. Similarly, the non-inoculated seedlings were sprayed with sterile distilled water only. One-time spraying was done using hand sprayer (atomizer) around the root zone (rhizosphere) of the seedlings 59 days after planting, when the groundnut growth reached the first pegging stage at a rate of 50 milliliters per plot.

2.2.3 Wheat straw mulching material

"Wheat straw was used as a source of mulching to increase the soil moisture holding capacity and reduce the terminal drought stress by decreasing evaporation rate. It is well known that pre-harvest contamination is higher under conditions of drought stress and higher soil temperature (25-32°C) during pod-filling period. Mulching could create conducive microclimatic conditions for the atoxigenic soil microorganisms and this helps them to suppress the groundnut leaf spot disease causal agents of *Cercopora arachidicola"* [12].

Wheat straw mulch was first chopped into pieces of size 5 to 10 cm to cover the plots properly. Wheat straw mulch was applied at a rate of 12 t ha^{-1} in split application of first half 27 days after planting and the second half 49 days after planting or 22 days after the first mulching based on the treatments randomizations and un-mulched (ML0) plots were used as control according to [13].

2.3 Treatments and Experimental Design

The treatments consisted of factorial combinations of three factors, four groundnut genotypes (ICGV00308, ICIAR19BT, Werer-961 and Rama local), two *T. harzianum* with and without inoculation (Tr1 and Tr0) and two wheat straw mulching with (ML1) and without mulching (ML0). The experimental plot size was 2 m long and 3.6 m wide with a plot size of 7.2 m^2 with six rows per plot. The net harvested area was 4.8 m^2 (2.4 m × 2.0 m) leaving one outermost row in both sides as borders. Groundnut genotypes were sown in row maintaining 0.60 and 0.20 m spacing between rows and plants, respectively. Each treatment and treatment combination was assigned to the respective plot randomly and the treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications. Spacing of 1 and 1.5m were maintained among plots and between adjacent replications, respectively.

2.4 Management of Experimental Field

Groundnut seeds were sown in rows on well-prepared land at Rama, Central Tigray, Northern Ethiopia on 13th of July 2016 G.C. Each plot was divided into six planting rows and data were collected only from the harvested four central rows in the plot, which was considered as net plot. Di ammonium phosphate (DAP) fertilizer was uniformly applied at planting at a rate of 100 kg ha-1 (18 kg ha-1 N and 46 kg ha-1P2O5) for all plots at planting. Similarly, all other management practices hand weeding and hoeing were done manually to all plots uniformly.

2.5 Disease Assessment

Groundnut early leaf spot disease incidence and severity was collected every fourteen days' interval for three times starting from 49 days after planting (DAP) up to 63 DAP for incidence and five times from 49DAP to 77DAP every fourteen days' interval for severity from twelve pre tagged plants of four middle rows.

Disease Incidence: Groundnut early leaf spot (GELSD) incidence was recorded every seven-day In plot basis from the central four rows and computed by the formula mentioned below and subjected to analysis.

$$\mathrm{DI}(\%) = \frac{\text{number of diseased plants}}{\text{Total number of plants inspected}}\,\mathbf{x}100$$

Diseases Severity: Disease severity was recorded every fourteen days from 12 pre-tagged plants using 1-9 scoring scale which means scoring scale 1 represents no foliar infection 2 = for 1-5% level of infection, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 41-60%, 8 = 61-80% and 9 = 81-100% to mean plants defoliated all leaves and remaining bare stem. according to (Chiteka *et al.*, 1997): Genotypes with disease score 4-6 were considered as moderately resistant, 7 and above considered as susceptible based on the 1-9 disease scoring scale (Pande and Rao. 2001). Finally, disease severity scores were converted into percentage severity as follows.

Disease assessment was done systematically from central four rows of each plot starting from the first appearance of the disease symptoms

$$\text{Disease severity}(\%) = \frac{\text{Area of diseased tissue}}{\text{Total tissue area}}\mathrm{x}100$$

The severity grades were converted into percentage severity index (PSI) for analyses as indicated by Wheeler [14].

$$\mathrm{PSI} = \frac{\text{Sum of materials rating}}{\text{No of plants scored x maximum disease score on scale}}\mathrm{x}100$$

Area Under disease progress rate (AUDPC): It was also computed from PSI values for each plot as described by Campbell and Madden [15].

$$\mathrm{AUDPC} = \sum_{\mathrm{i=1}}^{\mathrm{n-1}} 0.5(\mathrm{Xi} + \mathrm{xi} + 1)(\mathrm{ti} + 1 - \mathrm{ti})$$

Where, n is the total number of plants disease assessed, t_i is the time (days after emergence) of the ith assessment in days from the first assessment date and x_i is the PSI of disease at the ith assessment. AUDPC was expressed in %-days because severity(x) is expressed in percent and time (t) in days

Disease progress rate: Infection rate (R) was calculated using the logistic model equation [16].

$$R = \frac{(Ln\,\frac{y}{1-y}) - (Ln\,\frac{yo}{1-yo})}{t_n - t_1}$$

Where: R is infection rate,
y_o is initial disease severity,
y is final disease severity and
t_1 and t_n are the first and the last dates on which disease was assessed.

2.6 Data Analyses

All the collected data during the study were subjected to the Analysis of Variance (ANOVA) using SAS version 9.1.3 computer software [17]. The least significant difference (LSD) test was used to compare the treatment means at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Early Leaf Spot Disease Incidence (ELSD)

"Incidence of groundnut early leaf spot (ELSDD) was assessed at 49, 56 and 63 days after planting (DAP) by counting the number of plants infected by ELSD and converted into percentage of total number of plant populations in the plot" [18]. At initial disease incidence assessment 49

DAP, only wheat straw mulching showed significant ($p \leq 0.05$) difference on groundnut ELSD incidence. However, the main effect *T. harzianum*, genotypes and their interaction effect did not show any significant ($p > 0.05$) difference on ELSD incidence. This result showed that there were no significant ($p > 0.05$) differences among groundnut genotypes and between *T. harzianum* inoculated and non- inoculated plots. Thus, the result indicated that application of *T. harzianum* as a biocontrol agent did not significantly influence the ELSD incidence at 49 DAP. ELSD incidence similarly appeared all over the tested genotypes as well as on *T. harzianum* inoculated and non-inoculated plots. This might to be happened due the pre maturing of the mulching materials because mulching at the initial stage might create favorable condition for the disease causing microorganisms and gradually mulching increases the soil temperature and can inhibited the diseases causing pathogenic organisms.

The main effect genotype at 56 and 63 DAP and wheat straw mulching at 63 DAP showed highly significant ($p \leq 0.01$) difference on ELSD incidence, whereas the main effect *T. harzianum*, wheat straw mulching and the interaction effect of genotypes by *T. harzianum* at 56 DAP and the interaction effect of genotypes by wheat straw mulching at 63 DAP showed significant ($p \leq 0.05$) difference on ELSD incidence.

Maximum 81.75% ELSD incidence at 56 DAP assessment was recorded on ICIAR19BT, followed by 80.56% on genotype ICGV00308. However, the lowest (47.33%) ELSD incidence was recorded for Werer-961, followed by 49.94% for Rama local. This result indicated that there was no significant difference between ICGV00308 and ICIAR19BT for the ELSD incidence at 56 DAP. Similarly, *T. harzianum* showed significant effect on ELSD incidence at 56 DAP. ELSD decreased from the highest (68.47%) in non-inoculated to 61.32% in *T. harzianum* inoculated plots. This showed that at 56 DAP assessment, *T. harzianum* significantly reduced disease incidence by 7.15% and, similarly, wheat straw mulch also significantly ($p \leq 0.05$) influenced the ELSD incidence at 56 DAP. Higher 70.48% ELSD incidence was recorded on non-mulched plots than on straw-mulched with (59.31%). Genotypes at both 56 and 63 DAP highly and significantly influenced the incidence of groundnut ELSD. The current finding agrees with the result of Chalker-Scott [19] who reported that “mulching helps in the nutrition of many beneficial organisms which competes the incoming pathogenic spores or sometimes release the chemicals for the inhibition of pathogens and leads to reduce the chances of disease occurrence”.

The interaction effect of genotypes * *T. harzianum* at 56 DAP and genotypes * wheat straw mulching at 63 DAP showed significant ($p \leq 0.05$) difference on ELSD incidence. At the final assessment date 63 DAP, the highest (96.90%) percentage mean incidence occurred in the treatment combination of Rama local without application of wheat straw mulching, followed by 96.10, 93.68 and 89.59% for the treatment combinations of ICIAR19BT*ML0, ICGV00308*ML0 and ICGV00308*ML1, respectively. The lowest values of 52.22 and 51.73% GELSD incidence at the final assessment were recorded for Werer-961 and Rama local genotypes treated by wheat straw mulching, respectively. Application of wheat straw mulching significantly reduced ELSD incidence by 45.17 and 27.80% in Rama local and Werer-961, respectively, as compared to the non-mulched plots of the respective genotype. This result is also in agreement with Downer et al. [20] who elaborated and discovered management of root rot disease through short- and long-term mulching effects.

3.2 Early Leaf Spot Diseases Severity(ELSDS)

At the fourth and fifth times (70 DAP and 77 DAP), highly significant ($p \leq 0.01$) difference was recorded in ELSDD severity among the genotypes and similarly at 77 DAP wheat straw mulching showed highly significant ($p \leq 0.01$) difference between mulched and non-mulched plots. However, significant ($p \leq 0.05$) difference was observed at 56 and 63 DAP among the genotypes. Likewise, during 49, 56, 63 and 77 DAP assessment, ELSD severity assessment showed significant ($p \leq 0.05$) difference between *T. harzianum* inoculated and non-inoculated genotypes. Significant ($p \leq 0.05$) difference was obtained between mulched and non-mulched plots at 56 DAP. Similar result was reported by Singh *et al.* [21] damping of disease on tomato seedling was significantly reduced on *Tricoderma spp*. inoculated seedlings as compared to the non-inoculated seedlings.

Table 1. Interaction effect of groundnut genotypes by wheat straw mulching on the management of ELSD disease incidence at the final assessment during 63 DAP at Rama during main cropping season in 2016

Variety*Straw mulch	Percentage of GELSD disease incidence during 63 DAS
ICGV00308*M1	89.59 (72.78)^{ab}
ICGV00308*Mo	93.68 (78.11)^{ab}
ICIAR19BT*MI	82.49 (66.69)^{b}
ICIAR19BT*Mo	96.10 (81.17)^{a}
Werer961*M1	52.22 (46.36)^{c}
Werer961*M0	80.02 (64.16)^{b}
Rama local*M1	51.73 (46.44)^{c}
Rama local*Mo	96.90 (83.19)^{a}
LSD (0.05)	13.3
CV (%)	12.86

**=Interaction, LSD = Least significant difference, CV = Coefficient of variation, ML1 = Wheat straw mulched and ML0 = non-wheat straw mulched. Means followed by the same letter(s) in the same column are not significantly different from each other at 5% probability level. Numbers within the parentheses are transformed means for the percentage of GELSD disease incidence at the final assessment during 63 DAP*

Factors did not interact to significantly ($p>0.05$) affect ELSD severity during 49 DAP. At the second severity assessment, the highest 6.15% severity was recorded in Rama local, followed by 5.32% for ICIAR19BT and the lowest 4.02% severity was recorded for ICGV00308, followed by 4.32% for Werer-961. At the third and fourth ELSD severity assessment, the highest mean severity score 10.97 and 17.86% were recorded on ICIAR19BT and Rama local, respectively, followed by 10.92% on Rama local and 15.84% on ICIAR19BT. In the final severity assessment, the highest 26.26% ELSD score was recorded on Rama local, followed by 22.75% for ICIAR19BT and the lowest 15.08% severity was recorded from ICGV00308, followed by 16.05% in Werer-961. ELSD severity ranged from the highest 26.26% in Rama local to 15.08% in ICGV00308. Such variation might result from the complex interaction of the genetic by environmental factors [22].

During 49, 56, 63 and 77 DAP ELSDD severity assessment, the highest 2.31, 5.77, 10.42 and 21.07% mean severities were recorded on the non-*T. harzianum*-inoculated plots as compared to the values of 1.66, 4.14, 7.87 and 18.99% recorded from *T.harzianum* inoculated, respectively. Wheat straw mulch highly and significantly ($p\leq0.01$) decreased ELSDD severity during the final 77 DAP assessment periods as compared to the non-mulched plots with the highest disease severity of 21.91% as compared to the lowest severity of 18.15% in straw mulched plots. On the other hand, mulch significantly ($p\leq0.05$) lowered ELSDD severity at second 56 DAP assessment from 5.54% for non-mulched plots to 4.37% for straw-mulched plots. The highest 5.54%) severity level was observed on non-mulched plots as compared to 4.37% in straw mulched. Application of wheat straw mulching at a rate of 12 t ha^{-1} reduced ELSDD severity by 21.11% at 56 DAP. Thus, wheat straw mulching and *T. harzianum* inoculation suppressed ELSD severity by 17.16 and 9.87%, respectively.

This result is in agreement with findings of Wagle P. *et al.* [12] who reported that application of *lantana camara* and rice husk mulching significantly reduced disease severity of late leaf spot diseases of groundnut as compared to the non-mulched plots.

ICIAR19BT and Rama local were severely damaged by GELS as compared to ICGV00308 and Werer-961. The severity level in Rama local increased starting from the fourth (70 DAP) assessment (Fig. 1), whereas the ELSD severity for ICIAR19BT was similar during all the assessment periods. Kahsay [23] reported that the genotype Werer-961 with 22.8% late leaf spot severity was considered as susceptible compared to Sedi and NC-343 with 22.2 and 15.4% GELS, respectively.

3.3 Leaf Spot Disease Progress Rate (ELSDPR)

The rate of foliar disease development was quantified by repeated assessments of the percentage of leaf and stem area affected by early leaf spot disease in each plot started in 49DAP during the first disease onset. Logistic, ln [(Y/1-Y)], and Gompertz, -ln [-ln(Y)] [24] models were compared for estimation of disease progression parameters from each treatment [25].

Table 2. Effect of groundnut genotypes, *T. harzianum* and wheat straw mulching on groundnut ELS damage severity at Rama during main cropping season in 2016

Factors	Level of groundnut early leaf spot disease severity at different days after planting					AUDPC	DPR
	49 DAP	56 DAP	63 DAP	70 DAP	77 DAP		
Groundnut Genotype:							
Werer961	2.24 (1.62)a	4.32 (2.19)b	7.95 (2.89)b	12.67 (3.60)b	16.05 (4.04)c	100.51c	0.0712c
ICGV00308	1.85 (1.44)a	4.02 (2.09)b	6.76 (2.65)b	11.51 (3.45) b	15.08 (3.93)c	93.06c	0.0932a
ICIAR19BT	2.08 (1.52)a	5.32 (2.37)ab	10.97 (3.37)a	15.84 (4.03)a	22.75 (4.81)b	135.03b	0.0816b
Rama Local	1.77 (1.44)a	6.15 (2.53)a	10.92 (3.34)a	17.86 (4.27)a	26.26 (5.16)a	154.43a	0.0675c
LSD (0.05)	Ns	0.32	0.32	0.32	0.23	12.99	0.01
***T. harzianum*:**							
T. harzianum inoculated	1.66 (1.39)b	4.14 (2.12)b	7.87 (2.84)b	13.96 (3.77)a	18.99 (4.37)b	115.36b	0.0773a
T. harzianum non inoculated	2.31 (1.62)a	5.77 (2.47)a	10.42 (3.27)a	14.98 (3.90)a	21.07 (4.60)a	126.16a	0.0795a
LSD (0.05)	0.24	0.23	0.22	NS	0.16	9.18	0.0071
Wheat straw mulch:							
Mulched	1.69 (1.40)a	4.37 (2.16)b	8.83 (3.00)a	13.76 (3.74)a	18.15 (4.27)b	111.69b	0.0779a
Non mulched	2.27 (1.61)a	5.54 (2.43) a	9.47 (3.11)a	15.18 (3.94)a	21.91 (4.70)a	129.83a	0.0789a
LSD (0.05)	**NS**	**0.23**	**NS**	**NS**	**0.16**	**9.18**	**0.0071**
CV (%)	**27.76**	**17.18**	**12.59**	**10.04**	**6.29**	**12.91**	**15.36**

LSD = Least significant difference, CV = Coefficient of variation (%).

Means followed by the same letter(s) in the same column are not significantly different from each other at 5% probability level. Numbers within the parentheses are transformed means for the groundnut early leaf spot (GELS) severity

No significant (p>0.05) difference was shown due to the main effect of *T. harzianum*, wheat straw mulching and their interaction effect on groundnut early leaf spot disease progress rate. However, highly significant (p≤0.01) variation was obtained among main effects of groundnut genotypes on groundnut early leaf spot disease progress rate. The mean progress rate of Rama local, ICIAR19BT, Werer-961, and ICGV00308 genotypes were 0.0932, 0.0816, 0.0712 and 0.0675 units/day, respectively. The highest 0.0932 units'/day disease progress rate was recorded on Rama local, followed by 0.0816 units/day from ICIAR19BT, while the lowest disease progress rate was obtained from ICGV00308 and Werer-961 genotypes with a values of 0.0675 and 0.0712 units/day, respectively. This indicated that the disease progress rate on Rama local was faster than the other genotypes by 38.07, 30.89 and 14.21% of ICGV00308, Werer-961 and ICIAR19BT, respectively. The variation in disease progress rate of groundnut early leaf spot among the genotypes might be due to the genetic variability of the genotypes to react against the pathogen resistance level.

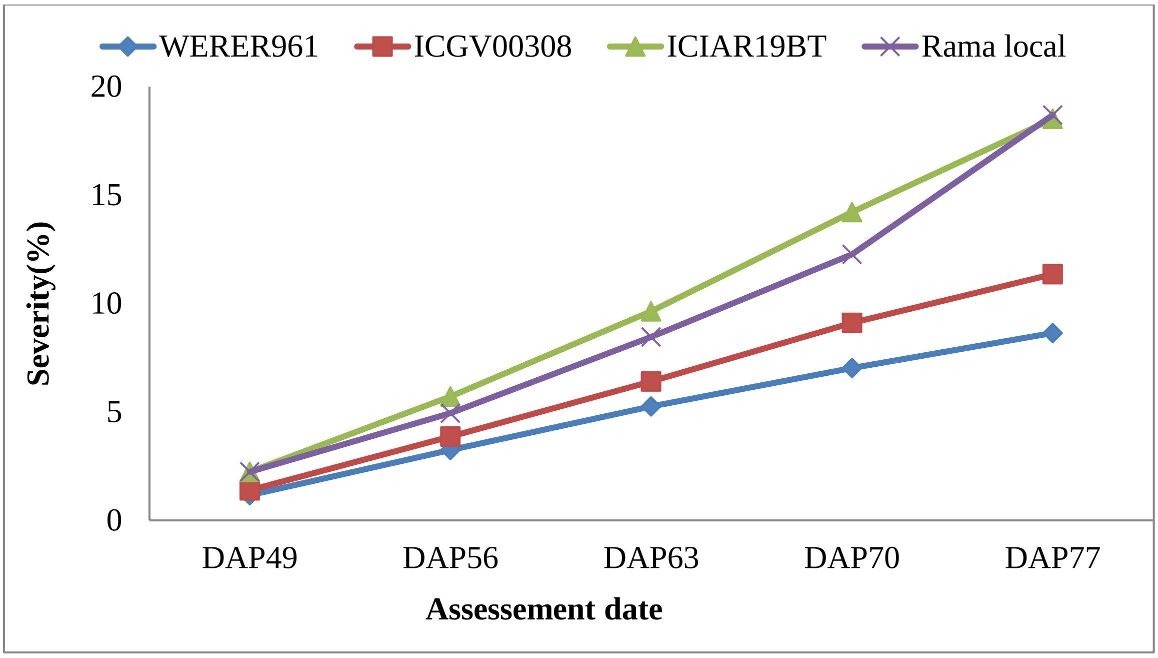
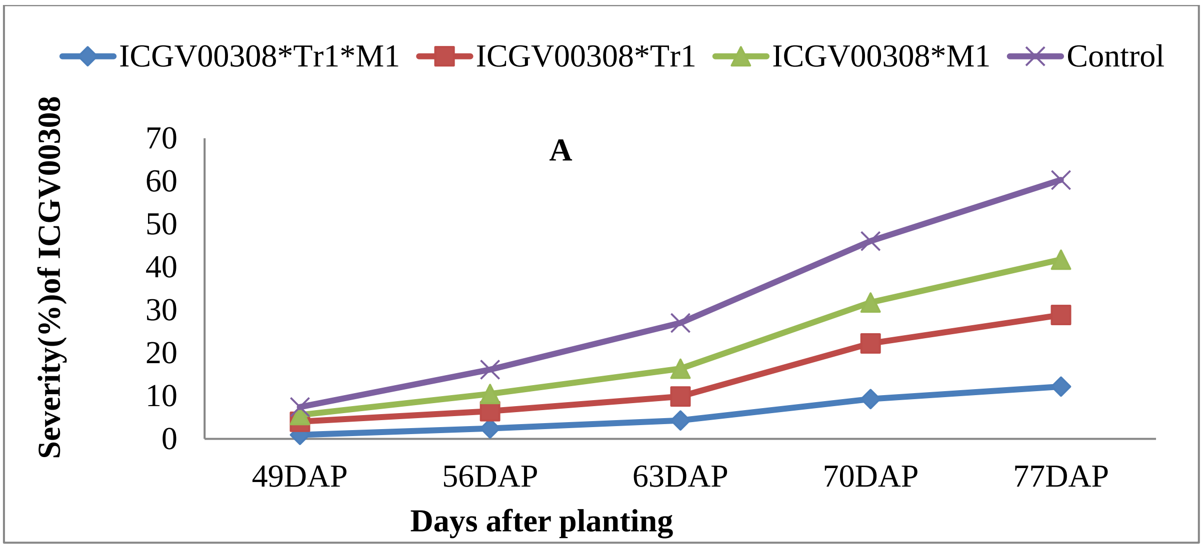


Fig. 2. GELS disease progress on different groundnut genotypes at Rama during main cropping season in 2016



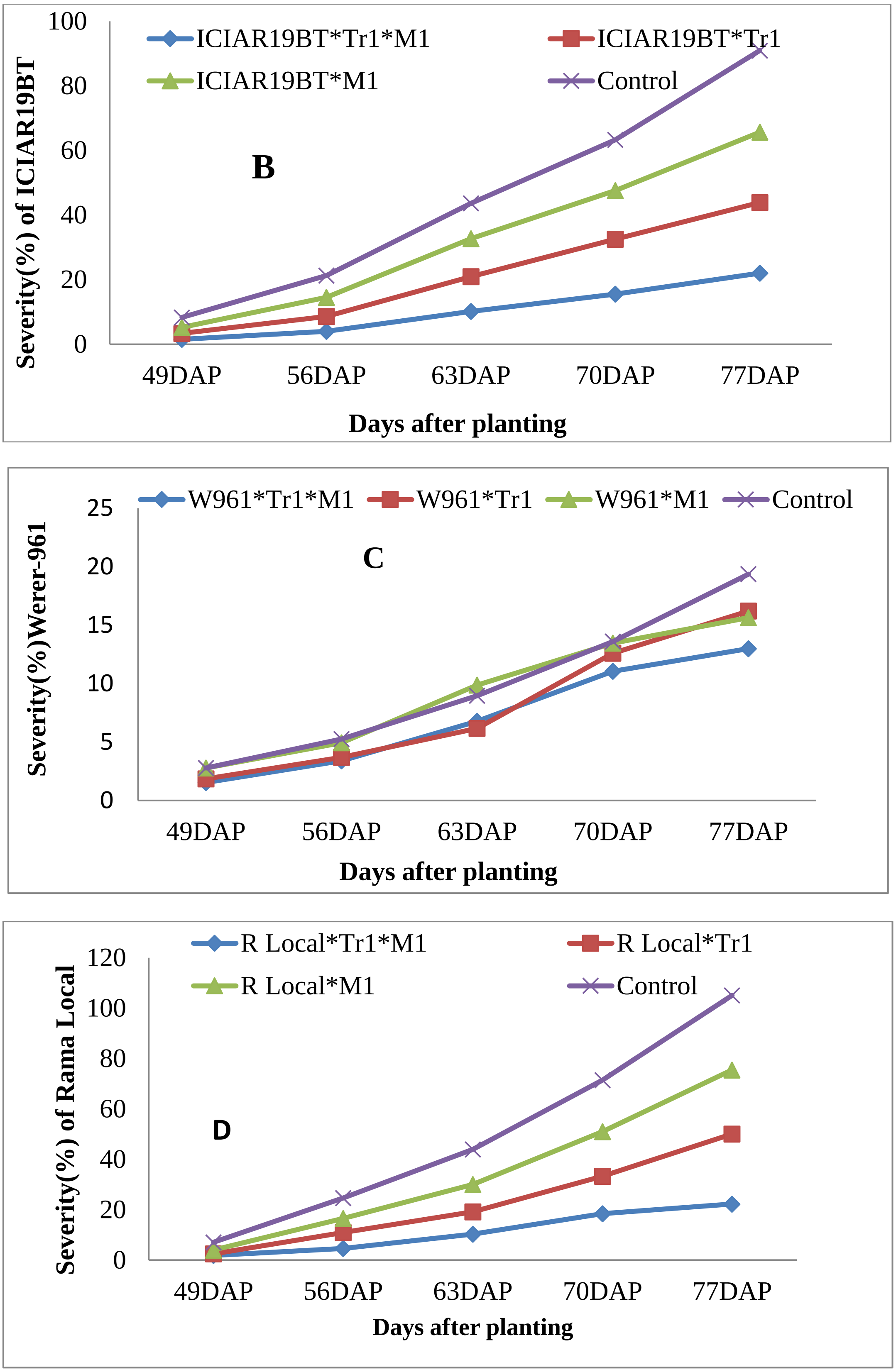


Fig. 3. GELS severity on each groundnut varieties in different treatments combinations at Rama during cropping season in 2016

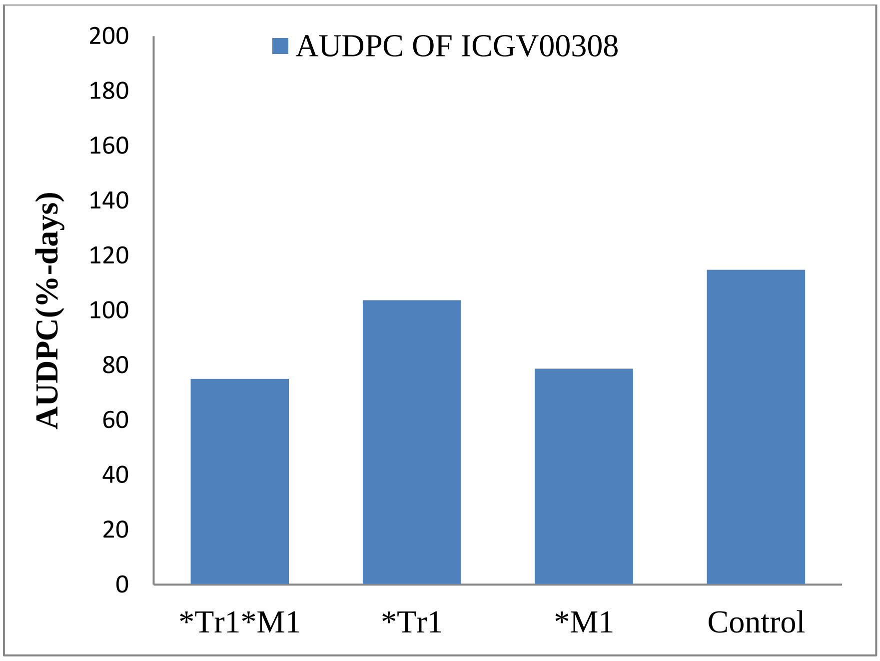
3.4 Area Under Disease Progress Curve (AUDPC)

Area under disease progress curve (AUDPC) is a very convenient summary of plant disease epidemics that incorporates initial disease severity, the rate parameter and the duration of the epidemic, which determines final disease severity (Madden *et al*., 2008).

AUDPC was computed from PSI values for each plot as described by Campbell and Madden (1990).

AUDPC showed highly significant ($p \le 0.01$) difference among the main effects of groundnut genotypes. Similarly, both *T. harzianum* inoculation and wheat straw mulching showed significant ($p \le 0.05$) difference between the inoculated and non-inoculated treatments and between mulched and non-mulched plots. The highest 154.43%-days AUDPC was recorded from Rama local variety, followed by ICIAR19BT with AUDPC values of 135.03%-days and the lowest 93.06%-day AUDPC value was recorded on ICGV00308, followed by AUDPC 100.51%-day value for Werer-961 genotype. Werer-961 and ICGV00308 were not significantly different from each other in AUDPC mean values, whereas these two groundnut genotypes showed higher significant reduction in AUDPC%-days than both ICIAR19BT and Rama local. The AUDPC values for ICGV00308 and Werer-961 were highly and significantly ($p \le 0.01$) different from the other two genotypes. There was highly significant difference between ICIAR19BT and Rama local in AUDPC values with mean values of 135.03 and 154.43% -days, respectively (Table 2).

Both *T. harzianum*-inoculated and wheat straw-mulched with AUDPC value of 115.36%-day and AUDPC 111.69%-days, respectively, were significantly ($p \le 0.05$) lower than the non-inoculated and non-mulched with AUDPC values of 126.16%-days and 129.83%-days, respectively. *T. harzianum* inoculation and wheat straw mulching reduced the AUDPC values by 10.8%-days and 18.14%-days as compared to the values from non-inoculated and non-mulched plots. However, the main effect of genotypes, *T. harzianum* and wheat straw mulches did not interact and did not significantly influence AUDPC%-days. All the factors showed separate effects on the management of GELS disease severity. This study indicated that both *T. harzianum* inoculated as biocontrol agent and wheat straw mulches reduced AUDPC values significantly as compared to the non-*T. harzianum*-inoculated and mulched-plots, respectively.



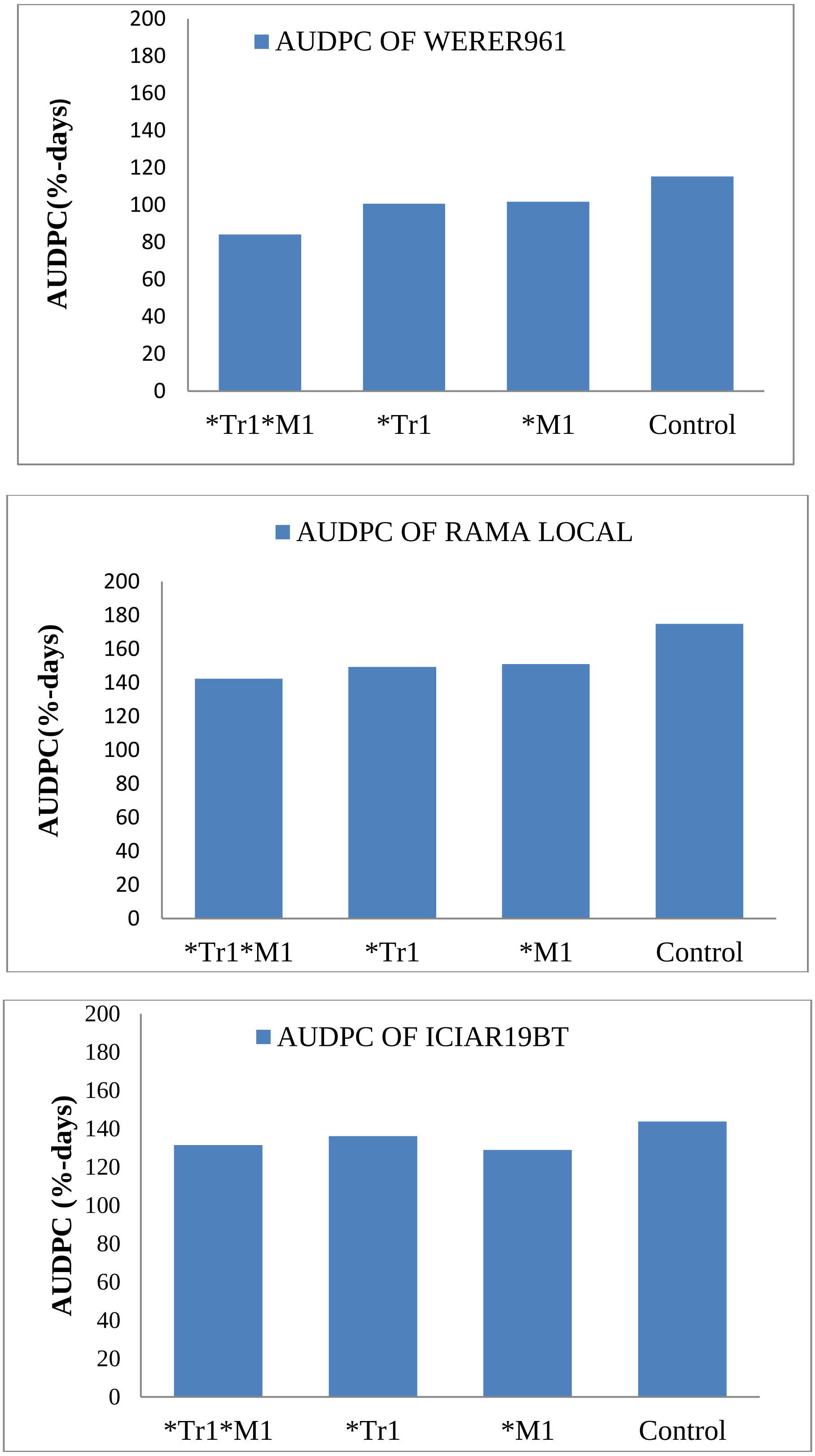


Fig. 4. AUDPC values of each groundnut variety at Rama during 2016 main cropping season in 2016

**Tr1*M1= genotype plus Tricoderma inoculation and mulched Tr1=Tricoderma inoculated, M1=Mulche*

4. CONCLUSIONS AND RECOMMENDATIONS

Rama is one of the lowland areas of Tigray, agro-ecologically ideal for groundnut production. Despite the fact that groundnut is the major source of income it is vulnerable to early leaf spot diseases. There was no reported researches conducted related to management of groundnut early leaf spot diseases in the study area. Therefore, a field experiment was carried out at Rama during 2016/2017 main cropping season to evaluate the integrated management of groundnut early leaf spot diseases using groundnut genotypes, *T. harzianum* BD-13 and wheat straw mulch. Highly significant ($p \leq 0.01$) difference was recorded on ELSD severity among genotypes and similarly at 77DAP mulching was also showed highly ($p \leq 0.01$) significant difference between mulched and non-mulched plots.

At all stages of severity assessment, the highest 2.31, 5.77, 10.42 and 21.07% mean severities were recorded on the non-*T. harzianum*-inoculated plots as compared to the values of 1.66, 4.14, 7.87 and 18.99% recorded from *T.harzianum* inoculated, respectively. Wheat straw mulch highly and significantly ($p \leq 0.01$) decreased ELSD severity during the final 77 DAP assessment periods as compared to the non-mulched plots with the highest disease severity of 21.91% as compared to the lowest severity of 18.15% in straw mulched plots. The highest 5.54%) severity level was observed on non-mulched plots as compared to 4.37% in straw mulched. Application of wheat straw mulching at a rate of 12 t ha^{-1} reduced ELSD severity by 21.11% at 56 DAP. Thus, wheat straw mulching and *T. harzianum* inoculation suppressed ELSD severity by 17.16 and 9.87%, respectively.

Therefore, the current research findings indicated that seed treatment with *T. harzianum* and application of wheat straw mulch 12t ha^{-1} significantly reduced early leaf spot diseases of groundnut due to retention of better soil moisture than non-mulched plots at maturity and at harvesting. Therefore, application of locally available mulching materials at a rate of 12 t ha^{-1} and inoculation of bio pesticide (*T. harizanium*) reduced the damage level of early leaf spot diseases due suppression power of treatments to diseases causal pathogens of early leaf spot. It is suggested that further extensive research should be conducted to verify the current research findings in the study area and other areas having similar agro-ecological conditions to come up with a final and conclusive recommendation for successful groundnut early leaf spot diseases management and sustainable groundnut production.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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