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Evaluation of biocontrol agent and wheat straw mulch on yield and yield components of groundnut (*Arachis hypogaea* L.) genotypes in Central Tigray, Northern Ethiopia

Nahom Weldu[1*] and Mashilla Dejene[2]

[1]Plant Pathology Assistant Researcher, Axum Agricultural Research Center, Tigray Agricultural Research Institute, P. O. Box 230, Axum, Ethiopia.
[2]Plant Protection Program, School of Plant Sciences, Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia.

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Groundnut (*Arachis hypogaea* L.) is the 13 and 4th most important food and oil seed crops in the world. Groundnut is a source of vitamin E. However, due to low soil fertility, drought stress, fungal diseases and lack of appropriate management, production has been constrained qualitatively and quantitatively in the study area. *Trichoderma harzianum* and wheat straw mulch could increase the growth performance of groundnut and soil moisture content at maturity and near harvest to overcome terminal drought stress. Therefore, a field experiment was conducted in Rama, Central Zone of Tigray, Northern Ethiopia, to evaluate the effects of wheat straw mulch and *T. harzianum* on yield and yield components of groundnut genotypes (ICGV00308, ICIAR19BT, Werer-961 and Rama local). The treatments were arranged in factorial randomized complete block design (RCBD) with three replications. Results showed that groundnut genotypes, *T. harzianum* and wheat straw mulch highly significantly ($p<0.01$) affected plant height with the tallest plant height 25.40 cm was recorded from Rama local while the shortest 23.15 cm from ICGV00308. The highest (37.06) mean number of seeds per plant was obtained from ICGV00308 treated with wheat straw mulch, followed by 32.05 and 32.91 from ICIAR19BT treated with wheat straw mulch and Rama local treated with *T. harzianum* and wheat straw mulch, respectively. Higher 28.44 and 24.97 numbers of pods per plant were recorded on ICIAR19BT and ICGV00308 genotypes, respectively that were mulched with wheat straw. ICGV00308 genotype produced the highest seed yield per plant (14.69 g), hundred seed weight (51.00 g) and total seed yield (1.00 t ha^{-1}) as compared to the other genotypes.

Key words: Groundnut genotype, *Trichoderma harzianum*, wheat straw mulch.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), is an annual legume crop originated from South America, and gradually

*Corresponding author. E-mail: nahomweldu373@yahoo.com. Tel: +251-(0) 9 14 18 99 57.

became the most popular and universal crop and it is currently cultivated over 107 countries in six continents of the world. According to Wiess (2000) 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 (USDA, 2017). The major groundnut growing countries of the world are India (20.92%), China (18.75%) and Nigeria (18.70%) and Sudan (7.10%) (USDA, 2017). Its cultivation is mostly confined to the tropical, sub-tropical and warm temperate regions of the world ranging from 40°N to 40°S (IOPEPC, 2017).

Italian explorers introduced groundnut from Eritrea to Ethiopia through Hararghe in 1920's and it is relatively a new crop to Ethiopia (Daniel, 2009). Its production accounted for about 75255.73 ha with a corresponding gross annual production of 115, 150.04 metric tons in 2015/2016 cropping season (CSA, 2017). 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 practice, the potential of the crop can reach up to 3.0 t ha^{-1} (CSA, 2009). Groundnut is widely growing in eastern part of the country, that is Hararghe (Daniel, 2009). The crop is also produced in Tanqua Abergelle and Mereb Leke in Central and some districts in northwestern zone of Tigray (Dereje et al., 2012; Gebreselassie et al., 2014; Brhane et al., 2016).

The crop is 13th most important food and the 4th most important oilseed crop of the world. Its kernel contains 40 to 50% oil, 20 to 50% protein and 10 to 20% carbohydrates and the seeds are also source of vitamin E, niacin, riboflavin, thiamine and rich source of some minerals, namely calcium, magnesium, phosphorus, potassium, iron and zinc (Surendranatha et al., 2011).

In spite of its multipurpose function crop, groundnut production is constrained both in quantity and quality by several biotic, abiotic and socio-economic factors. The biotic factors are associated with unique plant character of groundnut, where flowers are formed and fertilized above the soil surface, but the subsequent fruit development takes place under the soil. This unusual characteristic exposes the crop to different soil borne fungal pathogens. Due to this character, the pod is therefore in profound close contact with many soil microorganisms.

Rama is one of the lowland areas in 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} that is much lower than the national average of 1.53 t ha^{-1} (CSA, 2017). Lower productivity is mainly due to biotic and abiotic factors, such as poor soil fertility, prevalence of soil borne fungal diseases, occurrence of frequent drought stress, lack of appropriate agronomic technologies, low awareness of the producers towards aflatoxigenic fungi and aflatoxin contaminations, limited access to resistant/tolerant varieties and low integrated disease management practices (Kahsay and Mewael, 2014). Dereje et al. (2012) reported the presence of *Aspergillus flavus* and *Aspergillus niger* in the study area (Rama) with seed infection level of 41.5 and 12.3% by *A. flavus* and *A. niger*, respectively, and aflatoxin B_1 contamination ranged from 0.1 to 397.8 ppb. Thus, the detected aflatoxin B_1 value is much higher than the standard set for the European Union (5 ppb), FAO/WHO (15 ppb) and USA (20 ppb).

Therefore, the present research work focused on reduction of the inocula of soil borne fungi, specifically the pathogens *Aspergillus* species in the soil to reducethe yield loss and fungal infection level through integrated management using different groundnut genotypes, natural antagonistic fungal strain *Trichoderma harzianum* isolate BD-13 and wheat straw mulch to retain soil moisture and overcome terminal drought stress and stabilize soil temperature. Hence, the study was carried out with the specific objective of assessing the effects of application of biocontrol agent *T. harzianum* and wheat straw mulch singly or in integration on yield and yield components of groundnut genotypes.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Rama; Mereb-Leke District, Central zone of Tigray, northern Ethiopia, during the 2016 main cropping season. Rama is located at 14°22'25" N latitude and 038°47'32" E longitude at an elevation of 1390 meters above sea level (Figure 1). The area 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 the 2016 growing season was 33.9and 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 2016 main cropping season was 586.9 mm (NMA, 2017). 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.

Experimental materials

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 RUFORUM Groundnut Project. Werer-961 was released from Werer Agricultural Research Center in 2004 and the other two genotypes ICGV00308 and ICIAR19BT were introduced from ICRISAT.

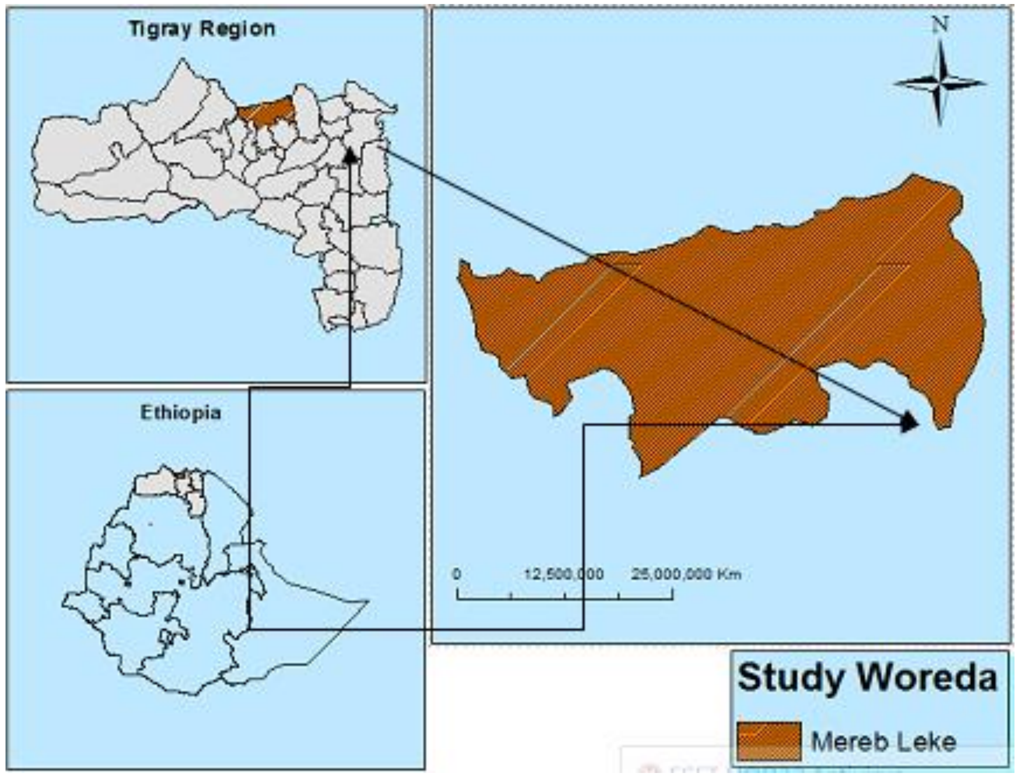

Figure 1. Map of the study area, Mereb-Leke District in Central Zone of Tigray, Northern Ethiopia.

T. harzianum

T. harzianum isolate 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.

Preparation of T. harzianum inoculums and inoculation techniques

Culture of *T. harzianum* isolate 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 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. 70 seeds of groundnut per plot were inoculated in 50 ml spores suspension by seed priming techniques (soaking seeds in the spores suspension) for 3 h just before planting.

The inoculated seeds (Tr_1) 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* isolate BD-13 prepared in a similar procedure with the aforementioned paragraph was sprayed to 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 milliliter per plot.

Wheat straw mulching material

Wheat straw was used as a source of mulching to increase the soil moisture holding capacity and to 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 *Aspergillus* species living in the soil. 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.

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 (Tr_1 and Tr0) and two wheat straw mulching with (ML_1) and without mulching (ML0) (Table 2). 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 (2.4 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. Distances (1 and 1.5 m) were maintained among plots and between adjacent replications, respectively.

Management of experimental field

Groundnut seeds were sown in rows on well-prepared land at Rama, Central Tigray, Northern Ethiopia on 13/07/2016. 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. Diammonium 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^{-1} P_2O_5) for all plots at the time of sowing of the groundnut seeds. Similarly, all other management practices (hand weeding and hoeing) were done manually to all plots uniformly.

Data collection

Data on soil moisture content

Soil moisture content was measured at harvest by taking undisturbed soil samples using the core sampler at a depth of 0 to 40 cm from each plot to see the effect of wheat straw mulch on soil moisture conservation capability and its indirect effect on the management of aflatoxin contamination level. Comparison among different treatments was performed to determine the capacity of mulching for soil moisture retention, management of *Aspergillus* species and its effect on groundnut yield improvement as well as suppression of the percentage seed infection by *Aspergillus* species.

Phonological and growth parameters' data

Days to 50% emergence is the number of days from sowing to the date on which 50% seedlings in each plot emerged was recorded and days to 50% flowering refers to the number of days from emergence to the date on which 50% of the plants in each plot had at least shown the first flowers. Similarly, Days to 90% physiological maturity is the number of days from emergence to the date at which 90% of the plants in each plot reached physiological maturity; pods were considered as matured when the kernels were fully developed, testa assuming the varietal color, the inside wall of pods become dark to brown and the pods were strong when pulling by fingers or when squeezed between the thumb and the index finger. Plant height measurement was done by measuring the height (in centimeters) of twelve randomly taken plants from the middle four harvestable rows from the ground level to the uppermost point and measurements were taken with a ruler. The measurements were averaged to get the plant height.

Yield and yield components

Number of pods per plant, number of seeds per pod and number of seeds per plant were computed from counts carried out on twelve randomly taken plants from the middle four harvested rows of each plot at harvest and average number of seeds per plant was calculated. Similarly, seed yield per plant (g $plant^{-1}$) was computed from twelve randomly taken plants from the central harvested four rows of each plot and average per plant was calculated. Seed yield (ton ha^{-1}) and hundred seed weight was computed from data collected in plot wise. These parameters were measured after harvesting, threshing and weighing.

Data analyses

All data collected during the study were subjected to analysis of variance (ANOVA) using SAS version 9.1.3 computer software (SAS Institute Inc., 2004). The least significant difference (LSD) test was used to compare the treatment means at 5% probability level.

RESULTS AND DISCUSSION

Effect of wheat straw mulch on residual soil moisture content at harvest

Wheat straw mulch highly and significantly ($p \leq 0.01$) influenced the soil moisture content at harvest. However, the main effect of groundnut genotypes, *T. harzianum* and their interaction effect did not show significant difference on the soil moisture content at harvest.

Significantly higher soil moisture content (24.64%) was recorded on wheat straw mulched plots as compared to 11.85% in the non-mulched plots. Application of wheat straw mulching on the groundnut plots increased soil moisture content at harvest by 12.79% as compared to the bare soil. Mulching protects the soil from direct sunshine, wind blowing, runoff and decreases the rate of evaporation (Bhardwaj, 2013). Similarly, wheat straw mulch increases the infiltration rate as straw holds and retains soil moisture for a longer period.

Straw mulch significantly affected yield and yield related groundnut parameters, like plant height, days to physiological maturity, number of pods per plant, number of seeds per plant, seed yield per plant and total seed yield, whereas parameters, like the number of seeds per pod and hundred seed weight, were not significantly influenced by the wheat straw mulching.

Ghosh et al. (2003) reported that soils covered with wheat straw mulch and black polythene retained higher amount of available soil moisture at 0 to 10 cm soil depth continuously through the crop growth period than the non-mulched plots. Khan and Chatta (2005) also reported that straw conserved higher soil moisture up to 55% more than non-mulched plots. Application of wheat straw mulch at a rate of 6730 kg ha^{-1} increased the available soil moisture significantly up to 1.5 m soil depth as compared to the bare soil (Khan and Chatta, 2005). The present result is in agreement with the observation of Bhatt et al. (2004) who reported that mulching significantly enhanced soil moisture content with maximum (17.0%) soil moisture content at harvest in mulched plot as compared to non-mulched soil (14.0%).

Effect of *T. harzianum* inoculation and wheat straw mulch on phenology and growth characters of groundnut genotypes

Days to 50% emergence and 50% flowering

There was no significant ($p > 0.05$) difference due to the main effects and their interaction effects on days to 50% emergence and days to 50% flowering. The absence of significant difference to 50% emergence and 50% flowering might be attributed due to the presence of sufficient soil moisture at earlier growth stages of the crop until flowering period for all treatment combinations. Thus, there might not be critical soil moisture difference as a result of the application of wheat straw mulch until flowering period. Genotypes did not also show significant difference on days to 50% seed emergence and flowering.

Plant height

Three-way interaction effect of genotypes, *T. harzianum* and straw mulch showed significant ($p \leq 0.05$) difference on plant height. The tallest plant heights of 28.78 and 28.19 cm were recorded in IRTr1ML1 and RLTr1ML1 treatment combinations, while the shortest 19.25, 22.17 and 22.39 cm were observed on IVTr0ML0, WTr0ML0 and IRTr0ML0 treatment combinations, respectively. The significant increase in plant height in the straw mulched and *Trichoderma* treated plots might be due to improved soil physical conditions, such as total N, available P, CEC and O.M and more soil water conservation available to the crop treated with wheat straw mulch than in the control plots. In line with this result, Pervez et al. (2009) obtained the tallest plant height and highest seed yields of from wheat straw mulched plots as compared to plants from the non-mulched plots.

Soils mulched with straw can decrease the rate of evaporation, run-off, soil erosion and can increase the rate of water infiltration because straw mulch holds or retains soil moisture available around the root zone for a longer period than in soil without mulching. Mulches may create sustainable and available soil moisture at the root zone throughout the whole growth period and this may lead to better growth performance and taller plants on mulched plots than on the non-mulched plots. In agreement with this result, Oberson et al. (2006) reported that rice straw mulch boosts soil biological activities, preserves soil organic matter and improves soil nutrients that, in turn, contribute to plant growth.

It was found that the biocontrol agent *T. harzianum* resulted in a highly significant ($p \leq 0.01$) difference on the plant height of groundnut. *T. harzianum* inoculated plants were 11.04% taller than non-inoculated plants. Thus, the difference in plant height between *T. harzianum* inoculated and non-inoculated might have resulted due to the bio-fertilization and growth stimulating nature of *T. harzianum*. Harman (2004) reviewed that some strains of *T. harzianum* are usually associated with plant roots, root ecosystems and, thereby, can enhance the growth performance of crops when inoculated with *Trichoderma* and described *Trichoderma* strains as plant symbiosis and opportunistic virulent organisms that are able to colonize plant roots by mechanisms similar to rhizobial bacteria.

Days to 90% physiological maturity

The main effect of wheat straw mulching had highly significant ($p \leq 0.01$) influence on days to 90% physiological maturity of groundnut. A significant ($p \leq 0.05$) difference was also observed in days to 90% physiological maturity among the tested groundnut genotypes. The earliness in days to 90% physiological maturity was observed in ICIAR19BT, Rama local and ICGV00308 with 96.92, 97.00 and 98.25 days, respectively, required to reach 90% physiological maturity after planting. Prolonged physiological maturity of 101 days was recorded in Werer-961 to reach 90% physiological maturity. Among the tested four groundnut genotypes, Werer-961 was found to be a late maturing variety with a mean value of 101 days as compared to the other tested genotypes and Rama local. However, there was no significant difference in days to 90% physiological maturity between *T. harzianum* inoculated and non-inoculated plots and interaction effect of the main effects.

The main effect of wheat straw mulch significantly ($p \leq 0.05$) affected days to 90% physiological maturity and prolonged maturity (101 days) was observed on straw-mulched plots as compared to the non-mulched plots that required shorter (95.58 days) to reach 90% physiological maturity. Application of wheat straw mulch significantly extended the number of days required to reach physiological maturity. Days to 90% physiological maturity of groundnut plants grown on mulched plots were exceeded by 5.42 days as compared to non-mulched plots (Table 1). This prolonged physiological maturity period (days) in the mulched plots might be attributed to the availability of enough soil moisture content. This indicated that application of straw mulch on groundnut planted plots at a rate of 12 t ha^{-1} avoided forced maturity and terminal moisture stress. Moisture stress was one of the most frequently occurring problems of groundnut production in the study area. Mulching retained soil moisture, protected the soil from direct

Table 1. Main effect of groundnut genotypes, *T. harzianum* and wheat straw mulch on groundnut plant height, days to 90% physiological maturity and number of pods per plant at Rama during 2016 main cropping season.

Factor	Plant height (cm)	Days to 90% physiological maturity (days)	Number of pods per plant
Groundnut genotypes			
Werer-961	24.86[a]	101[a]	19.66[ab]
ICGV00308	23.15[b]	98.25[b]	20.97[a]
ICIAR19BT	24.85[a]	96.92[b]	22.44[a]
Rama local	25.40[a]	97.00[b]	16.63[b]
LSD (0.05)	1.42	1.80	3.42
T. harzianum			
Inoculated	25.96[a]	98.50[a]	19.95[a]
Non inoculated	23.38[b]	98.08[a]	19.90[a]
LSD (0.05)	1.00	Ns	Ns
Wheat straw mulching			
Mulched	26.21[a]	101.00[a]	21.50[a]
Non mulched	23.13[b]	95.58[b]	18.35[b]
LSD (0.05)	1.00	1.27	2.41
CV (%)	8.91	2.20	20.59

LSD: Least significant difference, CV: coefficient of variation. Means followed by the same small letter(s) in the same column are not significantly different from each other at 5% probability level.

Table 2. Interaction effects among groundnut genotypes (G), *T. harzianum* (Tr) and wheat straw mulch (ML) on number of seeds per plant at Rama in 2016 main cropping season.

Treatment interactions	Mean number of seeds per plant
ICGV00308*Tr1*ML1	26.95[abcd]
ICGV00308*Tr1*ML0	28.19[abc]
ICGV00308*Tr0*ML1	37.06[a]
ICGV00308*Tr0*ML0	22.47[bcd]
ICIAR19BT*Tr1*ML1	29.89[abc]
ICIAR19BT*Tr1*ML0	21.89[bcd]
ICIAR19BT*Tr0*ML1	32.05[ab]
ICIAR19BT*Tr0*ML0	19.14[cd]
Were961*Tr1*ML1	25.72[abcd]
Were961*Tr1*ML0	18.33[cd]
Were961*Tr0*ML1	25.61[abcd]
Were961*Tr0*ML0	18.53[cd]
Rama local*Tr1*ML1	32.91[ab]
Rama local*Tr1*ML0	23.58[bcd]
Rama local*Tr0*ML1	15.47[d]
Rama local*Tr0*ML0	24.47[bcd]
LSD (0.05)	11.58
CV (%)	27.67

*= interaction, LSD: Least significant difference, CV: coefficient of variation, Tr1: with *T. harzianum*; Tr0: without *T. harzianum*, Ml1: with wheat straw mulching, and ML0: without wheat straw mulching. Means followed by the same letter(s) in the same column are not significantly different from each other at 5% probability level.

sunlight and consequently decreased the rate of evaporation. On the other hand, mulching might decrease immediate deep percolation of rainwater and increased soil moisture retention capacity. Due to this reason, plants grown on mulched plots had high probability of obtaining the required available amount of soil moisture during their late maturity stage and could mature slowly. This research result is in accordance with the finding of another researcher (Anonymous, 2007) who reported that straw mulches with a thickness of 3.81 cm reduced the rate of evaporation by 35% as compared to bare soil.

Effect of *T. harzianum* and wheat straw mulching on yield components and yield of groundnut genotypes

Number of pods per plant

Number of pods per plant was significantly ($p \leq 0.05$) influenced by the main effects of genotypes and wheat straw mulching. However, the main effect *T. harzianum* and the interaction effect of the three-factors (groundnut genotypes, bio-inoculant *T. harzianum* and straw mulches) were not significant on the number of pods per plant of groundnut. The highest number of pods per plant (22.44) was recorded by the genotype ICIAR19BTwhile the lowest number (16.63) was recorded by Rama local ((Table 1). Here, gives the possible reasons for the result and compare and contrast with similar studies. Straw mulched plots gave significantly higher number of pods per plant (21.50 g) than the non-mulching. The application of wheat straw mulch increased the number of pods per plant by 17.17% over the bare soil plots (Table 1). The increase in number of pods per plant with the application of wheat straw mulch might be due to the improvement of available soil moisture, plant nutrients and favourable soil temperature created throughout the crop growth period. The current result corroborates with the observation of Ghosh et al. (2006) who reported that straw mulch produced more pods, that is, 17 to 24% higher pod which crop than polyethylene mulch and no mulch due to the favourable soil moisture and soil temperature from straw mulch.

Similarly, Awal et al. (2016) stated that the important pea (give scientific name) yield contributing parameters, like number of pods per plant, number of seeds per pod, seed weight per plant and hundred seed weight, were significantly increased in mulched-plots as compared to non-mulched plots and attributed this to the availability of soil moisture. Other researchers also reported that mulches retained higher amount of soil water with efficient utilization of soil nutrients that might enhance plant growth and might maximize the yield attributes (Awal and Ikeda 2003; Awal et al., 2008). This current result also agrees with the findings of Ghosh et al. (2003) who reported that data collected for over eight years (1990-1997) in India revealed that application of wheat straw as a mulch on the soil increased pod yield by 19.4% over non-mulched plots. Similarly, Zayton et al. (2014) reported that mulching highly and significantly ($p \leq 0.01$) increased the mean number of pods per plant of groundnut as compared to the non-mulched plots. Number of pods per plant recorded from mulched plots was 37.56, while 33.25 was recorded from non-mulched plots.

Number of seeds per pod

The analysis of variance (ANOVA) showed that the main effect genotype highly significantly ($p \leq 0.01$) influenced the number of seeds per pod, whereas the other two main effects, that is, *T. harzianum* inoculation, wheat straw mulching and their interaction effects were not significant. Rama local produced the highest number of seeds per pod (2.58) than all the other tested genotypes. Thus, the highest number of seeds per pod recorded from Rama local might be due to the genetic potential of the crop to produce higher number of seeds per pod and the adaptability of the genotype to the area for a long period.

Number of seeds per plant

The main effect of mulching and the interaction effect of the three factors, that is, variety×*T. harzianum* × wheat straw mulch showed significant ($p \leq 0.05$) difference on number of seeds per plant of groundnut genotypes. Seed yield per plant of ICGV00308 under straw mulch gave the highest also include about *T. harzianum* mean number of seeds per plant (37.06), followed by the genotype ICIAR19BT (32.05) under no-mulch and no-*T. harzianum* treatment, and Rama local (32.91) under wheat straw mulch and *T. harzianum* application. On the other hand, the lowest number of seeds per plant was from Rama local under wheat straw mulch but *T. harzianum* untreated (Table 2). Similarly, wheat straw mulching significantly ($p \leq 0.05$) increased the number of seeds per plant from 22.11 in without mulching to 28.21 seeds per plant on straw mulched plots. This increased number of seeds per plant might have resulted due to the application of straw mulches increased soil moisture content and plant nutrition that might have been mineralized from the straw mulches.

In line with this result, Bhardwaj (2013) reported that mulching provides an environment conducive for the growth and development of crops; as a result, plants become vigorous and healthier than plants on non-mulched plots. Similarly, Albuquerque et al. (2001) have shown that in maize production higher number of seeds per cob was obtained from wheat straw mulched plots. This higher number of seeds per cob in maize might have resulted due to the change in soil physical, chemical and biological characteristics after the soils were mulched with wheat straw.

Seed yield per plant

Seed yield per plant was significantly ($p \leq 0.05$)influenced by the main effect of genotypes and wheat straw mulching but the main effect *T. harzianum* and the interaction effect of the three factors did not show significant effect on seed yield per plant. The highest mean seed yield per plant (14.69 g) was obtained from ICGV00308 whereas the lowest seed yield per plant (10.18 g) was recorded from Were-961. The genotype ICGV00308 produced 20.21, 29.66 and 44.30% higher seed yield per plant than ICIAR19BT, Rama local and Werer-961, respectively. This variation in mean seed yield per plant might be due to the inherent genetic potential of the genotypes. Likewise, wheat straw mulching had significant effect on seed yield per plant, where it enhanced seed yield per plant by 20.69% over the non-mulched plots. Mulched plots recorded higher seed yield per plant (13.24 g) than the non-mulched plots with a mean (10.97 g) seed yield per plant of 10.97 g.

Wheat straw mulching reduces soil deterioration through preventing the runoff and soil loss, minimizes the weed infestation and checks the water evaporation. Thus, it facilitates more soil moisture retention and helps in the control of soil temperature fluctuations, improves the soil physical, chemical and biological properties. In the present study, the effect of wheat straw mulch and *T. harzianum* treatment on available N, P and K was significantly higher than in soil conditionsin non-treated plots before harvest. Straw mulch supplies plant nutrients to the soil and ultimately enhances the growth performance and yield of crops (PatilShirish et al., 2013). Fang et al. (2011) also reported that straw mulching improved soil nitrogen availability, increased plant growth and influenced the physical and chemical properties of the soil. Awal et al. (2016) also stated that the important yield contributing parameters of pea, like number of pods per plant, number of seeds per pod, seed weight per plant and hundred seed weight, significantly increased in mulched-plots as compared to non-mulched plots. It was also recognized that the availability of soil moisture significantly improved the various yield parameters in field pea too (Awal et al., 2016).

Hundred seed weight (HSW)

Analyses of variance showed that groundnut genotypes and bio-inoculant *T. harzianum* significantly ($p \leq 0.05$) influenced hundredseed weight. However, the main effect of wheat straw mulch and the interaction effect of the three main effects did not show significant difference on hundred seed weight. There was significant difference among the tested four genotypes. The genotypes ICGV00308 and Werer-961 gave significantly higher hundred seed weight of 51.00 and 48.08 g, respectively. Hundred seed weight ranged from 51.00 for ICGV00308 to 43.08 g for ICIAR19BT. Thus, ICGV00308 resulted in 18.38 and 17.7% higher hundred-seed weight than the lowest ICIAR19BT and Rama local, which is currently the most popular variety under production in the study area. Therefore, this genotype could be considered as a better optional genotype for farmers of the study area.

Studies have confirmed that *T. harzianum* and *Trichoderma viridi* are capable of enhancing seed germination, and root and shoot length (Dubey et al., 2007) as well as increasing the frequency of healthy plants, and boosting yield (Rojoa et al., 2007). Similarly, Chaur-Tsuen and Chien-Yih (2002) screened *T. harzianum* strains for their effects on plant growth and root growth of bitter gourd, loofah and cucumber and noted that *Trichoderma* strains significantly increased the seedling height by 26 to 61%, root exploration by 85 to 209%, leaf area by 27 to 38% and root dry weight by 38 to 62% 15 days after sowing. Methanol extract of *T. harzianum* and *T. viridi* significantly improved various growth parameters of okra (Prasad and Anes, 2008). Vigour index (VI) was also significantly affected by the application of different *Trichoderma* strains both in the laboratory and under field conditions. This current result conforms to the findings of Harman (2006) who reported that *T. harzianum* strains frequently increased plant growth and productivity.

Seed yield

Seed yield was obtained as a function of different yield components like number of pods per plant, number of seeds per pod, number of seeds per plant, seed yield per plant and hundred seed weight. These all parameters had their own contribution to the final seed yield. The main effect of the tested groundnut genotypes and wheat straw mulch was significant to the seed yield (t ha^{-1}). On the other hand, the main effect of *T. harzianum* and the interaction effects among the three factors did not show significant variation in the seed yield. The highest (1.0 t ha^{-1}) seed yield was recorded from the genotype ICGV00308 and it was significantly higher than the other three genotypes tested in this study (Table 3). The mean value of seed yield ranged from 1.00 ha^{-1} for ICGV00308 to 0.63 t ha^{-1} for Werer-961. This indicated that the genotype ICGV00308 produced 58.7, 29.87 and 28.21% higher seed yield than Werer-961, Rama local and ICIAR19BT, respectively. Rama local is the only genotype currently under production in the study area. Therefore, ICGV00308 genotype can be considered as an important and superior genotype to the other tested groundnut genotypes to improve productivity in the study area.

Wheat straw mulch showed significant ($p \leq 0.05$) difference in seed yield as compared to the non-mulched

Table 3. Main effect of genotypes (G), *T. harzianum* (Tr) and wheat straw mulching (ML) on number of seeds per pod, seed yield per plant, hundred seed weight and seed yield at Rama in 2016 cropping season.

Factor/Treatment	Number of seeds per pod	Seed yield per plant (g)	Hundred seed weight (g)	Seed yield (t ha^{-1})
Genotypes				
Werer961	1.84^b	10.18^b	48.08^a	0.63^b
ICGV00308	1.89^b	14.69^a	51.00^a	1.00^a
ICIAR19BT	1.88^b	12.22^b	43.08^b	0.78^b
Rama Local	2.58^a	11.33^b	43.33^b	0.77^b
LSD(0.05)	0.11	2.44	3.58	0.16
T. harzianum				
T. harzianum inoculated	2.02^a	12.91^a	0.80^a	0.80^a
T. harzianum non inoculated	2.08^a	11.30^a	0.78^a	0.79^a
LSD(0.05)	NS	NS	NS	NS
Wheat straw mulching				
With mulching	2.06^a	13.24^a	46.42^a	0.86a
Without mulching	2.04^a	10.97^b	46.33^a	0.73b
LSD (0.05)	NS	1.73	NS	0.11
CV (%)	6.64	24.24	9.28	24.75

NS: Non significant, LSD: least significant difference, CV: coefficient of variation. Means followed by the same letter in the same column are not significantly different from each other at 5% probability level

plots. Mulched plots produced significantly higher (0.86 t ha^{-1}) seed yield (0.86 t ha^{-1}) than the non-mulched plots (0.73 t ha^{-1}). Seed yield from mulched plot was 17.80% higher than the non-mulched plots. Application of wheat straw mulch showed significant increase in seed yield which might be due to the soil moisture retaining ability of straws. Uwah and Iwo (2011) stated that plant height, seed yield per cob and the seed yields per hectare were significantly increased as the rate of straw mulch increased; hence, 61% yield increase was obtained as the mulch increased from 0 to 2 t $ha\text{-}^{1}$ and further increase in the mulch from 2 to 4 t $ha\text{-}^{1,}$ resulted in 87.5% yield increase, and finally 155.5% yield increase was recorded when the plot was mulched with 6 t $ha\text{-}^{1.}$ In agreement with this resulted. Zamir et al. (2013) also reported that highest number of seeds per cob was recorded from wheat straw mulched plots. This result is in agreement with the findings of Zayton et al. (2014) who reported that mulching highly and significantly increased the mean total kernel yield of groundnut as compared to the yield from the non-mulched plots. The total kernel yield recorded from mulched plots was 1.14 t $ha\text{-}^{1}$, while 0.918$ha\text{-}^{1}$ was recorded in non-mulched plots.

Conclusions

The analysis of variance (ANOVA) showed that plant height and number of seeds per plant were significantly influenced by the interaction effect of groundnut genotypes, *T. harzianum* and wheat straw mulching. However, soil moisture content at harvest, days to 90% physiological maturity, number of pods per plant, number of seeds per pod, seed yield per plant, hundred seed weight and total seed yield were significantly affected by the main effect of genotypes, *T. harzianum* and wheat straw mulch separately.

The highest soil moisture was conserved on wheat straw mulched-plots. The tallest plant height was observed in Rama local, werer-961 and ICIAR19BT with values of 25.40, 24.86 and 24.85 cm, respectively. The highest (22.44) number of pods per plant was recorded on ICIAR19BT, followed by ICGV00308 (20.97), while the least (16.63) number of pods per plant was recorded on Rama local. Rama local held the highest (2.58) number of seeds per pod as compared to the other genotypes. Genotype ICGV00308 was superior in number of seeds per plant, seed yield per plant, hundred seed weight and total seed yield compared to the other genotypes. The maximum number of seeds per plant was obtained from ICGV00308 treated with both *T. harzianum* and wheat straw mulching. Significantly, higher seed yield per plant as well as total seed yield was recorded in ICGV00308 genotype treated with wheat straw mulch. Likewise, higher hundred seed weight was obtained from the genotype ICGV00308 than the other genotypes when treated with *T. harzianum* biocontrol agent.

Application of wheat straw mulching at a rate of 12 t ha^{-1} as split application half at 27 DAP after the establishment of seedlings and the remaining half at 49

DAP showed significant effect on soil moisture conservation and agronomic parameters. From this observation, wheat straw mulch exerts significant effects on yield related parameters and yield of the crop. The newly introduced groundnut genotype ICGV00308 was highly superior in quantitative and qualitative yield related parameters and yield compared to other tested genotypes. The current research findings imply that field demonstration need to be conducted and seeds should be accessible to farmers through the responsible bodies, like Rural Development and Agricultural Offices, research centers, universities and other governmental and non-governmental organizations (NGO). Wheat straw mulched soils were also found to retain higher soil moisture than non-mulched plots at harvest and the maturity period of crops on mulched plot extended by five days more than that of the non-mulched plots. It is recommended that farmers have to use locally available mulching materials at a rate of 12 t ha^{-1} to solve late drought stress that forces early physiological maturity of groundnut. You need to say something about *T. harzianum* and its effects.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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