

Bio-fertilizers and Systemic Acquired Resistance in Fusarium Infected Wheat

S. K. Sabbagh^{1*}, A. Poorabdollah², A. Sirousmehr³, and A. Gholamalizadeh-Ahangar²

ABSTRACT

Bio-fertilizers have been introduced as an alternative to chemical fertilizers for plant growth and health. The objective of this pot culture experiment was to evaluate the effects of three Bio-fertilizers in single and mixed form containing arbuscular mycorrhizal fungus (*Glomus intraradices*), N+V on growth, yield components, and expression of some defense response genes in wheat infected with *Fusarium oxysporum*. Real time PCR was performed to determine the gene expression levels of β -1,3-glucanase, Oxalate Oxidase, and Chitinase genes. The application of bio-fertilizers significantly increased all studied parameters, except spike length, in infected plants. The highest shoot dry weight was found in Nitroxin+Vermicompost (N+V) treatment and the highest plant height, grain number, 100 grain weight, and biological yield was observed in treatment Mycorrhizal+Vermicompost (M+V). The use of bio-fertilizer resulted in the highest expression level of β -1,3-glucanase gene. The Chitinase gene showed the lowest expression level in all treatments. Our results indicate that vermicompost application could influence the improvement of mycorrhizal colonization and development of external hyphae.

Keywords: Bio-fertilizer, Fusarium head blight, Gene expression, Sustainable agriculture.

INTRODUCTION

Plants can be affected by environmental stresses (biotic and abiotic) and then respond to them like other living organisms (Allen, 1995). Biotic stresses are one of the most limiting factors which reduce crop yields. Fusarium Head Blight (FHB) or scab, caused by *Fusarium graminearum* is a destructive disease of bread wheat (*Triticum aestivum* L) and barley (*Hordeum vulgare* L.) (Rudd *et al.*, 2001; Tóth *et al.*, 2008). This disease reduced yield, seed quality, kernel weight, destroyed storage proteins and contamination with mycotoxin (Snijders, 1990). Several mycotoxins producing different cancer in human are frequently associated with infected cereal grains by scab fungi (Lemmens *et al.*, 2005; Snijders and Perkowski, 1990).

Various methods such as fungicides application, integrated pest management system and the use of resistant cultivars have been used to control head blight (Parry *et al.*, 1995; Pirgozliev *et al.*, 2003). The use of resistant cultivars with remarkable agronomic parameters is one of the best ways to disease control (Gilbert and Tekauz, 2000). Nutrients are a most important limitation to growth and development of plants (Fry, 2012). The use of fertilizers is an important factor in improving soil-nutrients availability reducing plant disease control (Huber, 1981). The effect of five different types of nitrogen fertilizers (organic and inorganic) on scab disease have shown that nitrogen application at early stage of plant growth significantly reduced fungal development in infected plants (Lemmens *et al.*, 2004) but had no significant effect on Deoxynivalenol (Glick *et al.* 2001) and

¹ Department of Biology, Campus of Science, Yazd University, Yazd, Islamic Republic of Iran.

* Corresponding author; e-mail: sksabbagh@yazd.ac.ir

² Department of Soil Science, Faculty of Agriculture, University of Zabol, Zabol, Islamic Republic of Iran.

³ Department of Agronomy, Faculty of Agriculture, University of Zabol, Zabol, Islamic Republic of Iran.



Nivalenol (NIV) toxins content in grain (Yoshida *et al.*, 2007). Mycorrhizal fungi are ubiquitous symbiotic microorganisms associated with plants which could have an important impact on plant interaction with pathogenic fungi and insects (Pozo and Azcon-Aguilar, 2007). There are several studies in literature review that have demonstrated the potential of Arbuscular Mycorrhizal Fungi (AMF) for biological control and their impact on sustainable agriculture (Azcón-Aguilar and Barea, 1997; Hooker *et al.*, 1994; Leyval *et al.*, 2002; Vigo *et al.*, 2000). The plant growth promoting rhizobacteria (PGPR) include free living bacteria that colonize the roots of monocots and dicots and enhance plant growth by an exorbitance mechanisms (Nadeem *et al.*, 2014; Vacheron *et al.*, 2013). The majority of PGPR systems induce the growth of plant which could lead to better defense mechanisms to control many pathogenic micro-organisms such as fungi, nematodes, bacteria and viruses organism (Vessey, 2003). Vermicomposts, which are produced by the fragmentation of organic wastes by earthworms, have a fine particulate structure and contain nutrients in forms such as nitrates, exchangeable phosphorus and soluble potassium, calcium, and magnesium that are readily taken up by plants (Arancon *et al.*, 2005; Atiyeh *et al.*, 2000; Orozco *et al.*, 1996). The role of vermicompost in reducing some pathogenic fungi and disease incidence have been reported (Edwards *et al.*, 2004; Litterick *et al.*, 2004). Several classes of systemic acquired resistance genes have been reported to induce resistance to FHB in wheat. One group of genes referred to Pathogenesis-Related (PR) or defense response genes, encode proteins such as β -1,3-glucanases, chitinases, thaumatin-like proteins (tlps) and thionins whose expression

often increase as part of the plant host defense response to pathogen attack (Linthorst and Van Loon, 1991). This study aimed to demonstrate the effect of different bio-fertilizers application on plant growth and some yield components in Fusarium infected wheat. To better understand the role of nutrition to induce systemic acquired resistance (SAR), the expression levels of some defense response genes against pathogenic fungi including β -1,3-glucanase, oxalate oxidase and chitinase genes were analyzed.

MATERIALS AND METHODS

Plant Culture

A wheat cultivar susceptible to head blight disease (cv. Tajan, Iran) was used in this study. Wheat seeds free of microbial contamination were cultivated in plastic pots (16.5×5.5 cm) containing sterilized (1 hour at 121°C) sandy-loam-clay soil (1:2:1) for one hours at 121°C. Chemical characteristics of the soil were analyzed before the experiment (Table1).

Fertilizer Treatments

This study was conducted on completely randomized design with four replications under greenhouse conditions. The bio-fertilizer application included control (Fusarium infected wheat without fertilizer), arbuscular mycorrhizal fungus (*Glomus intraradices*) (15% v/v), Nitroxin (priming), Vermicompost (20% v/v), Nitroxin+Vermicompost (N+V), Mycorrhizal+Vermicompost (M+V) and Mycorrhizal+Nitroxin (M+N) were used.

Table 1. Physical and chemical characteristics of soil and vermicompost.

| | Sand | Clay (%) | Salt | Zn | Fe (ppm) | K | P | N (%) | pH | EC (dSm ⁻¹) |
|--------------|------|----------|------|-----|----------|-----|----|-------|-----|-------------------------|
| Soil | 41 | 32 | 27 | 4.8 | 2.2 | 185 | 12 | 6.3 | 7.1 | 1.8 |
| Vermicompost | | | | | | 626 | 13 | 1.6 | 8.1 | 5.6 |

Wheat seeds were planted 3 cm deep in the soil and then were covered with 1.5 cm of autoclaved vermiculite. Yield components such as 100 seeds weight, root length, spike length, root dry weight, and biological yield were measured 72 hpi.

Fungal Inoculum

Standard isolates of *F. graminearum* species was used as inoculum. Macroconidia was produced by re-culture of fungi on Carnation Leaf Agar (CLA) in sterile condition. The cultures were incubated in darkness at 25°C for one week and then the conidia were washed from culture surface and counted using a haemocytometer. The suspension concentration was adjusted to 5×10^5 spores mL^{-1} , and stored at -20°C until use. Inoculation was carried out by injecting between the palea and lemma of 10 central spikelets per each spike on different plantlets using 1 mL cell suspension at 10^5 cells mL^{-1} (Nemati and Navabpour, 2012). The plants were grown in a night/day temperature of 18/24±5°C under greenhouse condition.

RNA Isolation and RT-PCR

Total RNAs from treated and control plants were isolated using GeneAll Kit (South Korea) and purified using RNA purification Kit (Promega, Cat. No.: AS1500). Total RNA was quantified using a Scandrop spectrophotometer (AnalytikaGena, Germany) and RNA quality was assessed by 1% agarose gel electrophoresis stained by ethidium bromide and photography by Geldocument (Vilber, France). First-strand cDNA was synthesized from total RNA using 2-Steps RT-PCR kit (Vivantis, Sinaclon Co. Cat. No.: RT5201) and then fifty to 100ng of total RNA was used to prepare double-strand cDNA:

Three genes including β -1,3-glucanase (Gene Bank TM accession number:

DQ090946.1), *Oxalate Oxidase* (AJ556991) and *Chitinase* (AY437443.1) were used for expression analysis. β -Tubolin gene was used as housekeeping gene.

qRT-PCR

Reverse Transcriptase-quantitative Polymerase Chain Reaction (RT-qPCR) was carried out in Roter Gene (RG-3000 Corbet Research) and PCR MasterMix for Syber Green Assays (Hot Tag EvaGreen, ROX, GeneAll, South Korea; Cat. No.: 16-100), according to the manufacturer's protocol. The amplifications were performed using the following concentration: 4 μL of SYBR Green PCR MasterMix, 1 μL of each oligonucleotide primer (final concentration 10 μM) and 1 μL of cDNA template in 30 μL reaction volume. Each gene amplification was prepared in triplicates and two biological repetitions were carried out. Triplicates were validated with technical error under 0.5 CT. The amplification condition was: 95°C for 10 minutes, 40 cycles at 95°C for 15 seconds and 60°C for 1 minute. Melting curves analysis were performed after each reaction, to exclude non-specific amplifications, with the thermal cycle at 95°C for 15 seconds, 60°C for 15 seconds and 95°C for 15 seconds. The optimal baseline and threshold values were determined using automatic CT function available. Relative gene expression levels for the three replications were calculated using the REST method (Pfaffl, 2001)

Data Analyses

The significant difference was set at $P \leq 0.05$ and determined using the Least Significant Difference (LSD) multiple range tests. Data for plant height (cm), shoot dry weight (kg), root dry weight (kg), 100 seed weight, seed number, biologic yield, seed yield, spike length (cm) and root length (cm) were recorded for each treatment and subjected to statistical analysis (One-way ANOVA) using SAS software.



RESULTS

The growth and yield compounds of infected wheat with *F. graminearum* as root length, plant height, shoot and root dry weight, weight and number of grains and biological yield parameters were significantly increased at the 1% probability level by all applied bio-fertilizers (Table 2).

Root Length and Plant Height

A significant difference among treatments for plant yield parameters was observed. Maximum plant height at 61 cm was recorded for combined M+V treatment whereas the lowest average plant height of 54 cm was obtained with mycorrhizal treatment (Table 2). The highest average root length of 15 cm was obtained with M+V and N+V biofertilizer combination (these treatments are listed statistically into one group), and the lowest average root length of 10 cm was found for mycorrhizal treatment (Figure 1).

Shoot and Root Dry Weight

According to the results of yield components assay, the highest average shoot dry weight of 5.7 g pot⁻¹ was found in N+V treatment and the lowest average amount of

2.71 g pot⁻¹ was record for mycorrhizal treatment. The results also showed that the highest average root dry weight of 2.14 g pot⁻¹ was obtained for control (this treatment was listed statistically into one group with N+V treatment) and the lowest average root dry weight of 0.78 g pot⁻¹ was recorded in N+M treatment (Figure 2). According to our observation, it seems that biological and organic fertilizers had no statistically significant effect on growth and development of Fusarium infected roots.

Grains Weight and Number

The effects of treatments on 100 grain weight showed a significant difference ($P < 0.05$) on 100 grain parameter in different treatments. The highest effect of bio-fertilizer on this parameter was found in the combined M+V application (2/44 g pot⁻¹), but there was no statistically significant difference in comparison with other applications. The lowest 100-grains weight was recorded in mycorrhizal treatment (1.68 g pot⁻¹). Data analysis showed the highest average seed yield (0.23 g pot⁻¹) in M+V treatment and the lowest average seed yield (0.03 g pot⁻¹) with mycorrhizal application (Table 3).

Table 2. Analysis of variance for dry weight, root dry weight, 100-seed weight, seed number, biological yield, seed yield, plant weight and spike length traits in wheat infected by *F. oxysporum* under different bio-fertilizers treatment.^a

| Treatment | Root length | Spike length | Plant height | Seed yield | Biological yield | Seed number | Seed weight |
|-----------|--------------------|-------------------|---------------------|--------------------|--------------------|-------------------|-------------------|
| Control | 12.5 ^b | 8.96 ^a | 54.66 ^{bc} | 0.94 ^d | 5.7 ^{ab} | 5.5 ^b | 1.75 ^d |
| My | 10 ^c | 8.33 ^a | 54 ^c | 0.03 ^e | 2.7 ^d | 3.83 ^c | 1.68 ^d |
| N | 12.4 ^b | 8.66 ^a | 55.66 ^{bc} | 0.12 ^c | 6.05 ^a | 6 ^b | 1.94 ^c |
| V | 13 ^b | 9.3 ^a | 58.66 ^{ab} | 0.18 ^b | 5.2 ^b | 7.5 ^a | 2.25 ^b |
| N + V | 15 ^a | 8.76 ^a | 57 ^{bc} | 0.17 ^b | 5.8 ^{ab} | 7.25 ^a | 2.18 ^b |
| M + V | 15 ^a | 9.41 ^a | 61 ^a | 0.23 ^a | 5.83 ^{ab} | 7.91 ^a | 2.44 ^a |
| M + N | 14.83 ^a | 8.76 ^a | 60 ^a | 0.038 ^e | 3.3 ^c | 2.58 ^d | 1.68 ^d |

^a Means in each column and for each treatment followed by similar letter(s) have not significantly different at 5% probability level.

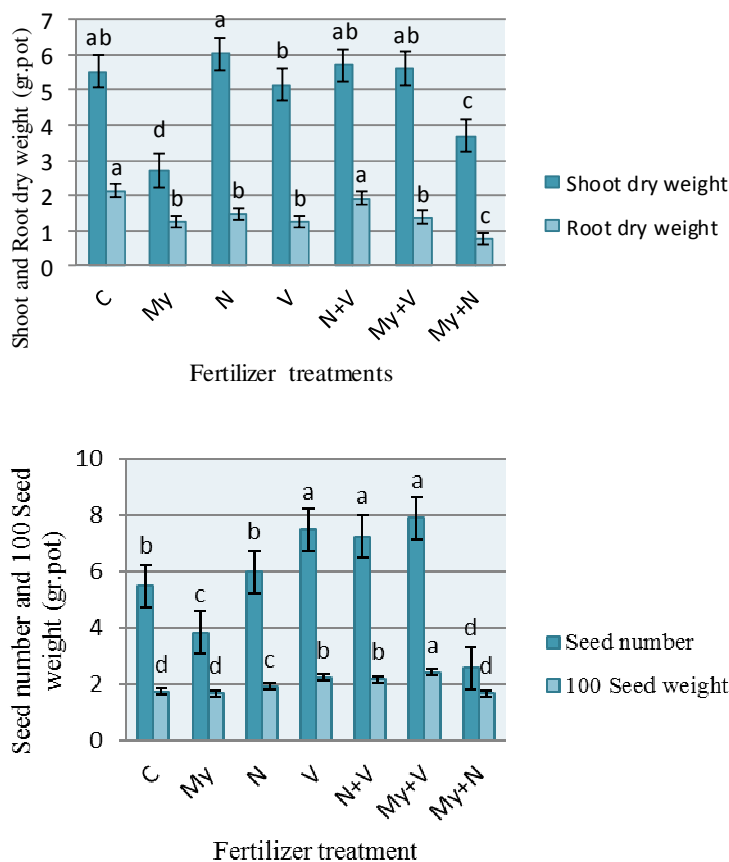


Figure 1. Effect of different bio-fertilizers on (a) shoot and root dry weight (b) seed number and 100 seed weight of wheat infected by *F. graminearum*. C: No fertilizer; M: Mycorrhizal ; N: Nitroxin, V: Vermicompost.

Table 3- Mean of shoot dry weight, root dry weight, 100-seed weight, seed number, biological yield, seed yield, plant weight and spike length under treatment of different bio-fertilizers in wheat infected by *F. graminearum*.

| | | Means of Square | | | | | | | | |
|-----------------|----|------------------|-----------------|-----------------|----------|------------------|------------|--------------|---------------------|-------------|
| S.O.V | df | Shoot dry weight | Root dry weight | 100-Seed weight | Seed No. | Biological yield | Seed yield | Plant weight | Spike length | Root length |
| Bio-fertilizers | 6 | 4.56** | 0.61** | 0.27** | 11.9** | 5.46** | 0.017** | 21.7** | 0.43 ^{n.s} | 10.27** |
| Error | 14 | 0.19 | 0.033 | 0.005 | 0.18 | 0.12 | 0.0014 | 6.1 | 0.32 | 0.73 |
| Cv(%) | 9 | | 12.5 | 3.84 | 7.46 | 7.07 | 9.6 | 4.3 | 6.38 | 6.45 |

Biological Yield

The biological yield assay showed a significant effect ($P < 0.05$) of bio-fertilizer

treatments (Table 2). The applied M+V and mycorrhiza treatments showed the highest (5.83 g pot^{-1}) and lowest (2.27 g pot^{-1}) effect on the biological yield characters, respectively (Table 2).



Gene Expression Analysis

Gene expression level of β -1,3-glucanase, oxalate oxidase and chitinase genes were assayed in plant infected with *F. graminearum* species which were treated with different bio-fertilizers. The results of gene expression analysis showed that β -1,3-glucanase gene was over expressed in all treatments compared to the control. Transcript levels were elevated in V+M treatment compared with water-treated control plants. For chitinase and oxalate oxidase genes expression, there was no significant difference between inoculated plants treated with mycorrhiza and the control. Chitinase gene expression in treated plants showed the lowest average value (Figure 3).

DISCUSSION

Wheat is the one of the most important grains in the food chain worldwide (Neo, 2011). *F. graminearum* is one causal agent of a destructive disease known as wheat scab in different parts of the world (Abedi-Tizaki et al., 2013). In this study, we investigated the effect of some bio-fertilizers in single or

combined forms on the growth, yield and systemic acquired resistance of fusarium infected wheat under greenhouse conditions. Head blight disease is one of the most destructive diseases of wheat, furthermore, it causes losses in quality and quantity of grains. Data presented in Table 2 demonstrate that the majority of bio-fertilizers application significantly increased ($P \leq 0.05$) grain yield, shoot and root length, root dry weight, plant height and biological mass when compared to the control. In general, the availability of water and essential nutrients, affect plant height through the number of nodes and internodes length (Morrison et al., 1999). The effect of fertilizers as source of nutrition is clear. The role of mycorrhizal fungi has been defined as hyphal growth prevention or competing for nutrient and space (Limón and Codón, 2004). In this research, our data presented in Table 2 show that mycorrhizal application did not approximately increase all yield components compared to the control plants such that the lowest average parameters was determined in mycorrhizal treatment which could possibly be due to the fact that the presence of pathogenic fungi *F.*

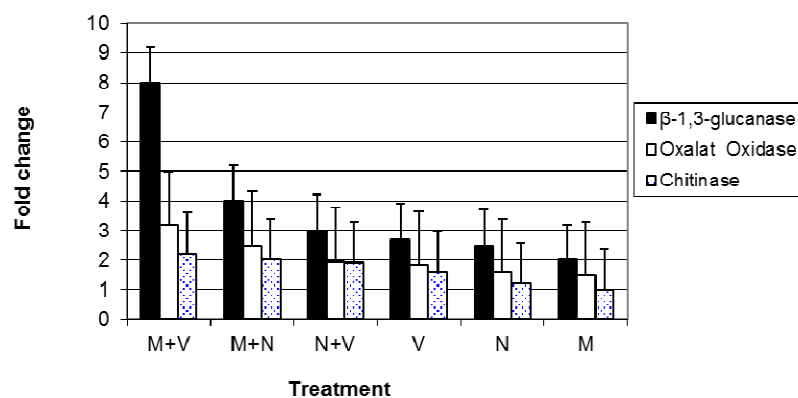


Figure 3. Quantitative real-time PCR analysis of β -1,3-glucanase, oxalate oxidase and chitinase genes. The relative fold change of target gene transcripts was calculated using the comparative cycle threshold method. Ratios are given as logarithmic values (base 2) of means of three independent experiments, means were calculated with REST. β -1,3-glucanase (black bar) shows higher expression than other tested genes (P -value 0.001, determined with REST). Gene expression analysis in infected wheat by *F. graminearum* treated with different bio-fertilizers.

graminearum led to reduction of bioprotection of arbuscular mycorrhizal fungi on head blight disease development. These results are not fully comparable with the positive result of mycorrhizal application in rhizosphere, because in this study, the locations of mycorrhizal (soil) and pathogenic fungi (aerial parts) agent were differed. Nitroxin bio-fertilizer containing a mix of nitrogen-fixing bacteria belong to *Azotobacter* and *Azospirillum* genus that cause an increase in growth and development of shoot and root of plants (Glick *et al.*, 2001). The biological fixation of the nitrogen by bio-fertilizers could have an important role in improvement and fertility of soil. Nitroxin is a biologic nitrogen fertilizer that contains *Azospirillum* (*Spirilaceae*) and *Azotobacter* (Vlassak *et al.*, 1992). It has been found that Nitroxin applications lead to the highest impact on seed weight and biological yield of rapeseed plant (*Brassica napus* L.) (Azimzadeh and Azimzadeh, 2013). In the present study, increase in shoot dry weight with combined N+V treatment could be due to the beneficial effect of *Azotobacter* and *Azospirillum* bacteria on root growth. Application of *Paenibacillus polymyxa* (SQR21) as a bioorganic fertilizer for improving the biocontrol efficacy to *Fusarium* wilt disease of watermelon showed that the number of colony-forming units of *Fusarium oxysporum* in rhizospheric soil was significantly ($0.05 \leq P$) inhibited compared to the controls (Ling *et al.*, 2010). In this study, pathogenic agent and biofertilizer microorganisms did not have any interaction and positive response to disease could be due to nutrition and improvement of plant growth condition. Also, in the study of Ling *et al.* (2010), there was not any interaction between bacterial strain and pathogenic fungi, in agreement with our results.

Plant Growth Promoting Rhizobacteria (PGPR) can affect the pathogens directly and indirectly and are able to elicit Systemic Acquired Resistance (SAR) in plants defense against different pathogenic agents

(Kumar *et al.*, 2005). Increase of 100-grain weight could be due to the effect of organic fertilizers on seed yield through nutrient assimilation and seed filling. The highest significant increase in 100-grains has been reported in Isabgol medical plant with mycorrhiza application (Singh *et al.*, 2003). Our observation showed that mycorrhizal fungi could not independently increase studied traits, but in combination with vermicompost had significantly influenced all growth parameters. Our results are in concordance with results of Norman and co-workers (2005) who showed that vermicompost had a positive effect on mycorrhizal symbiosis percentage and extension of external hyphae (Norman *et al.*, 2005). Also, the results showed that the highest average number of seeds per spike (7.91 g pot^{-1}) was recorded in the combined M+V treatment and the lowest average of 2.58 g pot^{-1} was obtained in the single mycorrhizal treatment (Table 2). The number of seeds is the most important yield component that is determined during the period from florets initiation to seed filling. In fusarioid disease, spike is the most important site effect of disease which lead to losses of grain weight, so, in this study, we did not expected high increase in this trait due to fungal growth in panicle. For this reason, all traits related to grain have not significantly increased and, in some treatment, they have been decreased when compared to the control. To illustrate the effect of bio-fertilizer on disease development and toxin production, a chemical analysis by HPLC method to determine quality of different trichothecene toxins is necessary (Abedi-Tizaki and Sabbagh, 2013). To increase yield production (seed number and weight), adsorption of nitrogen at the flowering stage should be increased (Ruffo *et al.*, 2003; Wiersma *et al.*, 1996). Other studies have shown that vermicompost application increases yield, improves soil biological properties, and also provides macronutrients in the soil (Norman *et al.*, 2005). Increase in biological yield of many higher plants



treated with symbiotic mycorrhizal fungi has been reported (Treseder and Cross, 2006). The application of nitrogen with mycorrhizal fungi increased biological yield in wheat and barley (Behl *et al.*, 2012) while the application of mycorrhizal fungi with vermicompost increased the biological yield in sorghum (Cavender *et al.*, 2003). Our data are in agreement with these observations. This study showed that vermicompost has no direct effect on mycorrhizal symbiosis percentage while it suggested that the effect of vermicompost was to provide nutrients for mycorrhizae development and growth of the host plant roots. Expression pattern of transcribed mRNAs in susceptible varieties of wheat using microarray and SSR approaches has shown an up-regulation of defense-related genes occurring early during fungal stress (Bernardo *et al.*, 2007). Recently, a set of cDNAs sequences as plant genes which confer resistant to tricothecene mycotoxins have been patented (Tumer *et al.*, 2014). Change of these genes could be used as a biomarker for determining mycotoxins in different state of disease in wheat infected by *F. oxysporum*, but unfortunately, at this time, these sequences were not accessible and we were obligated to use defense related genes in wheat that have been reported against different pathogenic agents (Kong *et al.*, 2005; Abedi-tizaki and Sabbagh, 2013). Gene expression analysis in susceptible and resistant cultivars of wheat showed that the timing of defense response gene induction correlates with *F. graminearum* infection and their transcripts were accumulated as early as 6 to 12 hours post infection and peaked at 36 to 48 hpi (Pritsch *et al.*, 2000). Based on these data, we analyzed the expression level of three defense response genes, 72 hpi in treated plantlets with different bio-fertilizers in single and mixed combination. Our data indicate that β -1,3 glucanase gene was over-expressed compared to the other tested genes in all treatments. These results are in agreement with those of Nemati and co-worker who reported an increase in expression of β -1,3

glucanase gene in FHB susceptible variety Sumi3 (Nemati and Navabpour, 2012). As shown in Figure 3, expression level of oxalate oxidase and chitinase did not show remarkable increase when compared to than β -1,3 glucanase gene. Lower expression of oxalate oxidase gene as a key enzyme in antioxidant activity could indicate that this gene has no important role in SAR reaction. For β -1, 3 glucanase gene, the highest expression level (8 fold change) was recorded for M+V treatment and the lowest was observed for mycorrhizal bio-fertilizer (2 fold change) application which confirmed the result of yield components where mycorrhizal treatment showed low effect on studied traits (Table 2).

Chitinase and β -1,3 glucanase genes have synergistic activity and simultaneous expression resulted in increased fungal resistance in infected tomato plants (Jongedijk *et al.*, 1995). In spite of low expression of chitinase gene in treated plants, according to accumulation role of chitinas and β -1,3 glucanase we can conclude that chitinase could have synergistic activity with β -1,3 glucanase to induced resistance.

Little information exists regarding the role of bio-fertilizers on induced resistance through soil improvement. In this work, we attempted to investigate the interactions of different bio-fertilizers in the rhizosphere and their effects on aerial parts by induced systemic acquired resistance.

Our data showed that all bio-fertilizers in single and combined forms are able to trigger systemic acquired resistance in Fusarium infected wheat. So, we can suggest biofertilizer combination for high yield components which could result in systemic resistance in infected wheat by *F. graminearum*. Applied M+V fertilizer was, however, the best combination to increase yield component and defense response genes expression. Expression level of chitanase gene was determined to be the lowest on all treatments, indicating that β -1,3 glucanase and oxalat oxidase genes had a key role in

SAR and their related pathogenesis proteins in resistance pathway.

CONCLUSIONS

Based on our results, we could conclude that the appropriate combination of effective bio-fertilizer is the mixture of vermicompost and mycorrhizal fungi. Therefore, combined application of these fertilizers could have more efficiency because of some positive interaction between their micro-organisms. Vermicompost improves the growth condition for mycorrhizal fungi. So, this could be proposed for use as an alternative bio-fertilizer in an application formula. However, this study was conducted in a greenhouse with autoclaved soil to reduce or eliminate fungal pathogens. Therefore, these results cannot be generalized for field conditions. Hence, it is recommended that the research be carried out under field conditions. However, heavy metal uptake by plants could increase by bio-fertilizers application. So, to elucidate toxicological activity of bio-fertilizers, especially bio-control fungus, preliminary tests for heavy metal accumulation assay in root of plant is necessary before recommending field application.

REFERENCES

1. Abedi-Tizaki, M., Sabbagh, S.K., Mazaheri Naeni, M. and Sepehriki, S. 2013. Chemotyping of *Fusarium graminearum* Using Tri13 Trichothecene Biosynthetic Gene. *J. Crop Protec.*, **2**:487-500.
2. Abedi-Tizaki, M., and Sabbagh, S. K. 2013. Detection of 3-Cetyldeoxynivalenol, 15-Acetyldeoxynivalenol and Nivalenol: Chemotypes of *Fusarium graminearum* from Iran Using Specific PCR Assays. *Plant Know. J.*, **2**: 38-42.
3. Allen, R. D. 1995. Dissection of Oxidative Stress Tolerance Using Transgenic Plants. *Plant Physiol.*, **107**:1049-1055.
4. Arancon, N. Q., Edwards, C. A., Bierman, P., Metzger, J. D. and Lucht, C. 2005. Effects of Vermicomposts Produced from Cattle Manure, Food Waste and Paper Waste on the Growth and Yield of Peppers in the Field. *Pedobiologia*, **49**: 297-306.
5. Atiyeh, R., Subler, S., Edwards, C., Bachman, G., Metzger, J. and Shuster, W. 2000. Effects of Vermicomposts and Composts on Plant Growth in Horticultural Container Media and Soil. *Pedobiologia*, **44**: 579-590.
6. Azcón-Aguilar, C. and Barea, J. 1997. Arbuscular Mycorrhizas and Biological Control of Soil-Borne Plant Pathogens: An Overview of the Mechanisms Involved. *Mycorrhiza*, **6**: 457-464.
7. Azimzadeh, S. M. and Azimzadeh, S. J. 2013. Effect of Nitroxin Biofertilizer and Nitrogen Chemical Fertilizer on Yield and Yield Components of Rapeseed (*Brassica napus* L.). *Inter. J. Agri. Crop Sci.*, **6**: 1284-1291.
8. Behl, R.K., Ruppel, S., Kothe, E. and Narula, N. 2012. Wheat×Azotobacter×VA Mycorrhiza Interactions towards Plant Nutrition and Growth: A Review. *J. App. Bot. Food Quality*, **81**: 95-109.
9. Bernardo, A., Bai, G., Guo, P., Xiao, K., Guenzi, A. and Ayoubi, P. 2007. *Fusarium graminearum*-Induced Changes in Gene Expression between Fusarium Head Blight-Resistant and Susceptible Wheat Cultivars. *Funct. Integr. Genom.*, **7**: 69-77.
10. Cavender, N. D., Atiyeh, R. M. and Knee, M. 2003. Vermicompost Stimulates Mycorrhizal Colonization of Roots of Sorghum Bicolor at the Expense of Plant Growth. *Pedobiologia*, **47**: 85-89.
11. Edwards, C. A., Domínguez, J. and Arancon, N. Q. 2004. The Influence of Vermicomposts on Plant Growth and Pest Incidence. Chapter 18. In: "Soil Zoology for Sustainable Development in the 21 st Century", (Eds.): Shakir Hanna S. H. and W. Z. A. Mikhail. Cairo., P.397-420.
12. Fry, W. E. 2012. Principles of Plant Disease Management. Academic Press. Ithaca, New Yourk, PP:378.
13. Gilbert, J. and Tekauz, A. 2000. Review: Recent Developments in Research on Fusarium Head Blight of Wheat in Canada. *Can. J. Plant Pathol.*, **22**: 1-8.
14. Glick, B. R., Penrose, D. M. and Ma, W. 2001. Bacterial Promotion of Plant Growth. *Biotechnol. Advan.*, **19**: 135-138.
15. Goswami, R. S. and Kistler, H. C. 2004. Heading for Disaster: *Fusarium*



- graminearum* on Cereal Crops. *Mol. Plant Pathol.*, **5**: 515-525.
16. Hooker, J., Jaizme-Vega, M. and Atkinson, D. 1994. Biocontrol of Plant Pathogens Using Arbuscular Mycorrhizal Fungi, Impact of Arbuscular Mycorrhizas on Sustainable Agriculture and Natural Ecosystems. Springer, PP. 191-200.
 17. Huber, D. 1981. The Use of Fertilizers and Organic Amendments in the Control of Plant Disease. In “*CRC Handbook of Pest Management in Agriculture*”, (Eds.): Pimentel, D. Boca Raton, Florida, P. 357-394.
 18. Kong, L., Anderson, J. M., and Ohm, H. W. 2005. Induction of Wheat Defense and Stress-related Genes in Response to *Fusarium graminearum*. *Genome*, **48**: 29-40.
 19. Jongedijk, E., Tigelaar, H., Van Roekel, J. S., Bres-Vloemans, S. A., Dekker, I., van den Elzen, P. J., Cornelissen, B. J. and Melchers, L. S. 1995. Synergistic Activity of Chitinases and β -1,3-Glucanases Enhances Fungal Resistance in Transgenic Tomato Plants. *Euphytica*, **85**: 173-180.
 20. Kumar, S., Rawat, C., Dhar, S. and RAI, S. K. 2005. Dry-matter Accumulation, Nutrient Uptake and Changes in Soil-fertility Status as Influenced by Different Organic and Inorganic Sources of Nutrients to Forage Sorghum (*Sorghum bicolor*). *Ind. J. Agri. Sci.*, **75**: 340-342.
 21. Lemmens, M., Haim, K., Lew, H. and Ruckenbauer, P. 2004. The Effect of Nitrogen Fertilization on Fusarium Head Blight Development and Deoxynivalenol Contamination in Wheat. *J. Phytopathol.*, **152**: 1-8.
 22. Lemmens, M., Scholz, U., Berthiller, F., Dall'Asta, C., Koutnik, A., Schuhmacher, R., Adam, G., Buerstmayr, H., Mesterházy, Á. and Krska, R. 2005. The Ability to Detoxify the Mycotoxin Deoxynivalenol Colocalizes with a Major Quantitative Trait Locus for Fusarium Head Blight Resistance in Wheat. *Mol. Plant-Microbe Inter.*, **18**: 1318-1324.
 23. Leyval, C., Joner, E., Del Val, C. and Haselwandter, K. 2002. Potential of Arbuscular Mycorrhizal Fungi for Bioremediation, Mycorrhizal Technology in Agriculture. Springer, PP. 175-186.
 24. Limón, M. C. and Codón, A. C. 2004. Biocontrol Mechanisms of Trichoderma Strains. *Int. Microbol.*, **7**: 249-260.
 25. Ling, N., Xue, C., Huang, Q., Yang, X., Xu, Y., and Shen, Q. 2010. Development of a Mode of Application of Bioorganic Fertilizer for Improving the Biocontrol Efficacy to Fusarium Wilt. *Biocontrol.*, **55**, 673-683.
 26. Linthorst, H. J. and Van Loon, L. 1991. Pathogenesis-related Proteins of Plants. *Critic Rev. Plant Sci.*, **10**: 123-150.
 27. Litterick, A., Harrier, L., Wallace, P., Watson, C. and Wood, M. 2004. The Role of Uncomposted Materials, Composts, Manures, and Compost Extracts in Reducing Pest and Disease Incidence and Severity in Sustainable Temperate Agricultural and Horticultural Crop Production: A review. *Crit. Rev. Plant Sci.*, **23**: 453-479.
 28. Morrison, M. J., Voldeng, H. D. and Cober, E. R. 1999. Physiological Changes from 58 Years of Genetic Improvement of Short-season Soybean Cultivars in Canada. *Agro. J.*, **91**: 685-689.
 29. Nadeem, S. M., Ahmad, M., Zahir, Z. A., Javaid, A. and Ashraf, M. 2014. The Role of Mycorrhizae and Plant Growth Promoting Rhizobacteria (PGPR) in Improving Crop Productivity under Stressful Environments. *Biotechnol. Adv.*, **32**: 429-448.
 30. Neo, H. 2001. Words of Food: Place, Power, and Provenance Food Chain. *Asian J. Sci.*, **39**: 409-41
 31. Nemati, M. Navabpour, S. 2012. Study on Quantitative Expression Pattern of *Oxalate oxidase* and β -1,3 *Glucanase* Genes under *Fusarium graminearum* Treatment in Wheat by Quantitative Real Time PCR. *Int. J. Agri. Crop Sci.*, **4**: 443-447.
 32. Norman, M., Simpson, M., Mogensen, J., Shaw, A., Hughes, S., Syrris, P., Sen-Chowdhry, S., Rowland, E., Crosby, A. and McKenna, W. J. 2005. Novel Mutation in Desmoplakin Causes Arrhythmogenic Left Ventricular Cardiomyopathy. *Circulation*, **112**: 636-642.
 33. Orozco, F., Cegarra, J., Trujillo, L. and Roig, A. 1996. Vermicomposting of Coffee Pulp Using the Earthworm *Eisenia fetida*: Effects on C and N Contents and the Availability of Nutrients. *Biol. Fertil. Soil.*, **22**: 162-166.
 34. Parry, D., Jenkinson, P. and McLeod, L. 1995. Fusarium Ear Blight (Scab) in Small Grain Cereals: A Review. *Plant Pathol.*, **44**: 207-238.

35. Pfaffl, M. W. 2001. A New Mathematical Model for Relative Quantification in Real-Time RT-PCR. *Nucl. Acid Res.*, **29**: 2002-2007.
36. Pirgozliev, S. R., Edwards, S. G., Hare, M. C. and Jenkinson, P. 2003. Strategies for the Control of Fusarium Head Blight in Cereals. *Europ. J. Plant Pathol.*, **109**: 731-742.
37. Pozo, M. J. and Azcon-Aguilar, C. 2007. Unraveling Mycorrhiza-induced Resistance. *Curr. Opin. Plant Biol.*, **10**: 393-398.
38. Pritsch, C., Muehlbauer, G. J., Bushnell, W. R., Somers, D. A. and Vance, C. P. 2000. Fungal Development and Induction of Defense Response Genes during Early Infection of Wheat Spikes by *Fusarium graminearum*. *Mol. Plant-Microbe Inter.*, **13**: 159-169.
39. Rudd, J., Horsley, R., McKendry, A. and Elias, E. 2001. Host Plant Resistance Genes for Fusarium Head Blight. *Crop Sci.*, **41**: 620-627.
40. Ruffo, M.L., García, F.O., Bollero, G.A., Fabrizzi, K. and Ruiz, R. 2003. Nitrogen Balance Approach to Sunflower Fertilization. *Comm. Soil Sci. Plant Annal.*, **34**: 2645-2657.
41. Singh, D., Chand, S., Anvar, M. and Patra, D. 2003. Effect of Organic and Inorganic Amendment on Growth and Nutrient Accumulation by Isabgol (*Plantago ovata*) in Sodic Soil under Greenhouse Conditions. *J. Med. Arom. Plant Sci.*, **25**: 414-419.
42. Snijders, C. 1990. Genetic Variation for Resistance to Fusarium Head Blight in Bread Wheat. *Euphytica*, **50**: 171-179.
43. Snijders, C. and Perkowski, J. 1990. Effects of Head Blight Caused by *Fusarium culmorum* on Toxin Content and Weight of Wheat Kernels. *Phytopathol.*, **80**: 566-570.
44. Tóth, B., Kaszonyi, G., Bartok, T., Varga, J. and Mesterhazy, A. 2008. Common Resistance of Wheat to Members of the *Fusarium graminearum* Species Complex and *F. culmorum*. *Plant Breed.*, **127**: 1-8.
45. Treseder, K. K. and Cross, A. 2006. Global Distributions of Arbuscular Mycorrhizal Fungi. *Ecosys.*, **9**: 305-316.
46. Tumer, N. E., McLaughlin, J. E., and Bin-Umer, M. A. 2014. Plant Genes that Confer Resistance to Trichothecene Mycotoxins and Fusarium Head Blight. In: Google Patents. NO: US 20140013470 A1.
47. Vacheron, J., Desbrosses, G., Bouffaud, M. -L., Touraine, B., Moëgne-Loccoz, Y., Muller, D., Legendre, L., Wisniewski-Dyé, F. and Prigent-Combaret, C. 2013. Plant Growth-promoting Rhizobacteria and Root System Functioning. *Front. Plant Sci.*, **4**: 356-364.
48. Vessey, J. K. 2003. Plant Growth Promoting Rhizobacteria as Biofertilizers. *Plant Soil*, **255**: 571-586.
49. Vlassak, K., Van Holm, L., Duchateau, L., Vanderleyden, J. and De Mot, R. 1992. Isolation and Characterization of Fluorescent Pseudomonas Associated with the Roots of Rice and Banana Grown in Sri Lanka. *Plant Soil*, **145**: 51-63.
50. Vigo, C., Norman, J. and Hooker, J. 2000. Biocontrol of the Pathogen *Phytophthora parasitica* by Arbuscular Mycorrhizal Fungi is a Consequence of Effects on Infection Loci. *Plant Pathol.*, **49**: 509-514.
51. Wiersma, J. V., Peters, E. L., Hanson, M. A., Bouvette, R. J. and Busch, R. H. 1996. Fusarium Head Blight in Hard Red Spring Wheat: Cultivar Responses to Natural Epidemics. *Agr J.*, **88**: 223-230.
52. Yoshida, M., Kawada, N. and Nakajima, T. 2007. Effect of Infection Timing on Fusarium Head Blight and Mycotoxin Accumulation in Open-and Closed-flowering Barley. *Phytopathol.*, **97**: 1054-1062.



کودهای بیولوژیک و القاء مقاومت سیستمیک در گندم آلوده به فوزاریوم

س. ک. صباغ، ع. پورعبداله، ع. سیروس مهر، و ا. غلامعلی زاده آهنگر

چکیده

کودهای زیستی به عنوان یک جایگزین کودهای شیمیایی برای رشد و سلامت گیاه معرفی شده اند. هدف از این آزمایش کشت گلخانه‌ای، ارزیابی اثرات سه کود زیستی به صورت تنها و مخلوط شامل قارچ میکریز آریسکولار (*Glomus intraradices*)، نیتروکسین و ورمی کمپوست بر روی رشد، اجزاء عملکرد و بیان چند ژن پاسخ دفاعی در گیاه گندم آلوده به فوزاریوم بود. PCR. در زمان واقعی برای تعیین سطح بیان ژن های بتا ۱-۳ گلوکاناز، اگزالات اکسیداز و کیتیناز انجام شد. استفاده از کود زیستی به طور قابل توجهی تمام پارامترهای مورد مطالعه به جز طول سنبله، در بوته های آلوده را افزایش داد. بالاترین میزان وزن خشک ساقه برای تیمار $N + V$ و بالاترین ارتفاع بوته، تعداد دانه، وزن ۱۰۰ دانه و عملکرد بیولوژیک برای تیمار $M + V$ مشاهده شد. استفاده از کود زیستی منجر به بالاترین سطح بیان در ژن بتا ۱-۳ گلوکاناز گردید. ژن کیتیناز پایین ترین سطح بیان را در تمام تیمارهای بکار رفته نشان داد. نتایج ما نشان می دهد که کاربرد ورمی کمپوست می تواند تحت کلنیزه کردن میکوریز را بهبود و روی توسعه هیف قارچ موثر باشد.