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Research Article

Evaluation of some fungicides for the control of Fusarium dry rot of potato

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Abstract: Five fungicides, with active ingredients azoxystrobin, imazalil, thiabendazole, azoxystrobin + difenoconazole and fludioxonil + difenoconazole, were tested against two isolates of *Fusarium solani* and two isolates of *F. oxysporum*, causing potato dry rot in Mashhad region. PDA media amended with the fungicides significantly inhibited the mycelia growth of all *Fusarium* isolates incubated at 25 °C for 7 days; however only Imazalil and Thiabendazole completely stopped the mycelia growth of all fungal isolates even at their lower concentration (40 and 5ppm respectively). The mean penetration of *F. solani* FPO-67 and *F. oxysporum* FPO-39, the more virulent of the four isolates, after 21 days of incubation at 25-27 °C indicated that imazalil and thiabendazole at concentrations of 1.5 and 2/1000, completely inhibited the penetration of *F. oxysporum* FPO-39 into potato tubers, but in the case of *F. solani* FPO-67 all treatments (1, 1.5 and 2/1000) significantly reduced the development of dry rot compared to untreated control. In natural condition, tuber treatment with Imazalil and Thiabendazole (2/1000), prior storage, reduced *F. solani* FPO-67 development by 68 and 71.69% respectively. According to the results, these fungicides could play a role in integrated pest management against tuber-borne fungal pathogens.

Keywords: Azoxystrobin, Difenoconazole, Fludioxonil, *F. oxysporum*, *F. solani*, Imazalil, Mashhad, Thiabendazole

Introduction

Fusarium dry rot of potato is a devastating post-harvest disease affecting both seed potatoes and potatoes for human consumption. In Iran, potato dry rot is caused by a complex of *Fusarium* species, the incidence and frequency of which depends on the area of cultivation. *F. culmorum*, *F. equiseti*, *F. semitectum*, *F. solani*, *F. sulphureum*, *F. oxysporum* and *F. trichoteciodes* are the most frequently isolated species from local tubers showing dry rot symptoms (Eskandari, 1997; Falahati Rastegar *et al*., 2000; Karimi, 1970; Ghalamfarsa and Banihashami, 2000; Nasr-Esfahani, 1998; Scharif and Ershad, 1966), however, *F. solani* has been reported as the most pathogenic species causing potato dry rot (Sharifi *et al*., 2009).

Benzimidazoles and Conazoles fungicides have been used since1970 (Leach, 1971). Benzimidazoles such as Benomyl, Carbendazim, Thiophenate-methyl and Thiabendazole are used against *Fusarium*, *Phoma exigua*, *Helminthosporium solani* and *Rhizoctonia solani* (Errampalli and Johnston, 2001). Tecnazene and Dichloran had little effect on germination of spores or growth of *F. solani* (Murdoch and

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Wood, 1972). Benomyl and Thiabendazole also had little effect on spore germination but did greatly decrease mycelia growth at 5ppm (Murdoch and Wood, 1972). Thiophenate-methyl, Carbendazim, Iprodione, Metalaxyl, Procymidone and Prochloraz inhibited dry rot development in tubers inoculated with *F. sambucinum* and other *Fusarium* species (Daami-Remadi and El Mahjoub, 1997; Cherif *et al*., 2001). Sandipan *et al*. (2016) reported that Carbendazim and Benomyl significantly inhibited the fungal growth of *Fusarium* sp., even at its lower concentration (100ppm) and among non-systemic fungicides, MEMC significantly inhibited the fungal development even at its lower concentration (1000ppm). Carnegie *et al*. (1990) showed the efficacy of Thiabendazole and a mixture of Thiabendazole and 2-aminobutane (butyl amine) on *F. solani* var. coeruleum at harvest time. Comparison between the effects of Imazalil, Prochloraz and Fenpiclonil alone or in combination with 2-aminobutane and Thiabendazole revealed that Fenpiclonil and the combination of Thiabendazole and Imazalil were more effective than Imazalil in controlling potato dry rot (Carnegie, 1998). Hymexazol, Azoxystrobin, Fludioxonil and Qoinoline significantly reduced the mycelial growth of *F. oxysporum* f. sp tuberosi, although the effect of Hymexazole was most pronounced (Ayed *et al*., 2006). Chlorothalonil, Azoxystrobin, and Hydroxyquinolin-sulfate inhibited the mycelial growth of several isolates, belonging to four *Fusarium* species. Fludioxonil showed higher efficacy and totally inhibited the mycelia growth of all tested *Fusarium* isolates. The development of *F. graminearum*, the most aggressive pathogen at inoculation and incubation conditions, and to a lesser degree the other *Fusarium* species were inhibited *in vivo* by more than 50% by Azoxystrobin, Hydroxyquinolin-sulfate and Fludioxonil treatments (Daami-Remadi *et al*., 2006a). An *in vitro* screening of some Tunisian isolates of *Fusarium* spp. for their resistance to some benzimidazoles showed that *F. solani*, *F. oxysporum* f. sp tuberosi and *F. graminearum* isolates were susceptible to these fungicides whereas *F. sambucinum* isolates were resistant (Daami-Remadi and El Mahjoub, 2006). The chemicals with a single-site mode of action such as benzimidazoles are more likely to lead to development of resistance (Kawchak *et al*., 2002). In Tunisia, *in vitro* and *in vivo* inhibition of benzimidazoles resistant isolates was achieved by several mixtures of fungicides tested individually or in dual combination (Daami-Remadi *et al*., 2006b). As some *Fusarium* species are resistant to Thiabendazole and Fludioxonil, estimating the sensitivity level of different *Fusarium* species to fungicides, for proper management of dry rot, would be essential. According to Esther *et al*. (2011) Thiabendazole can still be used to control *Fusarium* species causing dry rot except for *F. sambucinum*. The present study was conducted to evaluate the efficacy of some fungicides in suppressing Fusarium dry rot of potato under *in vitro*, *in vivo* and *in situ* conditions.

Materials and Methods

Pathogens

Fungal isolates (two isolates of *F. solani* and two isolates of *F. oxysporum*) were obtained from the Plant Protection Research Department, Agricultural and Natural Resources Center of Khorasan-Razavi. Pathogenic fungi were maintained on sterile sand at 4Ċ to be used in further studies.

Source of potato tubers

The potato cultivar Agria, the most cultivated in Iran, was used in current study. They were obtained from the Plant Protection Research Department, Agricultural and Natural Resources Center of Khorasan-Razavi, stored in a traditional store and brought to room temperature a couple of hours before use.

Fungicides

The characteristics of the five fungicides tested is listed in Table 1.

In vitro activity of tested fungicides against *Fusarium* spp.

Four isolates of *F. solani* and *F. oxysporum* were grown on Potato Dextrose Agar (PDA) at 25 °C for 7 days. Agar disks (5mm) bearing the fungus were taken from freshly growing colony and transferred on PDA amended with various concentrations of fungicides (Table 1). Culture media plus a same quantity of sterile distilled water served as untreated control. The radial growth of fungal colonies was recorded after incubation for 7 days at 25 °C. Each treatment was repeated four times. The data were collected as colony diameter values in mm per replication, and evaluated by one-way analysis of variance (ANOVA) using SPSS 16.0 for Windows.

In vivo activity of tested fungicides against _Fusarium_ spp.

Efficacy of fungicides (Imazalil and Thiabendazole) previously tested *in vitro* was estimated via development of dry rot on inoculated and treated tubers. The selected potato tubers of Agria were washed in running water, dipped in sodium hypochlorite (3%) for 10 min, rinsed abundantly with sterile distilled water (10 min) and air-dried. An isolate of *F. solani* (FPO-67) and one of *F. oxysporum* (FPO-39), being the most aggressive following pathogenicity tests, were used for tuber inoculation. Fungicides were suspended in water according to tested doses (1/1000, 1.5/1000 and 2/1000) and tuber treatment was realized by dipping tubers, for 10 min, in a fungicidal suspension prior to inoculation. Inoculation technique consisted of depositing an agar disc (5mm) colonized by pathogen in wounds (5 × 5mm). Tubers were incubated in a growth chamber, at 25Ċ for 21 days and at high relative humidity. All treatments consisted of four replicates with two tubers per replicate, and experiments were repeated two times. After incubation period, tubers were cut longitudinally through sites of inoculation, and after that parameters of dry rot induced (maximal width (w) and depth (d)) were recorded. The pathogen invasion into tubers was calculated using formula of Lapwood *et al*. (1984) as follows:

[1] Penetration = (w / 2 + (d - 6)) / 2

The invasion was evaluated by one-way analysis of variance (ANOVA) using SPSS 16.0 for Windows.

Table 1 Characteristics of fungicides tested against *Fusarium* spp.

Active ingredients (a.i)	Trade names (tn)	Concentration of a.i	*In vitro* tested doses of a.i (ppm)
Azoxystrobin	ORTIVA	25%	250 -500 - 1000
Imazalil	IMAZAGARD	5%	40 – 45 - 50
Thiabendazole	TECTO	60%	5 - 7.5 - 10
Azoxystrobin + Difenoconazole	ORTIVA TOP	200 g.l^{-1} + 150 g.l^{-1}	1000 - 2000
Fludioxonil + Difenoconazole	CELEST	25%	2 – 10 – 15 - 20

In situ activity of tested fungicides against _F. solani_ FPO-67

Imazalil and Thiabendazole, were also assessed for their *in situ* efficacy against dry rot development on treated tubers in comparison to controls. One month after harvest, potato tubers of Agria were disinfected as mentioned in *in vivo* test. Then the disinfected potato tubers were sprayed with prepared suspension (2/1000) of each fungicide. Sterile distilled water was used for control. Tubers were kept in a sterile place for 12 hours; after that, an agar disc colonized by *F. solani* FPO-67 was inoculated into a slight wound (about 2 × 2mm) in potato tubers. Fungal mycelium disc was used in positive controls and PDA disc as negative control. Inoculated tubers were placed in clean plastic crates kept in net bags, and incubated in a traditional storage in Mashhad (during December through March at about 5Ċ). After 4 months, disease incidence of Fusarium dry rot was assessed as the percentage of infected tubers out of total number of tubers in a replicate; disease severity was assessed as mentioned in *in vivo* test. Treatments were replicated four times, each replicate included 3000gr potato. The mean penetration of the fungus was evaluated by one-way analysis of variance (ANOVA) using SPSS 16.0 for Windows.

Results

Effect of fungicides on mycelia growth of *Fusarium* spp.

The effect of some fungicides, incorporated in the culture media, were tested against *in vitro* development of two isolates of *F. solani* and *F. oxysporum*. Table 2 shows that mean colony diameter, formed after 7 days of incubation at 25 °C, varied upon tested *Fusarium* isolates and treatments revealing existence of a significant interaction ($p < 0.05$) between both fixed factors. All fungicides applied *in vitro* significantly reduced mycelia growth of all tested *Fusarium* isolates in comparison to untreated control. Imazalil and Thiabendazole showed higher efficacy and totally inhibited the mycelia growth of all tested *Fusarium* isolates. Azoxystrobin, Azoxystrobin + difenoconazole and fludioxonil + difenoconazole have inhibited by more than 45% the mycelia growth of all tested *Fusarium* isolates in comparison to untreated control, although fludioxonil + difenoconazole had a better effect especially at 10ppm. Azoxystrobin showed less efficiency as mycelia growth was reduced by 45 to 72% for all tested isolates, Fungicides effects on *F. solani* and *F. oxysporum* was different; inhibition varied from 45% to 100% depending on *Fusarium* species and different isolates within the same species.

Table 2 In vitro efficacy of some fungicides on mycelial growth of four *Fusarium* isolates.

Treatments (concentration)	Mean colony diameter (mm)[1]			
	FPO-19[1]	FPO-67	FPO-35	FPO-39
Imazalil (40 ppm)	1.75i	3.50g	0g	0g
Imazalil (45 ppm)	1.00i	0h	0g	0g
Imazalil (50 ppm)	0j	0h	0g	0g
Thiabendazole (5 ppm)	4.00h	0h	0g	0g
Thiabendazole (7.5 ppm)	0j	0h	0g	0g
Thiabendazole (10 ppm)	0j	0h	0g	0g
Azoxystrobin (250 ppm)	23.50b	23.00c	25.00c	3.75c
Azoxystrobin (500 ppm)	23.75b	20.50d	22.75d	28.25d
Azoxystrobin (1000 ppm)	19.75d	19.75d	20.00e	22.75e
Azoxystrobin + difenoconazole (1000 ppm)	21.50c	17.25e	23.00cd	27.25d
Azoxystrobin + difenoconazole (2000 ppm)	19.50d	17.00ef	18.00e	22.75e
Fludioxonil + difenoconazole (2 ppm)	17.75e	29.75b	35.00b	36.75b
Fludioxonil + difenoconazole (10 ppm)	7.75g	15.75f	14.75f	19.25f
Fludioxonil + difenoconazole (20 ppm)	10.00f	17.50d	15.25f	21.00ef
Control	49.75a	41.25a	74.25a	77.00a

[1]Values (means of four replicates) in each column followed by the same letter(s) are not significantly different according to Duncan's multiple range test at $p < 0.05$.

Effect of imazalil and thiabendazole on *F. solani* FPO-67 and *F. oxysporum* FPO-39 under *in vivo* condition

Table 3 shows mean pathogen penetration in tubers cv. Agria. Individually inoculated by *F. solani* FPO-67 and *F. oxysporum* FPO-39, after 21 days of incubation at 25-27 Ċ, depending on different treatments. Obtained results revealed existence of a significant interaction (at $p < 0.05$) between treatments and *Fusarium* isolates. All tested doses fungicides significantly limited dry rot development on inoculated tubers by more than 50%. Maximum inhibition was reached by imazalil and thiabendazole, at three different doses, where development of dry rot was totally stopped, in comparison to untreated control in the case of *F. oxysporum* FPO-39. In vivo development of *F. solani* FPO-67, the most aggressive *Fusarium* isolate at these incubation conditions, was inhibited by more than 53.42% by all treatments. In fact, *F. solani* FPO-67 inhibition varied from 53.42% (1/1000) to 97.44% (2/1000) in the case of imazalil. Thiabendazole at 1/1000, 1.5/1000 and 2/1000 inhibited *F. solani* FPO-67 penetration by 60.36%, 70.85% and 88.98% respectively. (Figs 1-2).

Table 3 In vivo efficacy of imazalil and thiabendazole on *Fusarium solani* FPO-67 and *F. oxysporum* FPO-39.

Treatments (concentration)	Mean of fungus penetration (mm) [1]	
	F. solani FPO-67	*F. oxysporum* FPO-39
Imazalil (2/1000)	1.37d	0c
Imazalil (1.5/1000)	5.87b	0c
Imazalil (1/1000)	7.19b	5.7b
Thiabendazole (2/100)	1.70cd	0c
Thiabendazole (1.5/1000)	4.50bc	0c
Thiabendazole (1/1000)	6.12b	6.5b
Control	15.44a	14.7a

[1]Values (means of four replicates) in a column followed by the same letter(s) are not significantly different according to Duncan's multiple range test at $p < 0.05$.

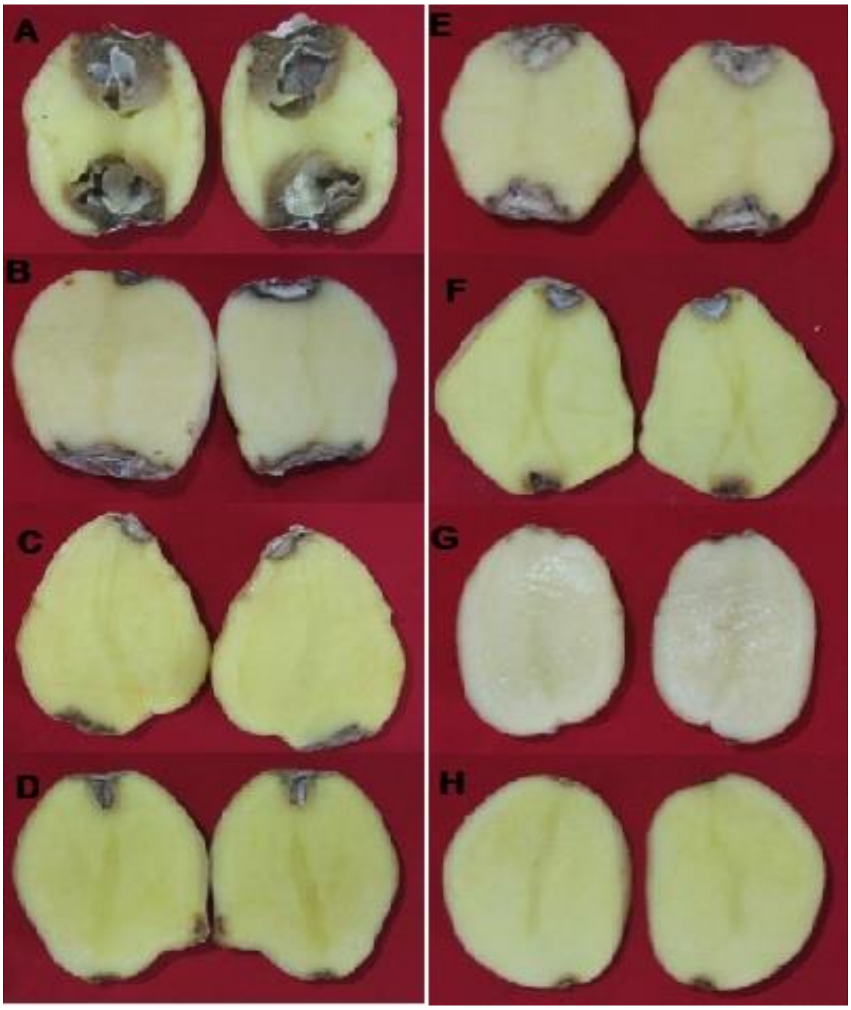

Figure 1 The effect of imazalil on Fusarium dry rot inhibition under *in vivo* condition. A: Control (*F. solani* FPO-67); E: Control (*F. oxysporum* FPO-39); B and F: Imazalil (1/1000); C and G: Imazalil (1.5/1000); D and H: Imazalil (2/1000).

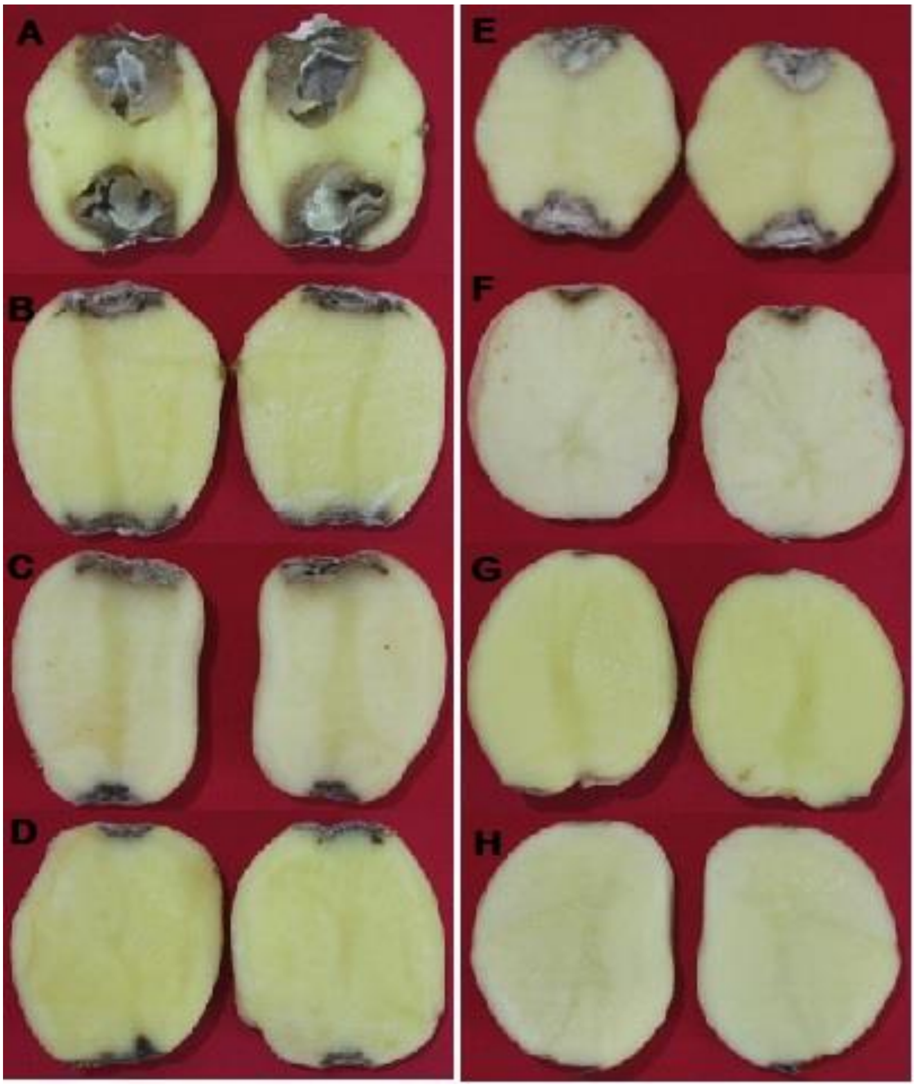

Figure 2 The effect of thiabendazole on Fusarium dry rot inhibition under *in vivo* condition. A: Control (*F. solani* FPO-67); E: Control (*F. oxysporum* FPO-39); B and F: Thiabendazole (1/1000); C and G: Thiabendazole (1.5/1000); D and H: Thiabendazole (2/1000).

Effect of fungicides on dry rot development in natural conditions of a traditional storage

The effect of imazalil and thiabendazole, applied individually, was evaluated on potato tubers cv. Agria, not previously inoculated. Table 4 shows that imazalil and thiabendazole, applied prior to final storage, inhibited development of dry rot in store by more than 65%. Thiabendazole with 71.69% inhibition and 19.4% disease incidence was the most effective treatment against *F. solani* FPO-67 (Table 4, Fig. 3).

Table 4 In situ efficacy of imazalil and thiabendazole on *Fusarium solani* FPO-67.

Treatments (concentration)	Mean of fungus penetration (mm)[1]	
	Penetration	Disease incidence
Imazalil (2/1000)	7.30cd[A]	38.43ab
Thiabendazole (2/1000)	6.14cd	19.40c
Control	21.69a	25.47a

[1]Values (means of four replicates) in a column followed by the same letter(s) are not significantly different according to Duncan's multiple range test at $p < 0.05$.

Figure 3 The effect of thiabendazole on prevention of dry rot in storage condition. A: Control (*Fusarium*. *solani* FPO-67); B: Imazalil (2/1000); C: Thiabendazole (2/1000).

Discussion

Dry rot is not just a minor problem like some caused by many other pathogens. It destroys tubers and leaves them completely inedible or unusable as seed in the future. Long-term storage losses have been reported to be as high as 60% while annual dry rot losses can range from 6 to 25% (Gachango *et al*., 2012). In this study first, the effect of imazalil, thiabendazole, azoxystrobin, azoxystrobin + difenoconazole and fludioxonil + difenoconazole were evaluated against two isolates of *F. solani* and *F. oxysporum* under *in vitro* condition, and quite satisfactory results were obtained. Thiabendazole significantly inhibited the fungal growth of all *Fusarium* isolates, even at its lower concentration (5ppm).these results were consistent with findings of Murdoch and Wood (1972). Similarly Lashin and Henriksen (1977) reported thiabendazole very effective under *in vitro* condition against *F. solani* var. coeruleum, causing dry rot of potato. Rafiq *et al*. (1955) reported that thiabendazole was most effective in checking the growth of *F. oxysporum*, *F. solani*, *F. roseum* and *Rhizoctonia solani* at all concentrations used. The next effective fungicide was imazalil, which stopped the mycelial growth of all *Fusarium* isolate at 50ppm. Similar results were obtained by Bains *et al*. (1999) where imazalil at 50ppm stopped the mycelia growth of *F. sambucinum* isolates that were resistant to thiabendazole. Imazalil also stopped the mycelia growth of *F. oxysporum* isolates at 40 and 45ppm. Azoxystrobin significantly limited fungal growth, in comparison to untreated control, in all used concentrations, but according to studies conducted in Tunisia, azoxystrobin at 200ppm, had no significant effect on reduction of mycelia growth of either *F. solani* or *F. oxysporum* (Daami -Remadi *et al*., 2006a). Considering that the fungicide had the same amount of active ingredient in both studies, it could be argued that isolates and different species in different regions may show different sensitivities to the same fungicide. Azoxystrobin also showed fungicidal activity against *F. oxysporum* f. sp. tuberosi isolates (Ayed et al., 2006). In the current study, fludioxonil + difenoconazole inhibited the mycelial growth of *Fusarium* isolates, when applied at 2ppm. At 2ppm, fludioxonil significantly (73%) inhibited mycelia development of *F. oxysporum* f. sp. tuberosi (Ayed *et al*., 2006). Fludioxonil showed higher efficacy by totally inhibiting the mycelia growth of all tested *Fusarium* spp. and isolates, including those of *F. sambucinum* resistant to benzimidazoles, when applied at 2ppm (Daami-Remadi *et al*., 2006a). Under *in vitro* condition, imazalil and thiabendazole proved statistically superior over the rest of fungicides tested at different concentrations. So, only these two fungicides were selected for *in vivo* tests against *F. solani* FPO-67 and *F. oxysporum* FPO-39, which were more virulent than the other two isolates. In the present work, the *in vivo* investigations revealed that thiabendazole and imazalil caused complete inhibition of dry rot caused by *F. oxysporum* FPO-39, and also had a noticeable effect on the inhibition of *F. solani* FPO-67. Under *in situ* condition, imazalil and thiabendazole had a noticeable effect on the incidence and severity of potato dry rot caused by *F. solani* FPO-67. The results of this study showed that the post-harvest dry rot disease of potato tubers could be controlled by imazalil and thiabendazole fungicides which show toxic effect on *F. solani* and *F. oxysporum*. In support to the present findings, there are reports suggesting the effectiveness of fungicides against *Fusarium* species and dry rot disease of potato. Carnegie *et al*. (1998) found that fenpiclonil and the mixture of thiabendazole and imazalil were more effective in controlling dry rot caused by *F. solani* var. coeruleum than imazalil alone. Similar results were shown by Maughan *et al*. (1991) who found that the post-harvest thiabendazole or imazalil treatments have been used primarily to prevent the development of dry rot in stored potatoes. On the other hand Carnegie *at al*. (2001) illustrated that dipping tubers in imazalil fungicide gave significant reduction in dry rot disease. Galben® mancozeb and Galben® copper fungicides had good potential for successful inhibition against *F. solani*, where Galben mancozeb was more effective than Galben copper (Awadall *et al*., 2008). Hide and Cayley (2008) stated that thiabendazole, imazalil and prochloraz applied to tubers immediately after wounding almost completely prevented dry rot. Treatment 3 days after wounding was less effective and the amount of disease increased with further delay; fungicides were more effective against *F. solani* var. coeruleum and *F. sulphureum* on tubers held at 5 Ċ than at 10 or 15 Ċ before treatment and storage. Due to limited access to post-harvest products for controlling storage pathogens, devising strategies to ensure pathogen-free tubers is essential. Post-harvest application of fungicides is one of the most effective methods for controlling the spread of storage diseases. Thiabendazole is the only fungicide registered for controlling Fusarium dry rot, but it is not effective in controlling *F. sambucinum* (Ocamb *et al*., 2007). Although *F. sambucinum* resistant to thiabendazole has been reported in Europe and the United States (Hide *et al*., 1992), yet many *Fusarium* species including *F. solani* and *F. oxysporum* are susceptible to these fungicides (Gachango *et al*., 2012). So thiabendazole can still play an important role in the management of post-harvest diseases especially if it is used in alternation with other compounds or in combination with biological products (AL-Mughrabi *et al*., 2013). Since investigations were not conducted on the use of different fungicides to control of potato dry rot in Khorasan province. Considering the importance of and need to control this disease, different fungicides were studied under *in vitro* and then *in vivo* and *in situ* conditions for the effective management of potato dry rot.

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References

AL-Mughrabi, K. I., Vikram, A., Peters, R. D., Howard, R. J., Grant, L., Barasubiye, T., Lynch, K., Poirier, R., Drake, K. A., Macdonald, I. K., Lisowski, S. L. I. and Jayasuriya, K. E. 2013. Efficacy of *Pseudomonas syringae* in the management of potato tuber diseases in storage. Biological Control, 63: 315-322.

Awadall, O. A., Abuel-Souod, S. M., Assawah, S. M. W. and El-Debaky, S. A. 2008. Control of dry and soft rot disease of potato tubers using essential oils, fungicides and antagonistic fungi. The Egyptian Society of Experimental Biology, 4: 1-11.

Ayed, F., Daami-Remadi, M., Jabnoun-Khiareddine, H., Hibar, Kh. and Mahjoub, M. E. 2006. Evaluation of fungicides for control of Fusarium wilts of potato. Plant Pathology Journal, 5 (2): 239-243.

Bains, P. S., Bennypaul, H., Kawchuk, L. M. and Holley, J.D.1999. Fludioxonil (Maxim) provides effective control of Fusarium dry rot of potatoes (*Fusarium* spp.). Proceeding of the Alberta Regional Meeting, The Canadian Phytopathological Society.

Carnegie, S. F., Ruthven, A. D., Lindsay, D. A. and Hall, T. D. 1990. Effect of fungicides applied to seed potato tubers at harvest or after grading on fungal storage diseases and plant development. Annals of Applied Biology, 116: 61-72.

Carnegie, S. F., Cameron, A. M., Lindsay D. A., Sharp, E. and Nevison, I. M. 1998. The effect of treating seed potato tubers with Benzimidazoles, Imidazole and Phenylpyrrol fungicides on the control of rot and skin blemish diseases. Annals Applied Biology, 133: 343-363.

Carnegie, S. F., Cameron, A. M. and Haddon, P. 2001. The effect of date of haulm destruction and harvest on the development of dry rot caused by F. solani var. coeruleum on potato tubers. Annals of Applied Biology, 139 (2): 209-216.

Cherif, M., Omri, N., Hajlaoui, M. and Boubaker, A. 2001. Effect of some fungicides on *Fusarium roseum* var. sambucinum causing potato tuber dry rot and on *Trichoderma* antagonists. Annales de 1 INRAT, 74: 131-149.

Daami- Remadi, M. and El Mahjoub, M. 1997. Fusarium of potato in Tunisia -IV: activity of four fungicides against local strain of *Fusarium*. Annales de 1 INRAT, 70: 3-19.

Daami-Remadi, M. and El Mahjoub, M. 2006. Presence in Tunisia of *Fusarium sambucinum* isolates resistant to benzimidazoles: in vitro growth and aggressiveness on potato tubers. Biotechnology, Agronomy, Society and Environment, 10: 7-16.

Daami-Remadi, M., Ayed, F., Jabnoun-Khiareddine, H., Hibar, K. and El Mahjoub, M. 2006a. In vitro, in vivo and in situ evaluation of fungicides tested individually or in combination for the control of the Fusarium dry rot of potato. International Journal of Agricultural Research, 1 (6): 564-572.

Daami-Remadi, M., Jabnoun-Khiareddin, H., Ayed, F. and El Mahjoub, M. 2006b. In vitro and in vivo interaction of four fungicides with the Fusarium species complex causing tuber dry rot in Tunisia. Plant Pathology Journal, 5 (3): 362-367.

Errampalli, D. and Johnston, H. W. 2001. Control of tuber-born black scurf (*Rhizoctonia solani*) and common scab (*Streptomyces scabies*) of potato with a combination of sodium hypochlorite and thiophanate-methyl preplanting seed tuber treatment. Canadian Journal of Plant Pathology, 23: 68-77.

Eskandari, M. 1997. Identification, Pathogenicity and distribution of potato dry rot agents in Khorasan. The final report of the research project of the agricultural and natural resources. Research Center of Khorasan province.

Esther, G., Lirk, W., Hanson, L., Rojas, A., Tumbalan, P. and Shetty, K. 2011. Baseline sensitivity of Difenoconazole, Fludioxonil, and Thiabendazole fungicides against *Fusarium* species associated with dry rot of seed potato tubers in Michigan. Proceeding of the 95th Annual Meeting of the Potato Association of America.

Falahati Rastegar, F. M., Ghaledozdani, H. and Jafarpour, B. 2000. Etiology of potato dry rot in Khorasan province. Proceeding of the 14th Iranian Plant Protection Congress; Isfahan Industrial University, Iran.

Gachango, E., Hanson, L. E., Rojas, A., Hao, J. J. and Kirk, W. W. 2012. *Fusarium* spp. causing dry rot of seed potato in Michigan and their sensitivity to fungicides. Plant Disease, 96 (12): 1767-1774.

Ghalamfarsa, M. R. and Banihashemi, Z. 2000. Diagnosis and pathogenesis of *Fusarium* isolated from potato in southeast of Fars province. Proceedings of the 14th Iranian Plant Protection Congress; Isfahan Industrial University, Iran.

Hide, G. A., Read, P. J. and Hall, S. M. 1992. Resistance to thiabendazole in *Fusarium* species isolated from potato tubers affected by dry rot. Plant Pathology, 41: 745-748.

Hide, G. A. and Cayley, G. R. 2008. Effect of delaying fungicide treatment of wounded potatoes on the incidence of Fusarium dry rot in storage. Annals of Applied Biology, 107 (3): 429-438.

Karimi, A. R. 1970. Wilt of potato plants and dry rot of potato tubers. Iran. Journal of Plant Pathology, 6: 35-53.

Kawchak, L. M., Hutchison, L. J., Verhaegha, C. A., Lynch, D. R., Bains, P. S. and Holly, J. D. 2002. Isolation of the β-tubulin gene and characterization of thiabendazole resistance in *Gibberella pilicaris*. Canadian Journal of Plant Pathology, 24: 233-238.

Lapwood, D. H., Read, P. J. and Spokes, J. 1984. Methods for assessing the susceptibility of potato tubers of different cultivars to rotting by *Erwinia carotovora* subspecies atroseptica and carotovora. Plant Pathology, 33: 13-20.

Lashin, S. M. and Henriksen, J. B. 1977. Control of gangrene and Fusarium dry rot on potato tubers with thiabendazole. Saertryk of Tidsskrift for Planteavl, 81 (3): 310-314.

Leach, S. S. 1971. Post-harvest treatment for the control of Fusarium dry rot development in potatoes. Plant Disease. Reporter, 55: 723-726.

Maughan, J. P., Shanmuganathan, N., and Hepworth, G. 1991. Fungicides treatments for the control of storage rots of seed potatoes. Australian plant pathology, 49: 142-144.

Murdoch, A. W. and Wood, R. K. S. 1972. Control of *Fusarium solani* rot of potato tubers with fungicides. Department of Botany and Plant Technology, 72: 53-62.

Nasr- Esfahani, M. 1998. *Fusarium* species associated with dry rot of potato tubers Isfahan. Iran. Journal of Plant Pathology, 34: 225-232.

Ocamb, C., Hamm, P. and Johnson, D.2007. Benzimidazole resistance of *Fusarium* species recovered from potatoes with dry rot from storages located in the Columbia basin of Oregon and Washington. American Journal Potato Research, 84: 169-177.

Rafiq, M., Mirza, H., Shakir, A. S. and Akhtar, K. P. 1995. Post-harvest fungal diseases of potato in Faisalabad. Pakistan. Journal of Phytopathology, 7 (1): 44-46.

Sandipan, P. B., Solanki, B. P., Patel, N. N., Patel, R. L., Verma, P. D. and Desai, H. R. 2016. Effect of different fungicides against dry rot pathogens of potato caused by *Fusarium* sp. under in vitro condition. Cercetari Agronomic in Moldova, 4 (168): 69-74.

Scharif, G. and Ershad, D. 1966. A list of fungi on cultivated plants. Shrubs and trees of Iran. Ministry of Agriculture, Plant Pests and Diseases Research Institute, Evin, Tehran.

Sharifi, K., Zare, Z., Zamanizadeh, H. and Arjemandian, A. 2009. *Fusarium* species causing dry rot of potato in Ardabil, Tehran and Hamedan provinces. Journal of Plant Pests and Diseases, 76 (2): 93-113.

ارزیابی تأثیر چند قارچکش در کنترل گونه‌های مهم فوزاریوم عامل پوسیدگی خشک غده سیب‌زمینی

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چکیده: پنج قارچکش آزوکسی استروبین، ایمازالیل، تیابندازول، آزوکسی استروبین + دیفنوکونازول و فلودیوکسنیل + دیفنوکونازول علیه دو جدایه‌ی بیماریزا از *Fusarium solani* و *F. oxysporum* ، عوامل ایجاد کننده پوسیدگی خشک سیب‌زمینی در منطقه مشهد، مورد بررسی قرار گرفتند. اندازه‌گیری قطر پرگنه قارچ در محیط کشت PDA بعد از ۷ روز نگه‌داری در دمای ۲۵ درجه سلسیوس نشان داد که همه قارچکش‌ها به‌طور قابل‌توجهی باعث کاهش رشد میسلیومی هر چهار جدایه فوزاریوم شده‌اند، اما تنها دو قارچکش ایمازالیل و تیابندازول توانستند حتی در کم‌ترین غلظت مورد استفاده، به‌ترتیب ۴۰ و ۵ پی‌پی‌ام، رشد مسلیومی همه جدایه‌ها را به‌طور کامل متوقف کنند. میانگین نفوذ دو قارچ *F. solani* FPO-67 و *F. oxysporum* FPO-39 که شدت بیماری‌زایی بیش‌تری نسبت به دو جدایه دیگر داشتند، بعد از ۲۱ روز نگه‌داری در دمای ۲۷-۲۵ درجه سلسیوس روی غده‌های تیمار شده با دوزهای مختلف ایمازالیل و تیابندازول مورد بررسی قرار گرفت. نتایج به‌دست آمده نشان دادند که هر دو قارچکش، در غلظت ۱/۵ و ۲/۱۰۰، به‌طور کامل مانع نفوذ *F. oxysporum* FPO-39 به داخل غده شدند، اما در مورد *F. solani* FPO-67 تمام تیمارها باعث کاهش معنی‌دار پوسیدگی در مقایسه با شاهد شدند. در شرایط انبار، تیمار غده‌های سیب‌زمینی با ایمازالیل و تیابندازول ، قبل از انبار نهایی آنها، به‌ترتیب باعث کاهش پوسیدگی خشک ناشی از *F. solani* FPO-67 از ۶۸ درصد تا۷۱/۶۹ درصد شدند. با توجه به نتایج به‌دست آمده این قارچکش‌ها می‌توانند نقش مؤثری در مدیریت تلفیقی پاتوژن‌های قارچی همراه غده داشته باشند.

واژگان کلیدی: آزوکسی استروبین، ایمازالیل، تیابندازول، دیفنوکونازول، فلودیوکسنیل، مشهد، *F. solani*، *F. oxysporum*