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FURFURAL APPROACHES AS CONTROL MEASURES AGAINST ROOT ROT AND ROOT-KNOT INCIDENCE OF TOMATO UNDER GREENHOUSE AND FIELD CONDITIONS

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Abstract: The fungicidal and nematicidal activity of an emulsifiable formulation of furfural [2-furancarboxaldehyde] against root rot and root-knot pathogens was studied in laboratory, greenhouse and field experiments. The linear growth of tested soilborne pathogenic fungi was dramatically reduced with the increasing of furfural concentrations added to the growth medium up to 4000 ppm where no growth was observed, while the bacterial and fungal bioagents showed more tolerance to these concentrations and failed to grow at 6000 and 7000 ppm, respectively. Pot and field experiments indicated that furfural at 6000 ppm combined with bioagent treatments proved to have superior suppressive effect against tomato root rot incidence, caused by *Fusarium solani* and *Rhizoctonia solani*, comparing with each individual treatment. Numbers of nematodes in soil declined sharply in direct response to furfural application with the sharpest reductions in its population. No symptoms of root-knot incidence, caused by *Meloidogyne incognita* as well as no detected galls and eggmasess were observed in the root system of tomato plants grown in either artificially or naturally infested soil with the parasite at the same concentration under greenhouse and field conditions. Results from these experiments indicate that a variety of effective broad-spectrum formulations of furfural can be developed for control of economically important soilborne pests.

Key words: Bioagents, Control, Furfural, *Fusariun*, *Rhizoctonia*, Macrophomina, *Meloidogyne*, Sclerotium, Tomato.

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INTRODUCTION

The growing concern over the use of pesticides with respect to human health and environment has brought increasing interest in the use of alternatives characterized by the lake of negative effect on the environment**.** Additionally, resistance of pathogens to pesticides has rendered certain pesticides ineffective, creating a need for new ones with other modes of action. Present research focuses on finding compounds that are safe to human and environment. An alternative to pesticide application is that, it may be possible to utilize a scheme of inducible plant defenses which may provide protection against a broad spectrum of disease-causing pathogenic microorganisms.

Furfural [2-Furancarboxaldehyde] is a naturally occurring compound, present in some essential oils and in foods such as bread, baked products, and coffee. It is prepared industrially by treatment with hot sulfuric acid of pentosans contained in agricultural residues, such as cereal straw, brans, and sugarcane bagasse. Furfural is a new pesticide active ingredient intended for the use as a fumigant to control root-infesting plant parasitic nematodes and fungal plant diseases. The technical formulation (Furfural Technical) contains 99.7% furfural and is for the use in formulating end-use products and is applied to growing media and/or soils in greenhouses and field. Al-Hamdany *et al.* (1999) studied the efficacy of furfural at different concentrations for control of the root-knot nematode *Meloidogyne javanica* on cucumber and eggplant. The results indicated that using 1000 and 2000 ppm of furfural significantly reduced the root galling index in cucumber while, no galls were observed on the roots when 4000 ppm of furfural was used. Similar results were also obtained with eggplant except that 5000 ppm were needed to completely inhibit root galling. Also, Stephan *et al.* (2001) reported that no galls of *M. javanica* or wilt symptoms of *Fusarium oxysporum* were observed on tomato plants when furfural was applied at the rate of 4000 ppm before planting. On the other hand Gerik (2005) reported that most of drip irrigation treatments reduced populations of *Pythium ultimum* and *F. oxysporum* and increased stem height compared with the nontreated controls. Metham sodium, furfural + metham sodium, sodium azide, and chloropicrin significantly reduced the incidence of Liatris stem rot caused by *Sclerotinia sclerotiorum*.

In the United States (Anonymous 2006), furfural is being investigated for the control of nematodes in turf, peanuts, vegetable crops, ornamentals and fruit and vine crops. Due to furfural's low phytotoxicity, applications can be made post-plant as well as pre-plant to crops. This unique property allows for in-season applications to provide season long nematode control. Furfural is a contact nematicide and must be mechanically incorporated or moved into the soil profile with irrigation. The product currently being tested is Multiguard Protect which contains 1.04 kg a.s./l of furfural. Rates ranging from 53.5 kg a.s./ha to 155.5 kg a.s./ha are currently being tested and activity has been demonstrated on *Belonolaimus* spp. (sting), *Hoplolaimus galeatus* (lance), *Criconemella xenoplax* (ring), *Meloidogyne* spp. (root-knot) and *Paratrichodorus minor* (stubby root) nematodes. Pre-plant applications up to 448 kg a.s./ha have been tested and shown to be safe on strawberries, tomatoes and peppers. Although furfural can be injected into soil, field and microplot studies have demonstrated that delivery by drenching results in the greatest pesticidal activity.

The present work focuses on the efficacy of furfural on the growth of some soil-borne pathogenic fungi and bio-agents *in vitro* as well as evaluation of furfural ap-

plication for controlling root-knot nematodes and tomato root rot pathogens under greenhouse and field conditions.

MATERIALS AND METHODS

Microorganisms

Different bacteria, i.e. *Bacillus subtilis* and *Pseudomonas flourescens* as well as fungi, i.e. *F. oxysporum, F. solani, R. solani, S. rolfsii, M. phaseolina, T. harzianum* and *T. viride* in addition to nematode *M. incognita* were used in this study. These microorganisms were obtained from Plant Pathology Dept., National Research Centre (NRC), Dokki, Giza, Egypt.

***In vitro* tests**

The direct effect of furfural at different concentrations on the growth of various bacterial and fungal isolates was evaluated *in vitro*.

A – Effect on bacterial viability

Plate count technique (Allen 1961) was used to determine the lethal dose of furfural on bacteria. Different volumes of furfural were added to conical flasks containing sterilized nutrient broth medium to obtain the concentrations of 1000, 2000, 3000, 4000, 5000, 6000 and 7000 ppm. A set of flasks containing furfural-free medium were kept as control. Prepared flasks were inoculated individually with 1.0 ml of either *B. subtilis* or *P. flourescens* bacterial growth grown in the same medium for 48 h, then incubated for 72 h at 28 ± 1°C.

Serial dilutions (10^{-1} to 10^{-4}), of each bacterial growth were made up. A volume of 1.0 ml of final dilution of each tested bacteria was poured into Perti dishes with 20 ml of nutrient agar medium. Petri dishes were then swirled gently to ensure even distribution of bacteria in the medium. Five Peri dishes were used as replicates for each particular treatment and control as well. All plates were incubated at 28 ± 1°C for 48 hr, then examined. Bacterial colonies were counted and the number of colony forming units (cfu) per 1.0 ml of bacterial suspension was calculated.

B – Effect on fungal growth

The inhibitory effect of different concentrations of furfural on the radial mycelial growth of different soilborne fungi was evaluated. Tested fungal isolates were grown on PDA medium for 7 days before assaying. The tested concentrations of each of 1000, 2000, 3000, 4000, 5000 and 6000 ppm were prepared in flasks with PDA medium, and then poured in Petri dishes, at the rate of 20 ml/dish. Another Petri dishes containing chemical-free medium were kept as control treatment. Disks, 5 mm in diameter, taken individually from fungal cultures were placed in the centre of each Petri dish. Five Petri dishes were used as replicates for each particular treatment. Inoculated Petri dishes were incubated at 25 ± 1°C for 7 days, then the average diameter of linear growth was calculated. Reduction in mycelial growth was calculated for furfural concentrations relative to the control treatment.

Disease control measures

The effect of chemical and biological measures on the incidence of diseases of tomato was studied under greenhouse and field conditions. Furfural as chemical treatment at concentrations of 6000 ppm in addition to *B. subtilis, P. flourescens, T. harzianum* and *T. viride* as biological agents individually or integrated with furfural were evaluated against disease incidence.

***In vivo* tests**

Greenhouse experiment

Pot experiment was carried out in the greenhouse of Plant Pathology Dept., NRC, Egypt. One aggressive isolate of *F. solani* and *R. solani*, in addition to pathogenic isolate of nematode *M. incognita* were used. The present experiment included the above mentioned pathogenic microorganisms alone or in combination with furfural at 6000 ppm and/or fungal and bacterial bioagents as stated in Tables 3, 4. Loamy soil was artificially infested individually (at the rate of 5% w:w) with the inoculum of each pathogenic fungus tested which was previously grown for two weeks on sand barley medium (1:1, w:w and 40% water) at 25 ± 2ºC. A set of varied infested soil was thoroughly mixed individually with different concentrations of furfural solutions (furfural:water, v:v) at the ratio of one liter per cubic foot of soil, then covered with plastic sheet. After three days the sheet was removed and the treated soil was left for one more week with continuous daily mixing to ensure of furfural evaporation (Abdel-Kader 1983), then filled in plastic pots (20-cm-diameter). The treated soils were then infested individually with inocula of either fungal or bacterial bio-agents relevant to the specific treatment. The fungal inocula were added to the soil at the ratio of 5% of soil weight, while bacterial inocula as liquid cultures (3×10^6 cfu/m) at the ratio of 100 ml/cubic foot of soil.

Another set of varied infested soils only with pathogens were filled in plastic pots (20 cm in diameter), and used for comparison treatment. Non-infested soil served as general check treatment. Five tomato transplants (Supper Strain B, cv.) were planted in each pot and six replicated pots were used for each particular treatment. Ten days after tomato transplanting non-infested soil was used for nematode infection evaluation. Artificial infestation with pathogenic nematode was carried out incorporating *M. incognita* culture (J_2) around tomato root system (Mohamed 2005) at a rate of 1000 larvae/pot (2 kg soil). Percentage of root rot and root-knot incidence were calculated 30 days after tomato transplanting. Population of nematode *M. incognita* was also determined.

Field experiment

Chemical and biological approaches for controlling tomato root rot and root-knot were applied under naturally heavily infested field with tomato phytopathogenic microorganisms, at Kafer Kandeel, El-Saf territory, Giza governorate. This field had been chosen during the author's survey in the previous season. A field experiment consisted of plots (3.5 x 6.0 m) each comprising of 12 rows and 50 cm spacing between plants. All plots were irrigated to full water holding capacity. After three days, the irrigated plots were sprayed with furfural emulsion at concentration of 6000 ppm at the ratio of 10 l/m^2, then covered with polyethylene sheet for another three days. After removal the polyethylene sheets the field soil was artificially infested with the inocula

of fungal or bacterial bioagents. Inocula of either *T. harzianum* or *T. viride* grown on sand-barley medium at the ratio of 120 g/m^2 (Abdel-Kader 1997) as well as inocula of *B. subtilis* or *P. fluorescens* grown on nutrient broth medium at the rate of 500 ml/row (3 x 10^6 cfu) after Sellam *et al.* (1978) were used. Bioagent inocula were incorporated in the top of 20 cm of the soil surface at planting row sites considering relevant treatments:

– Furfural alone
– Furfural + *B. subtilis*
– Furfural + *P. fluorescens*
– Furfural + *T. harzianum*
– Furfural + *T. viride*
– Untreated control

One week after artificial soil infestation, all treatments were irrigated and planted with tomato transplants (Supper Strain B, cv.) on August 15, 2006 (Nile Plantation season). The experiment was set up in randomized complete block design with three replicates. Plots received the traditional agricultural practices. Average per cent of root rot and root-knot incidence and population of nematode *M. incognita* as well as obtained yield were calculated.

Rhizosphere studies

The influence of furfural soil treatment at concentration of 600 ppm on the total fungal and bacterial counts was studied. The method developed by Louw and Weblely (1959) for studying the microflora of the root region was used. The plate count technique according to Allen (1961) was followed for both total fungal and bacterial counts. Three samples were examined for calculation of total microflora counts, just before tomato transplanting and at start of flowering stage and harvest time.

Statistical Analysis

All data were analyzed according to standard procedures for analyses of variance (Steel and Torrie 1980). Fisher's least significant differences were then calculated where F values were significant.

RESULTS AND DISCUSSION

***In vitro* tests**

The effect of increased concentrations of furfural on the growth and viability of some soilborne fungi and bacteria are presented in Tables 1, 2. Obtained results showed that furfural was significantly able to reduce gradually either the linear growth of tested soilborne fungi or viability of bacteria by increasing its concentrations. Complete growth inhibition of *F. oxysporum, F. solani, R. solani, S. rolfsii, M. phaseolina* was observed at concentration of 4000 ppm, while the bioagents *T. harzianum* and *T. viride* tolerated higher concentrations and failed to grow at 7000 ppm. The tested bacterial bioagents showed a similar trend loosing their viability at 6000 ppm. However, not much can be found in the literature regarding the efficacy of furfural against fungi and bacteria, the metabolism and effects of furfural in eukaryotic cells have been investigated for yeast cells. In this case, the conversion of furfural depends on the rate of oxidizing in yeasts. Furfural is oxidized to furoic acid under aerobic conditions, and it is reduced to furfuryl alcohol in anaerobic fermentation (Taherza-

deh *et al*. 1999). The authors indicated that when furfural was added to the culture medium, both cellulose and β-glucosidase activities decreased with increasing furfural concentration. The activity of both enzymes decreased by 50% when concentration of furfural increased from 0 to 1.2 g/l (1200 ppm). Furthermore, Flor (1926) first studied the fungicidal properties of furfural, reporting control of *R. solani* in potato. More recently, Canullo *et al.* (1992) demonstrated that soil treatments with furfural control southern blight caused by *S. rolfsii* in lentil, while stimulating development of *Trichoderma* spp. and bacteria antagonistic to *S. rolfsii*. These reports confirm the present findings.

Table 1. Total counts of viable bacterial cells in response to different concentrations of furfural

Furfural concentration [ppm]	Bacterial counts [10^6 cfu/ml]	
	Bacillus subtilis	*Pseudomonas flourescens*
0	73.2	83.4
1000	54.6	48.3
2000	31.3	28.6
3000	22.8	17.5
4000	12.7	7.6
5000	3.8	1.3
6000	0.0	0.0
7000	0.0	0.0
LSD at 5% for concentrations (c): 7.4, Bacteria (b): 8.2, between (cxb): 11.3		

Table 2. Reduction [%] in mycelial linear growth of some soilborne fungi in response to different concentrations of furfural

Fungi	Furfural concentration [ppm]						
	1000	2000	3000	4000	5000	6000	7000
Fusarium oxysporum	17.7*	24.4	72.2	100	100	100	100
Fusarium solani	16.7	22.2	66.6	100	100	100	100
Rhizoctonia solani	13.3	31.1	44.4	100	100	100	100
Sclerotium rolfsii	13.3	26.7	63.3	100	100	100	100
Macrophomina phaseolina	20.0	44.4	72.2	100	100	100	100
Trichoderma harzianum	0	0	5.6	12.2	14.4	24.4	100
Trichoderma viride	0	0	7.8	13.3	15.5	27.8	100
LSD at 5% for concentrations (c): 9.6, Fungi (f): 4.7, between (cxf): 12.4							

*Reduction in mycelial growth was calculated in furfural concentrations relative to the growth in control treatment

***In vivo* tests (greenhouse and field experiments)**

The efficacy in pot trial of controlling *F. solani* and *R. solani* (root rot fungi) as well as *M. incognita* (root-knot nematode) on tomato using chemical and biological measures was determined. The results presented in Tables 3, 4 showed superior effect of combined chemical and biological treatments against the incidence of either root rot or root-knot incidence comparing with each treatment alone and control as well. Significant reduction of root rot incidence was observed in furfural treated soil and/or

Table 3. Percentage of root rot incidence of tomato plants in response to different chemical and biological factors under greenhouse conditions

Treatment	Root rot incidence [%]
F. solani	26.6
R. solani	30.0
F. solani + *B. subtilis*	6.6
F. solani + *P. flourescens*	6.6
F. solani + *T. harzianum*	10.0
F. solani + *T. viride*	10.0
R. solani + *B. subtilis*	6.6
R. solani + *P. flourescens*	6.6
R. solani + *T. harzianum*	10.0
R. solani + *T. viride*	10.0
Furfural	3.3
Furfural + *F. solani*	10.0
Furfural + *R. solani*	10.0
Furfural + *F. solani* + *B. subtilis*	3.3
Furfural + *F. solani* + *P. flourescens*	3.3
Furfural + *F. solani* + *T. harzianum*	3.3
Furfural + *F. solani* + *T. viride*	3.3
Furfural + *R. solani* + *B. subtilis*	3.3
Furfural + *R. solani* + *P. flourescens*	3.3
Furfural + *R. solani* + *T. harzianum*	3.3
Furfural + *R. solani* + *T. viride*	3.3
Untreated control	16.6
LSD at 5%	2.84

Furfural applied at 6000 ppm

inoculated with the bioagents. The recorded percentage of tomato root rot incidence was 26.6 and 30% in soil inoculated with *F. solani* and *R. solani*, respectively. These percentages sharply decreased down to 6.6 and 10% in the presence of introduced antagonistic bacteria and fungi. More reduction of 3.3% in root rot incidence was observed when the antagonistic microorganisms were combined with furfural application. Root-knot incidence amounted to 100% in soil artificially infested with initial population of *M. incognita* at a rate of 1000 larvae/pot (2 kg soil) comparing with 27.8% in untreated control containing 358 initial population of the native nematode. Population density of *M. incognita* and number of galls and eggmasses showed higher figures in artificially infested soil than the natural one. The application of furfural to either artificially or naturally infested soil with *M. incognita* resulted in complete reduction in root-knot incidence. A similar trend was also observed under natural field conditions (Tables 5, 6). Furfural caused the reduction in root-rot incidence, being 75.43% comparing with untreated control when applied alone. Combined treatments with furfural and either bacterial or fungal bioagents showed a lower effect, although they reduced the disease incidence by more than 41%. A similar effect was also reported for tomato wilt caused by *F. oxysporum* (Stephan *et al.* 2001) and stem rot of liatris (*Liatris punctata*) caused by *S. sclerotiorum* (Gerik 2005). Moreover, botanical aromatics, furfural, citral and benzaldehyde showed potential for control of both fungal pathogens and phytoparasitic nematodes (Bauske *et al.* 1997) and they did not reduce colonization of cotton roots by plant growth promoting rhizobacteria (PGPR).

It is interesting to note that all applied treatments in the present study caused a complete reduction in root-knot incidence and population density of *M. incognita*. These results are in agreement with those obtained by Al-Hamady *et al*. (1999) and Stephan *et al.* (2001) who suggested that the nematode reduction my be attributed to the fact that furfural acts as organic matter. Mohamed (2005) studied the lethal efficacy of different concentrations against the nematode *M. incognita* under field conditions. He found that numbers of nematodes in soil declined sharply in direct response to increasing rates of furfural from 1000 up to 5000 ppm. A complete reduction of galls, females, eggmasses and J_2 in soil were observed at 4000 ppm.

There are a few cited reports explaining the furfural mode of action against soil microflora. In this regard, the end-use product containing 90% furfural in a liquid formulation is registered as commercial products, e.g. Crop guard, Multigaurd protect and Protect etc. (Anonymous 2005, 2006). Pamphlet sheet of Protect (2005–2006) has demonstrated efficacy in the control of plant parasitic nematodes and fungal pathogens, i.e. *Pythium, Fusarium, Phytophthora* and *Rhizoctonia.* Protect is a contact soil treatment that kills nematodes by irreversibly damaging the cuticle and kills fungi by reacting with the cellular wall and disrupting cellular functions. Also, it is obvious from Multigaurd fate sheet that it controls root infesting plant parasitic nematodes and fungal plant pathogens such as *Pythium, Phytophthora, Fusarium* and *Rhizoctonia*. Burelle (2007) reported that a commercial formulation of furfural (Multiguard® Protect) was evaluated in greenhouse trials over three seasons for effects on parasitic and beneficial nematode populations in roots and soil, plant growth, and galling on tomato and bell pepper caused by *M. incognita*. He found that Multiguard has an effect on either the host plant or the nematode that inhibits gall formation in tomato. Regardless the effects of Multiguard on nematode and microbial ecology, high rates of Multiguard effectively managed galling caused by *M. incognita* on tomato and pepper.

This effect varied depending on the host plant and rate of treatment, and may reflect effects on soil microoganisms. Moreover, many distinguished scientists supervised laboratory and field trails concerning the efficacy of furfural against soil microorganisms. They recorded that furfural is a natural bactericide, fungicide, insecticide and nematicide which interacts with the cuticle of the nematode, effectively stripping the protective layers which results in the cuticle swelling and disintegrating. Movement of the nematode is impeded and it subsequently dies through dehydration or attack by parasitic organisms. Due to its contact mode of action correct positioning of furfural is imperative for effective control. Residue analyses showed no levels of furfural above natural background levels found within the plant or fruit even after multiple applications during the growing season (Rodriguez-Kabana 2006; Steyn 2006).

Table 4. Effect of furfural application on tomato root-knot incidence and population density of *M. incognita* under greenhouse conditions

Treatment	Root-knot incidence [%]	Population of *M. incognita*			
		P_i*	No. galls	No. eggmass	Population density
M. incognita	100	1000	380	395	16290
Furfural	0.0	1000	0.0	0.0	0.0
Furfural + *M. incognita*	0.0	1000	0.0	0.0	0.0
Untreated control	27.8	358	64	42	576

* P_i – initial population of nematode

Table 5. Percentage of root rot and root-knot incidence of tomato plants and their yield in response to different chemical and biological factors under field conditions

Treatment	Root rot		Root-knot		Yield	
	incidence [%]	reduction [%]	incidence [%]	reduction [%]	kg/plot	increase [%]
Furfural	3.80	75.43	0.0	100	153.6	22.58
Furfural+*B. subtilis*	6.66	56.94	0.0	100	148.8	18.75
Furfural+*P.fluorescens*	7.38	52.29	0.0	100	147.6	17.79
Furfural+*T. harzianum*	8.80	43.11	0.0	100	145.2	15.88
Furfural+*T. viride*	9.04	41.56	0.0	100	144.8	15.56
Untreated control	15.47	–	63.5	–	125.3	–
LSD at 5%	1.20		1.0		1.8	–

Table 6. Effect of furfural application on tomato root-knot and population density of *M. incognita* uder field conditions

Treatment	Root-knot incidence [%]	Population of *M. incognita*			
		P_i *	no. galls	no. eggmass	population density
Furfural	0.0	350	0	0	0
Furfural + *B. subtilis*	0.0	340	0	0	0
Furfural + *P. fluorescens*	0.0	280	0	0	0
Furfural + *T. harzianum*	0.0	360	0	0	0
Furfural + *T. viride*	0.0	365	0	0	0
Untreated control	63.5	370	87	56	1380

* P_i – initial population of nematode

Rhizosphere studies

Data in Table 7 show a drastic, sharp reduction in fungal and bacterial counts after furfural application and the decline in fungal propagules from 174.86 down to 9.63 x 10^3 cfu/g soil and from 197.31 to 3.80 x 10^6 cfu/g soil for bacterial cells. During the growing season it was noticed that the total counts of fungi and bacteria in the rhizosphere of tomato plants increased as plants grew up reaching their maximum at harvest time where no significant differences were observed between treatments and control. Data also show that the average total fungal counts were higher in *T. harzianum* and *T. viride* treatments than those of *B. subtilis* and *P. flourescens* throughout the growing season, while the opposite feature was observed regarding bacterial counts. Another conclusion may be drawn from the fact that the microorganism counts curve showing fungal population of the rhizosphere in antagonistic fungal treatments were almost a mirror image of those representing bacterial counts in antagonistic bacterial treatments. These differences could be attributed to the initial inoculum of fungi or bacteria introduced to the soil. The high population density of fungi or bacteria introduced through soil treatment technique enables these microorganisms to adapt themselves against environmental conditions (Papavizas 1982) resulting in the dominance of high population observed. Application of furfural and benzaldehyde to soil causes both quantitative and qualitative shifts in the composition of the soil bacterial community (Bauske *et al.* 1997). After decreasing in the first 24 h after application, bacterial populations increased 1 week after application and remained higher than in non-treated control soils for 7 weeks (Kloepper *et al.* 1999). In the present study, increasing both fungal and bacterial population in treated rhizospheric soil to reach the nearest counts in untreated soil is an expected phenomenon for microbial equilibrium in nature. Initial population of soil microflora increasing throughout the growing season enhanced with favourable conditions lead to rapid propagation in the plant root region, e.g. root exudates, plant debris and other organic materials especially in tomato plants which received the traditional fertilizers needed (El-Said 1997).

In conclusion, the obtained results in the present study showed that furfural can have a considerable fungicidal and nematicidal activity in the soil. Its physical and

chemical properties suggest potential for commercial formulation and application. These factors combine with its relative safety to humans, low price and its ready degradation by soil microorganisms (Canullo *et al.* 1992). It is suggested that furfural could be considered as a broad spectrum microbiocide and nematicide.

Table 7. Frequency of occurrence of fungal and bacterial total counts in rhizosphere region of tomato plants in response to furfural application

Treatment	Total fungal counts [1 x 10^3]/gram of dry soil			Total bacterial counts [1 x 10^6]/gram of dry soil		
	before trans-planting	at flowering stage	at harvest time	before trans-planting	at flowering stage	at harvest time
Furfural	9.63	32.66	228.45	3.80	22.60	314.34
Furfural + *B. subtilis*	10.64	31.94	241.66	16.41	40.32	351.23
Furfural + *P. fluorescens*	10.32	30.96	239.34	16.32	41.07	348.63
Furfural + *T. harzianum*	14.27	44.71	252.73	8.26	28.64	294.52
Furfural + *T. viride*	14.38	43.14	250.32	8.24	29.17	287.69
Untreated control	174.86*	247.76	279.88	197.31*	251.38	384.78
LSD at 5%	68.2	73.4	n.s.	86.3	79.4	n.s.

*Soil microflora before furfural application were 197.31 x 10^6 cfu/ g soil for bacteria and 174.86 x 10^3 cfu/g of soil fungal counts

REFERENCES

Abdel-Kader M.M. 1983. Wilt disease of Egyptian lupin. M. Sc. thesis, Fac. Agric. Cairo Univ., 177 pp.

Abdel-Kader M.M. 1997. Field application of *Trichoderma harzianum* as biocide for control of bean root rot disease. Egypt. J. Phytopathol. 25: 19–25.

Al-Hamdany M.A., Al-Noaimi H.N., Aboud H.M., Salih H.M. 1999. Use of furfural for control of the root-knot nematode *Meloidogyne javanica* on cucumber and eggplant under greenhouse conditions. Arab. J. Pl. Prot. 17 (2): 84–87.

Allen O.N. 1961. Experiments on Soil Bacteriology. Burgess Publishing Co., Minnesota, USA, 214 pp.

Anonymous 2005. Environmental Fate and Effects Division Review of the New Chemical. U.S. Environmental Protection Agency, Office of Prevention Pesticides http://www.epa.gov/opprd001/factsheets/furfuralEFEDRA.pdf

Anonymous 2006. Furfural Chemical Documents. Fact Sheets on New Active Ingredients.U.S. Environmental Protection Agency. http://www.epa.gov/opprd001/factsheets/

Bauske E.M., Backman P.A., Harper K.M., Brannen P.M., Rodríguez-Kábana R., Kloepper J.W. 1997. Effect of botanical aromatic compounds and seed-surface pH on growth and colonization of cotton plant growth-promoting rhizobacteria. Biocontrol Science and Technology 7: 415–421.

Burelle N.K. 2007. Effects of furfural on nematode populations and galling on tomato and pepper. Nematropica, Unpublished.

http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=216587

Canullo G.C., Rodriguez-Kabana R., Kloepper J.W. 1992. Changes in soil microflora associated with control of *Sclerotium rolfsii* by furfuraldehyde. Biocontrol Science and Technology 2: 159–169.

El-Said S.I.A. 1997. Rhizospheric microflora in relation to some root diseases. Ph.D. Thesis, Fac. Agric., Ain Shams Univ., 190 pp.

Flor H.H. 1926. Fungicidal activity of furfural. Iowa State College. J. Sci. 1: 199–227.

Gerik J.S. 2005. Evaluation of Soil Fumigants Applied by Drip Irrigation for Liatris Production. Pl. Dis. 89: 883–887.

Kloepper J.W., Rodriguez-Kabana R., Zehnder B.G.W.E., Murphy J.F., Sikora A.E., Fernández C. 1999. Plant root-bacterial interactions in biological control of soilborne diseases and potential extension to systemic and foliar diseases. Australasian Plant Pathology 28: 21–26.

Louw H.A., Webely D.W. 1959. The bacteriology of root region of cat plant grown under controlled pot culture conditions. J. Appl. Bacteriol. 22: 216–226.

Mohamed M.M.M. 2005. Studies on nematode pests associated with some oil crops and their control methods. Ph.D. Thesis, Fac. Agric. Al-Azhar Univ., 182 pp.

Papavizas G.C. 1982. Survival of *Trichoderma harzianum* in soil and in pea and bean rhizosphere. Phytopathology 72: 121–125.

Protect 2005–2006. Protect is an emulsifiable concentrate soil treatment. http://www.cropguard.co.za/protect2/

Rodriguez-Kabana R. 2006. The nematicidal and herbicidal activities of furfural: A review. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Abstr., No. 41. http://www.mbao.org/2006/06Proceedings/mbrpro06.html

Sellam A.A., Abdel Razik A.A., Rushdi H. 1978. Antagonistic effect of *Bacillus subtilis* and *Cephalosporium maydis.* Egypt. J. Phytopathol. 10: 97–105.

Steel R.G.D., Torrie J.H. 1980. Principles and procedures of statistics. New York, McGraw-Hill Book Company Inc., 481 pp.

Stephan Z.A., Al-Hamadany M.A., Al-Din S.S., Dawood H.B. 2001. Efficacy of furfural treatment in controlling the disease complex of root-knot nematode and Fusarium wilt on tomato and egg plant under Lathouse conditions. Arab. J. Pl. Prot. 19: 97–100.

Steyn A. 2006. The efficacy of Crop® Guard (Furfural a.s.) as a nematicide on *Meloidogyne* sp. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Abstr., No. 44. http://www.mbao.org/2006/06Proceedings/mbrpro06

Taherzadeh M.J., Gustafsson L., Niklasson C., Lidén G. 1999. Conversion of furfural in aerobic and anaerobic batch fermentation of glucose by *Saccharomyces cerevisiae*. J. Biosci. Bioeng. 87: 169–174.

POLISH SUMMARY

BADANIE FURFURALU JAKO ŚRODKA PRZECIWKO WYSTĘPOWANIU ZGNILIZNY KORZENI I MĄTWIKA ZIEMNIACZANEGO NA POMIDORZE W WARUNKACH SZKLARNIOWYCH I W POLU

Badanie aktywności fungicydowej i nematycydowej emulgującej formy furfuralu (2-furankarboksyaldehyd) przeciw patogenom wywołującym zgniliznę korzeni pomidora oraz porazenie korzeni mątwikiem ziemniaczanym prowadzono w warunkach szklarniowych i polowych. Wzrost liniowy przenoszonych przez glebę grzybów patogenicznych był silnie inhibowany przez wzrastające do 4000 ppm stężenia furfuralu dodanego do pożywki wzrostowej. Przy stężeniu 4000 ppm nie obserwowano wzrostu tych patogenów. Natomiast wykorzystane w badaniach bakterie i grzyby antagonistyczne wykazywały większą tolerancję wobec stężeń furfuralu, a wzrost ich był wstrzymany odpowiednio w stężeniach 6000 i 7000 ppm. Wyniki doświadczeń szklarniowych i polowych wskazywały, że furfural zastosowany w stężeniu 6000 ppm w połączeniu z czynnikiem biologicznego zwalczania działał lepiej przeciwko porażeniu mątwikiem i zgniliźnie korzeni wywoływanej przez *Fusarium solani* i *Rhizoctonia solani*, niż gdy czynniki te były stosowane oddzielnie. W ziemi liczba nicieni gwałtownie spadała w wyniku zastosowania furfuralu. W przypadku mątwika ziemniaczanego nie występowały objawy porażenia korzeni pomidora ani narośla, nie stwierdzono również złóż jaj w systemie korzeniowym pomidorów rosnących zarówno w naturalnie, jak i sztucznie zakażonej mątwikiem ziemi w szklarni oraz w polu, gdzie ilość inokulum była taka sama. Wyniki badań sugerują, że możliwym jest opracowanie szeregu efektywnych formulacji furfuralu o szerokim zakresie działania przeciw patogenom o ekonomicznym znaczeniu, przenoszącym się za pośrednictwem gleby.