Egypt. J. Phytopathol., Vol. **47**, No. 1, pp. 257- 276 (2019)
ISSN 1110-0230

Management of Potato Post Harvest Tuber Rots by Some Organic Acids and Essential Plant Oils

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Dry and white rots incited by *Fusarium solani* and *Sclerotinia sclerotiorum* are responsible to cause the major postharvest losses in potato tubers cv. "Spunta" during cold storage. Isolation trials from potato tubers showing rot symptoms collected from local markets yielded forty-one fungal isolates belonging to six genera. The isolated fungi were purified and identified as *Fusarium solani* (nine isolates), *F. semitectum* (seven isolates), *Sclerotinia sclerotiorum* (six isolates), *Alternaria* sp. (six isolates), *F. oxysporum*, (five isolates), *Rhizoctonia solani* (three isolates), and *Penicillium* sp. (two isolates). Pathogenicity tests showed that *F. solani* and *S. sclerotiorum* were the most pathogenic fungi. The inhibitory effect of organic acids (boric, oxalic and salicylic acids) on the linear growth of *F. solani* and *S. sclerotiorum in vitro* showed that the tested organic acids resulted in different degrees of inhibition to the mycelial growth of the two tested fungi compared with control treatment. This inhibition was gradually increased by increasing the concentration of the tested organic acids. In addition, oxalic acid resulted in 100% inhibition to the mycelial growth of the two tested pathogens at 0.4 % concentration. The other organic acids gave intermediate inhibition. The effect of camphor oil (*Eucalyptus glabulus*), black seed (*Nigella sativa*), garlic and spearmint oils against *Fusarium solani* and *Sclerotinia sclerotiorum, in vitro* and *in vivo* on tubers during cold storage was determined. *Fusarium solani*, *F. semitectum* and *Sclerotinia sclerotiorum* were completely inhibited by the application of spearmint oil concentrations at 0.3 and 0.4%, *in vitro*. *In vivo* results showed also that *Nigella sativa* preparation was the most effective as it completely suppressed disease severity% caused by *Fusarium solani* and *Sclerotinia sclerotiorum* (0.0%) followed by Camphor oil during cold storage. Essential oils maintained highest tubers quality sprouting and reduced weight losses. Generally, treatment with both organic acids and essential plant oils gave effective control for the two pathogens and reduced the loss in fresh weight of potato tubers in addition to reducing the sprout of the tubers during cold storage at 13°C for two months.

Keywords: Potato, *Solanum tuberosum*, post-harvest tuber-rots, essential plant oils, camphor oil, black seed oil, garlic oil, spearmint oil, organic acids, salicylic acid, boric acid, oxalic acid, quality parameters of storage tubers.

Potato (*Solanum tuberosum* L.) is known as one of the most important crops overall the world. It is ranked as the fourth main food crop after wheat, maize and rice (Hawkes, 1994). The world production of potato reached about 368 million ton, of which 4.8 million tons are produced in Egypt (FAOSTAT, 2013).

Potato tubers are liable to infection by many fungi during storage leading to great loss in quantity and quality. One of the most common fungal diseases on potatoes is dry-rot causedby *Fusarium solani* (Jensen *et al*., 2011 and Naffa, 2012) and white-rot caused by *Sclerotinia sclerotiorum* (Catherino *et al.*, 2000; Siviero and Motton 2000 and Mansour and Naffa, 2005).

Potato dry-rot disease leads to significant losses in both quality and quantity of potato tubers. The causal pathogen kills potato sprouts and reduces crop establishment, when the crop losses reached up to 25% in the field and may be reached more than 60% of tubers during storage (Ghadiri *et al*., 2013).

Up to date, thirteen species of genus *Fusarium* were found to be the causals of potato dry-rot around the world. In this concern, the most important *Fusarium* spp. are *F. solani*, *F. sambucinum* and *F. avenaceum*. In North America and parts of Europe, *F. sambucinum* and *F. coeruleum* are considered to be the most significant causal agents of potato tuber dry-rot. In Britain, *F. coeruleum* is more prevalent, meanwhile in Iran and South Africa, *F. solani* is the main causal species of potato dry-rot (Chehri *et al*., 2011).

In Egypt, potato occupies an important position among all vegetable crops, and it is the second vegetable crop after tomato and the first for exportation.

Several strategies for controlling post-harvest potato tuber fungal diseases have been introduced over the years but serious losses still occur, largely because the effectiveness of these approaches is variable and often short lived (Benhamou *et al.*, 1994). Current thinking about plant protection and the environment suggests alternatives to pesticides (Liu *et al.*, 1995), so in this study, induced resistance was used for controlling plant diseases (Abd-El-Kareem, 2007)

Benzoic acid, salicylic acid and tannic acid have direct antifungal activity on *Fusarium solani*, *F. oxysporum* and *F. moniliforme* on media (Galal *et al.*, 2000).

Lui and Kushalappa, (2002) indicated that dry rot of potatoes causes significant yield loss in storage and may also produce mycotoxins and reduce plant yield and tuber quality.

Elbashir *et al*. (2011) revealed that spearmint oil was efficient treatment in reducing the sprouting and weight loss of two potato varieties (Diamant and Sinora). Also,Samane and Aminifard (2012) and Mohammadi (2012) found that application of the essential oils of ammi (*Carum copticum*) and anise (*Pimpinella anisum*) significantly increased the shelf life and inhibited the grey mould growth on tomato fruits completely in comparison to control .

The objective of this work is to study the effect of some organic acids and plant oils on protecting potato tubers from white and dry rots caused by *Sclerotinia sclerotiorum* and *Fusarium solani* and maintaining quality of tubers during storage at 13^{o}C for two months.

Materials and Methods

1- *Isolation, purification and identification the isolated fungi from potato tubers showing rot symptoms collected from local markets:*

Potato tubers showing post-harvest rot symptoms collected from the local markets were used to isolate the associated fungi with tuber rot. The infected tubers were thoroughly washed in running tap water and the infected parts were cut into small pieces with lesions having half healthy and half diseased tissue. The pieces were surface sterilized in 2 % sodium hypochlorite for two minutes. The tissue pieces were subsequently washed in three changes of sterilized water to eliminate excess sodium hypochlorite then the pieces were transferred onto PDA medium in Petri-plates. The plates were incubated at 25±2°C and observed periodically for growth of the emerged fungi. The isolated fungi were purified by hyphal tip method and/ or single spore technique and maintained on PDA slants .The purified fungi were identified on the basis of cultural, morphological characteristics using the descriptions of Booth (1971) and Domsch *et al*. (1980).

2- *Pathogenicity test of the isolated fungi:*

The purified fungi were tested for their pathogenicity on apparently healthy potato tubers (cv. Spunta), selected from local retail stores.

Apparently healthy and uniform in size potato tubers, cv. Spunta, were used in all pathogenicity tests. Tubers were held and sterilized as mentioned before. then inoculated by each of *Fusarium solani, F. semitectum, F. oxysporum, Sclerotinia sclerotiorum, Rhizopus stolonifer, Penicillium sp. Alternaria sp. and Rhizoctonia solani.* The progress of infection was examined daily on nine replicate tubers for each isolate. The inoculated tubers were stored for 10 days at room temperature 25±2°C except those inoculated by *S. sclerotiorum* were incubated in a refrigerator at 10±2°C.

Disease severity was calculated using a scale (0-4); where 0 = healthy, 1 = 1-25% infection, 2 = 26-50% infection, 3 = 51-75% infection, and 4 = 76-100% infection, as recorded by Hanounik (1986) as follows:

$$\% \text{ Disease Severity} = \frac{\Sigma (n \times v)}{4N} \times 100$$

Where:

n = Number of infected tubers in each category.

v = Numerical values of symptoms category.

N = Total number of tubers.

4 = Maximum of numerical values of symptoms categories.

3- *Source of the tested organic acids and the essential plant oils:*

Organic acids, *i.e.* salicylic, boric and oxalic acids were obtained from El-Gomhoria Chemical Co. Also, the essential plant oils of camphor oil (*Eucalyptus glabulus*), black seed (*Nigella sativa*), garlic and spearmint oils were obtained from Cairo Company for Oils, Cairo, Egypt.

4. *Effect of the tested organic acids and the essential plant oils on the linear growth of F. solani and S. sclerotiorum in vitro:*

The effect of the tested organic acids and essential plant oils on the mycelial growth of both *F. solani* and *S. sclerotiorum* was tested *in vitro*. The concentrations of 0.1, 0.2, 0.3 and 0.4% were prepared from the tested organic acids and the essential plant oils (with 0.5% Tween 20). Each concentration was added to the calculated PDA medium, just before solidification and poured into Petri-plates. After medium solidification, plates were inoculated with 5-mm discs of 7-day-old culture of any of both fungi and incubated at 25±2°C. Three plates were used for each concentration. The linear growth was measured when the plates of the control treatment were covered with the fungal growth. Inhibition percentage of mycelial growth of the tested pathogens was calculated by the formula:

$$I = (C- T) / C \times 100$$

Where:

I = Percent of inhibition in growth of the tested pathogen.

C = Linear growth of the pathogen (cm) in control.

T= Liner growth of the pathogen (cm) in treatment.

5- *Effect of the tested organic acids and the essential plant oils on management the infection by F. solani and S. sclerotiorum in vivo:*

Fresh potato tubers cv. Spounta apparently free of any damage and diseases were used in this experiment. Tubers were surface sterilized with sodium hypochlorite (2%) for 3 min. and washed several times with sterilized water. The effect of dipping potato tubers in some organic acids and the essential plant oils during cold storage period was studied. Such effect was studied in the naturally infected (uninoculated) tubers as well as the artificially inoculated tubers with any of *Fusarium solani* and *S. sclerotiorum*. Inoculation was carried out by fungal growth disks (3mm), inserted in the tuber. After 24 hours, the inoculated tubers were dipped in the given treatments. All treated tubers as well as the untreated (uninoculated and

inoculated by fungi) were stored at 13°C for two months and 90% R.H. The stored potato tubers were examined weekly for detection of decay symptoms of both fungal pathogens. Percentages of tubers rot severity was assessed eight weeks after inoculation with any of *F. solani* and *S. sclerotiorum.* Disease severity was calculated using the formula adopted by Hanounik (1986).

6- *Potato tubers quality parameters:*

The potato tubers quality parameters, *i.e.,* sprouting and loss in weight were determined in potato tubers inoculated with any of the two pathogens and uninoculated treated tubers.

a- Loss in weight:

Loss in potato tuber fresh weight % (gm fresh weight %) was estimated in the inoculated or uninoculated potato tubers of various treatments (average weight of 40 tubers for each treatment) according to the following equation:

$$\% \text{ L.W} = \frac{\text{(Initial weight - weight of potato at sampling date)}}{\text{Initial weight of potato tubers.}} \times 100$$

b- Sprouting

Spouting level was determined according to Naffa (1995), as follow: ++++ =100% sprouting; +++ = 75% sprouting; ++ = 50% sprouting; + = 25% sprouting and - = 5% sprouting.

7- *Statistical analysis:*

All data obtained were subjected to the proper statistical analysis using the MSTAT statistical software and comparison was made following Fishers L.S.D. (0.05) as described by Song and Keane (2006).

Results

1- Isolation, purification and identification of fungi isolated from potato tubers showing rot symptoms collected from local markets:

Isolation trials from potato tubers showing rot symptoms collected from local markets yielded forty-one fungal isolates belonging to six genera. The Isolated fungi were purified and identified as *Alternaria* sp., *Fusarium oxysporum* Schlecht. emend. Snyder & Hansen. *F. semitectum* Berk. & Ravenel; *F. solani* (Mart.) Sacc.; *Sclerotinia sclerotiorum* (Lib.) de Bary; *Penicillium* sp., *Rhizoctonia solani* J.G. Kühn and *Rhizopus stolonier* Vuillemin. The respective percentages of their frequency were 14.6, 12.2, 17.1, 21.9, 14.6, 4.9, 7.3 and 7.3%, respectively. The highest frequency was recorded by *F. solani* followed by *F. semitectum, Alternaria* sp. and *Sclerotinia sclerotiorum*, respectively. On the other hand, the fungus *Penicillium* sp., recorded the lowest frequency followed by both *R. solani* and *R. stolonifer*.

Table (1): Occurrence and frequency (%) of the isolated fungi from rotted potato tubers collected from different markets.

The isolated fungi	Occurrence of the isolated fungi	% Frequency
Alternaria sp.	6	14.6
F. oxysporum	5	12.2
F. semitectum	7	17.1
Fusarium solani	9	21.9
Sclerotinia sclerotiorum	6	14.6
Penicillium sp.	2	4.9
Rhizoctonia solani	3	7.3
Rhizopus stolonifer	3	7.3
Total	41	99.9

2- Pathogenicity test of the isolated fungi:

Pathogenicity test of the different isolated fungi from potato tubers (Table 2) reveal that all the tested fungi were pathogenic to the tubers at room temperature (25±2°C) except *Sclerotinia sclerotiorum* at refrigerator (10+2°C) under 90-95% relative humidity (R.H.), in pored cartoon boxes for at least two months and inoculation with the tested fungi. *F. solani, Sclerotinia sclerotiorum* and *Alternaria* sp. showed the highest level of infection for potato tubers. Meanwhile, *F. solani*, *F. oxysporum* and *F. semitectum* recorded intermediate figures of infection, being 55.56, 36.11and 25.0 % disease severity**,** respectively. However, the lowest infection on potato tubers was recorded by any of *Penicillium* sp. and *R. stolonifer* (19.44%).

Table (2): Pathogenicity test of the isolated fungi using potato tubers (cv. Spunta), ten days after incubation at 25±2°C. (*Sclerotinia sclerotiorum*) at refrigerator 10±2°C.

The tested fungi	% Diseases severity
F. solani	96.67
F. semitectum	25.0
F. oxysporum	36.11
*S. sclerotiorum**	91.66
Rhizopus stolonifer	19.44
Penicillium sp.	19.44
Alternaria sp.	88.89
Rhizoctonia solani	55.56
L.S.D at 0.05	1.2

*Potato tubers inoculated with *S. sclerotiorum* were kept in a refrigerator for ten days at 10±2°C.

3- Effect of the tested organic acids and the essential plant oils on the linear growth of F. solani and S. sclerotiorum in vitro:

3.1. Effect of the tested organic acids:

Data in Table (3) show that oxalic acid and boric acid showed complete inhibition of growth of *S. sclerotiorum* at 0.3 and 0.4% concentrations. While, *Fusarium solani* showed complete inhibition of growth only due to using oxylic acid.

Table (3): Effect of different concentrations of three organic acids on the linear growth (cm) of *F. solani* and *S. sclerotiorum in vitro*.

Treatments	Conc. (%)	*F. solani*		*S. sclerotiorum*	
		Linear growth (cm)	% Efficacy	Linear growth (cm)	% Efficacy
Boric acid	0.1	5.92	34.22	1.2	86.56
	0.2	5.25	41.67	0.33	96.33
	0.3	3.92	56.44	0.00	100.00
	0.4	3.33	63.00	0.00	100.00
	Mean	4.61		0.38	
Oxalic acid	0.1	4.92	45.33	3.19	64.56
	0.2	3.92	56.44	1.5	83.33
	0.3	0	100.00	0.00	100.00
	0.4	0	100.00	0.00	100.00
	Mean	2.21		1.17	
Salicylic acid	0.1	5.5	38.89	2.67	70.33
	0.2	4.33	51.89	2.33	74.11
	0.3	4.12	54.22	1.12	86.56
	0.4	2.67	70.33	0.33	96.33
	Mean	4.16		1.61	
Control		9	0	9	0
L.S.D at 0.05%					
Treatment (T)		0.6		0.43	
Concentration (C)		0.77		0.55	
T×C		1.34		0.95	

3.2. Effect of the essential plant oils:

Data in Table (4) indicate that spearmint oil was able to reduce the mycelial growth of *Fusarium solani* at concentrations 0.2, 0.3, 0.4 %, also, black seed oil was able to reduce the mycelial growth of *Fusarium solani* at concentrations 0.3 and 0.4%, while garlic oil was less effective in reducing growth of *Fusarium solani* of the same plant oils followed by camphor oil. The effect of these plant oils in reducing the growth of the tested pathogen in comparison with control treatment.

Spearmint oil and camphor oil were the best among all tested plant oils where their tested concentrations reduced the growth of the tested pathogen, *S. sclerotiorum* to 100%. While black seed oil was less effective on growth of the same pathogenic fungi at all different concentrations, followed by garlic oil. The effect of these plant oils in reducing the growth of the tested pathogen was more pronounced in comparison with control treatment.

Table (4): Effect of four essential plant oils on the linear growth of *F. solani* and *S. sclerotiorum in vitro.*

Essential plant oils	Conc. %	*F. solani*		*S. sclerotiorum*	
		Linear growth (cm)	% Efficacy	Linear growth (cm)	% Efficacy
Garlic	0.1	9.00	0.00	2.83	68.52
	0.2	8.67	3.67	1.91	78.76
	0.3	7.67	14.78	1.33	85.22
	0.4	7.00	22.67	0.00	100.00
	Mean	8.10		1.52	
Camphor	0.1	6.15	31.67	0.00	100.00
	0.2	4.50	50.00	0.00	100.00
	0.3	3.17	64.81	0.00	100.00
	0.4	2.68	70.22	0.00	100.00
	Mean	4.13		0.00	
Spearmint	0.1	5.48	39.17	0.00	100.00
	0.2	0.00	100.00	0.00	100.00
	0.3	0.00	100.00	0.00	100.00
	0.4	0.00	100.00	0.00	100.00
	Mean	1.37		0.00	
Nigella sativa	0.1	9.00	0.00	7.60	63.52
	0.2	7.60	15.56	7.50	80.93
	0.3	0.00	100.00	7.00	81.67
	0.4	0.00	100.00	0.00	100.00
	Mean	4.15		5.53	
Control		9.00	0.00	9.00	0.00
L.S.D at 0.05					
Oils (O)		0.19		0.16	
Conc. (C)		0.17		0.19	
O × C		0.39		0.32	

4- Effect of the tested organic acids and the essential plant oils on the severity of infection by F. solani and S. sclerotiorum in vivo:

4.1. Effect of the tested organic acids:

Data in Table (5) indicate that the three tested organic acids significantly reduced the severity of infection by *F. solani* and *S. sclerotiorum* comparing with control treatment *in vivo*.

Table (5): Effect of three organic acids on the severity of infection by *F. solani* and *S. sclerotiorum* on potato tubers.

Treatments	Conc. %	*F. solani*		*S. sclerotiorum*	
		% Disease severity	% Efficacy	% Disease severity	% Efficacy
Boric acid	0.2	3.78	58.76	25	35.72
	0.3	2.31	97.48	22.22	42.86
	0.4	0.00	100.00	19.44	50.01
	Mean	2.03		22.22	
Oxalic acid	0.2	1.95	97.98	27.8	92.85
	0.3	0.92	98.99	0.0	100.00
	0.4	0.00	100.00	0.0	100.00
	Mean	0.96		9.27	
Salicylic acid	0.2	11.11	87.9	22.22	42.86
	0.3	5.56	93.93	8.33	78.58
	0.4	4.63	94.95	5.56	85.70
	Mean	7.10		12.04	
Control	0.0	91.66	0.00	38.84	0.00
L.S.D at 0.5%					
Organic acids = (T)		0.25		0.42	
Concentration = (C)		0.29		0.48	
T × C		0.50		0.83	

4.2. Effect of the tested essential plant oils:

Data in Table (6) prove that disease severity % caused by either *Fusarium solani* or *S. sclerotiorum* was significantly decreased by all tested preparations comparing to the untreated control. The Disease severity % caused by both pathogens was significantly lower at 1.0 than at 0.5 concentrations. Camphor oil and *Nigella sativa* oil at both concentrations inhibited completely the infection of potato tubers with *F. solani*, while the infection of potato tubers cv. Spunta with *Sclerotinia sclerotiorum* was inhibited at 1% conc. in the garlic and camphor oils. Also, the results cleared that *Nigella sativa* treatment at both concentrations inhibited completely disease symptoms and prevented completely the infection of potato tubers caused by *Sclerotinia sclerotiorum.*

Table (6): Effect of four essential plant oils on severity of infection by *F. solani* and *S. sclerotiorum*

Treatment	Conc. %	*F. solani*		*S. sclerotiorum*	
		% Disease severity	% Efficacy	% Disease severity	% Efficacy
Garlic	0.5	5.56	71.39	27.78	49.99
	1.0	2.78	85.69	0.00	100.00
	Mean	4.17		13.89	
Camphor	0.5	0.00	100	5.56	89.99
	1.0	0.00	100	0.00	100.00
	Mean	0.00		2.78	
Spearmint	0.5	13.89	28.55	11.11	80.00
	1.0	2.78	85.69	8.36	84.95
	Mean	8.34		9.74	
Nigella sativa	0.5	0.00	100	0.00	100.00
	1.0	0.00	100	0.00	100.00
	Mean	0.00		0.00	
Control		19.44	0.00	55.56	0.00
L.S.D at 0.05					
Plant oils (P)		0.33		0.28	
Conc. (C)		0.21		0.18	
P × C		0.47		0.40	

5- Effect of the tested organic acids and the essential plant oils on the severity of the natural infection by tuber rots in vivo:

5.1. Effect of the tested organic acids:

Data in Table (7) show the effect of post-harvest treatments with three organic acids, *i.e.,* boric, oxalic and salicylic acids at 0.2 and 0.3% on the natural infection of potato tubers by rots eight weeks after storage. Immersing the tubers in the concentration of 0.2% of any of the three tested organic acids resulted in 22.22, 14.81 and 7.41% infection, respectively. Meanwhile, no infection by tuber rots was occurred by immersing the tubers in 0.3% concentration of any of the three tested organic acids up to eight weeks of cold storage at 13°C. Control treatment recorded 47.61 % infection.

5.2. Effect of the tested essential plant oils:

Data in Table (8) show the effect of potato tubers treatment with essential oils, *i.e.,* garlic, camphor, spearmint and *N. sativa* on natural infection of potato tubers after two months storage. Camphor and spearmint oils showed the highest efficacy (100%) at concentrations 0.5 or 1.0% on potato tubers compared with the control (0.0).

Table (7): Effect of potato tubers treatment with certain organic acids on infection with tuber rots under natural conditions.

Treatments	Conc. (%)	% Infection	% Efficacy
Boric acid	0.2	22.22	53.33
	0.3	0.00	100.00
	Mean	11.11	
Oxalic acid	0.2	14.81	68.89
	0.3	0.00	100.00
	Mean	7.41	
Salicylic acid	0.2	7.41	84.44
	0.3	0.00	100.00
	Mean	3.71	
Control	0.0	47.61	-
L.S.D at 0.5%			
Organic acids = (T)		0.36	
Concentration = (C)		0.31	
T × C		0.62	

Table (8): Effect of four essential plant oils on natural infection of potato tubers with rots.

Treatment	Conc. (%)	% Disease infection	Efficacy
Garlic	0.5	2.31	87.53
	1.0	0.92	95.03
	Mean	1.62	
Camphor	0.5	0.00	100.00
	1.0	0.00	100.00
	Mean	0.00	
Spearmint	0.5	0.00	100.00
	1.0	0.00	100.00
	Mean	0.00	
Nigella sativa	0.5	5.56	69.98
	1.0	3.70	80.02
	Mean	4.63	
Control		18.52	0.00
L.S.D at 0.05			
Plant oils (O)		0.28	
Concentrations (C)		0.17	
O × C		0.39	

6.1. Effect of the tested organic acids and the essential plant oils on the loss in tubers weight in vivo:

6.1. Effect of the tested organic acids:

Data in Table (9) indicate that boric, oxalic and salicylic acids concentrations at 0.2, 0.3, 0.4 % reduced the weight loss of naturally infected potato tubers more than those artificially infected by *F. solani* and *S. sclerotiorum* during storage at 13°C for two months.

The losses in fresh weight of potato tubers during cold storage were lower than in control. Such loss in weight was highly increased in untreated tubers during storage for two months.

Table (9): Effect of three organic acids on weight loss of potato tubers artificially infected by *F. solani* and *S. sclerotiorum* or naturally infected after two months storage.

Treatments	Conc. (%)	*F. solani*	*S. sclerotiorum*	Natural infection
Boric acid	0.2	5.5	5.1	3.3
	0.3	4.75	4.0	2.0
	0.4	3.75	3.2	1.2
	Mean	4.67	4.1	2.17
Oxalic acid	0.2	3.33	2.2	1.1
	0.3	2.4	1.0	0.5
	0.4	1.78	0.5	0.1
	Mean	2.50	1.23	0.57
Salicylic acid	0.2	5.0	4.23	2.1
	0.3	4.44	3.11	1.11
	0.4	3.20	1.84	0.99
	Mean	4.21	3.06	1.4
Control	8.49	7.1	0.1	Control

6.2. Effect of the tested essential plant oils:

Data in Table (10) indicate that garlic, camphor, spearmint and *Nigella sativa* oils at concentrations 0.5 or 1.0% reduced the weight loss of potato tubers either naturally infected or artificially inoculated with *F. solani* and *S. sclerotiorum* during the cold storage at 13°C for 2 months.

The losses in fresh weight of potato tubers during cold storage were lower than in control. Such loss in weight was highly increased in untreated tubers during storage for two months.

Table (10): Effect of four essential plant oils on weight loss of potato tubers artificially infected with each of *Fusarium solani, Sclerotinia sclerotiorum* and or left to natural infection and stored for two months.

Treatment	Conc. (%)	*F. solani*	*S. sclerotiorum*	Natural infection
Garlic	0.5	8.00	7.00	1.06
	1.0	7.50	5.50	0.43
	Mean	7.75	6.25	
Camphor	0.5	7.00	4.50	0.99
	1.0	7.00	4.00	0.27
	Mean	7.00	4.25	
Spearmint	0.5	7.00	5.50	2.96
	1.0	6.49	5.50	1.36
	Mean	6.75	5.50	
Nigella sativa	0.5	5.07	4.70	4.25
	1.0	5.00	4.10	2.35
	Mean	5.04	4.40	
Control		8.49	7.10	6.10

7- Effect of the tested organic acids and the essential plant oils on sprouting the tubers in vivo:

7.1. Effect of the tested organic acids:

Data presented in Table (11) show that all organic acid treatments resulted in reducing tubers sprouting during storage period. In general, the percentages of tubers sprout were higher in potato tubers inoculated with *F. solani* and *S. sclerotiorum* than those left to the natural infection either treated with the tested organic acids or of control treatment. Sprouting, being 5% was occurred when the inoculated tubers with the two pathogenic fungi and the naturally infected were treated with 0.4% of oxalic acid, in addition, with boric and salicylic acids at 0.4, 5% sprouting was occurred when the naturally infected tubers were treated with 0.3 and 0.4% of oxalic and salicylic acid , but with boric acid at 0.4%. Sprouting, was (-) in natural and artificial infection compared to the control (+++ and ++++) followed by boric acid and salicylic acid at the same concentration.

7.2. Effect of the tested essential plant oils:

Data in Table (12) show that all treatments decreased sprouting potato tubers compared with the control. Garlic, camphor, spearmint and *N. sativa* oils decreased sprouting (-) of naturally infected tubers while, *N. sativa* oil increased sprouting (+++) at concentration 0.5% and decreased it (+) at concentration 1.0%. Infection by *Fusarium solani*, *S. sclerotiorum* highly increased sprouting (++++) compared with natural infection (+++).

Table (11): Effect of three organic acids on sprouting of potato tubers artificially inoculated with *F. solani*, *S. sclerotiorum* or left to natural infection and stored for two months.

Treatments	Cons.	F. solani	S. sclerotiorum	Natural infection
Boric acid	0.2	++	++	+
	0.3	++	++	+
	0.4	+	+	-
Oxalic acid	0.2	+	+	+
	0.3	+	+	-
	0.4	-	-	-
Salicylic acid	0.2	++	++	+
	0.3	++	++	-
	0.4	+	+	-
Control		++++	++++	+++

++++ =100% sprout, +++ = 75% sprout, ++ = 50% sprout, + = 25% sprout and - =5% sprouting.

Table (12): Effect of four essential plant oils on sprouting potato tubers infected by *F. solani* and *S. sclerotiorum* and/or left under the natural infection two months after storage.

Treatment	Cons. (%)	*F. solani*	*S. sclerotiorum*	Natural infection
Garlic	0.50	+++	+	-
	1.00	++	-	-
Camphor	0.50	+	-	-
	1.00	++	+	-
Spearmint	0.50	+	-	-
	1.00	+	-	-
Nigellasativa	0.50	-	-	+++
	1.00	-	-	+
Control		++++	++++	+++

++++ =100% sprouting, +++ = 75% sprouting, ++ = 50% sprouting, + = 25% sprouting and - =5% sprouting.

Discussion

Potato is one of the most important vegetable crops in the world including Egypt. Potato plants are attacked by several plant pathogens causing serious diseases during the growing season and postharvest season (El-Gamal *et al*., 2007 and Abd-El-Kareem *et al*., 2013). Controlling of such diseases mainly depends on fungicides treatments. However, fungicidal applications cause

hazards to human health. Due to this, there is an increasing interest to find new strategies of fungicides alternative for using in plant disease control systems (El-Mohamedy and Abd-El-Latif 2015).

During the progress of this study, forty-one isolates of different fungi were isolated from naturally infected potato tubers collected from different localities and markets. The highest number of isolated fungi was recorded from potato tubers, *i.e.*, *F. solani, F. semitectum, Sclerotinia sclerotiorum* and *Alternaria sp*. On the other hand, *Penicillium sp, Rhizopus stolonifer* and *Rhizoctonia solani*, recorded low frequency. Vitale *et al.* (1999) mentioned that *Fusarium solani var. coeruleum* is the most important causal agent, followed by *F. sambucinum, F. avenaceum*. Secor *et al.* (1992) reported that *Fusarium* causes diseases in several crops, including potato where it can cause seed decay, wilt, and dry rot decay of potato in storage.

The pathogenicity of the isolated fungi, *Fusarium solani, Sclerotinia sclerotiorum,* and *Alternaria sp*. showed the highest level of infection for potato tuber rots. While *Rhizoctonia solani* and *F. oxysporum* showed the medium level of infection for potato tuber rots followed by *F. semitectum*. However, the lowest infection of potato tuber rots was recorded by *Penicillium sp*. and *Rhizopus stolonifer*. Lenc *et al.* (2008) found that the most frequently isolated fungi causing potato dry rot were *Fusarium spp.*, *F. sambucinum* (*F. sulphureum*), *F. solani*, (*F. coeruleum*), *F. oxysporum F.avenaceum, F. culmorum and F. equiseti.* Their pathogenicity towards potatoes varies in different parts of the world and so the designation of individual species as the main cause of disease is difficult and Han *et al*. 2013, recorded the first report of *Sclerotinia sclerotiorum* in Korea.

In vitro, oxalic, and boric acids showed complete inhibition of growth of *S. sclerotiorum* at tested concentrations, 0.3, 0.4 %. While salicylic acid was less effective on the growth of *S. sclerotiorum* at all concentrations. It was clear from the obtained results that *S. sclerotiorum* was the most sensitive among all tested pathogens to oxalic and boric acids with their concentrations while *Fusarium solani* was the least sensitive one. Also, it was clear that increasing the concentration of the tested acids (oxalic and boric), 0.3 and 0.4 % increased gradually the effect of these acids in reducing the growth of tested pathogens. Panahirad *et al.* (2012) and Rashied, (2008) found that salicylic acid at 0.25 % completely suppressed the *Fusarium* growth *in vitro*.

In vivo, boric, salicylic, and oxalic acids reduced disease severity on artificial inoculation with *Fusarium solani* or *S. sclerotiorum* and natural infection of potato tuber rots comparing with control. Rashied (2008) found that dry rot of potatoes reduced naturally infected or artificially inoculated by both ascorbic and salicylic acid particularly at 2% concentration during storage at 10°C for 90 days or 20°C for 45 days. The severity of infection of potatoes with dry rot was reduced close to zero by ascorbic and salicylic acids especially during storage at 10°C. Ascorbic acid was more effective than salicylic acid.

The *in vitro* results indicated that all tested plant oils reduced the growth of selected potato rots pathogens causing tuber rots *i.e., F. solani* and *S. sclerotiorum.* Morsy, *et al.* (2000) reported that plant extracts of garlic and onion reduced linear growth of *F. oxysporum*, *F. solani* and *S. rolfsii*.

In vivo, spraying of black seed, spearmint, garlic and camphor oils were sprayed on potato tubers cv. spunta two times before storage at concentrations of 0.5% and 1.0% to control dry rot caused by *Fusarium solani* and white rot caused by *Sclerotinia sclerotiorum*. Rashied (2008) found that cinnamon and carnation oils at 0.25 % and 0.5 % inhibited the dry rot on potato tubers kept at 10°C under 85-90 % RH for 90 days, while high infection with dry rot was found on tubers of either naturally infected or artificially inoculated tubers by all tested isolates of *Fusarium* spp. Similar trend of high inhibitory effect was obtained when potato tubers treated with cinnamon and carnation oils were stored at 20°C under 85-90% RH for 45days.

Treating potato tubers with salicylic, boric and oxalic acids at concentrations of 0.2, 0.3, 0.4% resulted in different degrees of reduction in the severity of tuber-rot caused by *F. solani* and *S. sclerotiorum* after storing for two months, compared to the control.

Hilal *et al.* (2006) found that salicylic and oxalic acid prevented the linear growth of *S. sclerotiorum* at the high concentration (1500 ppm) Also, (Naffa *et al*., 2006) indicated that thiourea, propyl parapen, bytylated hydroxylanisole and bytylated hydroxy toluene were significantly effective against *Sclerotinia sclerotiorum* on PDA medium.

Post-harvest treatment lowered the loss in fresh weight and sprouting of potato tubers, naturally and artificially inoculated with *Fusarium solani* and *S. sclerotiorum* during storage. All treatments performance to decrease of sprouting potato tubers compared with the control. Oxalic acid decreased sprouting (-) of artificially inoculated tubers with *Fusarium solani, Sclerotinia sclerotiorum* and naturally infected at 0.4 % concentration. Control untreated with organic acids and infected with *Fusarium solani*, *Sclerotinia sclerotiorum* increased sprouting (++++) compared with the control of natural infection (+++). Generally, organic acids decreased sprouting in tubers infected with *Sclerotinia sclerotiorum* followed by naturally infected and those infected by *Fusarium solani*, respectively. Plant oil treatments performance to decrease sprouting potato tubers compared with the control. Garlic, camphor, spearmint, and *Nigella sativa* oils showed No sprouting (-) of naturally infected while, *Nigella sativa* increased sprouting (+++) at 0.5 % concentration and (+) at 1.0 % concentration. Infection by *Fusarium solani*, *Sclerotinia sclerotiorum* highly increase sprouting (++++) compared with natural infection (+++). Eisa *et al.,* (2010) illustrated those plant oils, *i.e.,* thymol, anisol, eugenol, camphor oil and fennchone oils were effective in reducing the infection and disease severity percentages on detached pods infected with *S. sclerotiorum*, *B. cinerea* and *P. aphandermatum.*

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(Received 09/03/2019;
in revised form 30/03/2019)

مقاومة أعفان درنات البطاطس باستخدام بعض الاحماض العضوية و الزيوت النباتية

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يعتبر فطري *Fusarium solani* and *Sclerotinia sclerotiorum* التى تسبب بالترتيب العفن الابيض و العفن الجاف لدرنات البطاطس هما المسؤل عن الخسائر الريئسية فى درنات البطاطس صنف اسبونتا و ذلك بعد الحصاد اثناء التخزين البارد. أسفرت تجارب العزل من درنات البطاطس التي يظهرعليها أعراض العفن والتي تم جمعها من الأسواق المحلية عن واحد و اربعون عزلة فطرية تنتمي إلى ستة أجناس. تم تنقية الفطريات المعزولة وكذلك تعريفها كالاتى *Fusarium solani* (تسع عزلات) ، *F. semitectum* (سبع عزلات) ، *Sclerotinia sclerotiorum* (ستة عزلات) ، *Alternaria sp.* (ست عزلات) ، *F. oxysporum* ، (خمس عزلات) ، *Rhizoctonia solani* (ثلاث عزلات) ، *Penicillium sp.* (عزلتان). أظهرت أختبارات القدرة المرضية أن الفطرين *Fusarium solani* و *Sclerotinia sclerotiorum* هما أكثر الفطريات في شدة الإصابة على الدرنات. أظهر التأثير التثبيطي للأحماض العضوية (أحماض البوريك والأكساليك والساليسليك) انخفاضا ملحوظا على النمو الطولى لميسليوم الفطر *F. solani* والفطر*S. sclerotiorum* بالمقارنة مع الغير معاملة. تم زيادة هذا التثبيط تدريجياً عن طريق زيادة تركيز الأحماض العضوية المختبرة. بالإضافة إلى ذلك ، أدى حمض الأكساليك إلى تثبيط ١٠٠٪ للنمو الفطري للفطرين المختبرين بتركيز ٠,٤ ٪ ، بينما أعطت الأحماض العضوية الأخرى تثبيطًا متوسطا. تم دراسة تأثير زيت الكافور (camphor oil) ، و زيت الحبة السوداء (*Nigella sativa*) ،وزيوت الثوم والنعناع على نمو كلا من *Fusarium solani* و*Sclerotinia sclerotiorum* ،وذلك فى المعمل وعلى الدرنات أثناء التخزين البارد. وقد لوحظ تثبيط نمو كلا الفطرين عند استخدام زيت النعناع عند التركيزين ٠,٣ و ٠,٤ ٪ ، فى المعمل. كما أظهرت النتائج على الدرنات أن زيت حبة البركة *N. sativa* كان الأكثر فاعلية ، حيث منع حدوث الاصابة تمامًا بلفطرين *F. solani* و *S. sclerotiorum* يليه زيت الكافور وذلك اثناء تخزين الدرنات بتثبيط كامل لشدة الاصابة. حافظت الزيوت المختبرة على أعلى جودة للدرنات المخزنة سواء علي الانبات او الفقد فى الوزن. بشكل عام أعطت المعاملة بالأحماض العضوية والزيوت النباتية الأساسية تحكمًا فعالًا في نمو كل من الفطرين و شدة الاصابة بالمرض وقللت الفاقد في الوزن الطازج لدرنات البطاطس بالإضافة إلى تقليل الانبات أثناء التخزين البارد عند ١٣ درجة مئوية لمدة شهرين.