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Effects of certain fungicide alternatives on garlic yield, storage ability and postharvest rot infection

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Abstract

Three fungicide alternatives eg., peroxyacetic acid (PAA), potassium silicate(PS) and salicylic acid mixture) SA) were effective to reduce postharvest garlic rot. Fusarium spp that gave the most frequently found genera (65.1% frequency) were concerned in this study. The eight Fusarium isolate were able to rot garlic cloves and isolate F1 and F2 were the most virulent. Identification of the most two virulent isolates was F1 isolate *Fusarium subglutinans* where isolate F2 in *Fusarium solani*. In vitro study showed that all fungicide alternatives were effective to reduce postharvest garlic rot severity under either *F. subglutinans* or *F. solani* infection. The highest concentration tested was the most effective than the lowest concentrations. Under field experiments, garlic seed cloves soaking plus foliar spraying improved garlic production that assembly in enhancement of fresh weight, cured weight and cured significant reduction in weight losses. In addition, next planting cloves of fungicide alternatives treated garlic were more out standing against *F. subglutinans* and *F. solani* under artificial inoculation

Keywords: *Allium sativum*, peroxyacetic acid, potassium silicate, salicylic acid, *Fusarium* spp.

Introduction

Garlic (*Allium sativum* L.) is a crop of great importance throughout the world and is highly valued for its culinary and medicinal properties. Its secondary metabolites have been shown to positively affect health and contribute to the prevention of many common human diseases, particularly through their antioxidant, anti-inflammatory, and lipid-lowering effects (Ansary *et al.,* 2020)**.** Main part of the national garlic mass production is produced in middle Egypt especially Beni suef and El-Minya governorates, Egypt. Depletion of bulbs as well as rot of cloves is a serious problem that affects the crop different etiological agents are involved in inducing the disease syndrome. Fungal species which are reported to incite rot of garlic cloves include *Fusarium oxysporum, F. moniliforme, Aspergillus niger, A. ochraceus, Penicillium* spp. *P. pupurogenum* and *Fusarium proliferatum* (Galal *et al.,* 2002 and Gálvez and Palmero 2021)

Postharvest rot is one of the main causes of garlic bulb loss during storage. Its incidence is directly related to the occurrence of pathogens on harvested bulbs and is greatly influenced by postharvest handling processes of the bulbs (Sivakumar and Baños 2014 and Sholberg and Conway 2016). However, several pathogens initiate their infection during the growth development of plants in the field (Chretien *et al.,* 2020). The disease then progresses during the postharvest period. Some microbes may stay dormant and then develop during storage, causing losses of economic importance or acting as inoculum reservoirs in cloves used for sowing (Palmero *et al.,* 2013)

Gálvez and Palmero (2021) reported that the most prevalent postharvest disease was Fusarium dry rot (56.1%), which was associated with six Fusarium species. *Penicillium allii* was detected in 12.2% of the samples; it was greatly influenced by the harvest season and garlic cultivar, and three different morphotypes were identified. *Stemphylium vesicarium* and *Embellisia allii* were pathogenic to wounded cloves.

Accordingly, the present work was planned to evaluate the effects of certain fungicide alternatives applied as garlic seed cloves and/or foliar treatments on garlic growth, yield and postharvest rot development

Materials and Methods

Pathological studies

Sample Processing and description of symptoms

Garlic bulbs were peeled, and the cloves were separated for external visual analysis. Symptomatic cloves were then classified according to the following morphological characteristics of the lesion: color, surface appearance, contour, consistency, and the presence or absence of mycelia, as well as the color and consistency of the internal lesions. (Galal *et al* 2002)

Fungal isolation

Samples of garlic cloves rot were collected from different regions of El-Minia governorate, Egypt and isolation of the fungi associated with these symptoms was conducted. Diseased samples were firstly washed with tap water then surface sterilized by soaking them in 3% sodium hypochlorite (NaOCI) for 3min and washed thoroughly 3 times by sterilized distilled water**.** The plates were incubated at 25 C in the dark until fungal colonies were large enough to be examined and annotated. Initial fungal isolation was performed by transferring the growing mycelia to a Petri plate containing PDA, and monosporic cultures were obtained. according to Valdez *et al.* (2009)

Identification of fungal isolates

Preliminary identifications were performed based on the colony characteristics and micromorphology using a microscope and taxonomic criteria (Barnett and Hunter 1998 and Leslie and Summerell 2006)**.**

Pathogenicity tests

Pathogenicity tests were performed using healthy apparent garlic cloves after they have been surfaced sterilized as mentioned above. Five-mm disks of 7–day-old cultures of fungal isolates grown on PDA individually were inserted into 1-cm wound made by sterilized scalpel in the middle of each clove. Ten cloves were inoculated with each isolate tested. Inoculated cloves (cv. Sids 40) were kept in sterilized boxes containing piece of sterilized water-saturated cotton to ensure high humidity and incubated at 25°C. Ten days later, rot quantity (rot severity) was assayed. Rot quantity was assessed by determining the amount of rotten tissue produced in clove and the percentage of rotten tissue (rot severity) was calculated. Clove was weighed before and after removing rotted portion and estimated according to the formula: **Rot severity (w1–W2)/w1 x 100**

Where, w1 weight of whole clove and w2 weight of clove after removal of the rotten tissue (Kelman and Dickey, 1980).

In vitro effects of safety chemical solutions on garlic rot infection

Three safety solutions were tested: solution 1 was PAA at three concentrations as following 0.2 g/l Acetic acid + 2g/l H_2O_2, 0.1 g/l Acetic acid + 1g/l H_2O_2 and 0.05 g/l Acetic acid + 0.5g/l H_2O_2. Solution 2 consisted of four compound mixture as follow: 0.2 g/l salicylic acid + 0.2 g/l Ascorbic acid + 0.02 zinc sulfate +0.02 manganese sulfate, 0.1 g/l salicylic acid + 0.1 g/l Ascorbic acid + 0.01 zinc sulfate +0.01 manganese sulfate and 0.05 g/l salicylic acid + 0.05 g/l Ascorbic acid + 0.005 zinc sulfate +0.005 manganese sulfate. Solution 3 was potassium silicate at 0.2 g/l, 0.1 g/l and 0.05 g/l PS. As for chick, distilled water was used. Healthy apparent of uniformed size garlic cloves cv Sids 40 were peeled, surface sterilized as mentioned above then soaked (ten garlic cloves/treatment) separately in the test solution for 24h then air dried for one hour and subjected for inoculation by *Fusarium subglutinans* and *Fusarium solani* individually. Inoculation, incubation and rot severity were performed as described above.

Field experiments

Field experiments were carried out at the reclaimed area, west Samalout shousha region, H, S, Tony's Farm during the 2018/2019 and 2019/2020 growing seasons of garlic cv. "Sids 40" on October 25, 2018, and October 16, 2019, garlic cloves cv. "Sids 40" were planted. Garlic heads were chosen, largest size, free from all defects and the cloves were sorted to select the uniformed sized medium cloves and also free from the all defects. Then the different treatments (10 Treatments) were used as shown in Table (1).

The treatments were applied individual by soaking garlic cloves for 24h in each of the above solutions, then planted at 10 cm spacing on both sides of ridges spaced 60 cm and 3m long. Each experimental plot consisted of 4 rows. The 13 Treatments were arranged in a randomized complete block design with three replicates. The normal agricultural practices for garlic production were followed recommendations of Ministry of Agriculture and Land Reclamation

Garlic was harvested (70% of the plant leaves turned yellow) on 20th and 13th of March 2019 and 2020, respectively. After harvesting, garlic plants were left for 30 days as curing process and data were recorded for fresh yield, cured yield, percentage of weight loss during the curing process= (initial fresh weight- weight after curing /initial fresh weight X 100). Garlic cloves were taken from each treatment after curing to evaluate the carry over effects of field and/or pre planting treatments to Fusarium rot infection. Garlic gloves inoculation, incubation and rot assessment were followed as mention above in the pathogenicity tests.

Results

1-Frequency of fungi associated with postharvest decayed garlic cloves

Data summarized in Table (2) show eight fungal genera viz *Aspergillus* spp, *Penicillium* spp, *Fusarium* spp, *Rhizopus* spp, *Alternaria* spp, *Botrytis* spp, *Stemphylium* spp and *Sclerotium cepivorum* were differently associated with postharvest decayed garlic cloves along two growing seasons in El-Minya governorate, Egypt. The highest frequency was pronounced by *Fusarium* spp isolates (61.26 % frequency) followed by *Aspergillus* spp (9.90

%) and *Botrytis* spp (9.04%) *Rhizopus* spp and *Stemphylium* spp which recorded the least frequency (2.7%) per each. Other genera that associated with decayed garlic cloves were showed low frequency viz, *Alternaria* spp (5.40%) *Penicillium* spp(4.50%) and *Sclerotium cepivorum* (4.50%).

2- Pathogenicity tests

Pathogenicity tests performed by eight Fusarium isolates which gave the highest frequency associated with diseased garlic cloves (Table 3). All Fusarium isolates tested were able to infect garlic cloves and gave 100%, disease incidence. Disease severity (DS) was significantly varied with different Fusarium isolates. Isolate F1 provided the highest DS (65.53%) followed by F2 (63.74%) isolate F4 caused the least DS (20.50%) followed by F8 isolate (21.36%) other Fusarium isolates reacted as intermediate pathogens F3 (40.40%) F7 (39.94%) F5 (33.86%) to rot garlic cloves. Two fungal isolates of Fusarium isolate F1 and F2 which expressed the most virulent were selected and their identification was confirmed by Assiut University Mycological Centre (AUMC), Assiut University, Assiut, Egypt. Identification revealed that isolate F1 is belong to *Fusarium subglutinans* (code No. AUMC No:14493) while isolate F2 belongs to *Fusarium solani* (code No. AUMC No:14494).

3- In vitro effects of safety solutions on garlic rot infection

Twenty-four hours pre inoculation garlic cloves in PAA, PS or SA mix individually result insignificant reduction in rot severity specialty at the highest concentration of any test solutions (table5). Using PAA exhibited the highest protection at 50% protection (0.2 g/l AA/2.0 g/l H_2O_2) in case *Fusarium solani* 44.52% protection against *Fusarium subglutinans*. Increasing compound concentration increase protection. Potassium silicate (PS) at 0.05 g/l and 0.1 g/l treatment caused insignificant protection values against *Fusarium solani* or *Fusarium subglutinans.* Meantime, the highest PS concentration 0.2g/l (200 ppm) was effective to protect garlic cloves by 38.35% against *Fusarium subglutinans* and 13.3% protection against *Fusarium solani* infection. Treatment with SA mix (SA+AA+Zn+Mn) cause significant protection at all concentration tests against both *Fusarium solani* or *Fusarium subglutinans* infection severely. At concentration of (0.2 g/l SA+0.2 g/l AA+ 0.005 g/l Zn+0.005 g/l) caused protection value 38.9% protection against *Fusarium solani* and 24.6 % protection against *Fusarium subglutinans*

4.1 Fresh yield (Ton / feddan)

Garlic fresh yield (Ton/ feddan) was variously affected by various treatments (Table 5). Soaking seed cloves plus foliar sprayings PAA caused significant increase in garlic fresh yield by 23.69% as compared to control seed gloves. Soaking in PS increased fresh yield by 11.64% as compared to check treatment seed cloves soaking plus foliar spraying by SA mixture was significantly decreased fresh yield by 10.41% as compared to the control.

In addition, out of nine treatments six treatments show insignificant effects toward fresh yield, they were PAA soaks PAA spray, PS soaking plus spray SA mixture soaking and SA mixture soaking plus spraying.

4.2 Cured yield (ton/ feddan)

One-month postharvest plant weight called cured yield (ton/ feddan) was evaluated (Table 6). Two treatments viz PAA seed cloves soaking plus foliar spraying and PS seed cloves soaking were effective to enhance cured yield by 28.88% and 24.09% respectively. Meanwhile one treatment SA mixture seeds cloves soaking expressed negative effects that caused 12.83% decreased in curded yield as compared to control treatment. Other treatments eg., PAA seed cloves soaking, PAA foliar sprayings, PS foliar sprayings, PS cloves soakings plus foliar sprayings, SA seed cloves soaking, SA foliar sprayings and SA seeds cloves soaking plus foliar spraying were more or less expressed to control effect.

4–3 Six months storage weight (Ton / feddan)

All treatments except PS seed cloves soaking plus spraying, SA mixture seed cloves soaking and SA seed cloves soaking plus sprayings showed positive effects on this character as compared to control treatment (Table 7).

The greatest storage weight was detected by PAA seed cloves soaking plus sprayings which give high in storage weight as compared to control. PAA seed cloves soaking plus foliar sprayings that caused (37.09%) higher in storage weight followed by PS seed cloves soaking plus foliar sprayings (21.79%) increase and PAA seed cloves soaking (18.30%) than the control.

4–4 Weight losses (%)

Pre plant garlic seed soaking and /or foliar sprayings significantly reduced weight loss of garlic during storage as compared to control (Table 8) Application of PAA as seed cloves soaking plus foliar sprayings reduced weight losses by 53.47 % followed by PAA foliar sprayings (51.21%) and PAA seed cloves soaking (50.01%) PS seed cloves soaking plus foliar sprayings reduced weight losses by (43.76%.). In the meantime, SA mix seed cloves soaking plus foliar sprayings caused weight reduction by 34.08% preplant soaking garlic seed cloves was giving least redaction value 28.53% in weight loss.

4-5 Effect of Pre plant garlic seed cloves soaking and/or foliar sprayings on postharvest garlic rot infection

Pre plant garlic seed cloves soaking was significant effect garlic cloves infection by *Fusarium subglutinans* (table 9). However foliar sprayings or seed cloves soaking plus foliar application of safety compounds caused significant reduction in garlic cloves rot infected by either *Fusarium subglutinans* or *Fusarium solani.* Application of PAA as seed cloves soaking plus foliar sprayings, foliar sprayings and seed soaking caused significant reduction for garlic cloves *Fusarium solani* infection by 8.32, 16.05 and 17.49 protection respectively. In case of *F. subglutinans* infection garlic cloves rot was provided under PAA applied as seed soaking plus foliar sprayings 16.24 % protection and by using foliar sprayings 14.06 % protection. While PAA garlic seed cloves soaking was not effective to reduce garlic cloves rot. Application of safety compounds PS or SA mixture as preplant seed soaking plus foliar sprayings resulted in the lowest rot severity to garlic next planting under *Fusarium subglutinans* and *Fusarium solani* (51.41%) infection followed by foliar sprayings. Preplant seed cloves soaking plus foliar sprayings by PS was more protective compound against *Fusarium subglutinans* and *Fusarium solani* infection than using SA mixture which caused the lowest protection value against *Fusarium subglutinans* and *Fusarium solani* infection.

Table 1: List of safety chemical solutions tested in the experiment.

T	Treatment	concentrations
T 1	PAA(Soaking)	0.2 g/l Acetic acid+ 2g/l H_2O_2
T 2	Three Foliar Spray PAA	0.2 g/l Acetic acid+ 2g/l H_2O_2
T 3	Soaking PAA + Three Foliar Spray PAA	0.2 g/l Acetic acid+ 2g/l H_2O_2
T 4	PS (Soaking)	0.2 g/l
T 5	Three Foliar Spray PS	0.2 g/l
T 6	Soaking PS + Three Foliar Spray PS	0.2 g/l
T 7	SA& AA& Zn& Mn (Soaking)	0.2 g/l salicylic acid + 0.2 g/l Ascorbic acid + 0.02 zinc sulfate +0.02 manganese sulfate
T 8	Three Foliar Spray SA& AA& Zn& Mn	0.2 g/l salicylic acid + 0.2 g/l Ascorbic acid + 0.02 zinc sulfate +0.02 manganese sulfate
T 9	Soaking SA& AA& Zn& Mn + Three Foliar Spray SA& AA& Zn& Mn	0.2 g/l salicylic acid + 0.2 g/l Ascorbic acid + 0.02 zinc sulfate +0.02 manganese sulfate
T 10	control	Distilled water

*Foliar was separately sprayed three times at twenty days intervals

Table 2: Frequency of fungi associated with postharvest decay garlic bulbs grown in Minia governorates.

Fungi	Number of isolates		Total	Frequency
	Season 1	Season 2		
Aspergillus spp.	4	7	11	9.90
Penicillium spp.	3	2	5	4.50
Fusarium spp	35	33	68	61.26
Rhizopus spp	2	1	3	2.70
Alternaria spp	3	3	6	5.40
Botrytis spp	4	6	10	9.04
Stemphylium spp	1	2	3	2.70
Sclerotium cepivorum	2	3	5	4.50
Total			111	100

Table 3: Ability of Fusarium isolates to rot garlic cloves cv Sids 40 disease incidence (DI) and disease severity (DS) were evaluated ten days after inoculation and incubation at 25 °C.

Isolates	source of isolates	DI%	DS%
FA 1	EL-Minia	100	65.53
FA 2	EL-Minia	100	63.74
FA 3	Matay	100	40.40
FA 4	Malawi	100	20.50
FA 5	Malawi	100	33.86
FA 6	Malawi	100	27.46
FA 7	Matay	100	39.94
FA 8	Matay	100	21.36
Mean			39.09
LSD at 0.05 for DS			6.70

Table 4: Average means of diseases severity (DS) for garlic cloves rot caused by Fusarium subglutinans and Fusarium solani infection to garlic cloves after 24 hours soaking in test solutions. DS%) was measured ten days after inoculation and incubation at 25 °C.

	Fusarium Subglutinans				***Fusarium Solani***			
Treatment	Season 1	Season 2	Mean	Protection%	Season 1	Season 2	Mean	Protection%
PAA 1	57.00	63.00	60.00	17.81	66.00	59.00	62.50	8.09
PAA 2	45.00	48.00	46.50	36.30	64.00	68.00	66.00	2.94
PAA 3	43.00	38.00	40.50	44.52	32.00	36.00	34.00	50.00
PS 1	73.00	69.00	71.00	2.74	63.00	65.00	64.00	5.88
PS 2	67.00	71.00	69.00	5.48	64.00	61.00	62.50	8.09
PS 3	42.00	48.00	45.00	38.36	62.00	56.00	59.00	13.24
SA&AA&Zn&Mn 1	62.00	68.00	65.00	10.96	67.00	62.00	64.50	5.15
SA&AA&Zn&Mn 2	62.00	63.00	62.50	14.38	64.00	58.00	61.00	10.29
SA&AA&Zn&Mn 3	57.00	53.00	55.00	24.66	39.00	44.00	41.50	38.97
Control	72.00	74.00	73.00	0.00	67.00	69.00	68.00	0.00
L.S.D at 0.05 for Growing season(A)			3.10				2.90	
Treatments (B)			6.20				5.40	
(AxB)			N.S				N. S	

Table 5: Average of fresh weight (Ton/ feddan) for garlic cv Sids 40 as influenced by garlic seed cloves and / or foliar treatments with PAA, PS, and SA mixture during 2018/2019 and 2019/2020 growing seasons.

Treatment	2018/2019	2019/2020	Mean	increase percentage
PAA Soaking	13.00	12.50	12.75	2.40
PAA Spray	13.20	12.00	12.60	1.20
PAA Soaking & Spray	15.60	15.20	15.40	23.69
PS soaking	13.30	12.70	13.00	4.41
PS Spray	13.40	13.20	13.30	6.82
PS Soaking & Spray	13.20	14.60	13.90	11.64
SA&AA&Zn&Mn Soaking	12.50	12.10	12.30	-1.20
SA&AA&Zn&Mn Spray	13.00	12.20	12.60	1.20
SA&AA&Zn&Mn Soaking&Spray	11.30	11.00	11.15	-10.41
Control	12.70	12.20	12.45	00.00
L.S.D at 0.05 for Growing season (A) Treatments (B)			0.80 0.50	

Table 6: Average of cured weight (ton/ feddan) for garlic cv Sids 40 as influenced by garlic seed cloves and / or foliar treatments with PAA, PS, and SA mixture.

Treatment	2018/2019	2019/2020	Mean	increase percentage
PAA Soaking	9.50	8.64	9.07	2.13
PAA Spray	9.30	8.55	8.93	0.50
PAA Soaking & Spray	11.97	10.92	11.45	28.88
PS Soaking	11.40	10.64	11.02	24.09
PS Spray	9.12	8.07	8.69	-3.20
PS Soaking & Spray	9.69	9.31	9.50	6.98
SA&AA&Zn&Mn Soaking	7.69	7.79	7.74	12.83
SA&AA&Zn&Mn Spray	9.78	8.55	9.17	3.20
SA&AA&Zn&Mn Soaking&Spray	7.41	7.60	7.51	-15.48
Control	8.83	8.93	8.88	0
L.S.D at 0.05 for Growing season(A) Treatments (B)			0.22 0.48	

Table 7: Average of six months storage yield (Ton/Fedden) for garlic cv Sids 40 as influenced by garlic seed cloves and/or foliar treatment with PAA, PS and SA mixture.

Treatment	2018/2019	2019/2020	Mean	increase percentage
PAA soaking	8.36	7.60	7.98	18.30
PAA Spray	8.26	7.50	7.88	16.82
PAA Soaking & Spray	10.64	9.69	10.17	50.70
PS Soaking	9.59	9.02	9.31	37.95
PS Spray	7.79	6.84	7.32	8.45
PS Soaking & Spray	8.36	8.07	8.22	21.79
SA&AA&Zn&Mn Soaking	6.36	6.46	6.41	-4.96
SA&AA&Zn&Mn Spray	8.17	7.12	7.65	13.34
SA&AA&Zn&Mn Soaking&Spray	6.27	6.36	6.32	-6.37
Control	6.65	6.84	6.75	0
L.S.D at 0.05 for Growing season(A) Treatments (B)			0.78 0.46	

Table 8: Average of weight loss % for garlic cv Side 40 (cured weight–six months storage weight) as influenced by garlic seed cloves and/or foliar treatments with PAA, PS, SA mixtures.

Treatment	2018/2019	2019/2020	Mean	increase percentage
PAA Soaking	12.00	12.04	12.02	50.01
PAA Spray	11.18	12.28	11.73	51.21
PAA Soaking & Spray	11.11	11.26	11.19	53.47
PS Soaking	15.88	15.23	15.55	35.32
PS Spray	14.58	15.24	14.91	37.98
PS Soaking & Spray	13.73	13.32	13.52	43.76
SA&AA&Zn&Mn Soaking	17.30	17.07	17.18	28.53
SA&AA&Zn&Mn Spray	16.46	16.73	16.59	30.99
SA&AA&Zn&Mn Soaking&Spray	15.38	16.32	15.85	34.08
Control	24.69	23.40	24.05	00.00
L.S.D at 0.05 for Growing season (A) Treatments (B)			0.67 1.30	

Table 9: Response of garlic cloves progenies of pre plant seed cloves soaking and/or foliar sprayings to *Fusarium subglutinans* and *Fusarium solani* infection on next curd garlic cloves crop which inoculated and incubated at 25 °C for ten days

	Fusarium Subglutinans				*Fusarium Solani*			
Treatment	Season 1	Season 2	Mean	protection	Season 1	Season 2	Mean	protection
PAA soaking	61.63	61.42	61.525	2.74	58.33	58.31	58.32	8.32
PAA Spray	56.56	52.17	54.365	14.06	52.83	53.97	53.40	16.05
PAA soaking & Spray	51.51	54.46	52.985	16.24	53.56	51.41	52.49	17.49
PS soaking	60.41	61.37	60.89	3.75	62.69	60.25	61.47	3.36
PS Spray	51.68	55.69	53.685	15.14	59.43	56.45	57.94	8.91
PS soaking & Spray	55.83	51.09	53.46	15.49	57.25	59.10	58.18	8.54
SA&AA&Zn&Mn soaking	61.60	61.37	61.485	2.81	62.93	62.37	62.65	1.51
SA&AA&Zn&Mn Spray	56.99	53.99	55.49	12.28	58.83	55.49	57.16	10.14
SA&AA&Zn&Mn soaking & Spray	54.07	54.96	54.515	13.82	55.51	59.18	57.35	9.85
Control	62.03	64.49	63.26	0.00	64.04	63.18	63.61	0.00
L.S.D at 0.05 for growing season (A)			2.30				3.10	
treatments (B)			1.70				1.40	
(AxB)			N.S				N.S	

Discussion

Postharvest garlic cloves rot caused by fungi greatly affects their quality and devalues the final product. The most frequently isolated fungal diseases on harvested bulbs in El-Minya governorate, Egypt were primarily caused by eight fungal genera: *Aspergillus, Pencicillium, Fusarium, Rhizopus, Alternaria, Botrytis, Stemphylium and Sclerotium cepivorum*. Recent results indicate that this symptom is caused by trauma or injuries that occur during harvest or postharvest handling, followed by the growth of pathogenic or weakly pathogenic fungi. The appearance of the disease caused by *Fusarium* spp. differs depending on its evolution or environmental conditions. In the initial phase, brown lesions with a dehydrated appearance may emerge in different zones of the garlic clove. These spotted lesions are a few millimeters and can progress to cover the entire clove during the storage period. This disease is caused by Fusarium spp., and it is consistent with previous studies by different researchers (Galal *et al* 2002, Tonti *et al* 2012, Moharam *et al* 2013, Gálvez *et al* 2017 and Mondani *et al* 2021).

Of the postharvest symptoms watched in this work, Fusarium rot was detected with the highest frequency in Minya Governorate, Egypt (Galal et al 2002 and Mondani *et al* 2021). Due to its high frequency of *Fusarium* eight *Fusarium* isolates were subjected for pathogenicity tests, The present study shows various infectability to rot garlic cloves cv Sids 40. The strongest two virulent isolates Fusarium (F1 and F2) were concerned and confirmed their identification as *Fusarium subglutinans* (F1) and *Fusarium solani* (F2).

However, six *Fusarium* spacious eg: *F. proliferatum*, *F. oxysporum*, *F. solani*, *F. acuminatum*, *F. subglutinans*, and *F. redolens* were found to be associated with rotted garlic cloves more than 85% of symptomatic cloves in different countries (Dugan *et al* 2003, Palmero *et al* 2010, Tonti *et al* 2012, Polat *et al* 2012, Sankar and Babu 2012, Leyronas, *et al* 2018 and Anisimova *et al* 2021).

Fungicides and biological control might diminish the infection of fungal pathogens on postharvest bulbs (Dugan et al 2007, Gálvez *et al* 2017 and Mondani *et al* 2021) but the safety periods of different active ingredients, together with long postharvest periods, considerably reduce their effectiveness. On the contrary, the effect of gaseous ozone treatment during postharvest storage was evaluated, and the results for postharvest rot are promising (De Santis et al 2021). These and other tools should be planned at reducing the inoculum density to avoid the progression of Fusarium rot in garlic. The recent work was performed to evaluate some fungicides alternatives such as PAA, PS and SA mix that have been used successfully to diminish plant infection to various pathogens (Abd-Elkader 2016, Shama et al 2016, Galal 2017, Zyada and Bardisi 2018, Abdel-Latif et al 2019, Mohamed et al 2019, Tantawy et al 2020). In vitro experiment gives a promising data that explore the beneficial use PAA PS and SA mixture to reduce garlic cloves rot caused by *Fusarium subglutinans* or *Fusarium solani* infection. Soaking garlic cloves in the solution tested individually for 24h before inoculation resulted in satisfied protection values particularly at the highest concentration tested. A concentration of PPA (0.2 gm/l AA + 2 gm/l H_2O_2) compound PAA was superior to protect garlic cloves against *Fusarium subglutinans* 44.52% or *Fusarium solani* 50% protection followed by SA mixture (0.2 gm/l AA +0.2 gm/l SA + 0.02 gm/l Mn + 0.02 gm/l Zn) that provided 38.97% and 24.66% protection against *Fusarium solani* and *Fusarium subglutinans*, respectively. Potassium silicate was effective to protect garlic cloves rot caused by *Fusarium subglutinans* 38.36% more than *Fusarium solani* protection (13.24%).

On the light of in vitro studies, field experiments were run to evaluate PAA, PS and SA mixture as garlic seed cloves soaking and/or foliar sprayings to improve garlic production, reduce weight losses during storage and their indirect effects on the response of newly planting to *F. subglutinans* or *F. solani* infection. Soaking garlic seed cloves plus foliar sprayings by PAA obtained the greatest fresh weight giving 23.69% higher than control. Application of SA mixture as garlic seed soaking and foliar sprayings was ranked the second after PAA to increase fresh weight by 10.41% weight increase. Individually garlic seed soaking or foliar sprayings were effective to enhance fresh weight significantly but lesser than garlic seed cloves soaking plus foliar sprayings. As for cured yield, all treatments applied as garlic seed cloves soaking plus foliar sprayings were positively affected cured weight. Application of PAA as seed cloves soaking and foliar sprayings achieved the greatest cured weight by 28.88% than control followed by PS 24.09% and SA mixture 15.48% over the control. Insignificant effects were provided by individual garlic seed soaking or garlic foliar application using any of solution tested. Interestingly garlic seed cloves soaking plus foliar sprayings were effective to cause a significant reduction in weight losses of storage garlic and PAA was the most effective treatment to reduce weight losses when it used as seed cloves soaking and/or foliar sprayings (53.47, 51.21, and 50.01 %) respectively reduction in weight losses, as compared to control. Potassium silicate became after PAA to reduce weight losses that caused 43.7, 37.98 and 35.32 % reduction in. weight losses by seed soaking plus foliar sprayings, foliar sprayings and seed cloves soaking, respectively. Using SA mix show the least effects to reduce weight losses by 34.08, 30.99 and 28.53% redaction when it applied as garlic seed soaking plus foliar sprayings, foliar sprayings and seed soaking, respectively. To be noticed, foliar sprayings was more effective than garlic seed soaking to improve garlic production. While the most effective was explored by seed soaking plus foliar sprayings together.

Response of next garlic cloves crop obtained from bulbs grown from PAA-, PS and SA mixture–treated cloves showed decrease in garlic cloves rot severity caused by *F. subglutinans* or *F. solani* infection. The highest protection values were revealed by seed soaking plus foliar sprayings with PAA 17.49%

protection against *Fusarium solani* and 16.24% protection against *Fusarium subglutinans* infection. New crop from of PS- treated garlic cloves was more protected against *Fusarium subglutinans* 15.49% protection than against *Fusarium solani* 8.54 % protection when PS was applied as seed soaking plus foliar spraying. Silicon (Si) is a bioactive element associated with beneficial effects on mechanical and physiological properties of plants. Several studies have suggested that Si activates plant defense mechanisms, yet the exact nature of the interaction between the element and biochemical pathways leading to resistance remains unclear. It can act as a modulator influencing the timing and extent of plant defense responses in a manner reminiscent of the role of secondary messengers in induced systemic resistance; it can also bind to hydroxyl groups of proteins strategically involved in signal transduction; or it can interfere with cationic cofactors of enzymes influencing pathogenesis-related events. (Belanger *et al* 2003, Cruz *et al* 2013 and Wang *et al* 2017).

Rather than direct antimicrobial molecules, reactive oxygen species (ROS) such as O^{-}_{2}, H_2O_2, O, O_3, OH are more likely co-factors in redox reactions playing different roles in plant resistance (Torres, 2010, Galal 2018, Tantawy *et al* 2020 and Abdelrahim *et al* 2021). For example, ROS have been characterized as primary signaling molecules, regulating multiple physiological processes during plant growth and development (De Tullio, 2010, Tantawy *et al* 2020 and Abdelrahim *et al* 2021). Many Planed pathogen interaction have been affected by SA levels and signaling. (Galal and Adbou 1996, Galal *et al* 2002, Youssef *et al*.,2007 Liu *et al*., 2014).

Conclusion

Application of PAA, PS and SA is beneficial to improve garlic yield and storability. As well as enhance garlic resistance against garlic cloves rotting fungi e.g., F. subglutinans and F. solani. Using PAA, which is more potent than PS or SA, such safety compounds could be used as fungicide alternatives.

List of Abbreviations

AUMC	Assiut University Mycological Center
DI	Disease incidence
DS	Disease severity
PAA	Peroxy Acetic Acid
PS	Potassium silicate
ROS	Reactive oxygen species
PDA	Potato dextrose agar
SA	Salicylic acid
L.S.D.	Least significant difference
NaOCI	Sodium hypochlorite

Declaration of competing interest

The author declares no conflicts of interest.

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تأثير بدائل المبيدات على انتاج الثوم وتخزينه واصابته بعفن ما بعد الحصاد

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الملخص العربى

أظهرت ثلاث بدائل للمبيدات (بيروكسي حمض الخليك، سليكات البوتاسيوم ومخلوط حمض السالسليك) فاعلية في خفض امراض عفن ما بعد الحصاد لفصوص الثوم واهتمت الدراسة بانواع الفيوزاريوم التي أعطت اعلي تكرارا 65.1% للفطريات المصاحبة لعفن فصوص الثوم. اختبرت ثمان عزلات للفيوزاريوم حيث أحدثت جميعها عفن فصوص الثوم وكانت العزلتان F1,F2 اكثر قدرة مرضية وتم تعريف العزلتان ذات القدرة المرضية العالية حيث ان العزلة F1 تابعة *Fusarium subglutinans* بينما العزلة F2 كانت *Fusarium soloni* واظهرت الدراسات المعملية ان جميع بدائل المبيدات المختبرة ذات فاعلية لخفض شدة الإصابة بعفن فصوص الثوم ما بعد الحصاد تحت العدوة بكلا الفطريين المختبرين وكان أعلى تركيز تم اختباره هو الأكثر فعالية عن التركيزات المنخفضة.

كما أوضحت التجارب الحقلية ان معاملة الفصوص ورش المجموع الخضري للثوم اثناء النمو ادي الي تحسين الإنتاجية والتي تمثلت في زيادة الوزن الطازج وخفض معدل الفقد بعد شهر من التخزين والخفض المعنوي للفقد في الوزن اثناء فترة التخزين علاوة على ذلك أدت المعاملات انفه الذكر باستخدام بدائل المبيدات الي خفض معنوي للإصابة بالفطريين تحت ظروف العدوي الصناعية.

الكلمات الدالة: الثوم، بيروكسي حمض الخليك، سليكات البوتاسيوم، حمض السالسليك، أنواع فطر الفيوزاريوم.