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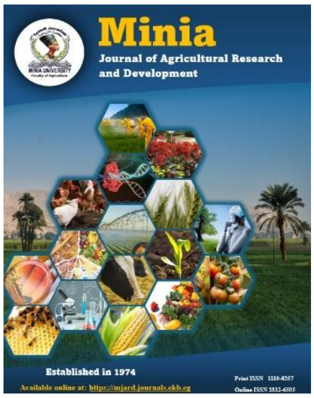

Fungicidal effect of hydrogen sulfide, iodine, and peroxy-acetic acid on tuber potato dry rot disease

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ABSTRACT

The current study investigates potato dry rot disease caused by *Fusarium oxysporum*, *Alternaria alternata*, and other fungi during storage and marketing. Both in vitro and in vivo experiments were conducted to evaluate the efficacy of iodine, hydrogen sulfide, peroxy-acetic acid (PAA), and the fungicide Diabolo® 10% SL in controlling F. *oxysporum* and A. *alternata*, the main pathogens associated with dry rot.

Amendment of the growth medium with any of the tested compounds significantly reduced the mycelial growth of the pathogens. The greatest reduction was observed with H_2S, followed by iodine, while PAA showed the lowest inhibitory effect. Complete inhibition of fungal growth occurred when Diabolo® 10% SL (150 ppm) was incorporated into the medium. A synergistic effect was recorded when PAA was combined with either H_2S or iodine. The highest inhibition was achieved when 1% H_2S or iodine was mixed with PAA (containing 4 mg/L H2O2 and 0.4 mg/L acetic acid).

Pre-planting treatment of potato tubers (cv. Cara) with iodine, H_2S, PAA, or Diabolo® 10% SL also significantly reduced disease incidence (DI%) and disease severity (DS%) of wilt symptoms caused by F. *oxysporum* and A. *alternata*. Among the treatments, the fungicide and H2S showed the highest effectiveness. The combination of PAA with iodine or H2S enhanced their individual effects, with the H_2S + PAA mixture providing greater disease reduction than the iodine + PAA mixture.

Overall, the study demonstrates that mixing PAA with either iodine or H2S can safely protect stored potato tubers and effectively control dry rot pathogens.

Keywords: Iodine, H_2S, PAA, Diabolo, *F. oxysporun, A. alternata*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the most important non-cereal food crop for human consumption and can significantly improve food security in developing countries. It is a sustainable food crop worldwide due to its varied distribution pattern and substantial cultivation as a cash crop in regions with high levels of poverty and

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malnutrition (**Devaux *et al.* 2020; and Lal *et al*. 2020-a).** Globally, 388 million tons of potatoes are produced annually on 19 million hectares of land **(FAOSTAT, 2019).** The fact that emerging countries consistently produce more potatoes than developed ones shows the importance of potatoes as a source of food, revenue, and jobs, particularly in Africa, Latin America, and Asia **(Devaux *et al*., 2020).**

The main causes of potato production loss and nutritional profile degradation are poor crop and post-harvest management, field and storage diseases, frost, and severe rains **(Lal *et al.*, 2020-b; Tiwari *et al.*, 2020-a)**. Potato tubers are susceptible to rots, galls, and blemishes during handling, storage, and transportation following harvest because they contain over 70% water. More than 40 pathogens exist, including fungi, bacteria, viruses, nematodes, and insects, harm potato tubers and foliar portions **(Kumar *et al.*, 2019 and 2020).** The tuber quality and yield are at risk due to these biotic agents, which can result in up to 22% direct or indirect losses in the potato production chain. In the past, potato rots were thought to be small and unavoidable; however, as consumer preferences have changed, producers are now quite concerned about them because they damage seed tubers and table potatoes in cold storage **(Bojanowski *et al*., 2013).**

Dry rot is a fungal disease characterized by tuber surface lesions that shrink, shrivel, and remain non-slimy **(Fiers *et al.*, 2012).** Potato dry rot is caused by several species of the genus Fusarium or others and is a highly destructive disease with a global impact. Although soil- and seed-borne inoculum can infect plants in the field, the most significant damage typically occurs during storage. Dry rot hampers crop establishment by suppressing sprout development and can lead to yield losses of up to 25%, with infection levels reaching as high as 60% during storage (**Wharton, 2007**). The severity of the disease is further exacerbated when it occurs alongside other storage diseases, such as soft rot and late blight.

One of the main strategies for managing postharvest deterioration is the use of synthetic chemicals such as germicides (**Tripathi and Dubey, 2004)**. However, there are two unsolvable challenges with chemical control: first, pathogen resistance will inevitably evolve, second, a number of commonly used germicides are being reviewed in several countries because of health and safety concerns (**Deng *et al.*, 2013)**. Therefore, there is an increasing need to create safer and more effective alternative therapies for postharvest diseases.

Hydrogen sulfide (H_2S), which previously believed to be a poisonous gas, is a gaseous signaling molecule in mammals, following carbon monoxide and nitric oxide (**Wang, 2012**). The relationship between postharvest pathogens and H_2S is not well understood. **Marsh (1929)** published the first relevant study on this subject and discovered that H_2S was poisonous to *Sclerotinia fructicola* spores that were just beginning to germinate. Although the underlying mechanism of H_2S's antifungal effect is unknown. H_2S plays various roles in plant development, abiotic stressors, and postharvest senescence **(Zhang *et al*., 2008; Jin *et al*., 2011; Hu *et al.*, 2012; Jin *et al.*, *2013***). Researchers pointed to H_2S released by 0.5 mM NaHS solution effectively controlled the fruit decay caused by *A. niger* and *P. italicum* **(Fu *et al*., 2014)**. **Haneklaus *et al.* (2007)** reported that the uptake of 10 µM/h H_2S by the pathogen would produce a fungicidal effect. H_2S acts as a Diabolo® 10%SL fungicide against the pear decay pathogens *Penicillium expansum* and *Aspergillus niger* and prolongs the postharvest storage of fresh-cut pears **(Hu *et al*., 2014)**. **Fu *et al*. (2014)** suggested that H_2S might be associated with increased ROS accumulation in H_2S-treated storage tested fungi, i.e., A. *niger, P. italicum*, and *R. oryzae*, yeasts, and several food-borne bacteria. Exogenous H_2S application extends the postharvest storage of fresh-cut kiwifruit, strawberries, broccoli, and mulberries by modifying the antioxidant system **(Hu *et al*., 2012; Gao *et al*., 2013; Li *et al*.,** 2014). **Hu *et al.* (2014)** recently demonstrated that H_2S might prevent fungal development and prolong the postharvest storage of fresh-cut pears.

Iodine is a necessary component for human health. It contributes to the production of thyroid hormones, which are crucial for metabolism and growth (**Velasco *et al*., 2018**). Iodine enrichment of fruits and vegetables can successfully increase human iodine intake (biofortification). Numerous farming methods (pot, field tests, hydroponics) have been developed to increase iodine concentration in the edible parts of different cultivated plants (e.g., lettuce **(Blasco *et al*., 2008, Hong *et al*., 2008, Voogt *et al*., 2010, Blasco *et al*., 2012, Lawson *et al*., 2015 and]**, spinach **(Zhu *et al*., 2003, Zhu *et al*., 2004, Dai *et al*., 2006**, **and Weng *et al*., 2008-b**), pakchoi **(Hong *et al*., 2009-a)**, cabbage **(Weng *et al*., 2008-a)**, chinese cabbage**,** tomato, carrot **(Hong *et al*., 2008, Caffagni *et al*., 2011 and Landini *et al*., 2011)**, strawberry **(Li *et al*., 2016)**, cucumber **(Voogt *et al*., 2014)**, celery **(Hong *et al*., 2009-a)**, radish **(Lawson *et al*., 2015)**, potato **(Caffagni *et al*., 2011),** rice **(Hong *et al*., 2018)** and bean (**Dobosy *et al*., 2020**). Iodine-based compounds effectively control certain tomato fungal infections **(Lantz, 2003).** Both the stomata and the cuticular waxes in the root and aerial structures absorb iodine **(Tschiersch *et al*., 2009).** After being absorbed, it travels through the xylem and accumulates in leaves in larger quantities **(Lawson *et al*., 2015).** Iodine is considered less harmful to the environment and preserves plants **(Lantz, 2003).**

Terrestrial species with the capacity to volatilize iodine include plants (**Saini *et al*., 1995; Redeker *et al*., 2004a)** and soil bacteria (**Amachi *et al*., 2003**). With the exception of ectomycorrhizal fungi **(Redeker *et al*., 2004b)** and the wood-rotting fungus *Phellinus pomaceus* (**Harper, 1985**). Filamentous fungi can affect iodine mobility and speciation through accumulation and volatilization **(Ban-nai *et al*., 2006**). *Alternaria alternata* and *Cladosporium cladosporioides* accumulate more than 40% of the iodine in their hyphae, showing high concentration factors of 22 and 18, respectively. Peroxyacetic acid (PAA) is a mixture of acetic acid and hydrogen peroxide (PAA) has been evaluated for eco-friendly management of many fungal, viral, and bacterial diseases, *such as* sunflower root/collar rot pathogen **(***Sclerotium rolfsii)* **(El-Ashmony *et al*., 2017),** *Septoria tritici*, which causes leaf blotch in wheat (**Shetty *et al*., 2007**), tomato bacterial wilt induced by *Ralstonia pseudosolanacearum* (**Hong *et al*., 2018),** *Acidovorax avenae* subsp. *citrulli*, which causes seedling blight and bacterial fruit blotch, and *Fusarium oxysporum* and *Didymella bryoniae*, which cause wilt and A gummy stem blight in cucurbits **(Hopkins *et al*., 2003)**. **El-Ashmony *et al.* (2017)** reported that drenching soil with PAA significantly reduced the severity of crown blight and root rot induced by *Sclerotinia sclerotiorum* compared with untreated control treatment.

The objective of this study was to evaluate the fungicidal effect of hydrogen sulfide, iodine, and peroxy-acetic acid on tuber potato dry rot disease

MATERIALS AND METHODS

Pathogens:

The most virulent isolates of *Fusarium oxysporum* (isolate F4) and *Alternaria alternata* (isolate A10) were previously isolated from rotted potato tubers, and their pathogenicity was tested **(Mousa *et al*., 2025).**

Chemical compounds

Sodium hydrosulfide (NaHS, $9H_2O$) was purchased from Piochym, 6th October City, Egypt, was used as a source of H_2S producing, iodine, H_2O_2 and Acetic acid were purchased from El-Nasr Pharmaceutical Chemical Company, Egypt. Diabolo® 10%SL fungicide Diabolo® 10%SL (Imazalil active ingredient) was produced by Domiatec Agri-Group, Egypt.

Stocks of different solutions were prepared as following: Na_2S and Iodine solutions were used at 0.1, 0.5, and 1.0%, and PAA was a mixture of H_2O_2 and Acetic acid was used by concentrations 0.1+ 1 mg/l, 0.2 + 2 mg/l, and 0.4+ 4 mg/l, respectively), whereas Diabolo® was used at 50, 100, and 150 ppm in the laboratory tests.

1- Efficacy of H_2S, iodine, PAA (Acetic acid and H_2O_2) and Diabolo® 10% SL fungicide on mycelial growth

In this experiment, 13 treatments were carried out as follows: NaHS solution (0.5 mM) was used to release H_2S, and stock solutions of two mixtures of acetic acid (AA) and hydrogen peroxide (H_2O_2) were prepared with distilled water and left for at least 10 days to form a PAA solution (**EPA, 2004).**

H_2S was used at concentrations of 0.1 % (T1), 0.5 % (T2), and 1% (T3). Iodine was also used at concentrations of 0.1 % (T5), 0.5 % (T6), and 1% (T7). PAA was used at concentrations of 0.1% + 1.0 % (T8), 0.2% + 2.0 % (T9), and 0.4% + 4.0% (T10). Diabolo® 10% SL fungicide was used at concentrations of 50 ppm (T11), 100 ppm (T12), and 150 ppm (T13). PD broth media free of compounds was used as control (T4).

The prepared different concentrations of tested chemicals (T1–T13) were added to 100 ml of autoclaved potato dextrose broth (PDB) medium in 250 ml conical flasks and inoculated with 5mm discs, cut with a sterile cork borer from the advancing margins of 5 days cultures of each pathogen. The inoculated flasks were incubated at 25±2ºC for 10 days. Control flasks with only PD broth free of compounds served as the control. Fungal growth samples were collected after 10 days through filtration using Whatman filter paper. The collected fungal mass was dried in a hot air oven at 70±5ºC for 1 day. The weight of dry mycelium was then calculated. Three replicates were used for each treatment. The percentages of growth inhibition were calculated as follows:

Inhibition (%) = (Control mycelial dry weight - Treatment mycelial dry weight) /Control mycelial dry weight.

2- Effect of mixing H_2S or iodine with PAA on mycelial growth

Seven mixtures of PAA and H_2S or iodine were tested as follows:

T4 = control, free of any chemical substance; T14 = (0.4+4.0) PAA+ 0.1 H_2S %, T15 = (0.4+4.0) PAA + 0.5 % H_2S; T16 = (0.4+4.0) PAA + 1% H_2S; T17 = (0.4+4.0) PAA + 0.1 % Iodine; T18 = (0.4 +4.0) PAA + 0.5 % Iodine; and T19 = (0.4+4.0) PAA + 1% Iodine. In addition, 1.35 ml of Diabolo® (recommended dose)/70 tubers (T20) was applied.

As previously mentioned, the conical flasks (250 ml) each contained 100 ml of autoclaved PD broth medium amended with different concentrations (T14–T19 treatments) of the tested substances, inoculated with 5mm discs, and cut from the advancing margins of 5 days cultures. The inoculated flasks were incubated at 25±2ºC for 10 days. Control flasks with only PD broth free of compounds served as the control (T4 treatment). The mycelial dry weight was measured, and the growth inhibition percentage was calculated as described before. Randomized Complete Design with 3 replicates was applied.

3-Efficacy of H_2S or iodine without or mixing with PAA on potato wilt

Cara potato tubers were gathered from a private farm in El-Minia Governorate at commercial maturity (mid-January 2022). The tubers were selected for their consistent size, color, and lack of mechanical or pathological damage. The tuber samples were packaged in net plastic boxes weighing 5 kg each, transferred to the Department of Plant Pathology research laboratory, and surface-disinfected with 2% sodium hypochlorite for 2 min. The samples were then rinsed with distilled water and air-dried.

Tubers were dipped in different solutions tested (H_2S at 5%; T2, iodine at 1%; T7, PAA at 0.4 AA + 4 mg/l H_2S_2; T10) for 20 min., and their mixtures of iodine or H_2S with PAA with concentrations [T15; (0.4+4.0) PAA + 0.5 % H_2S or; (0.4+4.0) PAA + 1% Iodine; T19]. Tubers dipped for 20 minutes in iodine or H_2S solutions for 20 min and then dipped in PAA solution for 20 min.

Seven-day-old PDA cultures of isolates F4 of *F. oxsporum* and A10 of *A. alternata* were used to prepare the inocula. In 500 ml Erlenmeyer flasks, 150 g of autoclaved barley grains were mixed with 200 ml of water, then the flasks were inoculated with 5 mm discs cut from the actively growing margins of 7-days- fungal cultures. The inoculated flasks were incubated at 25±1°C for 15 days. After incubation, the inoculum was used to infest the soil. The sterilized pots (30 cm in diameter) were filled with sterilized Nile clay soil. Soil infestation was performed 7 days before planting by thoroughly mixing each fungal isolate into the soil at a concentration of 2% (w/w). The inoculum was previously standardized to contain 4×10^5 conidia/g. After infestation, the soil was irrigated daily until planting, and the fertilizers recommended by the Ministry of Agriculture were applied.

For each treatment, five pots were used as a replicate and three replicates were used, with three tubers planted per pot. The control pots received sterilized, uninoculated barley grain medium only. A randomized complete block design was designed. All pots were irrigated when necessary. Plants were regularly monitored for disease symptoms, and final observations were recorded 60 days after planting.

Disease assessment:

Disease incidence (DI, %) and disease severity were recorded. A disease index was used to evaluate disease severity of wilt following **Jiménez-Fernández *et al.* (2013)** with minor modification using a scale (0 to 4) based on root rot or leaf discoloration as follows: 0 = No symptoms (healthy), 1 = Yellowing on less than 25% of the plants, 2 = Yellowing on (25- 50%) of the plants, 3 = Yellowing on 75% of the plants with root rot, and 4 = Over 75 % of the plants with wilted and plant death. Disease severity (DS%) was calculated as follows:

$$\text{Disease severity index (DSI)} = (\Sigma\, d/d\,\text{max} \times N) \times 100.$$

where d = the disease rating possible, and N = the total number of plants.

Statistical analysis:

Least significant difference (LSD) values at $P<0.05$ were determined to test the variants among treatments **(Gomez and Gomez, 1984).**

RESULTS

1- Effect of H_2S, iodine, PAA, and Diabolo® 10% SL fungicide on mycelial dry weight:

The effects of H_2S**,** iodine, PAA, and Diabolo® 10% SL fungicide on the growth of *Fusarium oxysporium* (F4 isolate) and *Alternaria alternate* (A10 isolate), the causal pathogens of potato tuber dry rot, were studied under laboratory conditions. The data in Figures (1 and 2) show that a positive effect occurred when fungi were grown on PD broth medium amended with the tested compounds. *Fusarium oxysporium* (F4 isolate) was reduced by 46.38%, 41.88%, and 28.05% when treated with H_2S**,** iodine, and PAA, respectively, whereas the growth of *Alternaria alternate* (A10 isolate) was reduced by 39.55%, 36.08%, and 26.33 % when treated with the mentioned compounds. The highest reduction was recorded when Diabolo® 10% SL was applied. The fungal growth was reduced by 55.9% and 55.38%, respectively, followed by H_2S or iodine. The lowest effect occurred when the fungi were treated with PAA. Complete growth inhibition occurred for both pathogens with Diabolo® 10%SL fungicide treatment at 150 ppm. The fungal growth significantly decreased with increase in the concentration of the tested compound. The maximum reduction was recorded when iodine or H_2S was used at a concentration of 1%, and PAA was applied at 4 H_2O_2 and 0.4% acetic acid.

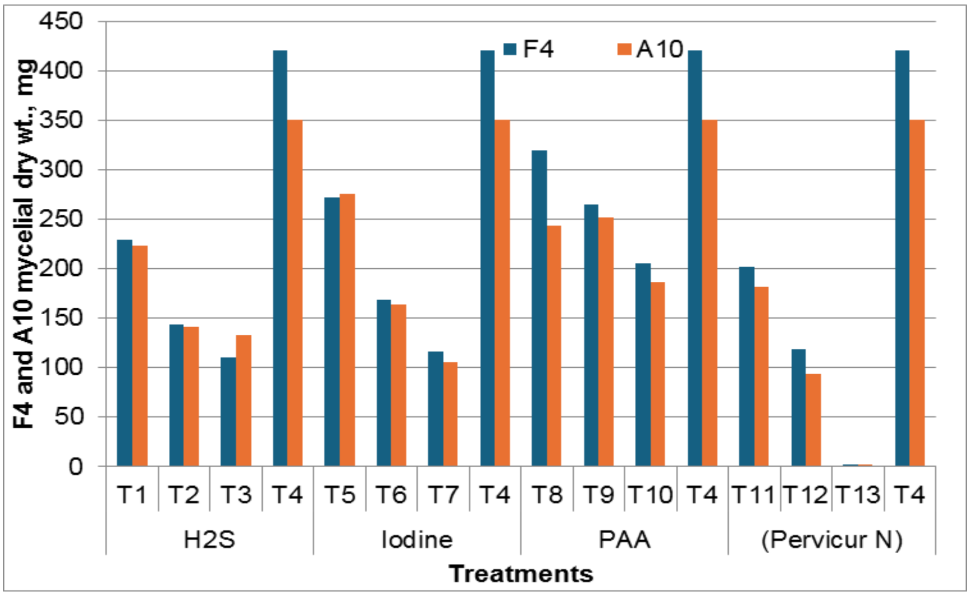

Figure (1): Effect of H_2S, iodine, PAA, and Diabolo® 10% SL fungicide treatments on the mycelial dry weight (mg) of F4 and A10 isolates.

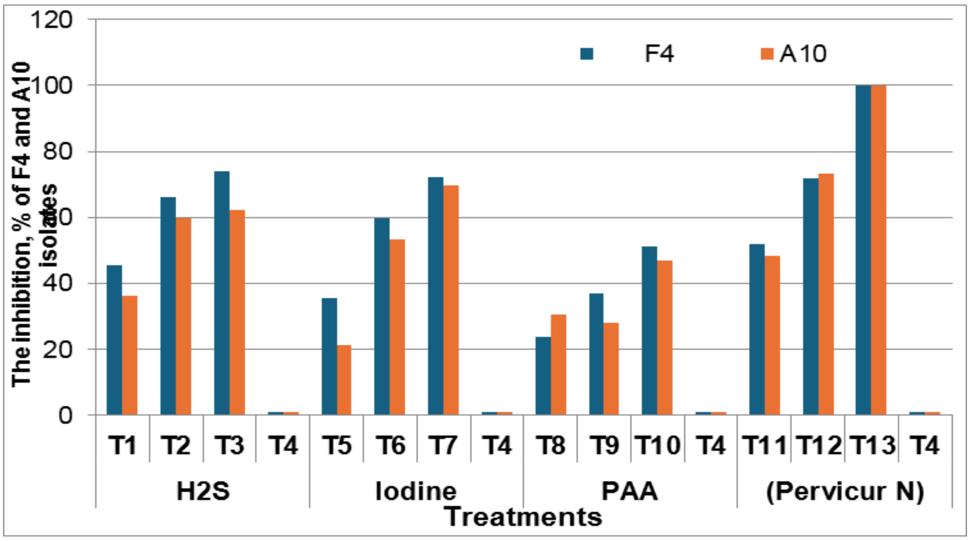

Figure (2): Mycelial growth inhibition of F4 and A10 isolates due to H_2S, iodine, PAA, and Diabolo® 10% SL treatments

2- Effect of the combination between PAA and H_2S or Iodine on mycelial growth of *F. oxysporum* and *A. alternata*, the causal pathogens of potato tuber dry rot

Data presented in Figures (3 and 4) demonstrated that combination PAA (4 mg/l of H_2O_2 and 0.4 mg/l Acetic acid) with different concentrations of H_2S or iodine significantly increased the effect of any tested substance alone and reduced the growth of both tested pathogens. A synergistic effect was observed when PAA was added to H_2S or iodine. The maximum effect was recorded when H_2S or iodine (at 1%) was mixed with PAA (4 and 0.4 mg/l of H_2O_2 and Acetic acid, respectively), inducing the reduction of F4 growth by 83.0% and 86.5% and 83.3%–88.1% for A10 isolate, respectively.

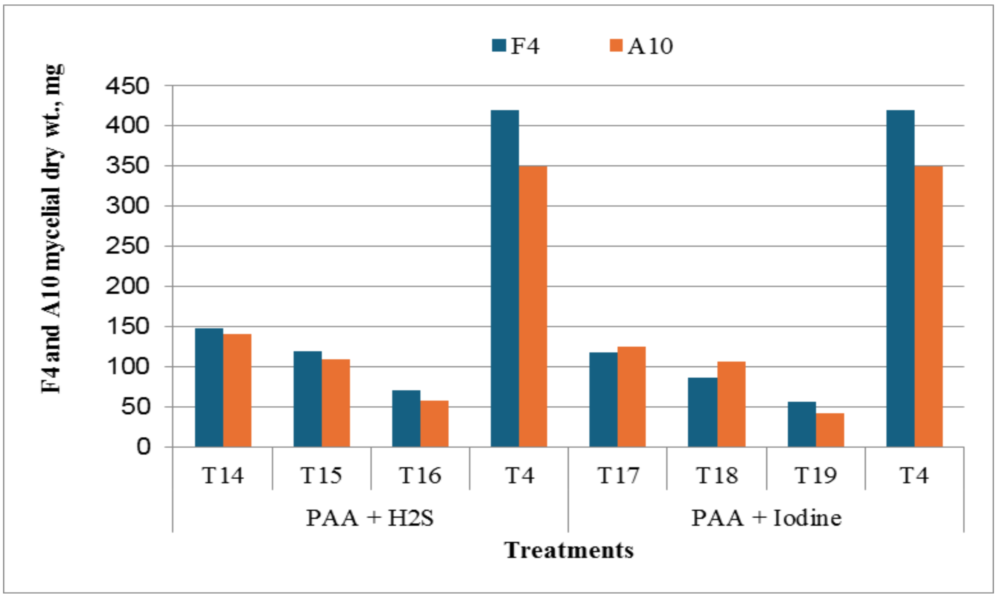

Figure (3): Effect of PAA + H_2S and PAA + iodine treatments on the mycelial dry weight (mg) of F4 and A10 isolates.

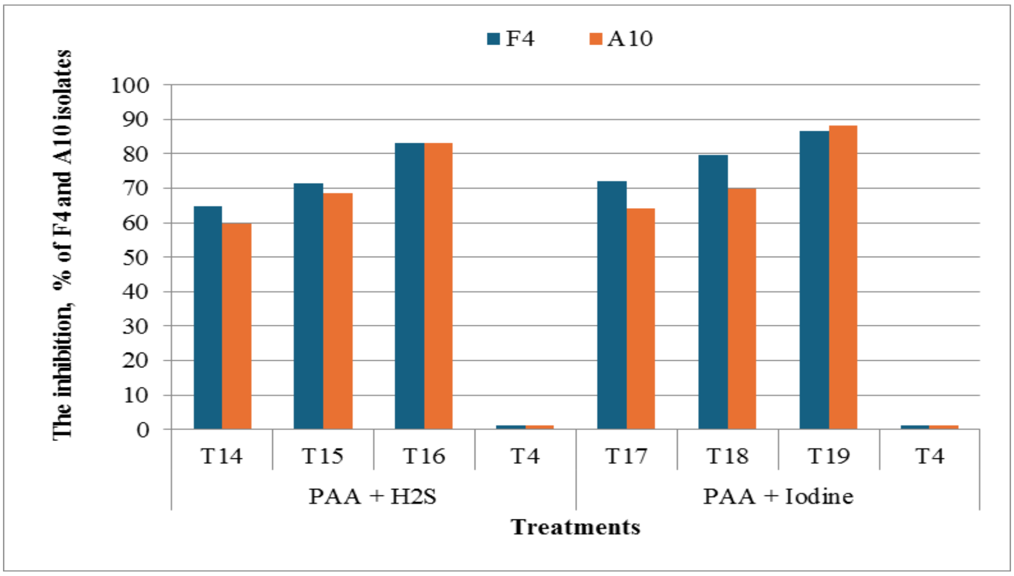

Figure (4): Mycelial growth inhibition of F4 and A10 isolates due to PAA + H_2S and PAA + iodine treatments.

3-Effect of H_2S, iodine, and their mixtures on potato wilt disease

Pre-planting potato tubers (Cara cv.) were dipped in H_2S at 0.5%, iodine at 1%, PAA (at 4 + 0.4 ml/100 ml H_2O_2 and AA) or Diabolo® 10% SL (at the recommended dose) solutions and then grown on pre-infested soil with F4 isolate of *F. oxysporum* or A10 of *A. alternata*. Figures (5 and 6) showed that the best treatment was H_2S, inducing a highest reduction in both DI% and DS% (41.3 and 40.9% for F4 isolate and 36.1 and 40.9% for A10 isolate, respectively), followed by iodine and PAA treatments.

Mixing H_2S or iodine with PAA increased their effect compared with each one alone. The reductions were 55.1 and 56.1% (DI%), while the DS% was 60.3 and 62.7% for F4 and A10, respectively, when the tubers were treated with PAA + H_2S (T15). The fungicide Diabolo® (T20) induced a reduction in both DI and DS% when plants were inoculated with either F4 or A10 isolates.

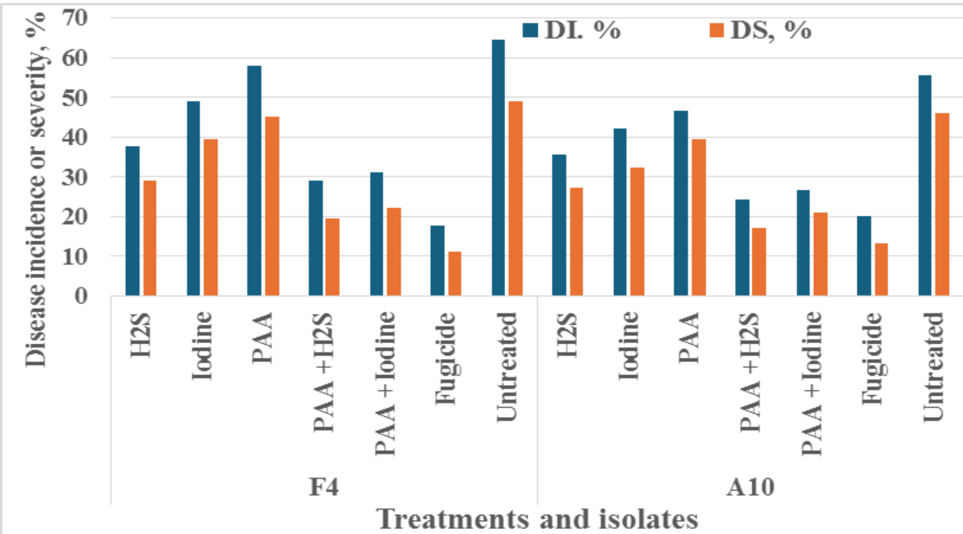

Figure (5): Effect of H_2S, iodine, PAA, Diabolo® 10% SL fungicide, PAA +H_2S, and PAA + iodine on disease incidence (DI, %) and disease severity (DS, %) induced by *F. oxysporum* (isolate F4) and *A. alternata* (isolate A10).

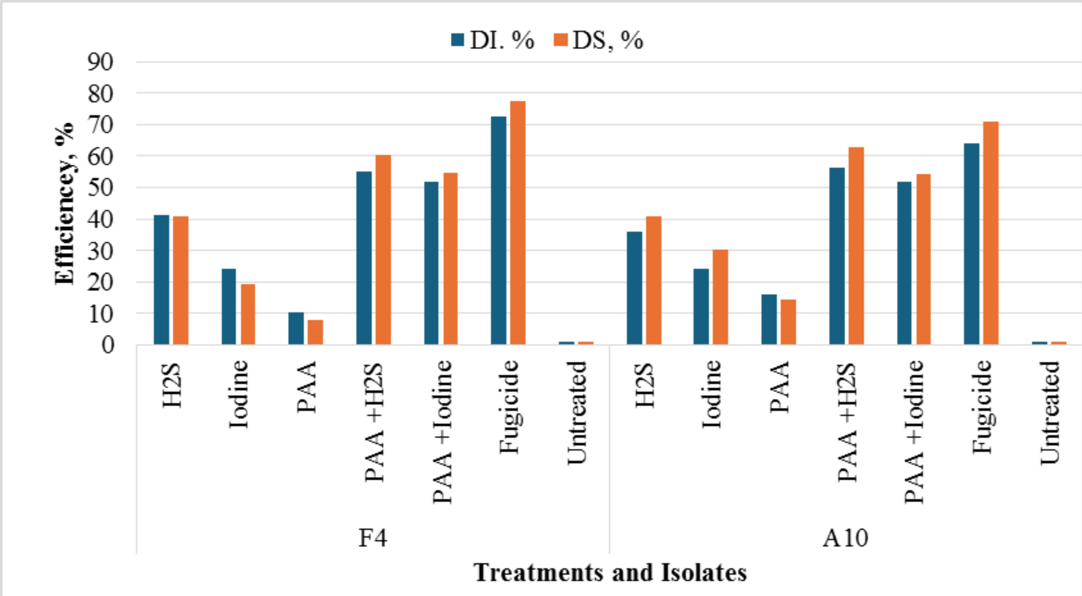

Figure (6): Efficiency (%) of H_2S, iodine, PAA, Diabolo® 10% SL fungicide, PAA +H_2S, and PAA + iodine on disease incidence (DI, %) and disease severity (DS, %) induced by *F. oxysporum* (isolate F4) and *A. alternata* (isolate A10).

DISCUSSION

Fusarium dry rot of potato is a disease of economic significance on a global scale during the storage period **(Hay *et al.*, 2019).** Depending on the kind of inoculum, cropping seasons, and storage circumstances, fusarium dry rot (FDR) of potato tubers is especially common in Egypt and other regions in the world and can cause partial or complete loss of stored tubers. More than 13 species of *Fusarium*, which cause dry rot, have been identified globally, and their genetic diversity varies by region. *Fusarium sambucinum*, *F. solani*, *F. graminearum*, and *F. oxysporum* f. sp. *tuberosi* are the most frequently isolated species from sick tubers **(Mejdoub-Trabelsi *et al.*, 2012).** *Fusarium oxysporum* is the most invasive fungus in Michigan, the United States, and other places worldwide (**Tiwari *et al.*, 2020-b).** The prevalence and severity of dry rot-causing *Fusarium* strains or other soil-borne fungi vary by region and are also influenced by dominant cultivars and environmental factors. To create a susceptibility and resistance rating, it is crucial to test newly created germplasm and existing cultivars against the disease.

The main purpose of fungicides is to prevent potato tuber rots, which are extremely dangerous for both the environment and human health. Nevertheless, eco-friendly management methods are necessary because they may lessen the demand for synthetic fungicides. The use of iodine compounds is an alternate technique.

Alternatives to fungicides, eco-friendly methods of controlling plant diseases have become essential to prevent the negative impacts of such dangerous fungicides on the environment and human health. H_2O_2-based chemicals are widely used as fungicides **(Adam *et al.*, 1993),** disinfectants **(Gómez-López, 2012),** and bactericides **(Kachroo *et al.*, 2003)** as alternatives to fungicides. Significant antifungal activities against potato tuber dry rot pathogens were demonstrated in this investigation.

In this study, we used H_2S, iodine, and PAA as eco-friendly agents compared with Diabolo® 10%SL as a fungicide for controlling potato dry rot disease. This study showed that this chemical induced significant efficiency against *the growth of Fusarium oxysporum* (isolate F4) and *Alternaria alternata* (isolate A10) *in vitro*. The growth of *F. oxysporum* was reduced by 46.38%, 41.88%, and 28.05% but *A. alternata* growth was reduced by 39.55, 36.08, and 26.33% when treated with H_2S, iodine, and PAA, respectively. H_2S induced the highest reduction for the two tested pathogens, followed by iodine and PAA, which exhibited the lowest effect.

Synergistic effects were observed when PAA was added to either H_2S or iodine. The reduction ranged from 83% to 88.1% when F4 or A10 isolates were grown on PD broth medium amended with H_2S or iodine mixed with PAA. These results are consistent with those obtained by several researchers. **Fu *et al.* (2014)** reported that the H_2S generated by 2.5 mM NaHS has a microbicidal effect in addition to preventing the development of bacteria, yeasts, and molds. They proposed that H_2S may directly cause *A. niger* to produce ROS and that excessive ROS damages molecules essential for mycelial growth and spore germination. They also proposed that H_2S may suppress gene expression and reduce superoxide dismutase (SOD) and catalase (CAT) enzyme activities, which may help explain the elevated ROS levels observed in *A. niger* treated with H_2S. **Bloem *et al*. (2004 and 2012)** proposed that when agricultural crops had a fungal infection, endogenous H_2S was released.

Iodine has fungistatic effects in plant pathogen management **(Ajiwe *et al*., 2019).** It is effective in controlling *Botrytis cinerea* in tomatoes and Fusarium wilt in basil **(Adams *et al*., 2003; and Lantz, 2003).** Eleven of the tested fungal strains volatilized a significant amount of iodine, in the form of methyl iodide (CH_3I), with the Basidiomectes fungus, *Lentinula edodes*, exhibiting the highest volatilization rate of 3.4% **(Ban-nai *et al*., 2006)**. They proposed that filamentous fungi can affect iodine mobility and speciation through volatilization and accumulation. With concentration values >1.0, six of the 12 fungal strains acquired a significant quantity of iodine from the medium. Of them, *A. alternata* and *C. cladosporioides* exhibited high concentration factors of 22 and 18, respectively, and gathered over 40% of the iodine in their hyphae. Iodine plays several roles in the plant resistant against the pathogens, as follows 1) iodine transport is mostly xylematic; 2) iodide translocation and accumulation in the aerial portion of plants are larger than those of iodate; and 3) iodine concentration in plants diminishes from the root to the fruit **(Umaly *et al*., 1971, Hong *et al*., 2007, Xie *et al*., 2007, Hong *et al*., 2009-b, and Yu *et al*., 2011)**. It should be noted, meanwhile, that iodine has a toxic impact on plants at higher concentrations, which lowers biomass output **(Weng *et al*., 2008, Hong *et al*., 2009-b, and Kiferle *et al*., 2013)**. The natural concentration of iodine in various soils ranges greatly from 0.1 to 150 mg/kg (**Johnson, 2003 and Medrano-Macías *et al*., 2016)**. Its chemical form and bioavailability are also affected by a number of soil characteristics, including pH, microbial activity, and the amount of OM or oxide minerals **(Medrano-Macías *et al*., 2016).** Because it is absorbed by positively charged iron and aluminum oxides or bonded to fulvic and humic acids, plants cannot absorb a comparatively large amount of iodine in the soil. Soil contains iodine in various chemical forms, including organic molecules, iodate (IO_{3-}), and iodide (I). Inorganic iodide compounds undergo a significantly quicker conversion to organoiodine than to iodate **(Yamaguchi *et al*., 2010 and Seki *et al*., 2013).**

According to several reports, H_2O_2 and acetic acid interact to generate peroxy acetic acid (PAA), a potent oxidant molecule (**Kitis, 2004; Thipaksorn *et al*., 2012; Wessels and Ingmer, 2013).** The environmentally friendly treatment of several bacterial, viral, and fungal plant diseases was assessed using PAA. **Hong *et al.* (2018)** reported that PAA significantly inhibited the growth of *R. pseudosolanacearum*, the causal agent of tomato bacterial wilt, in *vitro*. Peroxyacetic acid (PAA) acts as a broad-spectrum biocide, effectively reducing bacterial **(Hong *et al.*, 2018)** and fungal infections, such as *Botrytis cinerea*, the most redoubtable threat of tomato plants (**Ayoub *et al*., 2017**), soft rot, powdery mildew, and late wilt **(Abbas, 2023).** This powerful oxidizing agent can be applied in various ways, such as foliar spray, post-harvest dip, seed treatment, or for disinfecting growth media and equipment, depending on the dosage and application method. PAA is a sustainable option for integrated pest management because it breaks down into harmless by products like acetic acid, water, and oxygen (**Carrasco and Urrestarazu, 2010).**

Our study revealed that dipping potato tubers in H_2S (0.5%), iodine (1%), PAA (at 4 + 0.4 ml/100 ml H_2O_2 and AA, respecivel), or Diabolo® 10%SL (1.35 ml/70 tubers as a recommended dose) solutions significantly decreased the wilt incidence (41.3% and 36.1%, respectively) and severity (40.9%) induced by *F. oxysporum* (isolate F4) or *Alternaria alternata* (isolate A10) compared with the control. When PAA was mixed with H_2S or iodine, the disease incidence and severity were reduced to 55.1 60.3% and 56.1-62.7% for *F. oxysporum* and *A. alternata*, respectively.

Soil drenching with 1% PAA significantly decreased R. pseudosolanacearum seedling wilt **(Hong *et al.*, 2018).** In detached tomato leaves, treatment with PAA decreased pH and phytotoxicity. Compared with the application of 0.01% clove oil, the efficacy of PAA in preventing tomato bacterial wilt was relatively lower **(Lee *et al.*, 2012).** The emergence of fungicide-resistant strains necessitates the use of generally recognized safe GRAS) compounds, microbial antagonists, and silver nanoparticles to manage the disease with less environmental hazards and minimum pest resurgence. Novel phytohormones, such as melatonin and strigolactones, should also used.

In the past, synthetic chemicals, such as isopropyl-(n-3-chlorophenyl) carbamate, were used to prevent sprouting and infections after harvest **(Elbashir *et al.*, 2011).** However, these chemicals are no longer recommended because they can be toxic, harmful to the environment and human health, and may lead to pathogen resistance. In addition, harmful residues may remain in the treated potatoes **(Elbashir *et al.*, 2011).** For these reasons, researchers have sought safer alternatives **(Tian *et al.*, 2002)**. Boosting the natural disease resistance of fruits and vegetables using natural substances such as salicylic acid **(Bokshi *et al.*, 2003),** calcium chloride, and jasmonic acid **(Qin *et al*., 2003)** is a promising approach. These natural chemical treatments are safer and more cost-effective than synthetic pesticides for controlling disease and keeping potatoes in good condition after harvest **(Sánchez-González *et al.*, 2011).** Salicylic acid and jasmonic acid have been shown to reduce sprouting and infections after harvest **(Tian *et al.*, 2002)**, while calcium chloride helps strengthen cell walls and prevent the breakdown of potato tissue **(John, 1987).** This approach could be a practical and eco-friendly alternative to current disease control methods.

By altering the antioxidant system, exogenous H_2S administration can extend the postharvest storage of fresh-cut kiwifruit, strawberries, broccoli, and mulberries **(Hu *et al*., 2012; Gao *et al*., 2013;** Li *et al*., 2014) **. Fu *et al.* (2014)** suggested the possibility of an alternative strategy for postharvest fruit storage based on the exposure of infected fruit to H_2S released by NaHS. **Ajiwe *et al.* (2019)** found that the application of iodine compounds (potassium iodide, KI, and potassium iodate, KIO_3) at lower concentrations (0.5 and 1 mM, respectively) reduced the incidence and severity of Fusarium wilt and increased tomato yield.

CONCLUSION:

Dry rot is one of the most significant diseases that affects potato tubers during storage. According to our research, H_2S, iodine, and PAA, as well as their mixes, suppress the growth and development of fungi while also potentially protecting potato tubers against infection by dry rot fungi and extending the postharvest storage of fresh-harvested potato tubers**.**

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الملخص العربى

التأثير المبيد الفطرى لكبريتيد الهيدروجين، اليود و مركب بيروكسى حمض الخليك على العفن الجاف فى درنات البطاطس

مرزوق رجب عبد اللطيف، أنور جلال عبد العزيز، هنـاء عياد حليم أرمانيوس، فرج محمد فرج وثناء أبو العزم موسي
كلية الزراعة جامعة المنيا ومركز البحوث الزراعية

أجريت هذه الدراسة بهدف الوصول إلى طريقة آمنه لمقاومة مرض العفن الجاف للبطاطس الناتج عن فطريات الفيوزاريوم أوكسبوروم والألترناريا الترناتا وفطريات أخرى أثناء التخزين والتسويق. أجريت اختبارات في المختبر وفي الصوبة لتحديد فعالية مركبات اليود وكبريتيد الهيدروجين H_2S ومركب بيروكسي حمض الخليك PAA والمبيد الفطري Diabolo® 10%SL على نمو الفطرين *F. oxysporum* و *A. alternata* المسببان للعفن الجاف فى البطاطس. انخفض النمو الجاف للفطرين المسببين للمرض عند إضافة أي من المركبات المختبرة للوسط الغذائى. وكان أعلى انخفاض للنمو الفطرى بواسطة كبريتيد الهيدروجين، يليه اليود، ثم بيروكسى حمض الخليك الذي تسبب في أقل تثبيط للنمو الفطرى ى المعمل عند استخدام كل من هذه المركبات على انفراد، بينمـا زاد هذا التأثير عند إضافة بيروكسى حمض الخليك PAA إلى أى من كبريتيد الهيدروجين أو اليود. وكان أكبر انخفاض للنمو الفطرى عند إضافة كبريتيد الهيدروجين أو اليود بتركيز ١٪ إلى ال بيروكسى حمض الخليك (بتركيز ٤ ملج / لتر H_2O_2 و ٠.٤ ملج / لترحمض الخليك)، كما حدث تثبيط كامل للنمو الفطرى عند إضافة المبيد الفطرى Diabolo® 10% SL بتركيز ١٥٠ جزء/مليون إلى الوسط الغذائي...

كذلك، أدت معاملة درنات البطاطس (صنف كارا) قبل الزراعة بالغمر في محلول اليود، أو كبريتيد الهيدروجين، أو ال بيروكسى حمض الخليك (PAA)، أو المبيد الفطرى ديابولو® ١٠%SL إلى خفض كل من نسبتى الإصابة DI% و شدتهـا DS% لأعراض الذبول التي يسببها الفطر *F. oxysporum* أو *A. alternate* على نباتات البطاطس النامية من هذه الدرنات المعاملة. وكان استخدام المبيد الفطري متبوعًا بكبريتيد الهيدروجين (H_2S) أفضل المعاملات. وزادت إضافة المركب بيروكسي حمض الخليك إلى اليود، أو كبريتيد الهيدروجين، من تأثيرهما مقارنةً بكل منهما على حدة. وحدث أقصى انخفاض عند معاملة درنات البطاطس بخليط من ال بيروكسى حمض الخليك مع مركب كبريتيد الهيدروجين يليه معاملة الدرنات بخليط ال بيروكسى حمض الخليك مع اليود. وتُظهر هذه الدراسة أن معاملة درنات البطاطس بمركب بيروكسي حمض الخليك PAA الممزوج باليود أو بكبريتيد الهيدروجين H_2S يمكن أن تكون معاملة آمنة على درنات البطاطس المخزنة، ويساهم في مكافحة مسببات العفن الجاف.