International Scholars Journals

African Journal of Virology Research ISSN 2756-3413 Vol. 19 (8), pp. 001-010, August, 2025. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

In Vitro Evaluation of Essential Oils, Salts, and Antioxidant Acids Against Pathogenic Fungi Causing Postharvest Diseases in Bananas

Zoeir H. A.[1], El Zahaby H. M.[1], Ziedan E. H.[2]* and Maswada H. F.[1]

[1]Botany Department, Faculty of Agriculture, Tanta University, Tanta, Egypt.
[2]Plant Pathology Department, National Research Centre, Dokki, Cairo, Egypt.

Accepted 28 April, 2025

In vitro **clove essential oil (1.0%), sodium carbonate (2.0%) and sorbic, salycilic and propinic acids (0.5%) completely (100%) inhibited mycelial linear growth of** ***Colletotrichum musae*** **and** ***Fusarium moniliforme,*** **which is the cause of postharvest diseases in banana fruits.** ***In vivo*** **different application methods, that is, spray, soaking and dusting were tested on crown rot, neck rot, finger rot and flower end rot under artificial infestation with causal pathogens. Soaking method significantly reduced major postharvest diseases incidence in banana fruits than spray and dusting treatments. Soaking banana fruits in clove suspension (2%) and sodium carbonate (4.0%) was the best treatment that completely inhibited (100%) crown rot and flower end rot diseases and significantly reduced finger rot and neck rot diseases. So, clove oil and sodium carbonate were the most promising agents for controlling major postharvest diseases of banana fruits as eco-friendly and alternative synthetic fungicides.**

Key words: Banana, antioxidants, fungi, diseases, essential oil, salts.

INTRODUCTION

Banana (*Musa* species) is an economic and important fruit crop grown worldwide in more than 120 countries throughout tropical and subtropical regions. It is a popular worldwide staple food for more than 400 million people (Zhang et al., 2005). Postharvest diseases destroy 10 to 30% of the total yield of crops during handling, transportation, storage and marketing (Agrios, 2005). *Colletotrichum musae* and *Fusarium* species, that is, *Fusarium solani*, *Fusarium semitectum*, *Fusarium moniliforme* and *Fusarium musae* are the major fungi causing postharvest complex diseases (fruit rot, crown rot, finger rot, cigar end rot) of banana fruits (Bhattacharyya and Chakraborty, 2007; Diedhiou et al., 2014; Khleekorn et al., 2015; Marin et al., 1996; Abd-Alla et al., 2014; Abdullah et al., 2016; Triesta et al., 2016). Application of cultural, physical and biological methods is an alternative to synthetic fungicides for controlling postharvest diseases of banana fruits (Dionisio and Natsuaki, 2007; Lassois et al., 2008). Recently, essential oils, antioxidants, organic and inorganic salts were used as fungicidal alternatives, that is, basil oil (*Ocimum basilicum*), cinnamon oil (*Cinnamomum zeylanicum*) and clove oil (*Cymbopogon nardus*). Low concentrations of essential oils were used against banana crown rot disease and their fungal pathogens; they were also used to maintain quality during storage (Ranasinghe et al.,

*Corresponding author: E-mail: ziedanehe@yahoo.com.

2002; Anthony et al., 2003, 2004; Maqbool et al., 2010, 2011; Abd-Alla et al., 2014). Salts, that is, potassium sorbate, calcium propionate, sodium bicarbonate, sodium carbonate, and ammonium bicarbonate reduced crown rot incidence of banana fruits (Dionisio and Kobayashi, 2004). Antioxidants, that is, salicylic, citric, benzoic, ascorbic acids and hydroquinone have been used as protective and therapeutic treatments for plant diseases caused by a wide range of viral, fungal and bacterial pathogens (Mandal et al., 2009). Ascorbic acid, benzoic acid and butylated hydroxyl anisole (BHA) reduced mycelial growth of *C. musae,* the cause of anthracnose disease of banana fruits (Khan et al., 2001). Citric extract at 4% significantly reduced fruit rot incidence of banana, plus propionic acid (Ranasinghe et al., 2002; Cruz et al., 2013). The objectives of this study were to screen some essential oils, salts, and antioxidants against causal pathogens and their control of postharvest diseases of banana fruits.

MATERIALS AND METHODS

Causal pathogenic fungi

Highly aggressive isolates causing major postharvest diseases of banana fruit, that is, *C. musae* and *F. moniliforme* isolates were provided from Botany Department, Faculty of Agriculture, Tanta University, Egypt.

Agents tested

The agents tested included commercial essential oils of cinnamon oil (*C. zeylanicum* Blume), thyme oil (*Thymus vulgaris* L.), clove oil (*Syzygium aromaticum*), lemongrass oil (*Cymbopogon citratus* Stapf) and Black seed (*Nigella sativa* L.), antioxidants, that is, benzoic, sorbic, malic, salicylic and propionic acids and salts, that is, sodium benzoate, sodium carbonate, sodium carbonate sodium chloride, and sodium hypochlorite. All agents were provided from Chemical Industrial Development Company (CID), Egypt.

Antifungal against causal organisms

Antifungal activity against mycelia linear growth of *C. musae* and *F. moniliforme* on potato dextrose agar (PDA) of essential oils, that is, cinnamon, clove, lemon grass, and black seed were tested at 0.0, 0.1, 0.5, and 1.0% concentrations. Antioxidants, that is, benzoic, sorbic, malic, salicylic and propionic acids concentrations (0.1, 0.5, and 1.0%) and salts, that is, sodium chloride, sodium hypochlorite, sodium benzoate, and sodium carbonate at 1.0, 2.0, and 4.0% were tested at different concentrations by dissolving the requisite amounts in 0.5 ml of 0.1% Tween 80. Then, they were mixed completely in 100 ml of PDA medium before pouring in Petri dishes (9 cm-diameter). The control sets were prepared similarly using equal amounts of tween 80 on sterilized distilled water. Each plate was inoculated with 5 mm central disk for each fungus. Five plates were used as replicates and five plates free of each agent tested served as a control. The plates were incubated at 27±2°C for 6 days. Percentage of mycelial linear growth inhibition was calculated by the following formula (Skidmore and Dickinson, 1976) as follows:

Inhibition of fungal growth % = C - T /C×100

where C = the radial mycelia growth in control and T = the radial mycelia growth in the treatment

Application methods on postharvest diseases incidence of banana fruits

Different treatment methods used for banana fruits, that is, spray, soaking and dusting were the most effective agents used for mycelial linear growth. Suspension of clove oil (1.0%) and propionic acid (0.5%) were used as spray and soaking for 5 min. Meanwhile, sodium carbonate (4.0%) and salicylic acid (0.5%) were used as spray, soaking and dust treatments on banana fruits before artificial infestation with pathogens.

Fruit samples

Banana fruits Cv. Balady were purchased from private orchard in El-Gharbeia Governorate Egypt at maturity stage. They were disinfected by double immersion in 2 of 70% ethanol for 5 min and allowed to dry at room temperature under sterile conditions. Fruits were separated in polyethylene bags previously disinfected with 70% ethanol and exposed to UV light for 20 min. They were infested with mixture spore (1:1). Suspension ($1×10^6$/ml) of either *C. musae* or *F. moniliforme* was used for inoculation of banana fruits freshly prepared from 7 days old (PDA) cultures.

Determination of postharvest disease incidence

Postharvest disease incidence was calculated as the number of infected fruits showing symptom of crown rot, neck rot, finger rot, and flower end rot as follows:

Disease % of diseased fruits = Number of diseased banana fruits/Total number of banana fruits × 100

Disease severity was ranked by observing percentage of rotten symptom based on linear scale (0-4) as follows:

Disease severity (%) = Σ (n × r) × 100/N

where n= Number of fruits in each numerical disease grade; r = Number of the disease grade and N= Total number of inoculated fruits multiplied by the maximum numerical disease grade as follows:

0 = healthy fruit free rotten and discoloration;
1= 1-25% rotten and discoloration area;
2 = 26-50% rotten and discoloration area;
3= 51-75% rotten and discoloration area;
4 = 76-100% rotten and discoloration area.

Statistical analysis

Data were analyzed with analysis of variance (ANOVA).

Table 1. Effect of essential oil on mycelia growth *C. musae* and *F. moniliforme*.

Treatment		Mycelium fungal growth(cm)			
		C. musae		*F. moniliforme*	
Essential oil	Conc. (%)	L. growth	Reduction (%)	L. growth	Reduction (%)
Control	0.0	8.37[a]	0.00	7.87[a]	0.00
	0.1	7.00[bc]	16.41	6.66[b]	15.35
Cinnamon	0.5	7.00[bc]	16.41	6.00[bc]	23.80
	1.00	5.33[e]	36.32	6.00[bc]	23.80
	0.1	6.00[d]	28.35	6.00[bc]	23.80
Clove	0.5	3.00[f]	64.17	5.00[d]	36.50
	1.0	0.00[h]	100.00	0.00[e]	100.00
	0.1	7.50[b]	10.44	6.83[b]	13.23
Lemongrass	0.5	7.50[b]	10.44	6.66[b]	15.35
	1.0	7.50[b]	10.44	6.66[b]	15.35
	0.1	6.00[d]	28.35	6. 00[bc]	23.80
Black seed	0.5	6.50[cd]	22.38	5.33[cd]	32.27
	1.0	2.50g	70.149	5.33[cd]	32.27

Values in each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range.

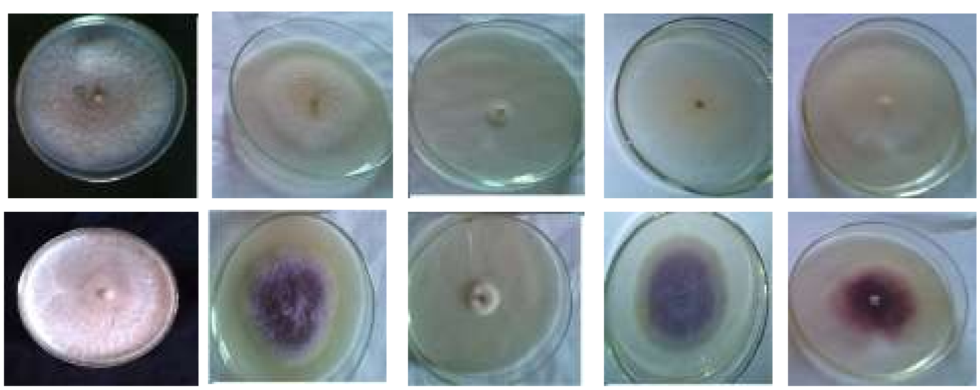

Figure 1. Effect of cinnamon, clove, lemongrass and black seed oils (1.0%) on mycelia growth of *C. musea* (above) and *F. moniliforme* (below).

Comparisons among means were made using Duncan's multiple range test (Snedecor and Cocharn, 1980) at *P* = 0.05.

RESULTS

Laboratory study

Antifungal activity of essential oils against causal organisms

Data presented in Table 1 and Figure 1 shows that all the different concentrations of essential oils tested significantly reduced mycelia linear growth of both tested fungi, that is, *C. musae* and *F. moniliformae* than the control. Data in Table 1 showed that increased essential oil concentrations led to the reduction of mycelial linear growth of two fungi tested. Clove oil (1.0%) was the best essential oil that completely inhibited (100%) linear growth of *C. musae* and *F. moniliforme* followed by black seed oil and then cinnamon oil. Clove essential oil included phenylpropanoids such as carvacrol, thymol, eugenol and cinnamaldehyde; its antimicrobial, antifungal, and antiviral activity (Chaieb et al., 2007). On

Table 2. Effect salts on mycelia growth *C. musae* and *F. moniliforme*.

Treatments		Mycelum fungal growth (cm)			
		C .musae		*F. moniliforme*	
Salts	Conc. (%)	L. growth	Reduction (%)	L. growth	Reduction (%)
Control	0.0	8.100^{a}	00.00	8.200^{a}	00.00
	1.0	6.83^{b}	15.64	6.00^{de}	26.82
Sodium chloride	2.0	6.33^{bc}	21.8	6.00^{de}	26.82
	4.0	6.500^{bc}	19.75	6.50^{cd}	20.73
	1.0	6.00^{c}	25.92	5.33^{efg}	34.96
Sodium hypochlorite	2.0	3.83^{e}	52.76	5.16^{fg}	37.00
	4.0	0.00^{g}	100.00	0.00^{i}	100.00
	1.0	6.00^{c}	25.92	7.50^{ab}	8.53
Sodium bicarbonate	2.0	4.16^{e}	48.65	6.50^{cd}	20.73
	4.0	2.66^{f}	67.8	5.66^{ef}	30.90
	1.0	2.66^{f}	67.8	6.66^{cd}	18.70
Sodium carbonate	2.0	0.00^{g}	100.00	4.33^{h}	47.15
	4.0	0.00^{g}	100.00	0.00^{i}	100.00
	1.0	6.33^{bc}	21.81	7.16^{bc}	12.60
Sodium benzoate	2.0	5.00^{d}	38.27	5.33^{efg}	34.96
	4.0	3.00^{f}	62.86	4.83^{gh}	41.06

Values in each column followed by the same letter are not significantly different at *P≤0.05* according to Duncan's multiple range.

the other hand, lemon grass oil was the least oil that reduced mycelial linear growth of two fungi tested. These results are in agreement with the results obtained *in vitro*, on fungi causing crown rot in banana fruits, that is, *Lasiodiplodia theobromae, Fusarium proliferatum* and *C. musae*. Ranasinghe et al. (2002) found that cinnamaldehyde (66.2%) is the major constituent of cinnamon bark oil, its fungistatic and fungicidal at 0.64 and 1.00 mg/ml of *C. nardus* and 0.2 to 0.6% (v/v) of *O. basilicum.* Anthony et al. (2004) and Maqbool et al. (2010) found that cinnamon oil suppressed mycelial growth and inhibited conidial germination (83.2%) of *C. musae*. Maqbool et al. (2011) reported that lemon grass at 0.05 and 0.4% had fungicidal activity against *C. musae* and *Colletotrichum gloeosporioides,* the causal organisms of banana and papaya anthracnose diseases, respectively. Abd-Alla et al. (2014) found that cinnamon, thyme oils completely inhibited 100% mycelium growth and conidial germination of *F. semitectum,* the cause of crown rot of banana fruits. In addition, Idris et al. (2015) reported that basil, cinnamon and rosemary oil (0.1%) completely inhibited mycelia growth of *C. musae*.

Screening of salts against causal organisms

Data in Table 2 and Figure 2 showed that all salts tested significantly reduced linear growth of both fungi tested more than the control. In general, increased essential oils concentration increased their reduction of mycelial growth of the two fungi tested. Sodium carbonate was the best salt that completely (100%) inhibited the linear growth of *C. musae* at 2% and *F. moniliforme* at 4% followed by sodium hypochlorite at 4%. Data in Table 2 indicated that sodium bicarbonate and sodium benzoate significantly reduced linear growth of *C. musae* by 67.8 and 62.8, respectively. Data in Table 2 and Figure 2 showed that sodium carbonate and sodium hypochlorite completely (100) reduced mycelial linear growth of *F. moniliforme* at 4%, but sodium benzoate had moderate effect on mycelial growth of *F. moniliforme* followed by sodium bicarbonate. On the other hand, sodium chloride had the least effect on mycelial growth of two fungi. These results are in agreement with Dionisio and Koabyashi (2004) who found that organic and inorganic salts, that is, Na_2CO_3 (4 g/L), NaClO (5 g/L), $NaHCO_3$, $CaCl_2$, and NaCl (6 g/L) completely inhibited spore germination of fungi causing crown rot diseases in banana, that is, *L. theobromae*, *Thielaviopsis paradoxa, C. musae, C. gloeosporioides, Fusarium verticillioides,* and *Fusarium oxysporum.* Turkkan and Erper (2014) found that sodium metabisulfite completely inhibited mycelial growth of *F. oxysporum.*f.sp.*capae,* the cause of onion basal rot.

Effect of organic and antioxidant acids against causal organisms

Data in Table 3, Figures 3 and 4 shows that all organic

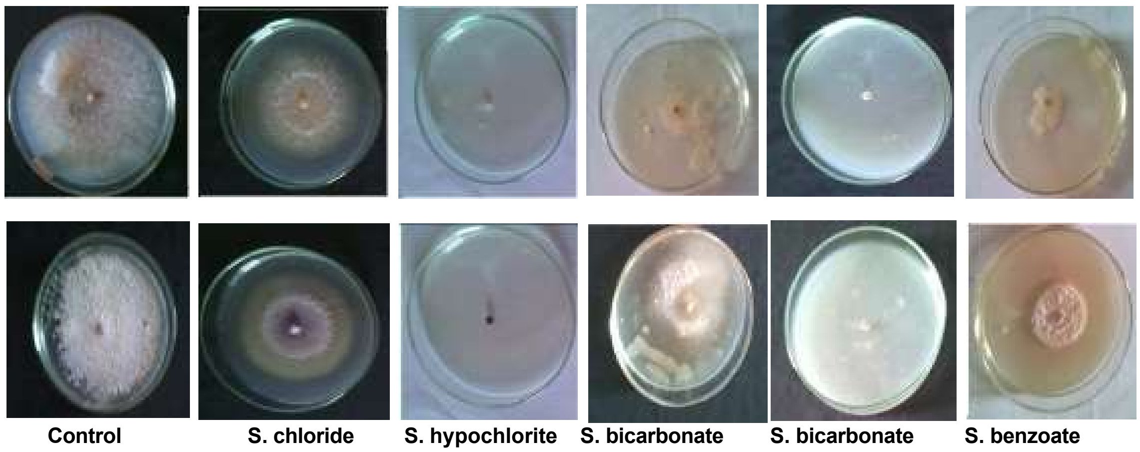

Figure 2. Effect of sodium chloride, sodium hypochlorite, sodium bicarbonate, sodium bicarbonate, and sodium benzoate salt on mycelia growth of *C. musea* (above) and *F. moniliforme* (below).

Table 3. Effect antioxidants on mycelial growth of *C. musae* and *F. moniliforme*.

Treatments		**Mycelium fungal growth(cm)**			
		C. musae		***F. moniliforme***	
Antioxidants	**Conc. (%)**	**L. growth**	**Reduction (%)**	**L. growth**	**Reduction (%)**
Control	0.0	8.58[a]	0.00	8.00[a]	0.00
	0.1	6.33[e]	26.21	7.00[b]	12.50
Benzoic acid	0.5	7.00[d]	18.44	6.83[b]	14.58
	1.0	1.50[h]	82.52	6.00[c]	25.00
	0.1	7.50[c]	12.61	2.83[f]	64.58
Propionic acid	0.5	0.00[i]	100.00	0.00[i]	100.00
	1.0	0.00[i]	100.00	0.00[i]	100.00
	0.1	1.33[h]	84.46	2.00[gh]	75.00
Sorbic acid	0.5	0.00[i]	100.00	0.00[i]	100.00
	1.0	0.00[i]	100.00	0.00[i]	100.00
	0.1	2.33[g]	72.81	3.33[e]	58.337
Citric acid	0.5	0.00[i]	100.00	2.33[g]	70.837
	1.0	0.00[i]	100.00	1.66[h]	79.175
	0.1	2.83[f]	66.99	3.66[e]	54.175
Malic acid	0.5	0.00[i]	100.00	2.16[g]	72.925
	1.0	0.00[i]	100.00	0.00[i]	100.00
	0.1	8.00[b]	6.79	5.00[d]	37.500
Salicylic acid	0.5	0.00[i]	100.00	0.00[i]	100.00
	1.0	0.00[i]	100.00	0.00[i]	100.00

Values in each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range.

and antioxidants acids tested significantly reduced linear growth of *C. musae* and *F. moniliforme* more than the control (untreated). In general, increased organic and antioxidants acids concentrations increased their reduction of mycelial growth of two fungi tested. Data in Table 3 clearly shows that propionic, salicylic and sorbic, and malic acids at 0.05 and 100% inhibited mycelial linear growth of fungi tested. Data in Table 3 shows that

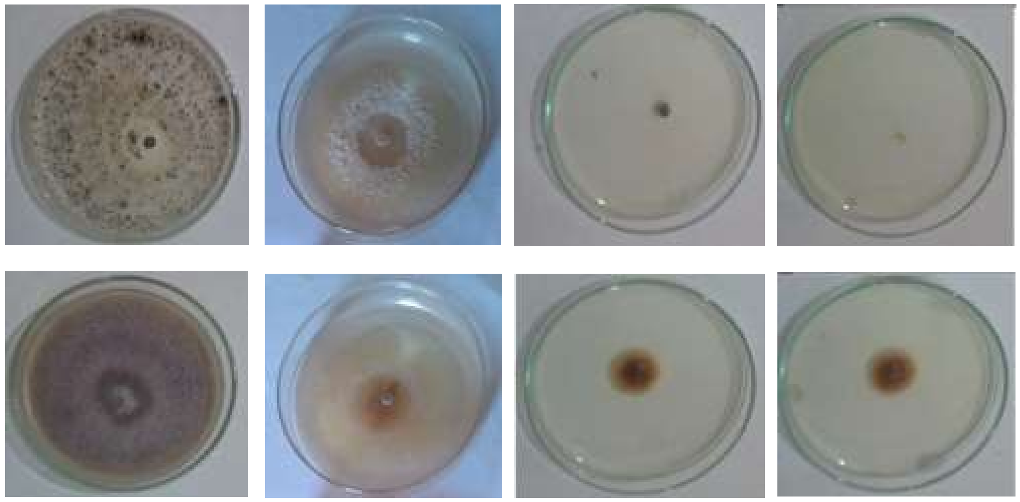

Figure 3. Effect of benzoic, citric, malic acids at (0.5%) on mycelia growth *C. musae* (above) and *F. moniliforme* (below).

citric acid (1.0%) completely (100%) inhibited mycelial growth of *C. musae* and significantly reduced linear growth of *F. moniliforme* by 79.1%.

On the other hand, benzoic acid was the least agent that reduced linear growth of both fungi. Antioxidants safe natural phenolic compound chemicals, that is, salicylic, citric, benzoic, hydroquinone and ascorbic acids had been used as alternative pesticides to protective and therapeutic treatments of plant diseases caused by a wide range of viral, fungal and bacterial pathogens. Mandal et al. (2009) and Khan et al. (2001) found the greatest antifungal activity of BHA and benzoic acid against *C. musae,* the cause of banana fruit anthracnose disease.

Effect of treatment methods on postharvest diseases of banana fruit Cv. Balady

Different treatment methods, that is, spraying, soaking and dusting were tested against postharvest diseases of banana, such as, crown rot, neck rot, finger rot, and flower end rot. Data in Table 4 showed that clove oil (1.0%) and propionic acid (0.5%) were used as spray and soaking treatments for banana fruits. Meanwhile, spraying, soaking and dusting treatment were used with sodium carbonate (4.0%) and salicylic acid (0.5%). Data in Table 4 indicated that all the different treatments with clove oil, propionic acid, sodium carbonate and salicylic acid significantly reduced crown rot incidence of banana fruits more than the control. Soaking treatment significantly reduced crown rot incidence and disease severity with clove oil, propionic acid, sodium carbonate and salicylic acid compared to spray and dusting treatments. Data in Table 4 clear indicated that they were no significant differences between all the treatment methods (spray, soaking and dusting) on neck rot diseases incidence of banana fruit, except soaking treatment with sodium carbonate. Table 4 indicated that soaking treatment in clove oil and sodium carbonate significantly reduced finger rot of banana fruits more than propionic acid, salicylic acid as spray and dusting treatments.

Furthermore, data in Table 4 shows that there are no significant differences in percentage of flower end rot disease and disease severity between treatments tested and control, except soaking treatment. Clove oil was the best and significantly treatment that reduced flower end rot incidence at zero level on banana fruit. In general, soaking treatment with clove and sodium carbonate were the best treatments that reduced crown rot and neck rot. These results are in agreement with Anyhony et al. (2003) and Abd-Alla et al. (2014).

Effect of different treatments on the management of postharvest diseases of banana fruits

Healthy ripe banana fruits Cv. Balady were soaked for 5 min, in each suspension of clove oil (2.0%), sodium carbonate (6.0%), sorbic acid (2.0%), propionic acid (1.0%) and salicylic acid (1.0%) before artificial infestation with causal pathogens (Figure 5). Data in Table 5 showed that banana fruits soaked for 5 min in clove oil suspension (2.0%), sodium carbonate (6.0%), sorbic acid (2.0%), propionic acid (1.0%) and salicylic acid (1.0%) significantly reduced postharvest diseases of banana fruits, that is, crown rot, neck rot, finger rot and flower end rot more than the control. Soaking banana fruit in clove suspension was the best and significantly treatment that

Table 4. Effect of treatment methods on postharvest diseases of banana fruits.

Treatment			Postharvest diseases incidence on banana fruits Cv. Balady							
			Crown rot		Neck rot		Finger rot		Flower end rot	
Agents	Conc. (%)	Method	%	D.S	%	D.S	%	D.S	%	D.S
Control	-	-	50.0^{a}	2.0^{a}	30.0^{b}	2.0^{a}	40.0^{b}	2.0^{a}	30.0^{a}	2.0^{a}
Clove	1.0	Spray	30.0^{c}	2.0^{a}	30.0^{b}	2.0^{a}	30.0^{c}	2.0^{a}	30.0^{a}	2.0^{a}
		Soaking	20.0^{d}	1.0^{b}	30.0b	2.0^{a}	20.0^{d}	1.0^{b}	0.0^{c}	0.0^{c}
Propionic acid	0.5	Spray	30.0^{c}	2.0^{a}	40.0^{a}	2.0^{a}	30.0^{c}	2.0^{a}	20.0^{b}	1.0^{b}
		Soaking	20.0^{d}	1.0^{b}	40.0^{a}	2.0^{a}	40.0^{b}	2.0^{a}	30.0^{a}	2.0^{a}
Sodium carbonate	4.0	Spray	30.0^{c}	2.0^{a}	30.0^{b}	2.0^{a}	20.0^{d}	1.0^{b}	30.0^{a}	2.0^{a}
		Soaking	10.0^{e}	1.0^{b}	10.0^{d}	1.0^{b}	20.0^{d}	1.0^{b}	30.0^{a}	2.0^{a}
		Dusting	40.0^{b}	2.0^{a}	30.0^{b}	2.0^{a}	50.0^{a}	2.0^{a}	30.0^{a}	2.0^{a}
Salicylic acid	0.5	Spray	20.0^{d}	1.0^{b}	20.0^{c}	1.0^{b}	30.0^{c}	2.0^{a}	30.0^{a}	2.0^{a}
		Soaking	30.0^{c}	2.0^{a}	20.0^{c}	10.0^{b}	30.0^{c}	2.0^{a}	20.0^{b}	1.0^{b}
		Dusting	40.0^{b}	2.0^{a}	30.0^{b}	2.0^{a}	40.0^{b}	2.0^{a}	20.0^{b}	1.0^{b}

Values in each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range.

Control **Propionic acid** **Sorbic acid** **Salicylic acid**

Figure 4. Effect of propionic, sorbic and salicylic acids at (0.5%) on mycelia growth of *C. musae* (above) and *F. moniliforme* (below).

completely suppressed (100%) crown rot and flower end rot incidence of banana fruits and significantly reduced finger rot. On the other hand, salicylic acid followed by propionic acid was the lowest treatments that reduced crown, neck and finger rots. These results are in line with that of Ranasinghe et al. (2002) study who found that, spraying embul banana with emulsions of cinnamom oil prior storage controlled crown rot stored up to 14 days at ambient temperature (28±20°C) and 21 days at 40°C in modified atmosphere. Also, banana fruits treated with emulsions of cinnamon oil combined with modified atmosphere packaging extended the storage life of Embul banana up to 21 days in a cold room and 14 days at 28 ± 2°C without affecting the organoleptic and

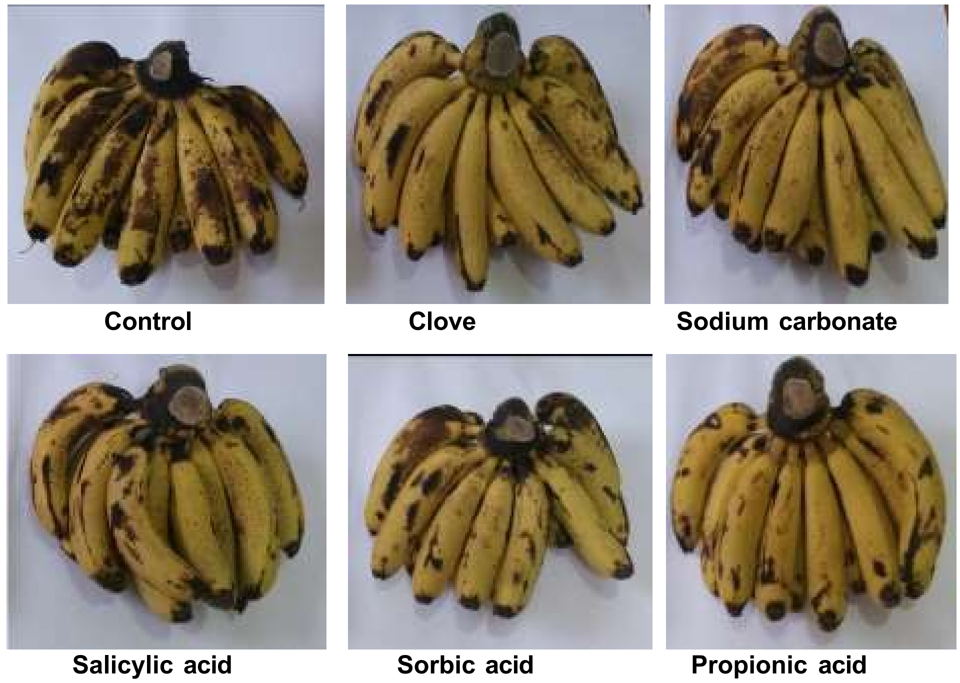

Figure 5. Effect of some essential oil clove (0.2%), sodium carbonate (6.0%), propionic and salycilic acids (1.0%) and sorbic acid (2.0%) for management of postharvest diseases banana fruit. After 15 days after artificial infestation by causal organisms.

Table 5. Management of post-harvest diseases after storage 15 days at 25 2°C**.**

Treatment		**Postharvest diseases incidence on banana fruits**							
Material	**Conc. (%)**	**Crown rot**		**Neck rot**		**Finger rot**		**Flower end rot**	
		%	**D.S**	**%**	**D.S**	**%**	**D.S**	**%**	**D.S**
Control	0.0	100.0[a]	4.0[a]	60.0[a]	3.0[a]	90.0[a]	4.0[a]	80.0[a]	4.0[a]
Clove	2.0	0.0[f]	0.0[e]	20.0[d]	1.0[c]	30.0[d]	2.0[c]	0.0[d]	0.0[c]
Sodium carbonate	6.0	20.0[e]	1.0[d]	20.0[d]	1.0[c]	40.0[c]	2.0[c]	20.0[b]	1.0[b]
Sorbic acid	2.0	30.0[d]	2.0[c]	40.0[b]	2.0[b]	40.0[c]	2.0[c]	20.0[b]	1.0[b]
Propionic acid	1.0	80.0[b]	4.0[a]	30.0[c]	2.0[b]	60.0[b]	3.0[b]	0.0[d]	0.0[c]
Salicylic acid	1.0	60.0[c]	3.0[b]	20.0[d]	1.0[c]	40.0[c]	2.0[c]	10.0[c]	1.0[b]

Values in each column followed by the same letter are not significantly different at *P≤ 0.05* according to Duncan's multiple range.

physico-chemical properties (Ranasinghe et al., 2005; Maqbool et al., 2010; Abd-Alla et al., 2014). Idris et al. (2015) found that treatment of banana fruits Cvs. Cavendish and Williams treated with essential oil (0.20%) of basil, cinnamon and rosemary essential oils reduced anthracnose of banana fruits after 19 days of storage. Singh and Tripathi (2015) showed that, *C. zeylanicum* oil treated banana fruits showed enhancement storage life up to 4 days. Dionisio and Kobayashi (2004) reported that dipping banana fruits in NaClO or $NaHCO_3$ for 10 to 15 min reduced the incidence of crown rot 17 days after harvest. Kazemi et al. (2013) reported that dipping of pomegranates fruits for 4 min in 4% calcium chloride solution combined with sodium hypochlorite (10%) was the best treatment to enhance postharvest factors of pomegranates. Cruz et al. (2013) reported that citric extract at 4% significantly reduced fruit rot incidence of banana by 19.44% more than 90.16% in the control.

Conclusion

Clove essential oil, sodium carbonate and sorbic acid were the most promising eco-friendly, antifungal and alternative synthetic fungicides against pathogenic fungi and their ability to deteriorate banana fruits during storage, marketing and transportation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abd-Alla MA, El-Gamal NG, El-Mougy NS, Abdel-Kader MM (2014). Post-harvest treatments for controlling crown rot disease of Williams banana fruits (*Musa acuminata* L.) in Egypt. Plant Pathol. Q. 4(1):1-12.

Abdullah Q, Mahmoud A, Al-Harethi A (2016). Isolation and identification of fungal postharvest rot of some fruits in Yemen. PSM Microbiol. 1(1):36-44.

Agrios GN (2005). Plant Pathology, 5thed Academic Press, USA. 922p.

Anthony S, Abeywickrama K, Wijeratnam SW (2003).The effect of spraying essential oils of *cymbopogon nardus, cymbopogan flexuosus* and *Ocimum basilicum* on postharvest diseases and storage life of Embul banana. J. Hortic. Sci. Biotechnol. 78:780-785.

Anthony S, Abeywickrama K, Dayananda R, Wijeratnam SW, Arambewela L (2004). Fungal pathogens associated with banana fruit in Sri Lanka, and their treatment with essential oils. Mycopathologia 157:91-97.

Bhattacharyya A, Chakraborty S (2007). Effect of inorganic salts on *Colletotrichum musae* and *Fusarium solani* - causal organisms of crown rot disease of banana. Assam Agricultural University, AICRP on Fruits, Jorhat, India, 290 p.

Chaieb K, Hajlaoui H, Zmantar T, Kahla-Nakbi AB, Rouabhia M, Mahdouani K, Bakhrouf A (2007).The chemical composition and biological activity of clove essential oil, *Eugenia caryophyllata* (*Syzigium aromaticum* L. Myrtaceae): a short review. Phytother. Res. 21(6):501-506.

Cruz M, Estrada KRF, Clemente E, Itako AT, Stangarlin JR, Cruz M (2013). Plant extracts for controlling the post-harvest anthracnose of banana fruit. Rev. Bras. Plant. Med. 15(4):727-733.

Diedhiou MP, Zakari HA, Mbaye N, Rokhaya F, Samb LP (2014). Control methods for postharvest diseases of banana (*Musa sinensis*) produced in Senegal. Int. J. Sci. Environ. Technol. 3:1648-1656.

Dionisio G, Kobayashi T (2004). Inhibitory influence of inorganic salts on banana postharvest pathogens and preliminary application to control crown rot. J. Gen Plant Pathol. 70:61-65.

Dionisio GA, Natsuaki KT (2007). Control of crown rot-causing fungal pathogens of banana by inorganic salts and a surfactant. Crop Prot. 26(11):1667-1673.

Idris MF, Ibrahim MA, Forsido FS (2015). Essential oils to control *Colletotrichum musae in vitro* and *in vivo* on banana fruits. Am-Eur. J. Agric. Environ. Sci. 15(3):291-302.

Kazemi F, Jafararpoor M, Golparvar A (2013). Effects of sodium and calcium treatments on the shelf life and quality of pomegranate. Intl. J. Farm Allied Sci. 2(S2):1375-1378.

Khan SHJ, Aked J, Magan N (2001). Control of the anthracnose pathogen of banana (*Colletotrichum musae*) using antioxidants alone and in combination with thiabendazole or imazalil. Plant Pathol. 50(5):601:608.

Khleekorn S, McGovern J, Wongrueng S (2015). Control of the banana anthracnose pathogen using antagonistic microorganisms. J. Agric. Technol. 11(4):965-973.

Lassois L, Bellaire L, Jijakli MH (2008). Biological control of crown rot of bananas with *Pichia anomala* strain K and *Candida oleophila* strain. Biol. Control 45:410-418.

Mandal S, Mallick N, Mitra A (2009). Salicylic acid induced resistance to *Fusarium oxysporum* f.sp.*lycopersici* in tomato. Plant Physiol. Biochem. 47:642-649.

Maqbool M, Ali A, Peter G, Alderson PG (2010). Effect of cinnamon oil on incidence of anthracnose disease and postharvest quality of bananas during storage. Int. J. Agric. Biol. 12:516-520.

Maqbool M, Ali A, Peter G, Aldersona PG, Mohamed MTM, Siddiqui Y, Zahida N (2011). Postharvest application of gum Arabic and essential oils for controlling anthracnose and quality of banana and papaya during cold storage. Postharvest Biol. Technol. 62:71-76.

Marin H, Sutton B, Blankenship M, Swallow H (1996). Pathogenicity of fungi associated with crown rot of banana in Latin America on grande naine and disease resistant hybrid banana. Plant Dis. 80(5):525-528.

Ranasinghe L, Jayawardena B, Abeywickrama K (2005). An integrated strategy to control post- harvest decay of Embul banana by combining essential oils with modified atmosphere packaging. Intl. J. Food Sci. Technol. 40:97-103.

Ranasinghe L, Jayawardena B, Abeywickrama K (2002). Fungicidal activity of essential oils of *Cinnamomum zeylanicum* (L.) and *Syzygium aromaticum* (L.) Merr et L M Perry against crown rot and anthracnose pathogens isolated from banana. Lett. Appl. Microbiol. 35:208-211.

Singh R, Tripathi P (2015). *Cinnamomum zeylanicum* essential oil in the management of anthracnose of banana fruits. J. Innov. Pharm. Biol. Sci. 2(3):290-299.

Skidmore AM, Dickinson CH (1976). Colony interactions and hyphal interference between *Septoria nodorum* and phylloplane fungi. Trans. Br. Mycol. Soc. 66:57-64.

Snedecor GW, Cochran WG (1980). Statistical Methods. 7th Ed. Iowa State Univ. Press, Ames. pp. 476-480.

Triesta D, Pierard D, De Cremer K, Hendrickx M (2016). *Fusarium musae* infected banana fruits as potential source of human Fusariosis : may occur more frequently than we might think and hypotheses about infection. Commun. Integr. Biol. 9(2):e1162934.

Turkkan M, Erper I (2014). Evaluation of antifungal activity of sodium salts against onion basal rot caused by *Fusarium oxysporum* f. sp. cepae. Plant Prot. Sci. 50(1):19-25.

Zhang P, Whistler RL, BeMiller JN, Hamaker BR (2005). Banana starch: Production, physicochemical properties, and digestibility-a review. Carbohyd. Polym . 59:443-458.