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Effect of various fungicides, biocontrol agents, phytoextracts and essential oils on post harvest management of banana anthracnose (*Colletotrichum musae* Berk. & Curt.)

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Abstract
Among the various fungicides, biocontrol agents, phytoextracts and essential oils on post harvest management of banana anthracnose under fruit dip method; twelve treatments including a control were applied. Results revealed that fruit treatment with carbendazim 12% + mancozeb 63% WP tested at 0.05% concentration gave minimum disease intensity (11.54%) and it was significantly superior over control and remaining other treatments. For obtaining residue free organic banana fruits cinnamon oil at 0.1% and *T. harzianum* (10^6 cfu/ml) were found best which minimized 36.87 and 52.89 per cent disease, respectively. Minimum weight loss of 9.31% was recorded in carbendazim 12% + mancozeb 63% WP and shelf life of fruits treated with these was also more (10 days) as compared to the untreated control fruits (3 days). Therefore, by economical and eco-friendly disease management shelf life and storage time of banana fruits were increased and maintained the quality of fruits.

Keywords: Fungicides, biocontrol agents, phytoextracts, essential oils, minimum disease intensity, weight loss, shelf life

Introduction
Banana (*Musa paradisiaca* L.) is an important fruit crop in tropical and sub tropical regions. Banana belongs to family *Musaceae* in order scitamineae. Banana is a staple food for millions of people and most important commercial fruit which can be grown round the year. Banana is cultivated in nearly 150 countries in the world. Banana is the fourth largest fruit crop of the world. Major banana producing countries are India, China, Philippines, Brazil, Ecuador, Indonesia, Costa Rica, Mexico, Thailand and Colombia. In world, 5.6 million ha of land are dedicated to banana with production of 118.9 million tonnes (Anon., 2018a) [2]. Among the fruits, banana holds first position in production and productivity in India. It ranks third in area after mango and citrus. In India, annual production of banana is 308.09 lacs MT from an area of 8.84 lacs ha has spread all over the country with the productivity of 34.86 MT/ha. In India, Gujarat holds first position among all states in production of banana by annual production of 41.85 lacs MT from an area of 0.65 lacs ha with the productivity of 64.70 MT/ha (Anon., 2018b) [2].

Banana fruits are highly perishable in nature. During storage, banana fruits deteriorate through the activity of microorganisms. The two primary postharvest rots of banana (*Musa* spp.) fruits are anthracnose and crown rot. Anthracnose is one of the most important postharvest diseases of banana, commonly caused by *Colletotrichum musae* (Berk. & Curt.), which infects wounded green fruits and also ripe fruit.

During post harvest storage and handling of banana, among the various plant disease control approaches, fungicides, biocontrol agents, natural plant products, including essential oils are a major important method for control of disease. The products which are bio-degradable, economical and environmentally safe can be use as alternative of agrochemicals. Therefore, this experiment was formulated to evaluate the efficacy of fungicides, biocontrol agents, natural plant products, and essential oils to control the anthracnose disease of banana fruits.

Materials and Methods

During the fruit dip experiment, six different fungicides namely, mancozeb 75% WP and captan 75% WP at 0.15%, carbendazim 50% WP, propiconazole 25% EC, carbendazim 12% + mancozeb 63% WP and carboxin 37.5% + thiram 37.5% DS at 0.05% concentrations and other six treatments (included in the groups *viz*., essential oils, phytoextracts and biocontrol agents) namely, cinnamon oil and basil oil at 0.1%, garlic extract and neem extract at 5%, *T. harzianum* (10^6 cfu/ml) and *P. fluorescens* (10^9 cfu/ml), including of a control were carried out in experiment.

Healthy banana fruits were washed and surface sterilized in 1% sodium hypochlorite solution for 2 minutes. Unripe healthy banana fruits were artificially inoculated by dipping in spore suspension (2×10^5 spores/ml) of test fungus, which were previously prepared in sterile distilled water with pure culture of *C. musae*. One hour after inoculation these banana fruits were treated with various fungicides, essential oils, biocontrol agents and phytoextracts. Four banana fruits were taken in each treatment which was repeated three times in complete randomized design. Treated fruits were air dried and kept in well aerated room at laboratory, Department of plant pathology, college of agriculture, JAU, Junagadh. Observations were recorded. The estimation of anthracnose was taken by using 0-5 scale described by Jagana *et al*. (2017) [8] and calculated the per cent disease intensity in each treatment.

Initial weight of each sample fruits before giving the experiment and final weight of each sample fruits after the completion of treatment were taken. Other characters of banana fruits like, colour, fruit condition (hardness/softness), ripening days, shelf life etc. were also noted. Periodically changes in different treated fruit's characters were recorded during the experiment period. Difference between initial and final weight after ripening of treated and control banana fruits were calculated. Banana fruit weight increased over control were also noted for further studies.

The per cent disease intensity (PDI) were calculated according to the formula suggested by Datar and Mayee (1981) [4] given as below.

$$PDI = \frac{\text{Sum of rating of infected fruits}}{\text{Total no.of fruits observed}} \times \frac{100}{\text{Maximum disease score}}$$

Per cent disease intensity decrease over control (PDIDOC) was calculated using following formula suggested by Kapadiya (2006):

$$PDIDOC = \frac{\text{PDI in control-PDI in treatment}}{\text{PDI in control}} \times 100$$

Per cent fruit weight loss was calculated using following formula suggested by Kapadiya (2006):

$$\text{Fruit weight loss (\%)} = \frac{\text{Initial fruit weight- Final fruit weight}}{\text{Initial fruit weight}} \times 100$$

Per cent weight loss decrease over control (PWLDOC) was calculated by using following formula suggested by Kapadiya (2006):

$$PWLDOC = \frac{\text{PWL in control-PWL in treatment}}{\text{PWL in control}} \times 100$$

Results and Discussion

The perusal of data presented in the Table 1 showed that all fungicides, biocontrol agents, phytoextracts and essential oils were capable of controlling per cent disease intensity (PDI) at all concentrations tried in the present investigation. Their mean PDI was ranged from 11.54 to 76.64 per cent.

Results revealed that all the treatments tested against anthracnose disease were significantly reduced disease as compared to the control. Minimum disease intensity (11.54%) was recorded in carbendazim 12% + mancozeb 63% WP tested at 0.05% concentration and it was significantly superior over control and remaining other treatments. Carbendazim 50% WP (20.94%) was remained better in reduction of anthracnose diseases of banana. Propiconazole 25% EC, mancozeb 75% WP and cinnamon oils noted 35.98, 36.07 and 36.87 per cent disease intensity, respectively and were also good, they remain at par. Bio agent *T. harzianum* (52.89%) also performed considerable reduction in anthracnose disease as compared to chemical fungicide. However, other treatments namely, carboxin 37.5% + thiram 37.5% DS, garlic extract, basil oil, *pseudomonas fluorescens*, neem extract and captan 75% WP were showed inferior in reduction with 64.33, 69.27, 69.85, 71.68, 71.98 and 76.64 per cent disease intensity, respectively. Control treatment recorded maximum disease (100%). Maximum (88.46%) disease intensity decrease over control was recorded in carbendazim 12% + mancozeb 63% WP followed by carbendazim50% WP, propiconazole 25% EC, mancozeb 75% WP, cinnamon oil and *T. harzianum* with 79.06, 64.02, 63.93, 63.13 and 47.11 per cent, respectively. Minimum PDI decrease over control was noted in captan 75% WP (23.36%).

All the treatments reduced weight loss as compared to control, its range from 9.31 to 19.79 per cent. Minimum weight loss of 9.31% was recorded in carbendazim 12% + mancozeb 63% WP. Next effective treatment was carbendazim 50% WP with 10.27% reduced weight loss of banana fruit. Biocontrol agents like *T. harzianum* (11.60%) were found better than rest of treatment, followed by propiconazole 25% EC and carboxin 37.5% + thiram 37.5% DS with 14.25 and14.97 per cent reduction in weight loss of fruit. Other remaining treatment was inferior in weight loss reduction and recorded in the range of 17.23 to 19.79 per cent. Maximum (28.14%) weight loss reduction was recorded in control treatment. All the treatments were recorded loss decrease over control. Maximum (66.92%) loss decrease over control was recorded in carbendazim 12% + mancozeb 63% WP followed by carbendazim 50% WP (68.50%). The biological control stands third in loss decrease over control with 58.78 per cent. Other treatment namely, propiconazole 25% EC, carboxin 37.5% + thiram 37.5% DS, captan 75% WP, mancozeb 75% WP and cinnamol oil were found good in loss decreased over control with 49.36, 46.80, 38.77, 37.92 and 37.31 per cent, respectively. Remaining other treatment noted inferior in loss decrease over control in the range from 33.34 to 29.67 per cent.

Shelf life after fruit ripening is very important for human consumption. Shelf life of banana fruits was found to be increase after adopting various treatments. Shelf life increase after 3 days was noted in control. Maximum 10 days shelf lives were recorded in carbendazim 12% + mancozeb 63% WP and carbendazim 50% WP followed by 8 days in propiconazole 25% EC and cinnamon oil; 7 days in carboxin 37.5% + thiram 37.5% DS, mancozeb 75% WP and garlic extract; 6 days in *T.harzianum* and neem extract and *P.fluorescens* and 5 days in captan 75% WP and basil oil.

Other character like colour, softness was found good with the increasing shelf life. The fruits treated with carbendazim 12% + mancozeb 63% WP and carbendazim 50% WP showed light

yellow colour and normal softness. Secondly fruits treated with cinnamon oil, propiconazole 25% EC, *T. harzianum* showed moderate yellow to yellow colour and normal to moderate softness. Control fruits which were not treated by any treatment became brownish black in colour and showed water soaked soft fruit pulp (Table 2).

Farmers/traders who are interested in organic/residue free banana fruits can use the cinnamon oil and *T. harzianum* for post harvest anthracnose disease control, which minimized 36.87 and 52.89 per cent disease and 63.13 and 47.11 per cent PDI decrease over control, respectively.

The results obtained were supported by the findings of Frossard *et al.* (1973) [5] who have recommended the use of bavistin (50% carbendazim) solution as one minute dip (at 200-300 ppm) against storage rot of banana caused by *C. musae.*

Similar result was found by Datar and Ghule (1998) [3] who studied that pathogens associated with fruit rot of banana can be effectively controlled by dipping the fruits in carbendazim (1000 ppm) for 10 min. Nath *et al*. (2014) [11] and Nath *et al*. (2015b) [10] who showed that minimum PDI was observed in propiconazole and carbendazim 12% + mancozeb 63% WP (1%) treated fruits with 25 maximum reduction of fruit rot disease (98.76%) followed by carbendazim (2.50%) with 96.79% reduced fruit rot disease.

The effectiveness of biocontrol agents was supported by reports of Tasiwal *et al*. (2012) [15], similarly results obtained in effect of phytoextracts was supported by findings of Win *et al*. (2007) [16], Garcia (2011) [6], and Saha and Shamsi (2016) [13]. Similar results in effectiveness of essential oils were obtained by Ranasinghe *et al*. (2002) [12], Idris *et al*. (2015) [7] and Singh and Tripathi (2015) [14] who reported that cinnamon oil found most effective.

Effectiveness of various treatments on increasing shelf life and decreasing weight loss was also obtained by Idris *et al*. (2015) [7] and Singh and Tripathi (2015) [14].

Table 1: Effect of different fungicides, essential oils, phytoextracts and bioagents on anthracnose disease intensity, fruit weight loss and shelf life

Treatment	Concentration (%)	Per cent disease intensity@	PDI decrease over control (%)	Fruit weight loss (%)@	Loss decrease over control (%)	Shelf life after ripening (days)
Mancozeb 75% WP	0.15	36.87 (36.07)*	63.93	17.47	37.92	7
Captan 75% WP	0.15	61.14 (76.64)	23.36	17.23	38.77	5
Carbendazim 50% WP	0.05	27.15 (20.94)	79.06	10.27	63.50	10
Propiconazole 25% EC	0.05	36.85 (35.98)	64.02	14.25	49.36	8
Carbendazim 12% + Mancozeb 63% WP	0.05	19.85 (11.54)	88.46	9.31	66.92	10
Carboxin 37.5% + Thiram 37.5% DS	0.05	53.45 (64.33)	36.67	14.97	46.80	7
Cinnamon oil	0.1	37.38 (36.87)	63.13	17.64	37.31	8
Basil oil	0.1	56.70 (69.85)	30.15	19.79	29.67	5
Garlic extract	5	56.44 (69.27)	30.73	18.76	33.34	7
Neem extract	5	58.05 (71.98)	28.02	19.49	30.74	6
Trichodermaharzianum	10^6cfu/ml	46.65 (52.89)	47.11	11.60	58.78	6
Pseudomonas fluorescens	10^9cfu/ml	57.84 (71.68)	28.32	19.54	30.56	6
Control	-	90.00 (100)	0	28.14	-	3
S.Em. ±	-	1.65	-	1.95	-	-
C.D. at 5%	-	4.81	-	5.66	-	-
C.V. %	-	6.26	-	20.07	-	-

@ Average of three replications

*Figures in parentheses indicate arc-sine re-transformed values

Table 2: Effect of different fungicides, essential oils, phytoextracts and bioagents on fruit colour and softness

Treatment	Concentrations (%)	Per cent disease intensity@	Fruit colour	Fruit softness
Mancozeb 75% WP	0.15	36.87 (36.07)*	Dark yellow with some brown spots	Light soft
Captan 75% WP	0.15	61.14 (76.64)	Yellowish brown	More soft
Carbendazim 50% WP	0.05	27.15 (20.94)	Light yellow	Normal soft
Propiconazole 25% EC	0.05	36.85 (35.98)	Moderate yellow	Normal soft
Carbendazim 12% + Mancozeb 63% WP	0.05	19.85 (11.54)	Light yellow	Normal soft
Carboxin 37.5% + Thiram 37.5% DS	0.05	53.45 (64.33)	Dark yellow with moderate brown spots	Moderate soft
Cinnamon oil	5	37.38 (36.87)	Yellow	Normal soft
Basil oil	5	56.70 (69.85)	Yellowish brown	More soft
Garlic extract	5	56.44 (69.27)	Dark yellow with brown spots	Moderate soft
Neem extract	5	58.05 (71.98)	Dark yellow with brown spots	More soft
Trichodermaharzianum (10^6cfu/g)	5	46.65 (52.89)	Moderate yellow	More soft
Pseudomonas fluorescens (10^9cfu/g)	5	57.84 (71.68)	Yellowish brown	highly soft
Control	-	90.00 (100)	Brownish black	Water soaked pulp

*Figures in parentheses indicate arc-sine re-transformed values

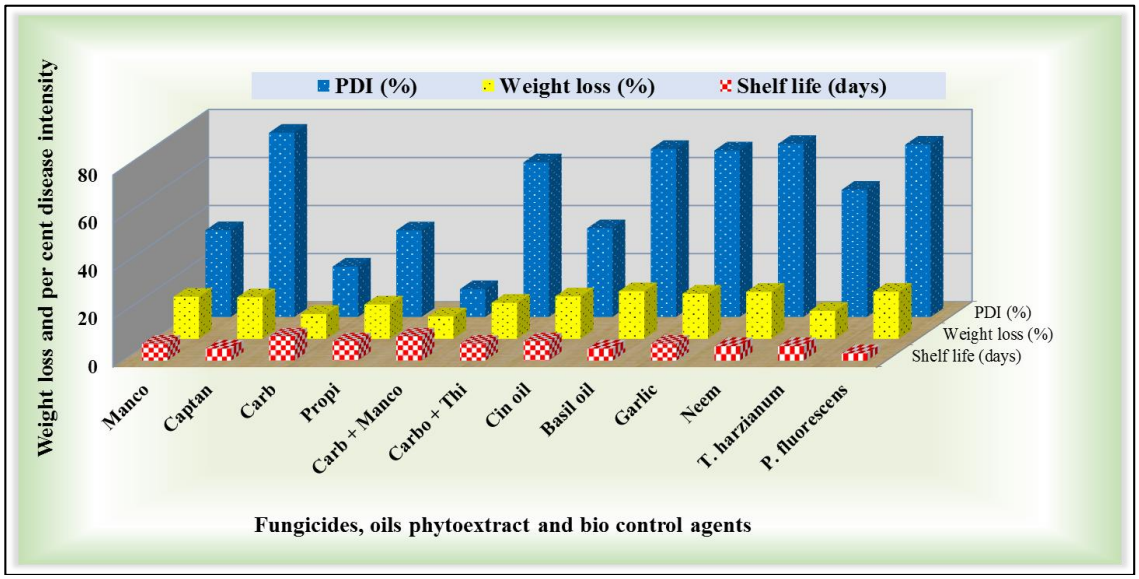

Fig 1: Effect of various treatments on anthracnose per cent disease intensity, weight loss and shelf-life (days) of banana fruits *in vitro*

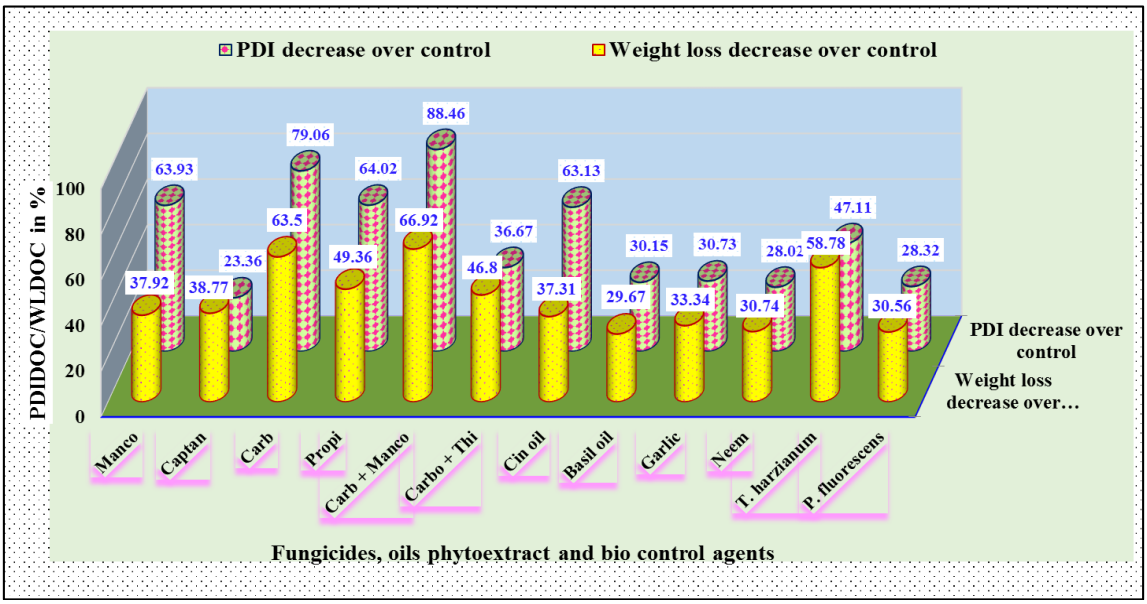

Fig 2: Effect of various treatments on PDI decrease over control and weight loss decrease over control of banana fruits

Fig 3: Effect of different fungicides, essential oils, phytoextracts and bioagents on anthracnose disease intensity

Treatments

1. Mancozeb 75% WP
2. Captan 75% WP
3. Carbendazim 50% WP
4. Propiconazole 25% EC
5. Carbendazim 12% + Mancozeb 63% WP
6. Carboxin 37.5% + Thiram 37.5% DS
7. Cinnamon oil
8. Basil oil
9. Garlic extract
10. Neem extract
11. Trichoderma harzianum
12. Pseudomonas fluorescens

Conclusion

Among the all bio agents, botanicals, essential oils and fungicides, the best two were tested for fruit dip treatment. The results revealed that among the all twelve different treatments minimum (11.54%) per cent disease intensity was recorded in fruits treated with carbendazim 12% + mancozeb 63% WP at 0.05% concentration. For obtaining residue free organic banana fruits cinnamon oil at 0.1% and *T. harzianum* (10^6 cfu/ml) were found best which minimized 36.87 and 52.89 per cent disease, respectively. Minimum weight loss of 9.31% was recorded in carbendazim 12% + mancozeb 63% WP and shelf life of fruits treated with these was also more (10 days) as compared to the untreated control fruits (3 days).

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