International Journal of Economic Plants

https://ojs.pphouse.org/index.php/IJEP

IJEP August 2024, 11(3): 188-204

Crossref

Article IJEP5317

Full Research

Doi: HTTPS://DOI.ORG/10.23910/2/2024.5317

Prevalence and Management of Post-harvest Rots of Apple in Himachal Pradesh

Neelam Kumari* and J. N. Sharma

Dept. of Plant Pathology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh (173 230), India

Corresponding Author

Neelam Kumari
e-mail: neelkumari90@gmail.com

Article History

Received on 21st March, 2024
Received in revised form on 06th June, 2024
Accepted in final form on 20th June, 2024

Abstract

During a survey of post-harvest diseases of apple in Himachal Pradesh conducted during July to September 2021, fourteen different types of rots were observed. Among these, *Penicillium expansum* (blue mould) was most destructive with exclusive incidence of 43.8%. Surveys of different markets/stores of Himachal Pradesh revealed that the total losses due to apple decay at various locations varied from 7.80 to 21.93%. Ten important commercial varieties of apple were screened for their comparative susceptibility against fruit decay.Tydeman's Early Worcester was found to be most tolerant to all the rot causing fungi with mean per cent rotting of 23.26%.Cow urine was found most effective in providing 79.21% growth inhibition of test fungi under study. The next best bio-products were *Emblica officinalis* (amla), *Melia azadirach* (darek) and *Dodonaea viscose* (mehandu) with per cent growth inhibition of 75.66, 73.59 and 68.48%, respectively. Under *in vitro* conditions, mancozeb (0.1%) was the most effective fungicide providing 84.83% growth inhibition.The efficacy of mancozeb as dip treatment at 0.1% concentration was judged to be significantly superior followed by 0.05% carbendazim with per cent control of 95.97 and 92.35%, respectively. Preharvest spray of mancozeb (0.3%) was highly effective in checking all the test fungi under different type of storage for 2 months. 1-methyl cyclopropene (MCP) fumigation of apple fruits immediately after harvesting for 12 hours was most effective in checking the test fungi under study providing 89.60% control.

Keywords: CA storage, fumigants, plant extracts, varietal susceptibility

1. Introduction

Apple (*Malus×domestica* Borkh.) is a member of Rosaceae family and considered as one of the most economically important fruit trees of temperate zones (Martinelli et al., 2008). Agro-climatic conditions in hilly regions of Himachal Pradesh offer immense natural potential for increasing area and production under temperate fruits, especially apple. Though the area and production under apple cultivation in Himachal Pradesh has increased during the last few decades, but the productivity per unit area has not increased proportionally and is quite low as compared to the advanced apple growing countries of the world. The reasons for low apple productivity could be many, but one of them is the post-harvest losses caused by different fungi (Sottocornola et al., 2023). The major losses are attributed to fungi belonging to two distinct groups, which differ in their methods of fruit contamination. The first group infects the fruit through wounds caused by weather accidents or mishandling during harvest. The second group enters the fruit via lenticels, which are often represented by slow-growing fungi with symptoms appearing during storage. Notably, diseases resulting from injuries pose a real threat to apple production. The main postharvest fungal diseases affecting apples include blue mold caused by *Penicillium expansum*, gray rot caused by *Botrytis cinerea*, brown rot caused by *Monilinia* sp., rot caused by *Altenaria* sp., and rot caused by *Gloeosporium album* (Valiuskaite et al., 2006). For apple fruit, estimates include 8.6% fresh apples lost at retail and 20% lost at the consumer level in the United States (Buzby et al., 2011). These estimates suggest a highly inefficient use of natural resources such as land, water, and energy for apple production (Buzby et al., 2011). Therefore, minimizing postharvest apple fruit losses is more sustainable than increasing production to compensate for these losses (Kader, 2005).

Blue mold, also known as soft or wet rot, is the most important postharvest apple disease (Yu et al., 2020). Gray mold caused by the necrotrophic pathogen *B. cinerea* is a

widespread postharvest apple disease (Xiao and Kim, 2008; Testempasis et al., 2021). More recently, a new problem of mouldy core rot associated with pink mould rot has been encountered in major fruit growing areas of Shimla and Kullu districts of Himachal Pradesh (Gupta and Sharma, 2008). Preliminary studies have indicated the association of several fungi involved in mouldy core and core rot of dropped as well as fully mature apple fruit on the trees, but *Alternaria alternata* is the predominant fungal pathogen responsible for mouldy core and core rot of apple in different regions of the world (Reuveni et al., 2002). Fruits brought from lower altitude of the Shimla district showed the dry rot symptom characterized by drying of infected tissue. Similar symptoms were reported by Sharma and Kaul (1997), Niem et al. (2007) and Shtienberg (2012). First symptoms of pink mould rot on apples caused by *Trichothecium roseum* were reported as water-soaked appearance of the infected tissue which later produced a mass of powdery pink coloured spores (Kwon et al., 2014).

There are several strategies available for the management of post-harvest losses. Among these, better post-harvest handling practices and use of pre- and post-harvest fungicides are the major management strategies. However, use of fungicides in the management of post-harvest diseases poses risk of residue. On the other hand, bio-chemicals derived from extracts of the plants or other bio-resources have no toxic effects and their use is gaining grounds as an alternative to the prevalent chemical control measures. Thus, there is great scope to improve post-harvest management practices for increasing the storability of the apple produced.

2. Materials and Methods

2.1. Disease survey

Survey of different markets/storesin Shimla and Solan districts of Himachal Pradesh was conducted during Aug-Sept in 2021for recording the incidence of different post-harvest rots of apple fruits. Areas surveyed included Sainj, Narkanda, Dhalli, Rohru, Gumma, Thanedar, Sandhasu, Dhambari in Shimla District and Parwanoo in Solan District of Himachal Pradesh. Per cent disease incidence of different rots of apple was calculated by the formula given below:

Disease incidence (%)=(No.of diseased fruits/Total no.of fruits)×100

During course of survey, rotted apple fruits were also collected from these areas and were kept in polythene bags and brought to the laboratory for the isolation of associated pathogens.

2.2. Varietal behavior of apple cultivars against different fruit rots

To determine the varietal behaviour, ten important commercial varieties of apple were tested for their comparative susceptibility towards different fungi. Each variety was replicated thrice and every replication contained five fruits for a particular test fungus. Well method of inoculation (Granger and Horne, 1924) was adopted. All the inoculated fruits were kept at temperature and humidity control chamber for comparison. Per cent fruit rot was calculated after one week of inoculation by the formula given by Srivastava and Tandon (1968):

Per cent fruit rot=(W-w/W)×100

Where,

W=Weight of the fruits before inoculation

w=Weight of the fruits after removal of the rotten tissue

2.3. Biological control

2.3.1. Effect of plant extracts/animal product on post-harvest rotting of apple

2.3.1.1. Under in vitro conditions

Six different bio-products *viz*., *Murraya exotica* (Gandla), *Dodonaea viscosa* (Mehandu), *Mentha piperita* (Pudina), *Emblica officinalis* (Amla), *Melia azadirach* (Darek) and Cow urine in comparison to control were evaluated at 10% concentration under *in vitro* conditions by Poisoned Food Technique (Falck, 1907) to study their inhibitory effect on the radial growth of test pathogens.

2.3.2. *Preparation of bio-products*

Fresh leaves and seeds (200 g) of each were taken and then washed under tap water and ground for 5 minutes in a blender by adding small quantity of sterilized warm distilled water. After grinding, 200 ml distilled water was added and homogenized in orbital shaker at 2000 rpm for half an hour to get 100% extract of plant parts. The plant material was then filtered through double-layered muslin cloth. Sterilization of the extracts was done in autoclave at 5 psi pressure for one hour for three consecutive days and then the extracts were kept in a refrigerator for further use.

Evaluation of the bio-products was done at 10% concentration by incorporating 10 ml of plant extract or animal product in 95 ml sterilized (autoclaved at 1.05 kg cm^{2-1} for 20 minutes) double strength PDA medium, cooled and poured in the sterilized Petri plates under aseptic conditions. The Petri plates were inoculated with 3 mm diameter bits of 7 days old culture of the test pathogens. Petri plates containing 50 ml sterilized double strength PDA medium added to 50 ml sterilized distilled water served as control for comparison. The experiment was planned in CRD (Completely Randomized Design) and each treatment was replicated thrice for a particular test pathogen. The Petri plates were incubated at 25±1˚C in BOD incubator. Inoculated plates were observed daily and the colony diameter of test pathogens was recorded till the control plates were fully covered with the mycelium of the test pathogens. The per cent inhibition was calculated according to the formula given by Vincent (1947):

I=(C-T/C)×100

Where:

I=Per cent inhibition

C=Linear growth in control (mm)
T=Linear growth in treatment (mm)

2.3.2.1. Under in vivo conditions

The bio-products studied under *in vitro* conditions were further tested at 10% concentration by following pre-and post-inoculation methods.

2.3.3. Pre-inoculation method

The healthy, semi-ripe, uniform sized apple fruits of cultivar Starking Delicious were surface sterilized by dipping in 1% sodium hypochlorite for one minute followed by three washings with distilled sterile water and inoculated separately by the well method of Granger and Horne (1924). The fruits were first dipped in bio-products (10%) separately and then inoculated with the test pathogens by keeping 12 hr interval. The fruits were dipped in the bio-products for 5 min and then air dried for 15–20 min. Each treatment was replicated thrice containing five fruits per replicate for a particular test fungus. Untreated inoculated fruits were kept as control for comparison. Observation on per cent rotting of fruits was taken after one week of inoculation. Per cent fruit rot was recorded by the formula given by Srivastava and Tandon (1968) as described above.

2.3.4. Post-inoculation method

In post-inoculation treatment, the fruits were first inoculated with the test pathogens and then treated with the bio-products. Rest of the procedure was followed as mentioned above.

2.4. Chemical control

2.4.1. Effect of different fungicides on post-harvest rotting of apple

2.4.1.1. in vitro screening of fungicides

Six different fungicides viz., mancozeb (0.1%), captan (0.1%), thiophanate methyl (0.05%), carbendazim (0.05%), azoxystrobin (0.05%) and pyraclostrobin (0.05%) in comparison to control were evaluated under *in vitro* conditions by Poisoned Food Technique (Falck, 1907) to study their inhibitory effect on the radial growth of the test pathogens. The Petriplates were incubated at 25±1˚C. Each treatment was replicated three times. Inoculated plates were observed daily and the colony diameter of the test pathogens was recorded till the control plates were fully covered with the mycelium of test fungus and per cent inhibition was calculated according to formula given by Vincent (1947).

2.4.1.2. Pre-inoculation dip treatment

The healthy, semi-ripe, uniform sized apple fruits of cultivar Starking Delicious were surface sterilized by dipping in 1.0% sodium hypochlorite for one minute followed by three washings with distilled sterile water and inoculated separately by the well method of Granger and Horne (1924). The fruits were first dipped separately in the fungicides tested *in vitro* and then inoculated with the test pathogens by keeping 12 h interval. The fruits were dipped in the fungicides for 5 min and then air dried for 15–20 min. Each treatment was replicated thrice containing five fruits per replicate for a particular test fungus. Untreated inoculated fruits were kept as control for comparison. Observation on per cent rotting of fruits was taken after 6 days of inoculation when the control fruits rotted completely. Per cent fruit rot was recorded by the formula given by Srivastava and Tandon (1968) as described above.

2.4.1.3. Post-inoculation dip treatment

In post-inoculation dip treatment, the fruits were first inoculated with the test pathogens and then treated with the fungicides separately. Rest of the procedure was followed as mentioned above.

2.4.1.4. Pre-harvest sprays

A field experiment of different fungicides was laid out in Randomized Block Design in a farmer's apple orchard at Kotkhai and Rohru in Shimla district of Himachal Pradesh for two consecutive years (2021 and 2022).

Seven fungicides *viz*. mancozeb (0.3%), captan (0.3%), thiophanate methyl (0.05%), carbendazim (0.05%), azoxystrobin (0.05%), pyraclostrobin (0.05%) and mancozeb+carbendazin (0.25%) were evaluated against post-harvest rotting of apple. Each fungicide was sprayed on three trees seven days before harvest. Three untreated trees served as control for comparison. After harvesting, both treated and untreated fruits were stored under three different conditions *viz*. ambient storage (20±2˚C), refrigerated storage (4˚C) and controlled atmosphere (CA) storage (1±0.5˚C temperature, 87 to 92% RH, 1.4% carbon dioxide and 1.2% oxygen concentration) for two months. After storage, fruits were observed for per cent fruit rot, which was calculated by the formula given by Srivastava and Tandon (1968) as described above.

2.5. Effect of fumigants on post-harvest rotting of apple

Fumigants were applied in the form of pellets made by putting the required fumigant in a small tissue bag. One such pellet was put at the bottom of each desiccator. A small piece of cotton soaked in water was also put in each desiccator to provide humid atmosphere for the efficient liberation of fumes. Healthy apple fruits of cultivar Starking Delicious were selected for the experiment. Fruits were washed under tap water; air dried and then inoculated with the test pathogens by lancet method of Kaul and Lall (1974). After 12 h of inoculation, fruits were kept over the wire gauge in the desiccators containing fumigant and were allowed to remain there for 3 h (12 h in case of 1-methyl cyclopropene). Each treatment was replicated thrice with each replicate containing five fruits for a particular test pathogen. Check fruits were also kept for the same period containing everything except the fumigant. The inoculated fumigated and non-fumigated fruits were kept at room temperature and observed for fruit rotting. After one week, per cent fruit rot was recorded by the formula given by Srivastava and Tandon (1968) as described above.

Fumigants used were:
1. Ammonium carbonate $(NH_4)_2CO_3$: 200 mg each pellet

2. Ammonium chloride (NH_4Cl) 6 g plus magnesium oxide (MgO) 3.22 g each pellet
3. Sodium metabisulphite ($Na_2S_2O_5$): 200 mg each pellet
4. 1-methyl cyclopropene (MCP): 1 µl l^{-1}

3. Results and Discussion

3.1. Prevalence of post-harvest rots of apple

During survey, fourteen different types of post-harvest fungal pathogens were found associated with rotting of apple fruits in Himachal Pradesh (Table 1). It is obvious from the enlisted data that blue mould rot due to *Penicillium expansum* was most destructive of all the rots as its exclusive incidence (43.8%) alone was more than the combined incidence of all other rots of importance. Next important post-harvest spoilage was observed due to bitter rot caused by *Glomerellacingulata* followed by pink mould rot caused by *Trichothecium roseum*, with incidence of 12.0 and 11.6%, respectively. In India, Kaul (1979) has reported 21 fungi responsible for apple rotting causing more than 14% loss in storage and canning units of the state. Of the five major pathogens, *Penicillium expansum* caused maximum up to 45% of the total spoilage.

The highest incidence of blue mould rot (*P. expansum*) on apple in transit, storage and marketing is also reported by Fisher (1922),), Baker and Heald (1932), Brooks et al. (1935), Ruehle (1937), Singh (1941), Tyler (1944), Agarwala and Sharma (1968), Blazek et al. (2006) and Lelde Grantina-Ievina (2015). The importance of *T. roseum* causing pink mould rot is also well documented in literature (Faes and Staehelin, 1925; Weber, 1938; Sprau, 1948; Borecki and Profic, 1962).

Table 1: Prevalence of post-harvest rots of apple in Himachal Pradesh

Common name of the rot	Causal organism	Per cent incidence
Black mould rot	*Aspergillus niger*	0.5
Bitter rot	*Glomerella cingulata*	12.0
Black rot	*Sphaeropsis malorum*	0.5
Alternaria rot	*Alternaria alternata*	1.0
Brown rot (Apple black)	*Monilinia fructigena*	10.0
Blue mould rot	*Penicillium expansum*	43.8
Pink mould rot	*Trichothecium roseum*	11.6
Core rot	*Alternaria alternata, Penicillium expansum, Fusarium oxysporum, Trichothecium roseum*	2.0
Fusarium rot	*Fusarium oxysporum*	0.5
Grey mould rot	*Botrytis cinerea*	1.7
Phytophthora rot	*Phytophthora cactorum*	0.5
Soft rot	*Mucor piriformis*	0.5
Sour rot	*Geotrichum candidum*	1.0
Whisker's rot	*Rhizopus stolonifer*	4.5

The total losses due to apple decay at various stores/markets in Himachal Pradesh varied from 7.80 to 21.93%, with mean per cent loss of 14.52 and 21.21 (Table 2). Maximum loss (21.93%) was recorded in Dhalli in district Shimla followed by Parwanoo (21.76%) in district Solan. Blue mould rot due to *P. expansum* was found to be the main cause of post-harvest rot of apple with a mean per cent incidence of 4.73 and 9.19 in Shimla and Solan, respectively. Blanpied and Purnasiri (1968) while working on apples also reported maximum incidence of *P. expansum* and *Botrytis cinerea* in storage. Brown rot (*Monilinia fructigena*) and black mould rot (*Aspergillus niger*) were found to be the next important post-harvest rot pathogens. Ivic et al. (2006) while working on dynamics and intensity of apple disease development during storage found that *M. fructigena*, *P. expansum* and *Rhizopus stolonifer* were the major fungi causing maximum losses to apple during storage.

From other parts of the country, isolated and sporadic reports of one or the other fungus occurring on the apple fruits in the markets have been made (Dey and Nigam, 1933; Mehta, 1937; Sinha, 1946; Jamaluddin et al., 1972; Khanna and Chandra, 1975; Thind et al., 1975; Laxminarayana and Reddy, 1975). Twenty-one species of fungi found invading apples in storage and markets of Himachal Pradesh are those which are normally prevalent in other apple growing areas of the world and differ mostly from those saprophytic species recorded on the over ripe fruits in the markets of plains of India (Jamaluddin et al., 1972; Khanna and Chandra, 1975; Thind et al., 1975; Laxminarayana and Reddy, 1975).

Present studies clearly indicate that five major rots were responsible for causing maximum spoilage of apples, and consequently further studies were concentrated on them and their respective causal organisms (*Alternaria alternata*, *Trichothecium roseum*, *Monilinia fructigena*, *Aspergillus niger*and *Penicillium expansum*) (Figure 1).

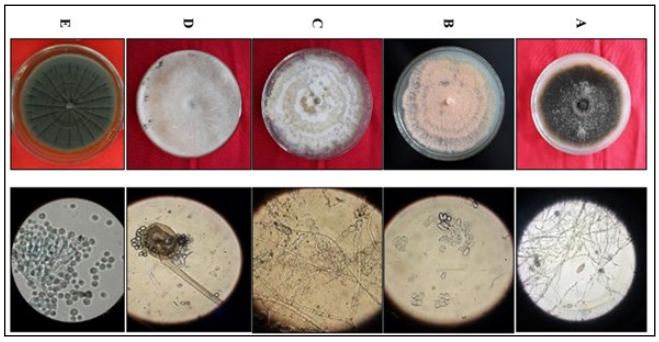

Figure 1: Macroscopic (pure culture) and microscopic features of most important post-harvest rots of apple, including *Alternaria alternata* (A), *Trichothecium roseum* (B), *Monilinia fructigena* (C), *Aspergillus niger* (D) and *Penicillium expansum* (E)

Table 2: Incidence of post-harvest rots of apple in different stores/markets of Himachal Pradesh

Districts	Locality	Per cent incidence						Total Loss
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Others	
	Sainj	2.52	1.32	1.66	0.79	4.41	0.63	11.33
	Narkanda	1.05	3.23	2.27	0.66	5.62	0.49	13.32
	Dhalli	1.17	2.18	3.43	2.34	9.69	3.12	21.93
	Rohru	2.11	0.12	5.20	1.67	4.31	2.77	16.18
	Gumma	1.23	1.77	8.42	0.63	4.13	1.21	17.39
	Sandhasu	0.28	1.68	4.51	0.00	2.67	1.82	10.96
	Thanedar	0.08	0.66	3.31	1.23	2.52	0.00	7.80
	Dhambari	1.69	1.45	5.71	1.88	4.45	2.02	17.20
	Mean	1.27	1.55	4.31	1.15	4.73	1.51	14.52
Solan	Parwanoo	1.66	2.19	4.12	3.21	8.31	2.27	21.76
	Solan	0.82	2.55	1.25	4.12	10.06	1.82	20.62
	Mean	1.24	2.37	2.69	3.67	9.19	2.05	21.21

3.2. Varietal behaviour of apple cultivars against different fruit rots

In order to find out the relative susceptibility of different varieties of apple, ten important commercial varieties were tested against decay causing fungal pathogens. The results obtained have been presented in Table 3. The varieties were observed to be highly significantly different as far as their susceptibility to various fungi is concerned. The susceptibility of Scarlet Spur was found to be highest followed by Golden Delicious with mean per cent rotting of 63.40 and 63.07%, respectively. The susceptibility of Oregon spur (58.88%), Vance Delicious (58.41%) and Royal Delicious (55.12%) was of the same order. Same was the case with Red Gold (43.45%), Red Velox (43.99%) and Super Chief (45.15%). Tydeman's Early Worcester was found to be most tolerant to all the rot causing fungi with mean per cent rotting of 23.26%.

The interaction between varieties and test fungi revealed that *P. expansum* caused maximum rotting in all the varieties except in Tydeman's Early Worcester there in showing some insignificant tolerance. The effect of *M. fructigena* was rated the next. *T. roseum* caused overall lowest per cent rotting in different varieties compared to other fungi. This type of rotting was minimum in Oregon Spur (5.05%) and maximum in Scarlet Spur (100.00%). *A. alternata* caused maximum rotting in Royal Delicious (45.63%) followed by Scarlet Spur (40.93%).

Table 3: Comparative susceptibility of commercial apple cultivars against different fruit rots

Cultivars	Per cent fruit rot					Mean
	A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	
Vance Delicious	22.72	25.41	69.75	84.45	89.74	58.41 (49.82)
Golden Delicious	18.64	56.29	71.42	79.55	89.45	63.07 (52.56)
Oregon Spur	30.59	5.05	80.56	85.64	92.57	58.88 (50.09)
Scarlet Spur	40.93	100.00	65.80	15.61	94.66	63.40 (52.75)
Red Gold	17.62	11.55	71.74	16.31	100.00	43.45 (41.22)
Royal Delicious	45.63	24.27	81.60	24.08	100.00	55.12 (47.92)
Red Velox	17.89	5.65	46.21	50.19	100.00	43.99 (41.53)
Super Chief	23.69	5.55	50.93	45.57	100.00	45.15 (42.20)
Tydeman's Early Worcestor	18.54	10.64	15.90	26.48	44.74	23.26 (28.82)
Red Chief	16.46	8.16	26.50	30.57	100.00	36.34 (37.06)
Mean	23.74 (29.15)	23.39 (28.91)	53.73 (47.12)	43.73 (41.38)	86.25 (68.21)	-

CD (p=0.05); Varieties=0.471; Test pathogen=0.317; Varieties×Test pathogen=1.052; *Figures in parentheses are arc sine transformed values

Some of the apple varieties reported to be resistant to various post-harvest fungal pathogens (Haussmann, 1934; Borecka, 1962 and Borecki and Profic, 1962) are not grown in Himachal Pradesh. Kaul (1979) while studying the behaviour of ten apple varieties found Red Gold to be highly susceptible followed by Allington Pippin. The susceptibility of Golden Delicious, McIntosh, Royal Delicious and Winter Banana was of the same order. Rus Pippin showed some tolerance as compared to other varieties. Apple cultivars Angold, Gala, Florina, Melodie and Meteor were proved to be partially resistant to storage diseases (Blazek et al., 2006). Golden delicious cultivar was found most susceptible and Galathe most resistant to *Colletotrichum gloeosporioides* causing bitter rot in apple (Onofre and Antoniazzi, 2014).

3.3. Biological control

3.3.1. Effect of plant extracts/animal product against post-harvest rotting of apple

3.3.1.1. Under in vitro conditions

Fungitoxicity of six different plant extracts/animal product at 10% concentration was evaluated under *in vitro* conditions against five test fungi causing decay in apple fruits by poisoned food technique. Data on diametric mycelial growth and per cent growth inhibition has been presented in Table 4. It is evident that cow urine was found most effective in providing 79.21% growth inhibition of test fungi under study. The next best bio-products were *Emblica officinalis* (amla), *Melia azadirach* (darek) and *Dodonaea viscose* (mehandu) with per cent growth inhibition of 75.66, 73.59 and 68.48%, respectively. *Mentha piperita* (pudina) and *Murraya exotica* (gandla) were least effective providing 49.49 and 64.56% growth inhibition of test fungi, respectively (Figure 2).

Among different fungi tested, *A. niger* was the least sensitive to all the plant extracts/animal product with 88.75 mm mycelial growth followed by *T. roseum* (40.04 mm), *A. alternata* (26.75 mm) and *M. fructigena* (13.13 mm).

The interaction study between bio-products and test fungi revealed that *M. fructigena* was completely inhibited by all the bio-products except for showing some tolerance to *Murraya exotica*. On the contrary, *A. niger* showed highest tolerance to all tested bio-products except cow urine showing some effectiveness. The mycelial growth of *P. expansum* was

Table 4: *In vitro* evaluation of plant extracts/animal product against post-harvest pathogens of apple

Plant extract/animal product	Conc. (%)	Diametric mycelial growth (mm)					Mean	Per cent growth inhibition
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*		
Murraya exotica (Gandla)	10	13.01	50.87	1.92	90.00	3.69	31.90	64.56 (53.44)
Dodonaea viscosa (Mehandu)	10	11.57	35.50	0.00	90.00	4.76	28.37	68.48 (55.82)
Mentha piperita (Pudina)	10	47.08	86.57	0.00	90.00	3.63	45.46	49.49 (44.69)
Emblica officinalis (Amla)	10	11.60	1.91	0.00	90.00	6.01	21.90	75.66 (60.41)
Melia azadirach (Darek)	10	13.97	10.08	0.00	90.00	4.80	23.77	73.59 (59.05)
Cow urine	10	0.00	5.35	0.00	81.24	6.94	18.71	79.21 (62.85)
Control	-	90.00	90.00	90.00	90.00	90.00	90.00	-
Mean	-	26.75 (31.13)	40.04 (39.24)	13.13 (21.24)	88.75 (70.37)	17.12 (24.43)	-	-

CD (p=0.05) Botanical=0.226; Test pathogen=0.191; Botanical×Test pathogen=0.506; *Figures in parentheses are arc sine transformed values

Figure 2: *In vitro* evaluation of plant extracts/animal product against *Alternaria alternata* (A), *Monilinia fructigena* (B), *Aspergillus niger* (C), *Penicillium expansum* (D) and *Trichothecium roseum* (E)

appreciably inhibited by all the bio-products. Amla, cow urine and darek provided effective inhibition of *T. roseum* with diametric mycelial growth of 1.91, 5.35 and 10.08 mm, respectively.

The results of present investigations agree with the results obtained by Raj and Sharma (2015). They noted the efficacy of seven different plant extracts against *Alternaria alternata* causing mouldy core and core rot in apple fruits under *in vitro*

conditions. *Dodonaea viscosa* was found to show maximum inhibitory effect (66.55%). Cow urine-based formulation made by using six different plant species was found effective in inhibiting the growth of *Botryosphaeria dothidea* causing white rot of apple fruits (Sharma and Raj, 2018). Singh and Sumbali (2003) noted that leaf extract of *Azadirachta indica* was most effective in inhibiting *Penicillium expansum* infecting apple fruits.

3.3.1.2. Under in vivo conditions

All the bio-products provided significant control of the fruit rots caused by test fungi under study over control both in pre- and post-inoculation treatments (Table 5).

Pre-inoculation: The results presented in Table 5 revealed that the minimum fruit rot (17.39%) and maximum disease control (82.61%) was noted in fruits treated with cow urine 12 hours before inoculation. The efficacy of cow urine in inhibiting many post-harvest rots of apple has also been reported by Tomar and Raj (2015). The next best treatment in order of merit was amla leaf extract (26.30%) followed by mehandu leaf extract (33.94%) which was at par with darek seed extract (34.61%). Pudina leaf extract was the least effective in reducing the fungal decays (55.40%) with 44.60% disease control.

The behaviour of test fungi was significantly different amongst themselves with *A. niger* resulting into maximum rotting of fruits (96.62%) and minimum by *M. fructigena* (20.19%) in different treatments. The next virulent pathogens were *T. roseum, P. expansum* and *A. alternata* with per cent fruit rot of 43.40, 29.78 and 28.61%, respectively.

The interaction studies between treatments and test fungi revealed that the bioproducts had no effect on the fruit rot

Table 5: Bio-efficacy of plant extracts/animal product on post-harvest rotting of apple cv. Starking Delicious

Plant extract/animal	Conc. (%)	Per cent fruit rot						
		Pre-inoculation (12 h)						
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Mean	Per cent control
Murraya exotica (Gandla)	10	17.09	59.83	9.45	100.00	5.58	38.39 (38.27)	61.61
Dodonaea viscosa (Mehandu)	10	14.77	42.64	7.88	100.00	4.41	33.94 (35.62)	66.06
Mentha piperita (Pudina)	10	42.52	89.56	11.70	100.00	33.24	55.40 (48.08)	44.60
Emblica officinalis (Amla)	10	10.94	4.94	3.63	100.00	12.01	26.30 (30.84)	73.70
Melia azadirach(Darek)	10	14.95	6.86	8.64	100.00	42.60	34.61 (36.02)	65.39
Cow urine	10	0.00	0.00	0.00	76.31	10.66	17.39 (24.64)	82.61
Control	-	100.00	100.00	100.00	100.00	100.00	100.00 (89.96)	-
Mean	-	28.61	43.40	20.19	96.62	29.78	-	-

Table 5: Continue...

Plant extract/animal	Conc. (%)	Per cent fruit rot						
		Post-inoculation (12 h)						
		A. alternata	T. roseum	M. fructigena	A. niger	P. expansum	Mean	Per cent control
Murraya exotica (Gandla)	10	17.37	59.83	9.45	100.00	5.58	38.45 (38.31)	61.55
Dodonaea viscosa (Mehandu)	10	15.26	42.92	8.55	100.00	5.13	34.37 (35.88)	65.63
Mentha piperita (Pudina)	10	43.16	90.31	12.90	100.00	34.23	56.12 (48.50)	43.88
Emblica officinalis (Amla)	10	12.04	5.89	4.74	100.00	12.93	27.12 (31.37)	72.88
Melia azadirach(Darek)	10	15.86	7.56	9.41	100.00	43.52	35.27 (36.42)	64.73
Cow urine	10	1.89	2.62	0.00	77.44	11.73	18.74 (25.64)	81.26
Control	-	100.00	100.00	100.00	100.00	100.00	100.00 (89.96)	-
Mean	-	29.37	44.16	20.72	96.78	30.45	-	-

CD (p=0.05) Botanical=0.360; Test pathogen=0.304; Botanical×Test pathogen=0.804 (Pre-inoculation); CD (p=0.05) Botanical=0.384; Test pathogen=0.325; Botanical×Test pathogen=0.859 (Post-inoculation); *Figures in parentheses are arc sine transformed values

caused by *A. niger* except for cow urine providing some control in pre-inoculation treatments. Cow urine provided 100% control of fruit rot caused by *A. alternata, T. roseum* and *M. fructigena.* Fruit rot caused by *P. expansum* was significantly controlled by all the treatments except for the darek extract. Pudina leaf extract was the least effective in controlling fruit rot caused by *T. roseum* and *A. alternata* with per cent fruit rot of 89.56 and 42.52%, respectively. *M. fructigena* was appreciably inhibited by all the bio-products with fruit rot ranging from 0 to 11.70% in different treatments.

Penicillium rot was appreciably controlled by using garlic and onion extracts (Ikeura et al., 2011; Niazi et al., 2016). In similar studies, Bobbarala et al. (2009) examined antifungal activity of selected plant extracts against phytopathogenic *Penicillium expansum*. In their study, forty-nine different plants were studied using agar well diffusion method. Among the forty-nine plants studied, 86% of the plants showed antifungal activity.

Post-inoculation: Significantly lowest fruit rot (18.74%) was recorded in fruits treated with cow urine after 12 hours of inoculation followed by amla (27.12%), respectively. The next best treatment in order of merit was mehandu and darek with mean per cent fruit rot of 34.37 and 35.27%, respectively. Pudina and gandla leaf extracts were least effective in checking fruit decays (Table 5).

The ability of various fungi in causing decay in variously treated fruits was different. Maximum decay (96.78%) was caused by *A. niger* followed by *T. roseum* (44.16%), *P. expansum* (30.45%), *A. alternata* (29.37%) and *M. fructigena* (20.72%).

From the interaction studies, cow urine completely inhibited the growth of *M. fructigena*, appreciably checked the growth of *A. alternata, T. roseum* and *P. expansum*, but was least effective against *A. niger*. *A. niger* was completely tolerant to all the other bio-products. Amla and darek were significantly effective against *T. roseum* and *M. fructigena* whereas, gandla and mehandu appreciably checked the growth of *P. expansum*.

3.4. Chemical control

3.4.1. Effect of different fungicides on post-harvest rotting of apple

3.4.1.1. in vitro screening of fungicides

Data on the effect of six fungicides tested *in vitro* against five different test fungi has been presented in Table 6. Mancozeb (0.1%) was the most effective fungicide providing 84.83% growth inhibition. The next best fungicides were captan (0.1%) and carbendazim (0.05%) with per cent growth inhibition of 82.83 and 73.99%, respectively. Pyraclostrobin (0.05%) and thiophanate-methyl (0.05%) were found at par with carbendazim providing 73.91 and 73.77% inhibition of mycelial growth of test fungi. The least effective fungicide was azoxystrobin (0.05%) with 63.76% growth inhibition (Figure 3).

Irrespective of the fungicides, *A. niger* was most tolerant with 81.69 mm mycelial growth followed by *A. alternata* (29.86 mm), *T. roseum* (18.79 mm), *P. expansum* (14.48 mm) and *M. fructigena* (13.91 mm).

From the interaction studies between fungicides and test fungi under study, the mycelial growth of *M. fructigena* was completely inhibited by mancozeb, captan, thiophanate methyl and carbendazim. *A. niger* was highly tolerant to thiophanate methyl, carbendazim and azoxystrobin whereas, captan, mancozeb and pyraclostrobin provided some inhibition of mycelial growth. *P. expansum* was completely inhibited by mancozeb, thiophanate methyl and pyraclostrobin, showing some tolerance to captan, carbendazim and azoxystrobin. Mycelial growth of *T. roseum* was completely checked by mancozeb.

Isolates of *A. Alternata* were also reported to be sensitive to mancozeb, difenoconazole, cyprodinil, boscalid and pyraclostrobin, reducing the fungal growth by 50% (Grantina –Ievina, 2015). Difenoconazole was found most effective and

Table 6: Effect of different fungicides against post-harvest fungal pathogens of apple under *in vitro* conditions

Fungicide	Conc. (%)	Diametric mycelial growth (mm)					Mean	Per cent growth inhibition
		A. alternata	T. roseum	M. fructigena	A. niger	P. expansum		
Mancozeb	0.1	3.05	0.00	0.00	65.20	0.00	13.65	84.83 (67.05)
Captan	0.1	9.76	7.33	0.00	57.88	2.31	15.45	82.83 (65.49)
Thiophanate methyl	0.05	25.94	2.08	0.00	90.00	0.00	23.60	73.77 (59.17)
Carbendazim	0.05	21.98	2.23	0.00	90.00	2.84	23.41	73.99 (59.31)
Azoxystrobin	0.05	34.70	27.57	4.61	90.00	6.20	32.62	63.76 (52.97)
Pyraclostrobin	0.05	23.62	2.31	2.73	88.74	0.00	23.48	73.91 (59.26)
Control	-	90.00	90.00	90.00	90.00	90.00	90.00	-
Mean	-	29.86	18.79	13.91	81.69	14.48	-	-

CD (p=0.05) Fungicide=0.264; Test pathogen= 0.223; Fungicide×Test pathogen=0.591; *Figures in parentheses are arc sine transformed values

Figure 3: *In vitro* evaluation of fungicides against *Alternaria alternata* (A), *Trichothecium roseum* (B), *Monilinia fructigena* (C), *Aspergillus niger* (D) and *Penicillium expansum* (E)

significantly superior among all the treatments with 75.01% average inhibition in mycelial growth of the white rot pathogen (*Botryosphaeria dothidea*) followed by tebuconazole with 71.68% inhibition under *in vitro* conditions. Pyraclostrobin was found least effective (Sharma, 2013).

3.4.2. Pre-inoculation dip treatment

Apple fruits were dipped in six different fungicides 12 hours before inoculation for evaluating their relative efficacy against the fungal decays under study and the data obtained on per cent fruit rot has been presented in Table 7. From the perusal of data, the efficacy of mancozeb at 0.1% concentration was judged to be significantly superior, followed by carbendazim (0.05%) with per cent control of 95.97 and 92.35%, respectively. Next best fungicides in order of merit were azoxystrobin, pyraclostrobin and thiophanate methyl with per cent control of 79.27, 71.00 and 68.81%, respectively. Captan was the least effective fungicide as dip treatment.

The reaction of different test fungi on variously treated fruits

Table 7: Effect of fungicidal dip treatments on post-harvest rotting of apple cv. Starking Delicious

Fungicide	Conc. (%)	Per cent fruit rot						
		Pre-inoculation (12 h)						
		A. Alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Mean	Per cent control
Mancozeb	0.1	4.54	4.59	2.26	6.67	2.10	4.03 (11.58)	95.97
Captan	0.1	71.89	2.69	3.59	100.00	2.58	36.15 (36.94)	63.85
Thiophanate methyl	0.05	17.66	2.64	2.44	100.00	33.24	31.19 (33.94)	68.81
Carbendazim	0.05	6.61	5.88	2.64	18.74	4.41	7.65 (16.05)	92.35
Azoxystrobin	0.05	11.63	3.11	4.81	80.64	3.45	20.73 (27.07)	79.27
Pyraclostrobin	0.05	30.89	11.63	5.03	89.64	7.80	29.00 (32.57)	71.00
Control	-	100.00	100.00	100.00	100.00	100.00	100.00 (89.96)	-
Mean	-	34.75	18.65	17.25	70.81	21.94	-	-

Table 7: Continue...

Fungicide	Conc. (%)	Per cent fruit rot						
		Post-inoculation (12 h)						
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Mean	Per cent Control
Mancozeb	0.1	5.51	5.49	2.26	6.67	2.10	4.40 (12.10)	95.60
Captan	0.1	72.73	3.43	4.47	100.00	3.50	36.82 (37.34)	63.18
Thiophanate methyl	0.05	18.17	3.55	3.26	100.00	34.01	31.80 (34.31)	68.20
Carbendazim	0.05	7.10	6.72	2.64	18.74	4.41	7.92 (16.34)	92.08
Azoxystrobin	0.05	12.42	3.71	5.64	81.93	4.08	21.56 (27.66)	78.44
Pyraclostrobin	0.05	31.74	12.57	5.93	90.86	8.56	29.93 (33.15)	70.07
Control	-	100.00	100.00	100.00	100.00	100.00	100.00 (89.96)	-
Mean	-	35.38	19.35	17.74	71.17	22.38	-	-

CD (p=0.05) Fungicide=0.331; Test pathogen= 0.279; Fungicide×Test pathogen=0.739 (Pre-inoculation); CD (p=0.05) Fungicide=0.386; Test pathogen=0.326; Fungicide×Test pathogen=0.863 (Post-inoculation); *Figures in parentheses are arc sine transformed values

revealed significant difference in their reaction. Maximum decay in treated fruits (70.81%) was caused by *A. niger* and minimum (17.25%) by *M. fructigena* followed by *A. alternata* (34.75%), *P. expansum* (21.94%) and *T. roseum* (18.65%) in descending order.

The interaction studies revealed that for *A. niger* almost all the fungicides were ineffective except mancozeb and carbendazim. *T. roseum* and *M. fructigena* were, however, significantly inhibited by all the fungicides under study. For *A. alternata*, captanwas least effective with 71.89% fruit rot whereas, for *P. expansum,* thiophanate methyl was least effective with 33.24% fruit rot, respectively. Dipping apple fruits in carbendazim, benomyl and thiabendazole effectively controlled the blue mould rot, pink rot, bitter rot and Aspergillus rot (Kaul, 1982; Dharam Vir, 1982; Chib et al., 1983).

3.4.3. Post-inoculation dip treatment

Data on the efficacy of post-harvest fungicidal dip treatments against the test fungi under study has been presented in Table 7 which revealed that mancozeb (0.1%) was found the most effective in preventing all the fungal decays under study followed by carbendazim (0.05%). The next effective fungicides were azoxystrobin and pyraclostrobin with mean per cent fruit rot of 21.56 and 29.93%, respectively showing 78.44 and 70.07% disease control whereas, captan and thiophanate methyl were the least effective among all the fungicides.

Irrespective of the fungicidal dip treatments, maximum fruit rot (71.17%) was observed in the fruits inoculated with *A. niger* followed by *A. alternata* (35.38%), *P. expansum* (22.38%), *T. roseum* (19.35%) and *M. fructigena* (17.74%) in this study.

The interaction between fungicides and test fungi revealed that *A. niger* was completely tolerant to captan and thiophanate methyl, partially tolerant to azoxystrobin and pyraclostrobin but was sensitive to mancozeb and carbendazim. *T. roseum* and *M. fructigena* were effectively controlled by all the tested fungicides. Captan and pyraclostrobin were the least effective against *A. alternata*. *P. expansum* was satisfactorily controlled by all the fungicides except showing some tolerance to thiophanate methyl.

In contrast, no post-harvest chemical applications are allowed in Germany and Denmark with the exception for 1-MCP during storage. Imazalil is registered in Spain and Portugal for post-harvest dipping of apples. In Belgium, Netherlands, Spain and Italy, the use of Philabuster (Imazalil and Pyrimethanil) as a post-harvest dipping treatment is permitted for pears (Vorstermans et al., 2005).

3.4.4. Preharvest sprays

3.4.4.1. Effect of preharvest fungicidal sprays on post-harvest rotting of apple stored at ambient temperature

It is evident from the data presented in Table 8 that preharvest application of all the fungicides in general was effective in controlling the post-harvest decay in comparison to control during 2 months of storage at ambient temperature. However, the per cent fruit rot varied with the treatments. The best control of all the test fungi under study (83.90% and 84.18%) was provided by mancozeb (0.3%) followed by mancozeb+carbendazim (0.25%) and captan (0.3%) providing 80.05, 79.94, 76.87 and 77.15% decay control during both the years of study. Further, carbendazim (0.05%) provided reasonably good control (69.33 and 69.57%) of apple decays under study which was statistically at par with azoxystrobin (0.05%) and thiophanate methyl (0.05%) with per cent decay control of 69.06, 68.89, 67.62 and 67.51%, respectively. Pyraclostrobin (0.05%) was the least effective fungicide with only 54.05 and 54.58% decay control.

Table 8: Effect of preharvest sprays of different fungicides against post-harvest rots of apple cv. Starking Delicious after 2 months of storage in ambient conditions at Shimla

Treatment	Conc. (%)	Per cent fruit rot						
		2021						
		A. alternata	*T. roseum*	*M. fructigena*	*A. Niger*	*P. expansum*	Mean	Percent control
Mancozeb	0.3	6.57	1.75	0.00	53.73	1.68	12.75 (20.91)	83.90
Captan	0.3	15.84	10.62	0.00	59.64	5.48	18.32 (25.33)	76.87
Thiophanate methyl	0.05	30.73	4.74	3.10	87.74	1.90	25.64 (30.41)	67.62
Carbendazim	0.05	24.96	4.27	0.00	87.00	5.21	24.29 (29.52)	69.33
Azoxystrobin	0.05	25.99	4.06	5.25	84.63	2.58	24.50 (29.66)	69.06
Pyraclostrobin	0.05	38.59	40.62	7.03	85.17	10.54	36.39 (37.09)	54.05
Mancozeb + Carbendazim	0.25	7.73	2.62	0.00	66.57	2.06	15.80 (23.41)	80.05
Control	-	62.39	68.50	88.40	88.08	88.56	79.19 (62.83)	-
Mean	-	26.60	17.15	12.97	76.57	14.75	-	-

Table 8: Continue...

Treatment	Conc. (%)	Per cent fruit rot						
		2022						
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Mean	Per cent control
Mancozeb	0.3	6.77	1.44	0.00	53.03	1.57	12.56 (20.75)	84.18
Captan	0.3	15.57	10.58	0.00	58.99	5.54	18.14 (25.20)	77.15
Thiophanate methyl	0.05	31.18	4.88	3.37	87.50	2.03	25.79 (30.51)	67.51
Carbendazim	0.05	24.75	4.56	0.00	86.61	4.85	24.15 (29.42)	69.57
Azoxystrobin	0.05	26.58	3.98	4.91	84.94	3.07	24.69 (29.78)	68.89
Pyraclostrobin	0.05	37.74	40.50	7.04	84.41	10.58	36.05 (36.88)	54.58
Mancozeb + Carbendazim	0.25	7.98	2.64	0.00	66.46	2.50	15.92 (23.51)	79.94
Control	-	62.23	68.60	88.78	88.83	88.40	79.37 (62.96)	-
Mean	-	26.67	17.21	13.01	76.35	14.82	-	-

*Figures in parentheses are arc sine transformed values; CD (*p*=0.05) Fungicide=0.372; Test pathogen=0.294; Fungicide× Test pathogen=0.833 (2021); CD (*p*=0.05) Fungicide=0.366; Test pathogen=0.287; Fungicide×Test pathogen=0.829 (2022)

During 2 months of storage at ambient temperature, maximum fruit rot control (83.90 and 84.18%) was recorded with mancozeb followed by mancozeb+carbendazim, captan and carbendazim showing 80.05, 79.94; 76.87, 77.15 and 69.33, 69.57% disease control during both the years of study.

The interaction studies between fungicides and test fungi revealed that *M. fructigena* was completely controlled by preharvest sprays of mancozeb, mancozeb+carbendazim, captan and carbendazim. All the fungicides provided significant control of *T. roseum, P. expansum* and *A. alternata* except pyraclostrobin which was least effective in controlling these pathogens. *A. niger* was somewhat tolerant to all the fungicides except mancozeb and captan providing some control.

Applications prior to harvest of the fungicides benomyl (Ben-Arie and Guelfat-Reich, 1973), cyprodinil (Sholberg et al., 2003), boscalid+pyraclostrobin (Xiao and Boal, 2009), and ziram (Sugar et al., 2003; Xiao and Boal, 2009) have been shown to be beneficial in reducing incidence of decay caused by various fungi in pome fruit. Three fungicides applied one week before harvest (pyraclostrobin+boscalid, thiophanate-methyl and trifloxystrobin) reduced the rate of increase in decay incidence in pear (Sugar and Basile, 2011). The effectiveness of various fungicides including iprodione, mancozeb, propineb, zineb, hexaconazole, dodine, difenoconazole and trifloxystrobin has also been reported against *Alternaria alternata* causing different diseases on different hosts by earlier workers (Kim et al., 1982; Tak et al., 1985; Glaser and Kaiser, 1986; Kock et al., 1991; Yousuf and Ahmad, 2001; Amenduni et al., 2003; Reuveni et al., 2002). Rizzolli and Acler (2006) found that iprodione showed a good efficacy against *A. alternata* causing core rot of apple and Reuveni (2006) reported that three foliar applications of Sygnum (pyraclostrobin+nicobifen) between the beginning of bloom and petal fall reduced the infected fruits by 55 to 70 and 45 to 80% respectively.

3.4.4.2. Effect of preharvest fungicidal sprays on post-harvest rotting of apple during refrigerated storage

Data pertaining to field efficacy of different fungicides against post-harvest rotting of apple after 2 months of refrigerated storage has been presented in Table 9. Preharvest spray of all the fungicides was effective in controlling the post-harvest decays of apple fruits stored under refrigerated storage in comparison to control. It is evident from the data that 100% control of all the test fungi under study was provided by preharvest sprays of mancozeb (0.3%), mancozeb + carbendazim (0.25%) and captan (0.3%) during both the years of study. Further, carbendazim (0.05%) provided reasonably good control (65.93 and 66.48%) of apple decays under study which was statistically at par with azoxystrobin (0.05%) and thiophanate methyl (0.05%) with decay control of 63.43, 63.57, 59.66 and 60.11%, respectively. Pyraclostrobin (0.05%) was the least effective fungicide providing 45.92 and 47.50% of decay control in comparison to control.

During 2 months of refrigerated storage, 100% fruit rot control was recorded with mancozeb, mancozeb+carbendazim and captan during both the years of study. Carbendazim was the next effective fungicide followed by azoxystrobin with per cent control of 65.93, 66.48 and 63.43, 63.57, respectively.

The interaction studies between fungicides and test fungi revealed that refrigerated storage of apples after preharvest sprays of all the fungicides resulted in complete control of *M. fructigena*. Similar was the case with *P. expansum* except for showing some tolerance to pyraclostrobin. *T. roseum* was completely inhibited by mancozeb, mancozeb+carbendazim, captan, carbendazim and azoxystrobin. Preharvest sprays

Table 9: Effect of different fungicides against post-harvest rots of apple cv. Starking Delicious after 2 months of refrigerated storage

Treatment	Conc. (%)	Per cent fruit rot						
		2021						
		A. alternata	*T. roseum*	*M. fructigena*	*A. Niger*	*P. expansum*	Mean	Percent control
Mancozeb	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Captan	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Thiophanate methyl	0.05	7.84	2.05	0.00	22.24	0.00	6.43	59.66
Carbendazim	0.05	5.78	0.00	0.00	21.39	0.00	5.43	65.93
Azoxystrobin	0.05	6.82	0.00	0.00	22.34	0.00	5.83	63.43
Pyraclostrobin	0.05	9.54	5.98	0.00	24.64	2.96	8.62	45.92
Mancozeb + Carbendazim	0.25	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Control	-	20.29	12.94	9.47	27.57	9.43	15.94	-
Mean	-	6.28	2.62	1.18	14.77	1.55	-	-

Table 9: Continue...

Treatment	Conc. (%)	Per cent fruit rot						
		2022						
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Mean	Per cent control
Mancozeb	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Captan	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Thiophanate methyl	0.05	7.53	2.08	0.00	22.62	0.00	6.45	60.11
Carbendazim	0.05	5.71	0.00	0.00	21.39	0.00	5.42	66.48
Azoxystrobin	0.05	6.63	0.00	0.00	22.80	0.00	5.89	63.57
Pyraclostrobin	0.05	9.75	5.96	0.00	23.66	3.05	8.49	47.50
Mancozeb + Carbendazim	0.25	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Control	-	20.04	13.84	10.01	27.48	9.50	16.17	-
Mean	-	6.21	2.74	1.25	14.75	1.57	-	-

CD (p=0.05) Fungicide=0.269; Test pathogen=0.212; Fungicide×Test pathogen=0.601 (2021); CD (p=0.05) Fungicide=0.265; Test pathogen=0.207; Fungicide×Test pathogen=0.613 (2022)

of mancozeb, mancozeb+carbendazim, captan resulted in complete control of *A. alternata* and *A. niger*, nevertheless, other fungicides provided less control of both the pathogens.

Minimum post-harvest disease incidence was reported when apple fruits were stored under Zero Energy Cool Chamber (temperature 3.10 to 19.80˚C, RH 90%) for a period of about 100 days after treatment with 10% wax and 2.5% $CaCl_2$ or 200 ppm Bavistin (Sharma et al., 2011). Most of the storage rots of apple are checked even when stored at 0 to 4˚C (Thind et al., 1976; Kaul and Sharma, 1998). Infection of apples by *Glio cephalotrichum bulbilium* does not take place below 10˚C and can therefore be controlled by storage below this temperature (Jamaluddin et al., 1973). Post-harvest decay of grapes caused by *B. dothidea, G. cingulata, P. canescens* and *A. niger* is checked effectively by storage at 0˚C (Takeda et al., 1983; Sharma and Dharam Vir, 1985). Storage of apricots at 5˚C effectively reduced the losses due to fungal pathogens (Sharma et al., 1990).

3.4.4.3. Effect of preharvest fungicidal sprays on post-harvest rotting of apple during controlled atmospheric (CA) storage

Data pertaining to field efficacy of different fungicides against post-harvest rotting of apple after 2 months of CA storage has been presented in Table 10. The perusal of data revealed that preharvest sprays of all the fungicides were effective in

Table 10: Effect of different fungicides against post-harvest rots of apple cv. Starking Delicious after 2 months of CA storage

Treatment	Conc. (%)	Per cent fruit rot						
		2021						
		A. alternata	*T. roseum*	*M. fructigena*	*A. Niger*	*P. expansum*	Mean	Percent control
Mancozeb	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Captan	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Thiophanate methyl	0.05	3.79	0.00	0.00	10.60	0.00	2.88	59.32
Carbendazim	0.05	0.00	0.00	0.00	8.15	0.00	1.63	76.98
Azoxystrobin	0.05	0.00	0.00	0.00	8.60	0.00	1.72	75.71
Pyraclostrobin	0.05	4.91	0.00	0.00	11.35	0.00	3.25	54.09
Mancozeb + Carbendazim	0.25	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Control	-	9.43	4.45	2.64	14.46	4.43	7.08	-
Mean	-	2.27	0.56	0.33	6.64	0.55		-

Table 10: Continue...

Treatment	Conc. (%)	Per cent fruit rot						
		2022						
		A. alternata	*T. roseum*	*M. fructigena*	*A. niger*	*P. expansum*	Mean	Per cent control
Mancozeb	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Captan	0.3	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Thiophanate methyl	0.05	3.61	0.00	0.00	10.11	0.00	2.74	60.58
Carbendazim	0.05	0.00	0.00	0.00	8.08	0.00	1.62	76.69
Azoxystrobin	0.05	0.00	0.00	0.00	8.64	0.00	1.73	75.11
Pyraclostrobin	0.05	4.64	0.00	0.00	10.54	0.00	3.03	56.40
Mancozeb + Carbendazim	0.25	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Control	-	8.31	4.44	3.42	14.23	4.35	6.95	-
Mean	-	2.07	0.58	0.43	6.45	0.54	-	-

CD (p=0.05) Fungicide=0.267; Test pathogen=0.211; Fungicide×Test pathogen=0.598 (2021); CD (p=0.05) Fungicide=0.255; Test pathogen=0.221; Fungicide×Test pathogen=0.590 (2022)

controlling the post-harvest decays of apple fruits stored under CA storage in comparison to control. It is evident from the data that 100% control of all the test fungi under study was provided by preharvest sprays of mancozeb (0.3%), mancozeb + carbendazim (0.25%) and captan (0.3%) during both the years of study. Further, carbendazim (0.05%) provided reasonably good control (76.98 and 76.69%) of apple decays under study which was statistically at par with azoxystrobin (0.05%) and thiophanate methyl (0.05%) with per cent decay control of 75.71, 75.11, 59.32 and 60.58%, respectively. Pyraclostrobin (0.05%) was the least effective fungicide providing 54.09 and 56.40% of decay control in comparison to control.

During 2 months of CA storage, 100% fruit rot control was recorded with mancozeb, mancozeb+carbendazim and captan during both the years of study. Carbendazim was the next effective fungicide followed by azoxystrobin with per cent control of 76.98, 76.69 and 75.71, 75.11, respectively.

The interaction studies between fungicides and test fungi revealed that CA storage of apples after preharvest sprays of all the fungicides provided 100% control of *T. roseum*, *M. fructigena* and *P. expansum* during both the years of study. Similar was the case with *A. alternata* except showing some tolerance to thiophanate methyl and pyraclostrobin. Preharvest sprays of mancozeb, mancozeb+carbendazim and captan resulted in complete control of *A. niger*, however, other fungicides provided less control of the fungi.

These findings further confirm the work of, Ceponis and

Cappellini (1985), Couey and Wells (1970), Reyes (1988), Sommer (1985), Spalding and Reader (1975) and Stewart (1979), who recommended using combinations of low oxygen and high carbon dioxide to reduce decay. Controlled atmosphere storage with carbon dioxide concentrations above 2.8% reduced the development of lesions incited by *Botrytis cinerea* (grey mould), *Penicillium expansum* (blue mould) and *Peziculamalicorticis* (bull's eye rot) in McIntosh, Delicious and Golden Delicious apples kept for 61 days at 0˚C (Sitton and Patterson, 1992).

Controlled atmosphere has been found useful to reduce fungal growth, mainly by extending host resistance but also by suppression of fungal pathogens with high CO_2 treatments inhibiting various metabolic functions (Qin et al., 2004). Several works with other apple cultivars have demonstrated that CA is effective to significantly delay the loss of firmness during storage (Erkan et al., 2004; Jinhe et al., 2005; Levesque et al., 2006).

3.5. Effect of fumigants on post-harvest rotting of apple

The perusal of data presented in Table 11 revealed that 1-methyl cyclopropene (MCP) fumigation of apple fruits for 12 hours was most effective in checking the test fungi under study providing 89.60% control. It could be observed clearly from the data that sulphur dioxide fumigation due to sodium metabisulphite was significantly effective in checking post-harvest fungal deterioration of apple fruit with 60.44% control, but ammonia producing formulations, *viz*. ammonium carbonate and ammonium chloride plus magnesium oxide were the least effective fumigants with per cent control of 27.34 and 36.28, respectively.

Inoculated and variously fumigated apples deteriorated significantly due to *M. fructigena* (70.79%) and *P. expansum* (62.89%) followed by *A. niger* (59.93%). The breakdown was somewhat less in *A. alternata* (55.56%) and *T. roseum* was successfully checked with mean per cent fruit rot of 37.17%, respectively. The interaction between fumigants and fungi revealed that ethylene inhibitor 1-MCP and sulphur dioxide liberating sodium metabisulphite completely inhibited *T. roseum*. 1-MCP appreciably checked all the other fungi under study. However, none of the ammonia releasing formulations appreciably checked any of the fungal decay.

1-MCP is applied to fruits, vegetables, and flowers, mainly apples, as a fumigant for a short period directly after harvest to preserve their quality and reduce losses during subsequent storage. Watkins and Nock (2004) supported this view for apples. It was reported that 1-MCP treatment for 12 h and storage at 10˚C seemed a promising way to extend the storage life of guava fruits (Singh and Pal, 2008).Ozone application to grapes (0.1 mg g^{-1} grapes) for 20 minutes reduced decay caused by *Rhizopus stolonifer* and prolonged shelf life. This treatment was as effective as sulphur dioxide (Sarig et al., 1996). Fumigation with acetic acid is effective in controlling *M. fructicola, R. stolonifer* and *Alternaria* species on peaches, nectarine, apricot, and cherries (Sholberg and Gaunce, 1996).

4. Conclusion

Post-harvest decay of fruits takes a heavy toll of the fruit produce in apple. The causative fungi can be controlled by various interventions like produce handling, skin coatings, fumigation, chemical treatments, and most importantly improved storage conditions, thereby minimizing the post-harvest losses in apple. Thus, there is an urgent need of developing infrastructure for cool chain and modern storage facilities to avoid post-harvest losses of apples in the country.

5. References

Agarwala, R.K., Sharma, V.C., 1968. Storage rot diseases of apple. Indian Phytopathology 21, 294–298.

Amenduni, M., D'Amico, M., Colella, C., Cirulli, M., 2003. Severe outbreaks of Alternaria leaf spot on Actinidia in Southern Italy. Informatore Fitopatologico 53(11), 39–43.

Baker, K.F., Heald, F.D., 1932. Some problems concerning blue mould in relation to cleaning and packing of apples. Phytopathology 22, 879–898.

Ben-Arie, R., Guelfat-Reich, S., 1973. Pre-harvest and post-harvest applications of benzimidazoles for control of storage decay of pears. HortScience 8(3), 181–183.

Blanpied, G.D., Purnasiri, A., 1968. *Penicillium* and Botrytis rot of McIntosh apples handled in water. Plant Disease Reporter 52, 865–867.

Blazek, J., Kloutvorova, J., Krelinova, J., 2007. Incidence of storage diseases on apples of selected cultivars and advanced selections grown with and without fungicide treatments. HortScience 33(3), 87–94.

Bobbarala, V., Katikala, P.K., Naidu, K.C., Penumajji, S., 2009. Antifungal activity of selected plant extracts against phytopathogenic fungi Aspergillus niger. Indian Journal of Science and Technology 2(4), 87–90.

Borecka, H., 1962. P. expansum Link as a pathogen of apple during the period of storage. Acta Agrobotanica 12, 67–78.

Borecki, Z., Profic, H., 1962. The fungi *Trichothecium roseum*, Peziculamalicorticis and Penicillium expansum as primary and secondary pathogens of apples. Acta Agrobotanica 12, 79–94.

Buzby, J.C., Hyman, J., Stewart, H., Wells, H.F., 2011. The value of retail- and consumer-level fruit and vegetable losses in the United States. Journal of Consumer Affairs 45, 492–515 doi: 10.1111/j.1745-6606.2011. 01214.x.

Ceponis, M.J., Cappellini, R.A., 1985. Reducing decay in fresh blueberries with controlled atmospheres. HortScience 20(2), 228–229.

Chib, H.S., Gupta, B.R., Andotra, P.S., Dar, C.N., 1983. Evaluation of some fungicides for the control of post-harvest rots of apple through fungicidal dip in Kashmir. Indian Journal of Mycology and Plant Pathology 13, 353–354.

Couey, H.M., Wells, J.M., 1970. Low-oxygen or high-carbon dioxide atmospheres to control post-harvest decay of strawberries. Phytopathology 60, 47–49.

Dey, P.K., Nigam, B.S., 1933. A soft rot of apple. Indian Journal of Agricultural Science 3(4), 663–672.

Dharam, V., 1982. Chemical control of post-harvest spoilage of apple fruits caused by *Aspergillus flavus*. Pesticides 16, 23–24.

Erkan, M., Pekmezci, M., Gubbuk, H., Karasahin, I., 2004. Effects of controlled atmosphere storage on scald development and postharvest physiology of Granny Smith apples. Turkish Journal of Agriculture and Forestry 28(1), 43–48.

Faes, H., Staehelin, M., 1925. Some fungi causing the decay of fruit. Annuaire Agricole de laSuisse 26, 59–72.

Falck, R., 1907. Machstungesctze, wachstumataktoren Und Temperature Werteder Holzer Storenden Mycelien 1, 153–154.

Fisher, D.F., 1922. Spoilage of apples after harvest. Thirty-second Annual Conventional British Columbia Fruit-Grower's Association Victoria B. C. 1922. 68 pp.

Glaser, T., Kaiser, H.U., 1986. Studies on the etiology and control of necrotic leaf spot of apple cultivar Golden Delicious. RocznikiAkademiiRolniczejw-Poznaniu, Ogrodinictwo 165, 49–62.

Granger, K., Horne, A.S., 1924. A method of inoculating the apples. Annals of Botany 38(149), 212–215.

Grantina-Ievina, L., 2015. Fungi causing storage rot of apple fruit in integrated pest management system and their sensitivity to fungicides. Rural Sustainability Research 34, 329.

Gupta, D., Sharma, J.N., 2008. Natural occurrence of water core and core rot of apple in Himachal Pradesh (abstract). Indian Phytopathology 61, 386.

Haussmann, G., 1934. A contribution to the knowledge of fungal diseases of fruit in cold storage. Annals Sperimentale Agriculture 15, 101–116.

Ikeura, H., Somsak, N., Kobayashi, F., Kanlayanarat, S.,Hayata, Y., 2011. Application of selected plant extracts to inhibit growth of *Penicillium expansum* on apple fruits. Plant Pathology Journal 10(2), 79–84.

Ivic, D., Cvjetkovic, B., Milicevic, T., 2006. Dynamics and intensity of apple disease development during its storage. Agriculture 12, 36–41.

Jamaluddin, Tandon, M.P., Tandon, R.N., 1972. A storage rot of apple fruits (*Malus sylvestris*). Indian Phytopathology 25, 593–595.

Jamaluddin, Tandon, M.P., Tandon, R.N., 1973. Studies on soft rot of apple (*Malus sylvestris*) caused by *Glio cephelotrichum bulbilium* Ellis. Proceedings of National Academic of Sciences, India Section B 43, 154–158.

Bai, J., Baldwin, E.A., Goodner, K.L., Mattheis, J.P., Brecht, J.K., 2005. Response of four apple cultivars to 1-methylcyclopropene treatment and controlled atmosphere storage. HortScience 40(5), 1534–1538.

Kader, A.A., 2005 Increasing food availability by reducing postharvest losses of fresh produce Acta Horticulture 682, 2169–2176. doi:10.17660/ActaHortic.2005.682.296.

Kaul, J.L., Lall, B.S., 1974. A new method for inoculating citrus fruits. Science and Culture 40, 375–376.

Kaul, J.L., Sharma, R.C., 1998. Postharvest diseases and their management. In: Chadha, K.L., Awathi, R.P., (Eds.), The Apple.

Kaul, J.L., 1982. Comparative effectiveness of systemic fungicides for the control of postharvest fungal rots of apple. Indian Phytopathology 35, 315–316.

Sharma, J.N., Kaul, J.L., 1997. Studies on the development of storage scab in apple and its management. Indian Phytopathology 50(3), 396–401.

Khanna, K.K., Chandra, S., 1975. A new disease of apple fruit (Khuskiaoryzae). Plant Disease Reporter 59, 329–330.

Kim, S.B., Yiem, M.S., Jang, H.I., 1982. Studies on the chemical control of Alternaria leaf spot in apple trees. Research Reports, Office of Rural Development, South Korea Horticulture 24, 77–82.

Kock, S.L., De Visage, T.R., Combrink, 1991. Control of core rot in Starking apples. The Deciduous Fruit Grower 41, 20–22.

Kwon, J.H., Min-Jeong, K., Chang-Ki, S., Hyeong-Jin, J., Sang-Dae, L., 2014. Pink mould rot on apple (*Malus pumila var.dulcissimaKoidz*.) caused by *Trichothecium roseum* (Pers.) Link ex Gray in Korea. The Korean Journal of Pesticide Science 18(4), 429–433.

Laxminarayana, P., Reddy, S.M., 1975. Hitherto unrecorded post-harvest disease of apple (Handersonulatoruloidea). Current Science 44, 442.

Levesque, P.G., Deell, J.R., Murr, D.P., 2006. Sequential controlled atmosphere storage for 'McIntosh' apples. HortScience 41(5), 1322–1324.

Martinelli, F.M., Busconi, F., Camangi, C., Fogher, A., Stefani, Sebastiani, L., 2008. Ancient pomoideae (*Malus domesticaBorkh. and Pyrus communis* L.) cultivars in "Appenino Toscano" (Tuscany, Italy): molecular (SSR) and morphological characterization. Caryologia 61, 320–331.

Mehta, P.R., 1937. A fruit rot of apples caused by a species of Rhizopus. Current Science 6, 58–59.

Niazi, M., Lal, A.A., Simon, S., 2016. Effect of botanicals against post-harvest rot fungi of Apple (*Malus×domestica Borkh*). International Journal of Multidisciplinary Research and Development 3(7), 202–208.

Niem, J., Miyara, I., Ettedgui, Y., Reuveni, M., Flaishman, M., Prusky, D., 2007. Core rot development in Red Delicious apples is affected by susceptibility of the seed locule to Alternaria alternata colonization. Phytopathology 97(11), 1415–1421.

Onofre, S.B., Antoniazzi, D., 2014. Behaviour of the fungus *Colletotrichum gloeosporiodes* (Penz &Sacc.) which

causes bitter rot in apples after harvesting. Advances in Microbiology 4(4), 202–206.

Qin, G., Tian, S.P., Xu, Y., 2004. Biocontrol of postharvest diseases on sweet cherries by four antagonistic yeasts in different storage conditions. Postharvest Biology and Technology 31(1), 51–58.

Raj, H., Sharma, J.N., 2015. Management of mouldy core and core rot of apple causing pre-harvest fruit drop in Himachal Pradesh. International Journal of Farm Sciences 5(1), 90–99.

Reuveni, M., Sheglov, D., Sheglov, N., Ben-Arie, R., Prusky, D., 2002. Sensivity of red delicious apple fruits at various phenologic stages to infection by Alternaria alternataand mouldy core control. European Journal of Plant Pathology 108, 421–427.

Reuveni, M., 2006. Inhibition of germination and growth of Alternaria alternataand mouldy core development in Red Delicious apple by Bromoconazole and Sygnum. Crop Protection 25(3), 253–258.

Reyes, A.A., 1988. Suppression of *Sclerotinia sclerotiorum* and watery soft rot of celery by controlled atmosphere storage. Plant Disease 72(9), 790–792.

Rizzolli, W., Acler, A., 2006. Efficacy of some fungicides against Alternaria alternata on apple. Giornate Fitopatologiche 2, 27–29.

Ruehle, G.D., 1937. Fungi which cause decay in apples in cold storage. Research Studies of the State College of Washington 5, 99–100.

Sarig, P., Zahavi, T., Zutkhi, Y., Yannai, S., Liskar, N.,Ben-Arie, R., 1996. Ozone for the control of post-harvest decay of table grapes caused by *Rhizopus stolonifer*. Physiological and Molecular Plant Pathology 48(6), 403–415.

Sharma, K., Raj, H., 2018. Use of local bioresources for post-harvest management of white rot of apple caused by *Botryosphaeria dothidea*. Journal of Applied and Natural Science 10(1), 491–499.

Sharma, R.C., Dharam, V., 1985. Influence of temperature and relative humidity on postharvest fungal spoilage of grapes (*Vitis vinifera* L.). Journal of Tree Science 4, 31–33.

Sharma, R.C., Kaul, J.L., Jindal, K.K., 1990. Studies on postharvest diseases of apricot and chemical control of whiskers rot. Indian Phytopathology 43(3), 385–388.

Sharma, S.K., Nautiyal, M.C., Issar, K., 2011. Postharvest rotting, quality and shelf life of apple as affected by chemicals, GA treatment and packaging. Acta Horticulturae 905(21), 201–209.

Sholberg, P.L., Gaunce, A.P., 1996. Fumigation of stone fruit with acetic acid to control post-harvest decay. Crop Protection 15(8), 681–686.

Sholberg, P.L., Bedford, K.E., Stokes, S., 2003. Effect of preharvest application of cyprodinil on postharvest decay of apple caused by *Botryis cinerea*. Plant Disease 87(9), 1067–1071.

Shtienberg, D., 2012. Effects of host physiology on the development of core rot caused by *Alternaria alternata* in Red Delicious apples. Phytopathology 102(8), 769–778.

Singh, S.P., Pal, R.K., 2008. Controlled atmosphere storage of gauva (*Psidium guajava* L.) fruit. Postharvest Biology and Technology 47(3), 296–306.

Singh, U.B., 1941. The soft rot of apple fruits in Kumaun. Indian Journal of Agriculture Science 11, 902–905.

Singh, Y.P., Sumbali, G., 2003. Management of Penicillium expansum rot of apple by certain plant extract and essential oils. Journal of Mycology and Plant Pathology 33, 504–504.

Sinha, S., 1946. Studies on decay of certain fruits in storage. In: Proceedings of Indian Academic Sciences Section B 24(4), 198–205.

Sitton, J.W., Patterson, M.E., 1992. Effect of high carbon dioxide and low-oxygen controlled atmospheres on postharvest decays of apples. Plant Disease 76, 992–995.

Sommer, N.F., 1985. Role of controlled environments in suppression of post-harvest diseases. Canadian Journal of Plant Pathology 7(3), 331–339.

Sottocornola, G., Baric, S., Stella, F., Zanker, M., 2023. Development of a knowledge-based expert system for diagnosing post-harvest diseases of apple. Agriculture 13(1), 177. doi: 10.3390/agriculture13010177.

Spalding, D.H., Reeder, W.F., 1975. Low-oxygen high-carbon dioxide-controlled atmosphere storage for control of anthracnose and chilling injury of avocados. Phytopathology 65, 458–460.

Sprau, F., 1948. Storage damage to pome fruit. Pflanzenschutz 1(2), 11–14.

Srivastava, M.P., Tandon, R.N., 1968. Influence of temperature on Botryodiplodia rot of citrus and sapodilla. Indian Phytopathology 21, 195–197.

Stewart, J.K., 1979. Decay of muskmelons stored in controlled atmospheres. Scientia Horticulturae 11(1), 69–74.

Sugar, D., Basile, S.R., 2011. Orchard calcium and fungicide treatments mitigate effects of delayed post-harvest fungicide applications for control of postharvest decay of pear fruit. Post-Harvest Biology and Technology 60, 52–56.

Sugar, D., Benbow, J.M., Powers, K.A., Basile, S.A., 2003. Effect of sequential calcium, ziram, and yeast orchard sprays on postharvest decay of pear. Plant Disease 87(10), 1260–1262.

Tak, S.K., Verma, O.P., Gupta, A.K., Pathak, V.N., 1985. Control of *Alternaria* rot of apple fruits by post-harvest application of chemicals. Indian Phytopathology 38, 471–474.

Takeda, F., Saunders, M.S., Saunders, J.A., 1983. Physical and chemical changes in muscadine grapes during postharvest storage. American Journal of Enology and Viticulture 34(3), 180–185.

Testempasis, S., Tanou, G., Minas, I., Samiotaki, M., Molassiotis,

A., Karaoglanidis, G., 2021. Unraveling interactions of the necrotrophic fungal species *Botrytis cinerea* with 1-Methylcyclopropene or Ozone-treated apple fruit using proteomic analysis. Frontiers in Plant Science 12, 644255. doi: 10.3389/fpls.2021.644255.

Thind, T.S., Saksena, S.B., Agarwal, S.C., 1975. Soft rot of apple caused by Clathridiumcorticola (Fcke) Shoem and Muller. Current Science 44, 714.

Thind, T.S., Saksena, S.B., Agarwal, S.C., 1976. Effect of temperature in the control of soft rot of apple fruits caused by Clathridiumcorticola. Indian Phytopathology 29, 256–258.

Tomar, M., Raj, H., 2015. Use of native local bio resources and cow urine for the effective management of post-harvest diseases of apples in Northwest Himalayan States of India. Journal of Plant Pathology and Microbiology 6(10), 316.

Tyler, L.J., 1944. Apple storage diseases in New York. Plant Disease Reporter 28, 298–311.

Valiuskaite, A., Kvikliene, N., Kviklys, D., Lanauskas, J., 2006. Post-harvest fruit rot incidence depending on apple maturity. Agronomy Research 4, 427–431.

Vincent, J.H., 1947. Distortion of fungal hyphae in the presence of certain inhibitors. Nature 159(4051), 850.

Vorstermans, B., Creemers, P., Bylemans, D., Garnier, A., 2005. A new post-harvest fungicide to control fruit rot on apple and pear. Communications in Agricultural and Applied Biological Sciences 70(3), 79–89.

Watkins, C.B., Nock, J.F., 2004. Effects of delays between harvest and 1-methylcyclopropene (1-MCP) treatment on ripening of air-stored and controlled atmosphere stored apple. HortScience 40(7), 2096–2101.

Weber, A., 1938. Apple diseases in the storage room. Tidsskr Planteavl 43(2), 337–345.

Xiao, C.L.,Boal, R.J., 2009. Preharvest application of a boscalid and *pyraclostrobin* mixture to control postharvest grey mould and blue mould in apples. Plant Disease 93(2), 185–189.

Xiao, C.L., Kim, Y.K., 2008. Postharvest fruit rots in apples caused by *Botrytis cinerea, Phacidiopycnis washingtonensis* and *Sphaeropsis pyriputrescens*. Plant Health Progress 9(1), 34. doi: 10.1094/PHP-2008-0919-01-DG.

Yousuf, V., Ahmad, Q.N., 2001. Impact of single autumn application of chemicals on primary inoculum production of *Alternaria mali* the causal agent of Alternaria blotch of apple in Kashmir. Applied Biological Research 3, 23–27

Yu, L., Qiao, N., Zhao, J., Zhang, H., Tian, F., Zhai, Q., Chen, W., 2020. Postharvest control of *Penicillium expansum* in fruits: A review. Food Bioscience36, 100633. doi: 10.1016/j.fbio.2020.100633.