

Strategies for Onion Post-Harvest Diseases Management

ABSTRACT

India is first globally in terms of area under onion cultivation and second in terms of output, behind only China in both categories. In comparison to other nations, the production is still fairly low. In India, the crop is the most promising source of foreign cash. The onion (*Allium cepa*), a crop of commercial significance, is grown extensively all over the globe and used as a vegetable, spice, or flouring agent. In India, onions are one of the most delicate vegetables prized for pungency. It has significant amounts of various phytonutrients, polyphenols, minerals, and vitamins. Domestically the use of common uses for onions in food preparation includes curry, sauce, salad, chutney, puree, and a lot more. Both raw and processed forms of it are used in salads. It reduces blood pressure and perhaps prevents certain types of cancer and diseases. The capacity of onions to be preserved for a long time eight to ten provided they are handled correctly before and after harvest, accounts for their success in agriculture. It is attacked by several microbial diseases like fungal, bacterial, viral and nematode. Approximately 35-40% of onions are lost owing to damage from storage diseases. During the storage of various kinds, the fungal bulb rot contributes to losses of between 15 and 30 percent. Red onion, yellow onion, and white onion are the varieties of onions cultivated worldwide. The development of strategies like bionanofungicides, including the potential use of plant extracts or other bioagents is required to reduce the onion losses during storage.

Keywords: onion diseases, plant pathogens, diseases management, seed-borne, soil-borne diseases, post-harvest diseases, bio-agents, nanoparticles.

1. INTRODUCTION

The most common and farmed species of the genus *Allium*, which belongs to the family Alliaceae, is the onion, or *Allium cepa* [1]. The term "onion" comes from Latin and means big pearl also called the queen of kitchen. It is an evergreen biennial plant that may reach heights of up to 0.6 meters (2 feet) and has hermaphrodite blooms that are pollinated by insects [2-4]. Onion has a lot of flavonoids and phenolics, which have anti-inflammatory and antioxidant properties [5]. Onions are the staple food of daily meals, consumed both fresh in salads and cooked in vegetables to meet the year-round demand of consumers. Singh and co-workers (1994) [6] reported that minerals, vitamins, polyphenols, and a variety of phytonutrients are present in onions in ample amounts. Onions have been proven to offer a variety of medical uses for the human body, and frequent consumption will improve overall health [2]. It reduces blood pressure and diabetes and protects against certain cancers [7, 8]. It is used in the processing of a variety of products, including onion juice, oil, pickles, salt, and dried foods in the form of rings, powder, and kibbles. Onion bulbs may vary in color from red to yellow to pink to white due to mutations in structural and regulatory genes in the complicated and multi-gene-interacted flavonoid biosynthesis pathway [9].

The crop onion is Asian in origin. China is the leader in terms of area and onion production, while India comes in second place in terms of production and exports of onion to countries like Dubai, Kuwait, Saudi Arabia, the Middle East, Malaysia, Singapore, Bangladesh, and Sri Lanka. Approximately 88.5 million metric tonnes of onions are produced worldwide each year, with roughly 2 million metric tonnes produced in Nigeria [8, 10]. The onion plays a key role in improving agricultural revenue, global food security, and nutritional safety. The onion of three colors i.e. red, yellow and white has different properties and nutrition value shown in Table-1.

Table 1: Physical and chemical characteristics of samples of red, white and yellow onion (source: Jiwan et al., 2019)

Cultivar	Part of bulb	Moisture content in fresh sample, % wb	Total sugar	Total phenolic content (mg/g Gallic acid equivalent)	Glucose (% mean \pm S.D., dry weight basis)	Fructose (% mean \pm S.D., dry weight basis)	Sucrose (% mean \pm S.D., dry weight basis)
US Onion White	Outer layers	91.9 \pm 0.6	40	15.1 \pm 0.2	17.4 \pm 0.2	19.0 \pm 0.1	3.6 \pm 0.2
	Middle layer	92.1 \pm 0.5	67.8	10.7 \pm 0.3	32.2 \pm 0.5	29.0 \pm 0.5	6.6 \pm 0.2
	Inner layer	90.8 \pm 0.6	80.9	5.1 \pm 0.6	35.1 \pm 0.5	35.1 \pm 0.2	10.7 \pm 0.5
US Onion Yellow	Outer layers	89.0 \pm 0.6	31.5	20.8 \pm 0.3	11.1 \pm 0.1	11.4 \pm 0.1	9.0 \pm 0.1
	Middle layer	88.4 \pm 0.4	77.2	16.4 \pm 0.2	16.8 \pm 0.4	14.4 \pm 0.1	14.5 \pm 0.3
	Inner layer	87.4 \pm 0.4	52.6	15.8 \pm 0.3	20.5 \pm 0.2	15.2 \pm 0.1	16.9 \pm 0.2
Indian Onion Red	Outer layers	86.5 \pm 0.6	41.3	22.2 \pm 0.1	17.5 \pm 0.2	11.6 \pm 0.2	12.2 \pm 0.1
	Middle layer	86.5 \pm 0.3	42.2	11.6 \pm 0.1	17.5 \pm 0.2	9.3 \pm 0.1	15.0 \pm 0.1
	Inner layer	86.5 \pm 0.3	36.1	4.7 \pm 0.4	17.0 \pm 0.2	7.4 \pm 0.1	11.7 \pm 0.2
Egyptian Onion Red	Outer layers	84.5 \pm 0.4	22.1	20.7 \pm 1.3	5.8 \pm 0.1	7.8 \pm 0.1	8.5 \pm 0.4
	Middle layer	83.0 \pm 0.2	26.2	10.5 \pm 0.6	7.4 \pm 0.1	8.5 \pm 0.2	10.3 \pm 0.2
	Inner layer	82.3 \pm 0.6	18.9	5.2 \pm 0.3	4.6 \pm 0.2	4.7 \pm 0.1	9.6 \pm 0.3
New Zealand Onion Golden	Outer layers	88.8 \pm 0.7	45.1	22.6 \pm 0.3	13.8 \pm 0.2	18.1 \pm 0.4	13.2 \pm 0.4
	Middle layer	88.6 \pm 0.3	62.3	14.3 \pm 0.2	18.0 \pm 0.4	22.8 \pm 0.7	21.5 \pm 0.1a
	Inner	87.4 \pm 0.1	55.9	11.2 \pm 0.3	19.7 \pm 0.3	19.5 \pm 0.3	16.7 \pm 0.3

	layer						
Saudi Onion White	Outer layers	92.6 ± 0.2	58.4	8.2 ± 0.4	26.2 ± 0.3	26.4 ± 0.5	5.8 ± 0.1
	Middle layer	91.2 ± 0.5	67.8	6.2 ± 0.3	31.2 ± 0.4	27.4 ± 0.3	9.2 ± 0.2
	Inner layer	89.7 ± 0.6	59.4	3.7 ± 0.1	28.6 ± 0.3	22.2 ± 0.3	8.6 ± 0.2

Benefits of onions

Medicinally it is important crop used in various problems and disorders. The anti-allergenic, anti-inflammatory, cardioprotective, vasodilatory, anticarcinogenic, and antioxidant effects of flavonoids were attributed to them. Numerous epidemiological researches revealed that using onions could lower the chance of developing chronic diseases including cancer, diabetes, and coronary heart disease. There have been several reports of flavonoids having antibacterial and antifungal effects. According to pharmacology, eating onions inhibits DNA damage and breakdown. In cardiovascular studies, it reduces blood lipid levels, raises fibrinolysis, reduces platelet aggregation, lowers blood pressure, and decreases cholesterol and triglyceride levels. Due to the presence of quercetin in onions, eating may also lower the risk of cardiovascular disorders. The signaling of platelet aggregation is affected by high blood levels of quercetin, which lowers the incidence of cardiovascular illnesses.

Due to the presence of allyl propyl disulphide, onions have demonstrated strong oral hypoglycemic activity in diabetes, although other compounds including quercetin and anthocyanidin also play a major role. By competing with insulin for sites of degradation, allyl propyl disulphide lowers glucose levels while lengthening the half-life of insulin. Onions are used to treat asthma, and they appear to be more effective than garlic in treating psoriasis and atopic dermatitis, two disorders linked to elevated levels of lipoxygenase byproducts (leukotrienes). When tumor cells were implanted in rats, an onion extract was discovered to be cytotoxic to the tumor cells in vitro and to stop the formation of the tumor. The antimicrobial, antifungal, antibacterial, and anthelmintic properties of onion are present, although they are not as strong as those of garlic. The ability of essential oil extracts of red, yellow, and green onions and garlic to fight against different germs.

The top states and districts in India for the production of onions are Maharashtra, Madhya Pradesh, Karnataka and Gujarat. Although it is primarily a crop for the Rabi season, it makes up around 10–15 percent of the overall yield throughout the Kharif season. In India, the overall demand for personal use, bulk consumption in hotels, weddings, etc., seed, losses, and processing was 20.25 million MT in 2017-18. Rajasthan is India's seventh-most productive state in terms of area, output, and productivity overall. In Rajasthan, onion is cultivated in the districts of Jodhpur, Sikar, Nagaur, Alwar, Jhunjhunu, and Kota.

For long-term usage, the storage conditions are crucial. The optimal fresh frozen temperature is between 2 and 18°C with a relative humidity of 67–70% in a pack that is gastight. The ideal storage time ranges from 3 to 12 months. Peak harvesting occurred in April in Maharashtra, March and April

in Madhya Pradesh, April to June in Karnataka, September and October in Rajasthan, and April to June in Bihar (March to April 2018). In the 2017–18 financial year, India exported 1588.99 thousand MT worth 3, 08,882.23 lakh rupees to other nations [11].

Even if superior onion varieties are available and production technology has advanced, post-harvest losses during storage remain a serious problem that may result in considerable qualitative and quantitative losses of up to 25–30% [12, 13]. Bulb development, growth, yield, and quality were impacted by water stress, excessive wetness, day length, temperature, CO₂ concentration in the atmosphere, and soil salinity. Various diseases that target onions have severely damaged onion production in India and across the world [5,14]. Significant losses occur as a result of inadequate transportation infrastructure, a lack of expertise, bad management, inadequate market facilities, or negligent product handling on the part of producers, market intermediaries, and consumers [15]. Even today, these post-harvest losses happen because there aren't enough good places to store crops after harvest. In a study conducted at Jodhpur, Rajasthan, to determine how much onion was lost after harvest [13, 16]. Approximately 35–40% of onions are lost or damaged during post-harvest storage as a result of post-harvest infections.

2. ECONOMICAL AND HEALTH IMPACT OF POSTHARVEST DISEASES OF ONION

Onions are rendered unsuitable for human consumption owing to possible health hazards as a result of postharvest diseases, which also result in quality and quantitative losses. Carcinogenic mycotoxins and mutagenic secondary metabolites generated from black, white, and yellow fungi are the main causes of many postharvest diseases [3, 4, 5, 8, 17]. Estimating the value of the food lost due to postharvest waste requires taking into consideration expenditures associated with harvesting, packing, and transportation in addition to primary and secondary agricultural techniques. Onion storage life is influenced by several factors, including physiological activity, biochemical activity, and microbial invasion. India's temperature regime renders it vulnerable to the growth of several fungal diseases of various genera and species, which in turn cause harm by producing rot during storage [18].

Several species of saprophytic *Aspergillus* fungi that are cause postharvest diseases and generate the carcinogenic secondary metabolite aflatoxin. The blue molds are typically isolated from sick onion bulbs kept locally [19]. *Aspergillus flavus* can create mycotoxins, a powerful liver carcinogen in both people and animals, which lowers the quality and quantity of food goods and feedstuff [20-25]. Tripathi et al. (2013) [25] say that per the World Trade Organization (WTO) a comprehensive plan is required to regulate aflatoxins in the trade and export market, including biosecurity, biowarfare, biodiversity, and biosafety. Fungi infestation leads to spoiling, which eventually lowers the quality and quantity of food [21, 22, 23, 26, 27]. Different pathogens may spread via contaminated soil or seeds, and diseased bulbs exhibit neck discoloration, black mycelia, and concealing spores in the outer dry scales [28].

3. CHALLENGES OF POST-HARVEST LOSSES IN ONION

Maintaining the quality of the crop and reducing quantitative losses will be accomplished by using effective postharvest management techniques that are backed by good technology and by enhancing postharvest systems. The understanding of bio-fungicides and plant-based bioproducts for commercial use is limited and the farmers' limited knowledge of the application of bio-fungicides in India. There is only in vitro results are available but they are not used on a large scale by the farmers. It is necessary to create a variety of methods for fungus pathogen detection to pinpoint the pathogen affecting onion bulbs in the post-harvest stage. To effectively combat post-harvest rotting and decay, strategies for identifying location- and region-based ecotypes and pathogens that persist in various geographic locations must be developed.

4. CAUSES OF POSTHARVEST DISEASES

Fungi and bacteria are often the cause of onion postharvest diseases and losses. When the pathogen infects the plant before harvest in the field, the postharvest diseases are sometimes classified according to whether the infection is "quiescent" or "latent." Anthracnose, a postharvest disease brought on by *Colletotrichum* spp., and grey mold rot, a postharvest disease brought on by *Botrytis* spp., are examples. Postharvest infection occurs during storage and transportation after it has been harvested. The host tissues were infected and spread immediately due to a lack of natural defensive systems.

5. DETECTION OF POSTHARVEST PATHOGENS

Based on macroscopic and microscopic examination of colony and conidia/spore morphology, sero-diagnostics (ELISA, dot-blot tests), and nucleic acid (PCR)-based procedures, pathogens were isolated on the standard blotter method and agar medium and identified. Establish the existence and amount of the pathogen(s) for legal purposes of quarantine. It is necessary to use the IPM/IDM (Integrated Disease Management) for the control of various diseases. Calculate the number of pathogens in a given area across time and space and preparation of documents of it is necessary. Calculating pathogen populations based on seasonal and geographical factors is important in disease incidence. So it is necessary to find new post-harvest pathogens (diseases) in onions and make their list for the future as a repository.

6. FUNGAL DISEASES

Onions are considered to be incredibly nutritious so they must be kept under precise conditions and stored in the right way to retain their nutritional value [3]. An important cause of green onion market loss is post-harvest diseases. Bacterial soft rot, white rot, smudge, white tip, and grey mold are the most prevalent postharvest diseases of onion.

Contamination with pathogenic bacteria and fungi that cause postharvest diseases shortens their shelf life [29, 30]. Roughly 20–30% of onion postharvest loss is related to mechanical damage sustained during transit in addition to microbiological diseases [31,32]. Consuming infected or tainted produce has been identified as one of the primary causes of several human disorders [33-35]. From onions fungi such as *Aspergillus niger*, *A. flavus*, *Rhizopus stolonifera*, *A. fumigatus*, and *Fusarium* species

have been identified [36]. Rasiukeviciute, Suproniene, and Valiuskaite (2011) [37], Alegbeleyem, Singleton, and Sant'Ana (2018) [38] reported the farmworkers, soil, irrigation water, air, insects, fertilizer, livestock, and wildlife are all potential sources of pathogenic bacteria and fungi that cause spoilage.

Multiple microbial infections have been shown to co-exist and co-express their virulence to worsen diseases in onion tissues [39]. The interaction between viruses and plants in natural ecosystems goes beyond the usual scenario of one pathogen causing one disease and instead involves a complex interplay between several infections [40]. Fungal species like *Aspergillus fumigatus*, *Gibellula suffulta*, and *Hirsutella saussueri* were found associated with onion including the most frequent fungal isolates responsible for onion bulb rotting like *Aspergillus flavus*, *A. niger*, *Fusarium solani*, *Penicillium digitatum*, and *Rhizopus stolonifera*. According to Shehu and Muhammad (2011), [41] *Aspergillus fumigates* were responsible for the postharvest degradation of onion bulbs that were sold at several Sokoto, Nigeria, marketplaces. The possibility of spoilage in commercially bought onion bulbs, especially in tropical regions [42]. Onion bulbs are a perfect breeding ground for a variety of storage fungi since they are perishable if retain 86.8% moisture. Along with *A. fumigates* and *Alternaria porri*, isolated the five fungal species from decaying onion bulbs [41, 43].

In a study diseased onion bulbs were found in three marketplaces near Lagos State University in Ojo, Nigeria. A proxy analysis was conducted on infected onion bulbs to find out how the fungus affected the levels of moisture, ash, crude fat, protein, and ascorbic acid. All identified fungi caused disease symptoms when artificially inoculated on healthy onion bulbs (pathogenicity testing). *A. niger* produced the biggest rise in moisture content, while *A. flavus* was responsible for the greatest loss in nutritional composition. Abubakar and Naqvi (1996), Narayana et al. (2007), and Kumar et al. (2015) [44-46] reported that *Aspergillus* spp. was the most virulent pathogens in the field and storage. Mold-related storage losses of up to 60% have been documented [47]. When fungi vulnerable to rot are handled, losses in the range of 10–50% owing to bulb rot may occur during storage within three months [48]. According to El-Nagerabi and Ahmed (2003) [49], fungi that cause significant pre- and post-harvest losses and are mostly seed-borne restrict onion output.

In Bangladesh, decaying bulbs of five different types of onions were used to extract *Penicillium* sp., *F. oxysporum*, *A. flavus*, and *A. niger* [50, 51]. Black mold-causing *Aspergillus* sp. was identified as the main isolate from decaying onions by Tyson and Fullerton (2004) [52]. *F. oxysporum* is responsible for as much as 35% of those losses [53]. Raju and Naik (2007) [54] found the same diseases as the significant post-harvest ailments of onions in Karnataka, India. According to Raju and Naik (2007) [54], this is due to favorable weather conditions and high relative humidity during the rainy season. The main fungi associated with seeds of the onion of the Bawku Red variety were *Alternaria porri*, *A. niger*, *A. flavus*, *R. stolonifer*, *Penicillium* sp., *F. oxysporum*, *F. verticilloides*, *F. poae*, and *Botrytis* sp. When onions are kept at room temperature, black mold is a serious rot disease [51, 55]. According to Padule et al. (1996) [56], fungi are the primary causes of

onion bulb storage losses. Aveling et al. (1993) [57] reported from diseased onion seeds in South Africa. According to El-Nagerabi and Abdalla (2004) [49], *Aspergillus* was the most often discovered genus from the onion seeds studied in Sudan.

Pre-emergence damping-off caused by *A. niger*, in severe instances, hinders the growth of roots and shoots [58, 59]. It decreases seed germination, seedling emergence, and seedling vigor [60-62]. According to Hayden et al. (1994) [62], *A. niger* may spread from infected seeds to preserved onion bulbs, which can result in black mold diseases. Onion neck rot is brought on by *Botrytis* species, while basal plate rot is brought on by *F. oxysporum*, which may spread from seeds to onion sets [60]. According to Suheri and Price (2000), [63] *Alternaria porri* is the global cause of purple blotches on onions. According to Abd-El Razik et al. (1990) [64], *F. verticilloides* is pathogenic and causes seedling damping-off before and after emergence.

The following are the major bacterial and fungal diseases and their management-

Damping-off disease: Damping-off disease, which is more common during the kharif season and produces roughly 60–75% damage, is brought on by a variety of species, including *Fusarium oxysporum* fsp. *cepae*, *Pythium* sp., *Sclerotium rolfsii* and *S. cepivorum*, and *Colletotrichum* sp. The disease develops as a result of excessive soil moisture, moderate temperatures, and high humidity, particularly during the rainy season. Two distinct kinds of symptoms are seen: pre- and post-emergence damping-off.

Purple Blotch: The disease is brought on by *Alternaria porri*, a serious condition that affects all regions where onions are grown. The development of the disease is favorably influenced by a hot, humid climate with temperatures between 21 and 30°C and relative humidity levels between 80 and 90%. In the Kharif season, it is more frequent. On leaves and flower stalks, the symptoms appear as tiny, sunken, whitish flecks with purple centers.

Stemphylium Blight: In the northern regions of the country, the Stemphylium blight (*Stemphylium vesicarium*) poses a serious threat, particularly to the seed crop. Onion leaves and flower stalks are frequently affected by this disease. Small yellowish to orange flecks or streaks in the middle of the leaves are the first signs of the disease, which quickly progress to elongated, spindle-shaped spots with a pinkish margin.

Basal Rot: The prevalence of the disease known as basal rot (*Fusarium oxysporum* f.sp. *cepae*) is higher in areas where onions are grown continuously. A temperature range of 22 to 28°C is ideal for the development of disease. The leaves begin to dry from the tip down. The roots of the plants turn pink in the early stages of infection, and later rotting occurs. In later stages, the lower ends of the bulb start to rot, and eventually, the whole plant dies.

Downy Mildew: Northern plains and hilly terrain, particularly those with high humidity levels, are where downy mildew (*Peronospora destructor*) disease is reported to occur. Indicators first appear as a violet-colored fungus growth on the surface of leaves or flower stalks, which later changes to a pale greenish-yellow color before collapsing.

Onion Smut: *Urocystis cepulae*, which causes onion smut disease, is found in regions where the temperature is consistently below 30°C. The disease develops on the young plant's cotyledons shortly after they emerge because the fungus is still present in the soil. Near the base of seedlings, smut appears as long, dark, slightly thickened areas. On planting, the black lesions emerge close to the base of the scales.

Onion Smudge: *Colletotrichum circinans* is the causal agent for the diseased onion smudge. It affects different kinds of white onions and lowers the market value of the bulbs. Small, dark green to black patches that emerge on the outer scales are the disease's defining feature.

Black Mold: A black mould is caused by *Aspergillus niger* a prevalent disease in onions kept in warm climates where the temperature varies between 30 and 45°C. The outside of the scales is covered in a black powdery mass of spores, which serves as its identifying feature. Inner scales may also be observed to have black spore masses. The commercial value of the bulbs is diminished.

White Tip: The soil-borne fungus *Phytophthora porri* is the causal agent behind the diseases. The leaf tips become white and fade back many centimeters. Near the base of the leaves, water-soaked regions occur, and the leaves get distorted. The bulbs may get seriously rotten during storage.

Onion Yellow Dwarf: It is a viral disease spread by both, mechanical and insect vectors. The disease causes severe plant stunting, dwarfing, and flower stalk twisting as symptoms. The damaged leaves and stems turn different shades of yellow from their usual green color. The affected leaves have a tendency to flatten and curl, which causes them to bend over.

Anthracnose: In Anthracnose, leaves are harmed to shrivel and droop caused by the soil-borne fungus *Colletotricum circinans*. The disease may be controlled by curing the bulb after harvest and keeping the bulbs in well-ventilated spaces the fungi may generate and can persist in the soil for many years and become severe during protracted rainy spells. Small black bodies that develop smudgy areas on the green onion's bulb part are the external signs.

White rot or sclerotium blight: *Sclerotium rolfsii* is the causative agent of onion bulb rot and blight an emerging disease noted in several studies. The disease cut the production of fresh onion bulbs by a lot, which caused huge economic losses [65].

Sclerotium cepivorum, another soil-borne fungus that causes white rot, is a devastating postharvest disease that affects green onions grown in poorly drained soils or during the rainy season. Plants may seem to be in excellent condition when they are harvested, but during storage and marketing, they may degrade. A delicate deterioration and the growth of a fluffy white mold at the bulb's base are signs of the disease. Sclerotia, tiny, hard, black, spherical entities, form on the surface and within the fleshy scales. The bulb eventually becomes fully rotted.

Neck rot: *Botrytis allii* causes neck rot, which often develops in the field before showing signs in storage. It becomes worse when it's humid right before and during harvest, while onions are curing in the field. The prevalence of disease, which affects mild onions more severely than pungent onions, is

increased by excessive nitrogen and inadvertent watering. The fungus causes the scales, which seem to be wet, to soften. On the surface of the scales, a grey fungal mat forms in damp environments.

Gray Mould: Another typical postharvest degradation of green onions is the disease grey mold, which is brought on by several species of the fungus *Botrytis*. The first signs are inside-the-leaf lesions that are light brown and wet. The green onion bunch may eventually get spoiled, the leaves shriveling and becoming brown. Infected onion seeds, which may harbor the fungus in their interior tissues, are a significant cause of these diseases. Even if these seeds produce sick plants, symptoms may not be immediately apparent.

7. BACTERIAL DISEASES

Bacterial Brown Rot: *Pseudomonas aeruginosa* causes dangerous bacterial brown rot disease that affects onions in storage through the wounds the infection. The rot starts at the bulbs' necks, and when pressed, it spreads a bad odor through the neck.

Bacterial soft rot: Numerous bacteria may cause bacterial soft rot, but *Erwinia carotovora* and *Pseudomonas* species are the main causal agents. Based on biochemical and physiological testing, 41 of 88 bacterial pathogen isolates from collected rotten onion bulbs were identified in the research. The species *Pantoea* spp., *Burkholderia cepacia*, *Erwinia cacticida*, *E.c.* subsp. *atroseptica*, *E.c.* subsp. *betavascularum*, and *E.c.* subsp. *carotovora* were isolated from decaying onion bulbs. An unpleasant odor is released by the decomposing tissue.

Streptocycline (0.02%) spraying is advised if rain falls during maturation. Propionic acid, streptomycin, and Actinomycetes are administered as post-harvest sprays and dust formulations to combat infection by soft rot bacteria. It is taken care of by different irrigation and fertilizer treatments that take into account how long the crop can be stored. Some other bacteria species have been found with onions including *Klebsiella* sp., *Bacillus subtilis*, *Staphylococcus aureus*, *Enterobacter* sp., *Pseudomonas* sp., *Flavobacterium* sp., and *Escherichia coli* [36, 66].

According to Yurgel et al. (2018) [66] results, the rotting onion bulbs kept in Canada's Annapolis Valley also included bacteria like *Flavobacterium* spp., *Pseudomonas* spp., *Enterobacter* spp., and *Acinetobacter* spp. Orpin et al. (2017) [67] found that *Bacillus* and *Staphylococcus* species had been found in onion bulbs sold in Dutsinma Metropolis, Nigeria. *Erwinia* spp., *Pseudomonas aeruginosa*, *Enterobacter* spp., *Bacillus* spp., *Escherichia coli*, and *Staphylococcus* spp. are a few of the well-known bacteria isolates linked to onion bulb rot [31, 42, 66, 68, 69].

The pathogens *E.c.* subsp. *carotovora* and *Burkholderia cepacia*, which cause onion bacterial rot, were tested for their antagonistic effects against 45 Actinomycetes strains that Abdalla et al. (2013) [70] obtained from Egyptian soils. For preventing onion bacterial rot, *Streptomyces lavendulae* and *Streptomyces coelicolor* (the most powerful) are utilized. Streptomycin prevented tissue deterioration brought on by *E.c.* subsp. *carotovora* at 20°C. Decay accelerated gradually as the temperature rose (Abdalla et al., 2013). When there is damping off, the healthy seed should be chosen for planting and treated with Thiram at a rate of 2 gm per kg of seed.

Field cleanliness, collection, and burning of crop leftovers help manage the *Stemphylium* blight and reduce the spread of infection. Spraying mancozeb (0.25%) and monocrotophos (0.05%) with sticker triton on disease symptoms every two weeks prevents the spread of the diseases. The disease may be controlled by treating seeds with thiram (2 g/kg of seeds) and applying carbendazim, thiophanate methyl (Topsin-M), or benomyl (0.1%) to the soil. Onion crop basal rot is considerably reduced by seedling dipping in carbendazim (0.1%) or with antagonists such as *Pseudomonas cepacis* and *Trichoderma viride*.

The disease is controlled by removing and destroying the sick plants to stop it from spreading. Spraying of Malathion (0.1%) or Metasystox (0.1%) on the vectors to kill those can stop the disease from spreading further. The seeds are treated with Thiram (4 g/kg of seed) and soaking the soil with Mancozeb (0.25%) is beneficial. The disease inoculum is reduced by *Trichoderma viride* applied to the soil. There are more than 50 different fungicides used to control diseases of onions before and after harvest, including carbendazim, mancozeb, maleic hydrazide (prohibited in 2009), bavistin, and bronopol. Use carbendazim and maleic hydrazide at rates of 1000 and 2000 PPM before 30 days of harvesting to reduce physiological and rotting losses in onions and to increase shelf life and quality [71].

Plant extracts and bio-fungicides may be a significant eco-friendly replacement for pathogen toxicity and resistance [4,72]. The diseases BNR, purple blotch (*Alternaria porri*), pink root (*Phoma terrestris*), and stemphylium leaf blight (*Stemphylium vesicarium*) are fungal and bacterial infections that may attack Vidalia onions and cause serious crop loss. The virus that causes BNR may harm 70% of the whole stored crop in certain years [73]. When the circumstances are right, the virus enters the onion bulb's dead or dying tissue and then descends via the neck into the bulbs [74]. Diseases after harvest may begin before or after the harvest [75].

8. POST-HARVEST DISEASE MANAGEMENT

A. Cultural and physical control measures:

Currently, it is believed that between 35 and 40 percent of the onions produced in India are lost as a result of postharvest losses throughout different processes, such as handling and storage. Due to decaying and sprouting, storage results in significant losses were discovered [4, 76].

(i) Curing Neck cut in onion bulbs for storage: Onions should not be kept until they have sufficiently dried, either naturally or artificially. The neck tissue and outer scales must be dried until they rustle when touched for the bulbs to avoid spoiling while being stored. The storage capacity of onions with well-dried necks was shown to be higher than that of onions with inadequately dried necks by Randhawa and Nandpuri (1966) and Kepkowa and Umiceka (1970) [77,78]. According to Udry (1972) [79], onions kept at -0.6 to 2.0°C with 75 to 80 percent relative humidity had a greater frequency of mold formation (4.8 to 9.5%) than onions with tops (0.4 to 2.0 %). According to Ali and Shoabraway (1979) [80], bulbs with a neck of 1 to 2 cm exhibited less infection and storage loss than those without a neck.

Laul et al. (1984) [81] experimented with several curing techniques to extend the shelf life of onions. Onion cultivars with a medium-to-large bulb weight, a larger pole diameter, and a slender neck have superior keeping qualities, according to Shaha and Kale (1985) [82]. Sidhu and Chadha (1986) and Pandey (2001) [76,83] discovered that when harvested bulbs were maintained for 15 days to dry with a 2.0 to 2.5-cm neck-cut, sprouting was reduced. Sulfur dust fumigation was found to reduce the percentage of rotting in an assessment of chemicals for controlling storage rot of onion bulbs, whereas bavistin, dithane M-45, and streptomycin spraying were effective in that order [84]. Sulfur fumigation (50g m⁻³) was applied to onion bulbs of the variety N-2-4-1 for varying lengths of time to lessen disease infection during storage [85].

The storage life of bulbs was enhanced by windrow-curing onions for four days on the field before curing them in a shed for 21 days before storage. Small onions were treated to improve dormancy, prevent water loss while being stored, and increase shelf life by preventing disease access [86]. The greatest temperature that could be safely used to cure onions in the field was 37.8°C for 3–5 days; however, it was discovered that artificially curing onions for 16 hours at 40°C would minimize losses [87]. The ideal conditions for storing onions are above 15°C, 60–70% relative humidity, and medium-sized bulbs with a neck length of 2–3 cm [88]. The post-harvest onion quality and successful storage was to raise onions at a 60–80 percent top-down angle, field cure the bulbs, and then remove the foliage after curing [2, 89].

(ii) Gamma irradiation: Gamma irradiation has undergone extensive research as a method of prolonging the storage life of ordinary onions with doses ranging from 2 krad to 100 krad [90, 91]. There was a widespread misconception that gamma-irradiating food would leave some residual harm, which was debunked, scientifically [92]. When onion bulbs were exposed to 2 kR of radiation for two weeks after harvest, Mullins and Burr (1961) [93] discovered that sprouting was prevented. They discovered that irradiation, regardless of dosage, from 2 to 250 kR, applied after 11 weeks had passed after harvest, was ineffective in preventing sprouting. According to Ogata (1973) [94], the impact of gamma irradiation on the prevention of sprouting in onion bulbs was lessened by delaying irradiation after harvest.

It was essential to irradiate common onions produced from seed within three to four weeks of harvest and those grown from sets within five to six weeks, according to Kalman (1978)[96], who found that gamma irradiation with an intensity of 5 kR, stopped sprouting and decreased spoiling in stored common onions. After six months of storage, Benkeblia et al. (2004) [97] looked into the effects of temperature and gamma radiation doses on the fructooligosaccharides of onion bulbs. Silva et al. (1975) [90] and Menniti (1977) [98] found a similar decrease in weight loss in storage when compared to untreated bulbs. According to Curzio et al. (1983)[99], the cumulative weight loss throughout the storage period was roughly 60% in the untreated control but only 23% in the CO-irradiated bulbs. In comparison to ambient storage of untreated onion bulbs, weight loss, rotting, and black mold infections were reduced in cold storage using gamma-irradiated bulbs [100].

(iii) Sprouting: Gamma rays at 2000–3000 rads entirely stopped growing in ordinary onions [101]. Nandpuri (1966) [102] noted that onion bulbs exposed to at least 12,000 units of gamma radiation for eight months completely inhibited sprouting. According to Ali et al. (1970)[103], a dosage of 8 krad prevented sprouting without changing the flavor or pungency. During the six months that onions were stored, the irradiation treatment (6–8 Kr gamma rays) exhibited no sprouting losses. Murray (1983) [104] discovered that onions' nutritional value was not considerably affected by treatment with 0.02 to 0.06 conversion of ascorbic acid to dehydroascorbic acid. According to Bongirwar and Shirsat (2000) [105], sprouting was prevented by gamma irradiation at 60–90 Gy without influencing TSS, dry matter content, lowering sugars, color, pungency, or flavor intensity of the onion.

In India, poor packing methods result in significant post-harvest losses. For four months, cured onion bulbs (cv. Agri Found Dark Red) were kept at room temperature in bamboo baskets [106]. In comparison to uncured bulbs, bulbs stored with dried foliage had the lowest percentage of total loss (50.47) during sun-curing [107]. The occurrence of bulb rot was delayed and post-harvest losses were decreased when onion bulbs of the Red Creole variety were kept at 0°C, cured by sun-drying, and packed in wooden boxes. Additionally, it worked when bulbs were kept at 27°C [108]. Staking, HSC bags, netlon bags, and plastic crates were used as diverse packaging materials and storage techniques for onion cv. N-2-4-1. When onions were held for 18 weeks in a ventilated experimental bin or crate after being treated with maleic hydrazide, Paterson and Wittwer (1953) [109] observed a decrease in sprouting and root development. Yamaguchi et al. (1957) [110] noted the sprouting of bulbs kept at 10 and 15°C. At 25°C and above, or below 10°C, no sprouting was seen. After 120 days, onion bulbs housed in wooden boxes saw a 50% weight loss and a 40% sprouting rate, according to Singh and Singh (1973) [111].

Musa et al. (1974) [112] found that losses from shrinkage, pests, and diseases were 30 and 18%, respectively, when the bulbs were kept for six months in crates made of straw. According to Kak' M' Kova (1975) [113], onions held during the winter in typical store attics showed the least amount of bolting, while those kept in basements showed the most amount of bolting. According to Chavan et al. (1992) [114], the caged mode of storage was beneficial for minimizing bulb rots during long-term storage (90 days), whereas the hanging method of storage was effective for short-term storage (45 days). The cured onion bulbs were maintained at room temperature and packaged in bamboo baskets (35°C).

Warade et al. (1997) [115] found that onion bulbs stored in modified storage structures with 0.2% mancozeb spraying, perforated pipes, 45–55 mm bulb diameter, 4 cm bulb neck, shed curing for 21 days, and 4 days field curing reduced storage losses by up to 32.38%. According to Adamicki (1998) [116], the 17 onion cultivars were kept at 0°C and in an ambiently ventilated storage for six months. The low storage temperature of 0°C made sprouting much less likely, but it did not affect the growth of the roots.

According to Benkeblia et al. (2002) [117], maleic hydrazide treatment did not affect the storage of carbohydrates since it reduced the respiration rate of onion bulbs kept at 10 and 20°C compared to control bulbs. After six months at 10 and 20°C, Benkeblia et al. (2002) [117] observed an increase in fructans, notably DP 5-8, in onion bulbs. When kept in CA (1% or 0.5% O₂ with less than 0.3% CO₂ at 2°C), the high-dry-matter onion cv. Sherpa had a longer shelf life than when stored in air conditioning (when tested for 3 weeks at 18°C after 9, 27, and 36 weeks of storage) [118]. After 9 weeks after being stored at 0.5°C under the CA settings (2% O₂, 2% CO₂, 2% O₂, and 8% CO₂), the pyruvate content in onion bulbs cv. Hysam reduced; however, it rose when the bulbs were stored in an ambient atmosphere [119].

Total phenolics and peroxidase activity were both 20°C decreased as a result of these low temperatures. Adamicki (2005) [116] reported that a controlled environment comprising 3% CO₂ and 5% O₂ or 3% CO₂ and 1.0–2.0% O₂ as well as maleic hydrazide was the most efficient for preventing sprouting during storage and extending the shelf life of onions by three weeks at 20°C. When onions were stored in CA conditions, the amount of ABA was reduced, and minimal ABA concentration corresponded with the start of sprout development [120]. The Walla Walla Sweet onions' four-week shelf life at 22°C saw a rise in the average pyruvate, 3,4-dimethyl thiophene, and disulfide content as well as the soluble solids of the inner scales [121]. The pyruvate concentration of onion cv. SS1 kept in CA for 42 days was lower than that of onion CV. SS1 is stored in the air for 42 days [122].

According to Chope et al. (2007) [123], the endogenous ABA content of onion bulbs was unaffected by the administration of exogenous ABA or an ABA analog (82-methylene ABA methyl ester; PB1-365). Chope et al. (2007b) [124] discovered that after harvest, a single application of 1-MCP (1 l l-1, 24 h, 20°C) decreased sprout length and preserved higher glucose and fructose concentrations in onion bulbs of the cv. SS1 variety kept at 12°C. Treatment of onion bulbs with 1-MCP (0.25 l l-1, 5 h, and 20°C) four weeks after harvest (two weeks drying at 25°C plus two weeks storage at 18°C) resulted in a two-week reduction in dormancy when stored at 18°C in comparison to the control [125]. Copra cv. button onions from Arka's CV Pragathi that were field-cured for 10 days and then kept for 30 days in a ventilated chamber showed decreased weight loss (10.13%), sprouting (1.16%), and rotting percentage (1.16%) during storage [126].

B. Pre-harvest spray of chemicals

These substances significantly aid in maintaining the quality of onion bulbs while they are stored by preventing sprouting, re-rooting, and reducing physiological weight loss. Abscisic acid (ABA), gibberellin (GA₃), auxin and cytokinin (CK) [127], maleic hydrazide (MH), cycocel (CCC), and ethrel [128], trakephon and ethrel [129], and paraquat [130] on bulbs while they are stored by preventing sprouting, re-rooting, and reducing physiological weight loss.

(i) **Cycocel:** the chemical cycocel (2-chloroethyl trimethyl ammonium chloride), the most widely used plant growth inhibitor, reduces the vegetative development of plants and increases the yield of a variety of horticultural and crops. Cycocel acts in an anti-gibberellin manner.

(ii) **Ethrel:** ethephon, an ethylene-releasing chemical, caused bulbing in onions grown under non-inductive photoperiods was made by Levy and Kedar in 1970. Later studies by Lipe, (1975) [132] showed that Ethephon's ability to improve bulb size and yields depends on time and optimum concentration. Ethephon enhanced post-harvest diseases and sprouting in onions for 4–12 days before they were removed for field curing. It was concluded that onion storage degradation was accelerated by foliar desiccation by ethephon [130].

In typical onion bulbs, it was discovered that larger amounts and a tendency of reducing sugars at lower levels of ethrel over storage. Reduced individual bulb weight, overall marketable yields, and an increase in the prevalence of rotten and cull bulbs were seen in onions after the application of ethephon at 1000 or 3000 ppm [133]. The pre-harvest ethephon treatment dramatically reduced production by decreasing onion bulb width and weight [134].

According to Thompson and Rankin (1983) [135], ethephon at 1000–3000 ppm decreases onion bulb sprouting losses. After four months (3.0%; 0.0%) and eight months (5.5%; 1.3%) of storage, onion bulbs treated with pre-harvest ethrel 2.5 ml l⁻¹ showed a considerably lower percentage of rotting and greening than those treated with the control treatment [136]. Before harvesting, Ethephon (Ethrel at 3.6 or 6.0 l ha⁻¹) was given to the onion cultivars Sochaczewska and Blonska at 3.6 or 6.0 l ha⁻¹. This mostly stopped the bulbs from sprouting while they were stored at 20°C.

According to Qadir et al. (2007) [137], using ethanol (0.91 g kg⁻¹) on onion cv. Tazan for a month-long storage period prevented roots, sprouting, and rotting. Onion bulbs of the Sherpa and Wellington varieties were given a single dose of ethylene for 24 hours at 20°C before or after curing (28°C for six weeks). These treated bulbs were kept at 0 to 1°C for 38 weeks. Downes et al. (2010) [138] found that onion bulbs had lower rates of sprouting and higher levels of phenolics, flavonoids, and pyruvate in general.

(iii) Chemical control

There are several applications of fungicides such as Benzoyl and Carbendazim at 0.5 percent, which exhibit improved control of neck rots [80]. Due to species of *Aspergillus*, *Fusarium*, and *Botrytis*, the Falisolan (Carbendazim 60%+Bronopol 6%) is most successful in reducing storage diseases. These species reported that disease prevalence rose dramatically during the third month of storage [139]. In the Karnal district of Haryana during the Rabi season, pre-harvest foliar treatment of Mancozeb at 0.25 at 30 days after transplanting and repeated at fortnightly intervals was shown to be more effective in suppressing fungal infections and increasing onion production [140]. A pre-harvest application of carbendazim (50% WP) is useful to minimize storage losses caused by fungal pathogens by 40 % [141]. According to Bose et al. (2003) [142], sulfur dust fumigation reduces losses and maintains the quality of onions throughout storage.

It was discovered that the combination application of carbendazim and maleic hydrazide at concentrations of 1000 and 2000 ppm, respectively, decreased the percentage of rotting and fungal infection in onion crops [143]. A was administered artificially to the collected bulbs (*A. niger* and *P. digitatum*) using the pinprick technique and kept at room temperature (27°C) for three months. At biweekly intervals, the percent disease decrease compared to control was reported. The highest disease decrease from the black mold was achieved with carbendazim 0.1% (Bavistin) at 15 days after storage (DAS) and 56.91% after 90 DAS. The incidence of *Aspergillus niger* was significantly decreased by post-harvest fumigating onion bulbs with sulfur dioxide for four hours or by immersing the bulbs in acetic acid at a higher concentration (0.4%) [144].

C. Biological control

Postharvest environmental factors like temperature and humidity may be tightly regulated to fit the demands of the biocontrol agent, and biological control of postharvest diseases has considerable promise [145]. With these bioagents, disease control or suppression may be accomplished to a similar degree as with chemicals. The postharvest diseases of crops are managed biologically by using microorganisms such as fungi, bacteria, Actinomycetes, and viruses (bacteriophages) [146-149].

(i) **Bio fungicides:** Synthetic fungicides may be replaced with natural bio fungicides made from different plant components or microorganisms. Many attempts have been made over the last year to find cutting-edge antifungal compounds from natural sources [150-152]. Naguleswaran et al. (2014) [153] found that treating the onion bulbs along with a foliar spray of *Trichoderma viride* increases yield and factors related to yield, such as the diameter of the base, the circumference of the bulbs, and the average number of bulbs per bunch. It was noted that multiple infections attacked the onion crop resulting in production losses, with *Botrytis allii* being one of the major causing pathogens [154]. *Trichoderma viride* (86%) produced the biggest decrease in growth compared to other species for *T. viride* (84%), *T. harzianum* (85%), respectively. *T. viride* performed well as a biocontrol agent in a greenhouse, but an on-site investigation is necessary to corroborate these findings [155].

Various plant extracts have antimicrobial properties as *Moringa oleifera* stems and leaves were ethanologically extracted to combat the *Aspergillus niger* strain. Application of *Moringa oleifera* leaf extract at a 75% concentration inhibits *A. niger* [156]. Different concentrations of extract i.e., 12.5%, 25%, 50%, and 75% in PDA and Potato Dextrose Broth are utilized. *Penicillium* species can be used as biological control agents against *Aspergillus niger*. *A. niger*'s growth was severely restricted by *Penicillium roqueforti* and *P. viridicatum* by 66% and 60%, respectively. Cinnamon, clove, pepper, cardamom, star anise, and stone flower were among the fourteen spices evaluated in the first round of antifungal screening that showed inhibitory efficacy against the black mold against *A. niger* at various concentrations ranging from 15 to 120 mg/mL, and the minimum inhibitory concentration (MIC) values were calculated. Cinnamon and clove showed significant inhibitory activity at a dosage of 15 mg/mL. At 30 mg/mL, a stone flower was able to suppress the pathogen, while cardamom showed modest inhibition [157].

(ii) Nanoparticles

Combining silver nanoparticles with fluconazole (an antifungal drug) may increase the effectiveness of disinfectants [158]. Testing for antibacterial properties using silver nanoparticles (AgNps) is done on bacteria such as *Aspergillus niger* and *Staphylococcus aureus* [159]. A 7 PPM silver nanoparticle liquid solution was utilized to treat onion white rot [160]. By using copper, silver, and copper-silver nanoparticles, Sahar et al. (2014) [161] showed antifungal resistance against two plant pathogenic fungi, *Alternaria alternata*, and *Botrytis cinera*. Copper nanoparticles are crucial for the control of pathogens. By using zinc oxide nanoparticles was found antimicrobial resistance in two plant pathogenic fungi, *Aspergillus flavus* and *Aspergillus fumigants* (ZnO NPs). According to Srinivasan et al. (2015) [162], *Aspergillus niger* may be efficiently controlled by using pure zinc oxide nanoparticles.

(Ia). Silver nanoparticles

Silver nanoparticles (AgNps) produced by *Aspergillus terreus* (KC462061) it was observed to have an inhibitory effect on the growth and aflatoxin production of five isolates of *Aspergillus flavus*. All five *A. flavus* isolates were inhibited at various silver nanoparticle concentrations, but the best inhibition was at 150 ppm with a significant difference. AgNPs disrupted cellular processes, resulting in fungal hyphae deformation, which prevented *A. flavus* from growing. According to Gajbhiye et al. (2009) [158], fluconazole and nano-sized silver particles can increase the antifungal effectiveness of disinfectants.

According to San et al. (2013) [159], silver nanoparticles made through reduction with mycelia, *Schizophyllum* culture, and silver nitrate have antimicrobial properties. *Aspergillus niger*, *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans* are tested for silver nanoparticles' antimicrobial properties. The largest inhibition area was produced by the silver nanoparticles with *Staphylococcus epidermidis* and the silver nanoparticles produced by the interaction of silver nitrate and mycelia fungus with *Staphylococcus aureus*. Khadri et al. (2013) [163] used a green synthesis method as opposed to a traditional chemical method. To characterize the physical properties using FTIR, UV-Vis, and TEM analysis, the enzymatic mechanism of the olive seeds was first put through a process to produce silver nanoparticles and test their effectiveness as antifungal agents. The ability of pullulan, composite films, and Ag nanoparticles (NP) to inhibit *Aspergillus niger* growth. These new materials were created from Ag hydrosols containing the polysaccharide as transparent cast films [164].

(Ib). Copper nanoparticles

Copper nanoparticles are crucial for inhibiting pathogen growth copper nanoparticles had antifungal activity against *Fusarium oxysporium* and discovered that bavistin's antifungal activity increased when combined with CuNPs in *Fusarium oxysporium* cases. Copper (CuNPs), silver (AgNPs), and silver/copper (Ag/CuNPs) nanoparticles' antifungal efficacy against the two plant pathogenic fungi *Botrytis cinera* and *Alternaria alternata* [161]. The application of silver nanoparticles at a

dosage of 15 mg L⁻¹ resulted in the greatest amount of fungal hyphal growth suppression. Zinc oxide nanoparticles (ZnO NPs) shown to be effective against *Fusarium oxysporum* and *Penicillium expansum*. ZnO NPs' antifungal activity was discovered to be concentration-dependent [165]. The maximum mycelial growth suppression was reported for *F. oxysporum* and *P. expansum* at a concentration of 12 mg/L, which matched the maximum experimental concentration.

(Ic). Sulfur and Zinc oxide nanoparticles

Sulfur in its micron- and nanoscale forms has been studied against two different species of pathogenic Schutte fungus by Massalimov et al. (2013) [166]. Sulfur particles' antifungal effects in field tests and saline media have been documented. Nanosulfur is superior to its elemental form in combating *Aspergillus niger*. Zinc oxide nanoparticles were tested by Srinivasan et al. (2015) [162] for their effectiveness against *A. nigar* and *A. flavus*. The pure zinc oxide nanoparticles worked well as fungicides against *A. niger* although the zinc oxide nanoparticles released by the aluminum drops were effective against *A. flavus*. Zinc oxide nanoparticles (ZnO NPs) were tested against two strains of plant pathogenic fungus, *A. flavus* and *A. fumigatus*. The ZnO NPs (size 20–25 nm) may be active when present at concentrations of 100 g/mL. According to Singh et al. (2013) [167], zinc oxide nanoparticles have more antifungal activity than ordinary zinc oxide particles do against several different types of bacteria and fungi.

Zinc oxide nanoparticles (ZnONPs) were tested by Yehia et al. (2013) [165] studied efficacy against the pathogenic fungi *Fusarium oxysporum* and *P. expansum* and found maximum zone of mycelial growth inhibition at 12 mg/L. Wani et al. (2012) [168] investigated the antifungal properties of magnesium, iron, and zinc nanoparticles. It was discovered that all of the nanoparticles, at varying doses, significantly inhibited the germination of *Aspergillus niger*, *Penicillium notatum*, and *Nigrospora oryzae* spores *in vitro*. Higher concentrations of nanoparticles were shown to have the greatest inhibition on the germination of all test fungi, followed by lower amounts.

The most efficient in reducing spore germination was found to be nano-MgO at the greatest concentration, followed by nano-FeO and nano-ZnO at the same concentrations. Zinc oxide nanoparticles (ZnONPs) exhibit strong antifungal activity against the two post-harvest fungal diseases, i.e., *Penicillium expansum* and *Botrytis cinera*, during storage [169, 170] and bacterial soft rots [171]. ZnONPs stop the conidiophores and conidia of *P. expansum* from growing, which eventually kills the fungus. Nanoparticles have a significant impact in limiting the pathogenicity of several post-harvest diseases.

9. POST-HARVEST HANDLING OPERATIONS OF ONION CROPS

To reduce the supply of primary inoculum for postharvest infections, cleanliness must be maintained at all phases of postharvest handling. Clean-up of containers is necessary. Equipment for packaging and grading is sterilized; in particular, rollers and brushes are employed. There are two ways to harvest: manually by digging or mechanically [172,173]. Time is saved as harvesting is completed quickly when using a machine. After harvesting, curing is a crucial step since it will remove extra

moisture from the onion bulbs' outer skin and neck. It prolongs the life of onion bulbs in storage. The process of curing improves the skin's economically important color. The onion bulbs may usually be cured in 10 to 15 days. Sprouting in stored onions is usually a severe issue in post-harvest treatment. Suppressants such as isopropyl N-chlorophenyl carbamate (CPIC), TNCB, and MH are used to prevent sprout inhibition. Additionally, sprout inhibition has been demonstrated to be successful with irradiation [174,175]. Regardless of crop season, weather conditions, or storage method, exposure to radiation during the latent stage of the onion bulb after harvest at a dose of between 60 and 90 Gy prevents sprouting. Consider using irradiation in conjunction with better storage and offering irradiation facilities at the production level to prevent microbiological and other losses [176-178].

10. CONCLUSION

Decaying onion bulbs should be kept apart from new ones to prevent cross-infection. The different types of microorganisms linked to onion bulb rot that were found in this study may help control the disease after the harvest. Under the World Trade Organization (WTO) framework, it is necessary to combine diverse methods for managing postharvest diseases, such as postharvest handling systems, sanitation, and the integration of botanicals and plant essential oils, microbial bio agents, and safe chemicals. The greatest hope for the future of postharvest disease management of onion is the understanding of biocontrol, which is anticipated to lead to new, creative methods to reduce product postharvest degradation. Future studies in this area will focus on pathogenesis, an accurate and reliable diagnosis of the diseases, and the development of innovative, long-lasting defense mechanisms against the catastrophic postharvest infections that affect vegetable crops.

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