Review Article

Updated review on post-harvest diseases of onion and strategies for their 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 white rot (*Sclerotium cepivorum*), damping off (species of *Pythium, Phytophthora, Rhizoctonia solanii,* and *Fusarium*), purple blotch (*Alternaria porri*), stemphylium blight (*Stemphylium vesicarium*), downy mildew (*Peronospora destructor*), basal rot (*Fusarium oxysporum*), and root knot disease (*Meloidogyne* spp). 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. As a consequence of interactions with pathogens present in the environment, some diseases are linked to the bulb during manufacturing or storage [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 top states and districts in India for the production of onions are Maharashtra (Nashik, Ahmednagar, Pune, Aurangabad, Jalgaon, etc.), Madhya Pradesh (Indore, Sagar, Shajapur, Khandwa, Ujjain, etc.), Karnataka (Bijapur, Bagalkot, Chitradurga, Dharwad, Koppal, etc.); Gujarat (Bhavnagar, Nalanda, Katihar, Muzaffarpur, Patna, Pashchi). Of the state's total vegetable crops, they take up around 25–30% of the space. 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. In the country, various varieties are cultivated to get economic yield.

For long-term usage, the storage conditions are crucial. The optimal fresh frozen temperature is between 2 and 180C 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%. Up to 25% of the entire yield of vegetables was claimed to have been lost altogether [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]. Well-managed post-harvest operations for vegetables resulted in improved yields and producer revenues.

Anbukkarasi et al. (2013) [3] reported that good storage facilities for onions during the off-season are important for both consumers and producers to prevent onions from rotting and sprouting, which can cause big losses. Injuries sustained at the farm level during harvest, de-topping, doubles, bolters, rotting bulbs, drying, undersized unmarketable bulbs, poor storage and transportation, and incorrect handling of the goods during marketing all add to the issue. It is urgent and necessary to teach vegetable producers scientific post-harvest practices. Paying close attention to how things are stored on the farm [13] can help reduce losses after harvest.

Even today, these post-harvest losses happen because there aren't enough good places to store crops after harvest [13, 16]. In a study conducted at Jodhpur, Rajasthan, to determine how much onion was lost after harvest. Post-harvest losses are at their highest (24.47 kg/q) at the producer level. Onion post-harvest losses were determined to reach 3.22 kg/q at the wholesale level and 3.09 kg/q at the retailer level. Additionally, a total loss of 30.87 kg/q was noted. There are significant losses (15.54 kg/q) during agricultural storage. The losses are greatest at the farmer level in onions throughout all stages [13].

Approximately 35–40% of onions are lost or damaged during post-harvest storage as a result of post-harvest infections. During the storage of various kinds, the fungal bulb rot contributes to losses of between 15 and 30 percent [4]. In the post-harvest storage phase, a variety of fungal pathogen species, including various species of *Aspergillus, Penicillium, Alternaria, Fusarium, Rhizopus, Colletotrichum, Pseudomonas, Lactobacillus, Erwinia,* and *Botrytis*. The most virulent fungal pathogen in the field and during post-harvest storage is *Aspergillus* spp., particularly *A. niger*).

2. ECONOMICAL AND HEALTH IMPACT OF POSTHARVEST DISEASES OF ONION

Onion bulb rotting is caused by a variety of microorganisms, although fungi are the primary causal agent behind pre- and post-harvest losses. 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. Farmers' poor storage practices, microbial contamination, sprouting, and inadequate and inappropriate field curing after harvest are the major causes of ongoing losses. 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]. Low-temperature storage and fumigation may minimize onion post-harvest losses by 10–20%. Grinstein et al. (1992) [26] reported that chemical therapy is more effective in controlling black mold and other fungal diseases [4].

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. To combat the hazardous residual effects of conventional synthetic fungicides on human health, there is an urgent need to produce environmentally friendly fungicidal formulations against fungal diseases. 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. Nanotechnology may help to keep onions from going to waste after they have been picked that are good for the environment and will last.

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. On poorly cooled green onions, they may become serious within a few days, particularly if the wash water is tainted with bacteria that cause rot and/or the onion. 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*, *Gibellulasuffulta*, and *Hirsutellasaussueri* 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). It was found that the fungus made the bulbs contain more water and made them less healthy overall [2]. *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. Different pathogenic fungi linked to onion seeds might cause bulbs to rot while being stored [43].

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]. Shehu and Muhammad (2011) [41] observed that *R. stolonifer* was one of the most harmful fungi; leading to fast disintegration of the infected onion bulbs recorded the maximum rot on the bulbs. Additionally, the onion bulbs experienced more rot due to *A. niger*. 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. The capacity of *A. niger* to take advantage of the weakness of the blossoms to enter the onion seeds may be the cause of the high prevalence of the organism on the seeds [43, 58].

Pre-emergence damping-off caused by *A. niger*, in severe instances, hinders the growth of roots and shoots [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. According to Sumner (1995) [28], *R. stolonifer* on onion seeds may induce mushy rot on bulbs, especially in the neck area. 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. Some of these pathogens are known to cause post-harvest diseases in onions, including *A. niger, Botrytis* sp., and *F. oxysporum* [43].

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. In post-emergence damping-off, the pathogen destroys the collar area of seedlings on the soil's surface. Pre-emergence damping-off causes seeds and seedlings to rot before they emerge from the soil. The seedlings eventually collapse and perish as a result of the collar component rotting.

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. The lesions might encircle the leaves or stalk and make them droop. The diseased plants are unable to produce bulbs.

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. At the 3-4 leaf stage, in late March and early April, transplanted seedlings become infected on their radial leaves. 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. The disease that shows up on the inflorescence stalk causes a lot of damage to the seed crop.

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. Initially, yellowing of the leaves and stunted plant growth are seen. Later on, 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 (*Perenospora destructor*) disease is reported to occur. The disease is most severe in damp environments, and late crop planting, the use of higher fertilizer doses, and frequent irrigation all made the disease worse. 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: *Urocystiscepulae*, 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. The impacted leaves abnormally bend downward. On older plants, near the base of the leaves, there are many raised blisters. A black, powdery mass of spores is often exposed to plant diseases at all stages.

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 mound 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 *Colletotricumcircinans*. 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. Only late in the cropping season, when the crop is half-ripe and just before harvest, does the disease become noticeable? The disease cut the production of fresh onion bulbs by a lot, which caused huge economic losses [65]. The root, stem plates, and scales are destroyed. The bulbs swell and suck up water. The infected bulbs exhibit profuse black sclerotia that resemble mustard grain and fluffy or cottony mycelium growths.

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. Frequent downpours encourage the growth of grey mold.

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., *Burkholderiacepacia*, *Erwinia cacticida*, *Erwinia carotovora* subsp. *atroseptica*, *Erwinia carotovora* subsp. *betavasculorum*, and *Erwinia carotovora* subsp. *carotovora* were isolated from decaying onion bulbs. The bacteria may cause water-soaked spots and discolored slimy rot when they infect the leaf and bulb tissue. An unpleasant odor is released by the decomposing tissue.

Proper curing and quick drying of the bulbs after harvest are keys to preventing and treating bacterial brown rot. Before storing, affected bulbs should be thrown away. 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 istaken 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].

A comprehensive knowledge of the prevalence and variety of the pathogenic microbial population linked to onion rotting in Nigeria is studied. Gram-positive bacteria were found in all 35 isolates, including 11 Staphylococcus species (31.4%), 9 Micrococcus species (25.7%), 8 Bacillus species (22.9%), 7 and Flavobacterium species (20%) [8]. The bacteria Staphylococcus spp. and Bacillus cereus spp., which were linked to soft rot in onion bulbs and tested for pathogenicity, are found naturally in certain soils.

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 *Erwinia carotovora* subsp. *carotovora* and *Burkholderiacepacia*, 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. When *S. coelicolor* is put on onion plants, it improves their foliar growth indices and photosynthetic pigments. This shows that it helps plants grow.

Streptomycin prevented tissue deterioration brought on by *Erwinia carotovora* subsp. *carotovora* at 200C. 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. To lower the risk of infection, it is best to avoid establishing nurseries continuously in the same plot. *Trichoderma viride* is applied to the soil at 1.2 kg per ha, and a 250-gauge polythene sheet is stretched over the bed for 30 days before planting to solarize the soil, both of which are shown to be very efficient in controlling damping-off.

By using healthy seeds for sowing and rotating crops for 2-3 years with unrelated crops, it is possible to manage the *Alternaria porri-caused* purple blotch disease. The incidence of the disease is decreased by spraying Mancozeb (0.25%), Chlorothalonil (0.2%), or Iprodione (0.25%) after one month after transplantation at intervals of every two weeks. Spray solution should be used with the sticker triton or Sandovit.

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. Due to the soil-borne nature of the disease, basal rot is challenging to manage. Rotation of crops and mixed crops both lower disease occurrence. Infectious propagules are reduced via soil solarisation, which involves covering the soil with 250-gauge polythene sheets throughout the summer for 30 days. 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*.

Onion bulbs intended for seed crops should be exposed to sunlight for 12 days to kill the fungus that causes downy mildew, which is successfully controlling the diseases. Spraying with Tridemorph (0.1%), Karathane (0.1%), or Zineb (0.2%) effectively controls the diseases. Treatment of the seeds with captan or thiram (2.5 g per kg of seed) before planting is a control for onion smut. Methyl bromide (1 kg/25 m2) applied to seed beds effectively controls the smut disease.

Anthracnose of onion may be controlled by curing the bulb after harvest and keeping the bulbs in well-ventilated spaces. When black mold is allowed to dry on the field for two days, death and diseases may be effectively controlled. Before storage, these bulbs should continue to dry for another 10 to 15 days in the shade. The bulbs should be handled carefully to prevent damage after harvest. Carbendazim (0.2%) should be applied to the crops 10–15 days before harvest.

The disease is controlled by removing and destroying the sick plants to stop it from spreading. Bulb sowing should only employ healthy varieties. Spraying of Malathion (0.1%) or Metasystox (0.1%) on the vectors to kill those can stop the disease from spreading further. Avoid cultivating onions repeatedly on the same plot of land and rotate your crops with cereal crops to prevent white rot. 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.

Neck rot is effectively controlled by killing the pathogen by allowing the affected area to dry out for two days. Before storage, these bulbs should continue to dry for another 10 to 15 days in the shade. The bulbs should be handled carefully to prevent damage after harvest. Carbendazim (0.2%) should be applied to the crops 10–15 days before harvest. Since the virus depends on agricultural debris to survive, cleanliness efforts and the eradication of contaminated crop debris aid in the disease's reduction. The disease can be treated with sprays of Mancozeb (0.25%), Carbendazim (0.1%), or thiophanate Methyl (0.1%) on the leaves.

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]. An appropriate subsite for chemical fungicides is to be used to reduce the effects of chemical residues and pathogen resistance [4].

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 (*Phomaterrestris*), and stemphylium leaf blight (*Stemphylium vesicarium*) are fungal and bacterial infections that may attack Vidalia onions and cause serious crop loss. In postharvest storage of onions, BNR disease is crucial. 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. To extend the shelf life of onions, pre-harvest sprays of growth regulators, including cycocel, ethylene compounds, and fungicides, are essential. Onion bulb neck cutting and gamma radiation treatment for storage have both been shown to be effective curing methods for extending shelf life by postponing sprouting and eventual degradation. Throughout the aforementioned post-harvest handling procedures, onion bulbs undergo a series of physiological and biochemical changes [2]. Due to decaying and sprouting, storage results in significant losses. Losses from weight loss, sprouting, and decay were discovered [4, 76].

(i) Curing Neck cut in onion bulbs for storage: Bulbs must be stored properly to ensure both seed generation and consumption. 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. Temperature influences onion sprouting, while relative humidity affects onion roots [2].

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. This approach did not affect dry matter or TSS, however, and it had the fewest storage losses. 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].

Anbukkarasi (2010) [71] noted that pre-harvest spraying of maleic hydrazide at 2000 ppm and carbendazim at 1000 ppm 30 days before harvest, along with a 2 cm neck length of bulbs, resulted in decreased physiological weight loss of 1.22 and 1.28 percent and sprouting loss of 0.01 and 0.02 percent, and improved quality parameters like TSS (13.86 and 13.97 Brix) and pyruvic acid content.

(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 krads to 100 krads [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.

According to Heins (1975) [92], modest dosages of gamma irradiation improved the storage life of onions. The ideal dosage for onions, according to Langerak (1975) [93], is 75 krads; greater doses exacerbated discoloration and produced an off-flavor. 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. After six months, both the irradiated and control bulbs' glucose, fructose, and sucrose levels reduced somewhat but not dramatically, but temperature and irradiation had a significant impact on the bulbs' fructans [3].

The weight loss of the stored and radioactively irradiated common onion bulbs was minimized. 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 kradprevented 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 [3].

Packaging serves as a representation of value addition, a guarantee of quality and quantity, and a barrier against post-harvest losses, among other duties. The bulb continually breathes and seeps, which causes significant weight loss and makes it vulnerable to numerous infections and spoiling as a consequence of improper packing. 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 27oC [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. The findings showed that after five months of storage, the HSC bags and plastic crates housed in the controlled, forced-ventilated chambers had the lowest total losses (31.1%) [85].

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 150C. At 25oC and above, or below 10oC, 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 (35oC). Anbukkarasi et al. (2013) [3] found that the outer scales also changed, but not as much as the inner ones.

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 0oC made sprouting much less likely, but it did not affect the growth of the roots.

In Sudan, onions were kept in mud or straw houses. About 50–60% of the bulbs were marketable after this technique of storage lasted for four to five months [87]. 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 20oC compared to control bulbs. After six months at 10 and 20oC, 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 2oC), the high-dry-matter onion cv. Sherpa had a longer shelf life than when stored in air conditioning (when tested for 3 weeks at 18oC after 9, 27, and 36 weeks of storage) [118]. After 9 weeks after being stored at 0.5oC 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]. After being exposed to cobalt-60 Gy radiation, onion bulbs were kept in cold storage for four months (0-2°C and 65-70% RH, respectively). Compared to unirradiated ambiently stored onions (87.12%), the overall loss in irradiated cold storage onions after four months was 50.3% [3, 85].

Onion bulbs treated for four weeks at 0°C and then kept in the dark at 20°C were subjected to measurements of respiration rate, soluble sugars, total phenolics, and peroxidase activity [97]. Total phenolics and peroxidase activity were both 20oC 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 20oC. Compared to 40% of air-kept bulbs, only 3–10% of onions of the variety Rumba stored in CA (0.5%, 1%, or 2% O2 with 3% CO2 at 0oC) for 36 weeks sprouted after three weeks at 20oC.

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, 20oC) decreased sprout length and preserved higher glucose and fructose concentrations in onion bulbs of the cv. SS1 variety kept at 12°C.

The onion bulb (cv. Talaja Red) was kept in a forced-ventilated storage facility for up to three months. Comparing the storage structure to a naturally ventilated storage structure, the amount of TSS, total sugars, and pyruvic acid increased over the storage time (Dabhi et al., 2008). Treatment of onion bulbs with 1-MCP (0.25 L l-1, 5 h, and 20oC) four weeks after harvest (two weeks drying at 25oC plus two weeks storage at 18oC) resulted in a two-week reduction in dormancy when stored at 18oC 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].

Anbukkarasi (2010) [71] noted that the pre-harvest spray at 30 days before harvest, a combination of maleic hydrazide and 2000 ppm + carbendazim at 1000 ppm, with 2 cm neck length of bulbs stored in an inexpensive bottom ventilated storage structure extending the shelf life (up to six months), the treatment mentioned above decreased physiological weight loss (5.72 and 5.18%), sprouting loss (0.58 and 0.62%), rotting, rooting, and total loss (6.58 and 6.78%), and improved quality indicators such as TSS content (17.14 and 17.22 °Brix), total sugar (6.76 and 6.83%), reducing sugar (1.44 and 1.49%), and sulfur content (0.697). In this experiment, the concentrations of ascorbic acid (10.19 and 10.24 mg/100 g-1), pyruvic acid (2.48 and 2.53 mol g-1), and total phenolic content (621.11 and 625.56 g g-1) decreased throughout a three-month storage period. The activity of some enzymes, such as polyphenol oxidase, peroxidase, and phenylalanine ammonia-lyase, decreased as storage time increased.

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 [3].

(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. When the onion is crop sprayed with cycocel (lihocin) at 2500 ppm 75 and 90 days after transplanting showed good results by reducing the rotting percentage [3].

(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].

According to Misra and Pande (1979) [128], moisture content increased as ethrel concentrations decreased and storage progressed. After 30 days of storage, common onion bulbs treated with 2,000 ppm of ethrel had the lowest levels of TSS and the highest levels of ascorbic acid [3]. 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 20oC.

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 20oC before or after curing (28oC for six weeks). These treated bulbs were kept at 0 to 1oC 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

Postharvest disease of onion is often managed using chemical fungicides sprayed strategically as systemic fungicides or at field level throughout the cropping season for postharvest diseases that affect the product before harvest. The fungicides are applied to the produce in the form of waxes, coatings, fumigants, treated wraps, box liners, dips, sprays, and fumigants. In postharvest treatments, dip and spray techniques are quite popular.

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]. Additionally, it was discovered that applying a post-harvest spray with 0.25 percent mancozeb, 0.1% carbendazim, or 0.1% benomyl helped lower storage losses over six months [88].

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 post-harvest dip application of carbendazim at a concentration of 0.1% was discovered to be the most efficient method. 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].

Carbendazim (0.1%) was used post-harvest to prevent spoiling throughout the storage period. Compared to the control, the carbendazim achieved a 100% decrease in black mold diseases and a 90.7% reduction in blue mold diseases [54]. While sulfur dust fumigation was most beneficial for the long-term preservation of onions, the application of bavistin (0.1%) showed effectiveness for short-term storage [114]. Because of the widespread use of synthetic fungicides and public concern about the safety of food and the environment, pathogen resistance has evolved. Because of this, new ways to fight disease have been made that may be safe for human health and the environment.

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].

Only 18 different kinds of biopesticides have been registered in India thus far under the 1968 Insecticide Act. *Trichoderma viride, T. harzianum, Pseudomonas fluorescens,* and *Bacillus subtilis* are the most potential bioagents among agriculturally significant microbes because they produce biologically active metabolites like antibiotics and bacteriocin and act as inducers and elicitors of systemic resistance in plants.

(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 [22, 23, 150-152]. It is normal practice to use several synthetic fungicides to control onion post-harvest diseases, but their toxicity and the development of pathogen resistance make it necessary to produce fungicidal formulations derived from plants to control fungal infections [72].

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 ethanolically 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. Penicillium species against the pathogen *Aspergillus niger* fourteen Penicillium species were isolated from the rhizosphere of several plant types. After investigation, it was shown that these isolates had a strong antagonistic impact on the mycelium development of *Aspergillus niger*. 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 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. Zinc nanoparticles coated with aluminum work well against *Aspergillus flavus*. Scientists found that elemental and nano-sized sulfur particles stopped *Aspergillus niger* [4].

(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. AgNPs have unique effects that result in spore destruction and damage, including a decrease in spore number, abnormality, and hypertrophy. 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, Schizophylum 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 (66–74 m thickness) [164]. The presence of such silver nanocomposite films inhibited microbial growth. The white rot of green onions caused by *Sclerotium cepivorum* is inhibited by the use of silver nanoparticles in the liquid formulation at a concentration of 7 ppm [160].

(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. In this study, the effects of ZnO against five pathogens-*Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis, Aspergillus niger,* and *Candida albicans*-as well as the effect of particle size of these inorganic powders were studied.

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 *Nigrosporaoryzae* 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]. If rotting onions are not disposed of right away, they may create pollution and annoyance. Only one option is to make compost, manure, or vermicomposting out of the huge amounts of bad bulbs, scales, peels, and parts of onion bulbs that are thrown away by processing plants.

After curing, onions are sorted and classified both manually and with grading equipment. Classification and grading are essential for both domestic and international markets. Removed before storage are bulbs that are doubled, damaged, or rotting and have undesirable characteristics. Jute bags are used to package onions before being transported by trucks, trains, or even airplanes to far-off markets. Traditional storage methods cause significant losses in stored onions; as a consequence, it is crucial to adopt better storage buildings, appropriate storage varieties, careful fertilizer usage, timely watering, and post-harvest technologies to minimize losses in stored onions. Bullock carts, tractor trolleys, trucks, and railway carriages are employed to transfer onion supplies across larger distances inside the nation.

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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