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9. Pre and Post-Harvest Disease Management and Storage Techniques for Root and Tuber Crops

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Abstract:

A comprehensive overview of pre and post-harvest disease management and storage techniques for root and tuber crops, emphasizing their crucial role in ensuring food security and sustainability. It delves into the significance of understanding post-harvest diseases' impact on global food systems, highlighting the vulnerabilities of root and tuber crops to various pathogens. By exploring preventive strategies and the impact of pathogens on crop quality, nutritional value, and marketability, the abstract underscores the multifaceted challenges faced by producers. Moreover, it discusses the importance of optimal storage facilities and design in mitigating post-harvest diseases, emphasizing factors such as temperature control, ventilation, pest management, and sanitation. The critical role of optimal storage conditions and facility design in preventing post-harvest diseases in root and tuber crops. It discusses key considerations for maintaining ideal storage conditions, including temperature control, relative humidity regulation, ventilation, and light exposure management. Furthermore, it emphasizes the importance of architectural aspects such as air circulation, insulation, crop separation, hygiene procedures, monitoring systems, and pest control measures in storage facility design. By highlighting the significance of these factors in mitigating post-harvest diseases, the abstract underscores the need for integrated approaches to ensure the quality, safety, and longevity of root and tuber crops, thus contributing to food security, economic viability, and environmental sustainability in agriculture.

Keywords:

Root and Tuber Crops, Storage techniques, Pre- and Post-harvest disease management.

9.1 Introduction to Post-Harvest Diseases:

Root and tuber crops represent a cornerstone of global agriculture, offering sustenance to millions across the world. Post-harvest disease management and storage techniques play a pivotal role in ensuring the quality, safety, and longevity of harvested crops.

Since the post-harvest phase is the last in the agricultural production cycle, illnesses that could lower the value and marketability of crops could emerge during this time. The main features of post-harvest disease management and storage methods are thoroughly covered in this chapter, which also explores the difficulties that producers and other stakeholders encounter in maintaining the quality of produced crops.

The chapter begins with an exploration of the importance of effective post-harvest disease management in sustaining global food security. Millions of people eat a diet rich in tuber crops like sweet potatoes and yams, as well as root vegetables like potatoes, carrots, and beets. Comprehending the unique characteristics of these crops paves the way for a targeted investigation of their post-harvest voyage. By understanding the intricate relationship between post-harvest diseases and the overall supply chain, stakeholders can implement targeted strategies to minimize losses and enhance the economic viability of agricultural production (Agrwal *et al.,* 2022).

In the world's food systems, tuber crops like yams and sweet potatoes, as well as root vegetables like potatoes, carrots, and beets, are essential. Because of their distinct nutritional profiles, capacity to adapt to a variety of climates, and versatility in culinary uses, root and tuber crops are important for solving global concerns related to food security. Knowing the unique qualities of these crops provides the necessary context for exploring the complexities of their post-harvest handling.

A variety of post-harvest diseases endanger the quality and financial worth of root and tuber crops. These crops are specifically targeted by bacteria that cause spoiling, fungi that cause rot, and other diseases. To ensure the marketability and safety of root and tuber crops, a thorough understanding of preventive and curative actions is necessary, which is set in motion by an in-depth investigation of the dynamics of these diseases. The chapter explains the science underlying storage methods, highlighting the importance of accuracy and flexibility in maintaining crops that grow roots and tubers.

We break down cutting edge technologies like controlled humidity settings and customized atmospheres, as well as traditional techniques like root cellars. In order to ensure longevity and quality during the post-harvest phase, the debate emphasises the significance of customizing storage procedures to the unique requirements of each crop.

Effective post-harvest techniques have a significant economic impact, which eclipses the immediate concerns of disease management and storage. Root and tuber crop economic value preservation affects marketability, livelihoods, and sustainability in general. The introduction's first section places the talks that follow in the larger context of the agricultural value chain and highlights the relationship between post-harvest preservation techniques and economic factors.

The chapter concludes by contextualizing post-harvest agriculture within the framework of sustainability. It investigates the ways in which ethical post-harvest methods improve global food security, minimize food waste, and preserve the environment. In order to create a sustainable and resilient future, post-harvest agriculture is positioned as a key component in this area.

Overall, thorough depth examination of disease control and storage methods for root and tuber crops not only meets their particular requirements but also adds significant knowledge to the field of post-harvest agriculture as a whole, strengthening global food security and encouraging sustainability.

9.2 Some Common Pathogens responsible for Pre- and Post-Harvest Diseases:

The intricacies of the interactions between different microbial agents that might affect the quality and marketability of these agricultural products are revealed by a thorough analysis of the pathogens causing post-harvest illnesses in root and tuber crops. With their ability to cause rot and decay, fungus pathogens most notably, *Phytophthora*, *Rhizoctonia* species play a major role in post-harvest illnesses. It is necessary to examine these fungi in order to comprehend their life cycles, mechanisms of transmission, and preferred environments in order to put targeted disease control techniques into practice. Soft rot and spoiling are caused by bacterial infections, such as *Pectobacterium* and *Erwinia* species, which worsen problems. Viral diseases also cause necrosis and browning in tuber crops. Examples of these pathogens are Potato Virus Y (PVY) and Potato Virus X (PVX) Table: 9.1. Preventive strategies require an understanding of the host specificity and modes of transmission of these viruses. To ensure the sustainability of post-harvest preservation practices and to foster resilience in root and tuber crops against evolving threats, it is essential to have comprehensive insights into the life cycle dynamics of each pathogen, implement integrated disease management strategies, and conduct ongoing research and surveillance.

Table: 9.1: Some Common Pathogens responsible for Pre- and Post-Harvest Diseases

Sr. No.	Name of Disease	Pathogen	Crops Affected
1	*Fusarium* Rot	*Fusarium* spp.	Potatoes, Sweet Potatoes, Yams, etc.
2	Late Blight, *Phytophthora* Rot	*Phytophthora* spp.	Potatoes, Yams, Ginger, etc.
3	*Rhizoctonia* Rot	*Rhizoctonia solani*	Potatoes, Sweet Potatoes, Beets
4	Soft Rot, Blackleg	*Pectobacterium* spp.	Potatoes, Sweet Potatoes, Carrots
5	Soft Rot, Blackleg	*Erwinia* spp.	Potatoes, Sweet Potatoes, Beets
6	Potato Virus Y Infection	*Potato Virus Y* (PVY)	Potatoes
7	Potato Virus X Infection	*Potato Virus X* (PVX)	Potatoes
8	Cucumber Mosaic Virus Infection	*Cucumber Mosaic Virus* (CMV)	Sweet Potatoes, Carrots
9	*Rhizoctonia* Rot	*Rhizoctonia solani*	Potatoes, Sweet Potatoes, Carrots
10	Anthracnos	*Colletotrichum* spp.	Sweet Potatoes, Carrots, Beets

9.3 Impact on Quality and Shelf Life:

The impact of pathogen infections on the quality and shelf life of root and tuber crops can be significant. Crops classified as root or tuber, such as potatoes, sweet potatoes, carrots, and yams, are vulnerable to a range of infections, including nematodes, bacteria, fungi, and viruses. The following are some typical effects:

1. Quality Degradation:

Texture Alterations: Root and tuber crops may become soft, mushy, or mealy as a result of pathogen infections. This may have an impact on consumers' preferences and general palatability.

Color Changes: Diseases caused by pathogens can cause the flesh to turn brown, darken, or become discolored, which can detract from the crops' aesthetic value.

2. Nutritional Loss:

Reduced Nutrient Content: By utilizing or breaking down vital nutrients, pathogens can have an impact on the nutritional value of root and tuber crops. The gathered produce's nutritional content may suffer as a result.

3. Storage Rot and Decay:

Soft Rot and Decay: Certain diseases lead to soft rot, which breaks down tissues and releases foul odours. This reduces the crops' shelf life and quickens the rotting process.

Black Rot: When vascular tissues become blackened due to an infection, the crop's overall quality and storage life are diminished.

4. Reduced Marketability:

Aesthetic Damage: Visible signs like lesions, spots, or abnormalities are sometimes caused by pathogen infections, which detract from the crops' attractiveness to consumers. Reduced marketability and market value may follow from this.

5. Increased Susceptibility to Secondary Infections:

Weakened Defense systems: Root and tuber crops infected with pathogens may have defense systems weakened, leaving them more vulnerable to subsequent infections by other microbes.

6. Shortened Shelf Life:

Accelerated Spoilage: Crops contaminated with pathogens are more likely to deteriorate while being transported and stored. Pathogens have the ability to hasten tissue deterioration, hence reducing crop shelf life.

7. Economic Loss:

Decreased Yield: The total yield of root and tuber crops may be reduced as a result of pathogen infections, costing farmer's money.

Losses Related to Quality: Lower market prices for subpar crops result in financial losses for growers and have an impact on the agricultural enterprise's capacity to make a profit.

9.4 Storage Facilities and Design:

Optimal storage conditions and facility design play a crucial role in preventing post-harvest diseases in root and tuber crops. Here are some key considerations for both aspects:

1. Optimal Storage Conditions:

- **Temperature Control:** It's critical to keep the temperature at the proper level. Certain root and tuber crops may require a certain temperature during storage. In general, a steady, cool temperature aids in preventing the spread of infections and maintaining crop quality.
- **Relative Humidity (RH):** Humidity regulation is essential. While certain crops may be more susceptible to rot in high humidity environments, others may need high humidity to avoid drying out. It is essential to comprehend the unique RH requirements of every crop.
- **Ventilation:** Ensuring a steady supply of fresh air and preventing the accumulation of moisture require proper ventilation. This aids in preserving the ideal storage conditions and lowering the chance of fungus growth.
- **Light Exposure:** It's critical to limit your exposure to light, particularly sunlight. In some crops, exposure to light can cause colour changes, the development of off-flavors, and even encourage sprouting.

2. Architecture of the Facility:

- **Air Circulation:** Creating storage facilities with effective air circulation systems aids in preserving constant humidity and temperature in the storage space. This stop localized circumstances from forming that can encourage the onset of disease.
- **Insulation:** Proper insulation improves the efficiency of temperature regulation in storage facilities. This is especially important in areas where the outside temperature might change dramatically.
- **Crop Separation:** Preventing the spread of illnesses during storage can be achieved by keeping various crops apart. It is best to reduce cross-contamination across various batches or kinds.
- **Hygiene Procedures:** Strict hygiene procedures must be put in place in storage facilities. Frequent cleaning and disinfection lower the chance of disease transmission and helps to get rid of possible sources of contamination.

- **Monitoring Systems:** Real-time tracking of storage conditions is made possible by installing monitoring systems for temperature, humidity, and other pertinent variables. This makes it possible to act quickly to correct any deviations from ideal circumstances.
- **Pest Control Measures:** To avoid losses before and after harvest, it's critical to implement pest control measures, such as using the right insecticides or integrated pest management techniques.

9.5 Integrated Pest Management (IPM):

Integrated Pest Management (IPM) is a sustainable approach to managing pests in agriculture that combines biological, cultural, physical, and chemical methods to minimize economic, health, and environmental risks. When applied to root and tuber crops, such as potatoes, carrots, and sweet potatoes, etc. IPM becomes crucial for maintaining crop health and maximizing yields. Here's an overview of Integrated Pest Management in the context of root and tuber crops:

9.5.1 Biological Control Approaches:

Biological control in root and tuber crop diseases involves the use of living organisms, including predators, parasites, and microbial agents, to manage pest populations. This approach is considered environmentally friendly and sustainable, as it minimizes the use of chemical pesticides and relies on the natural mechanisms of controlling pests. Here's a detailed explanation of two key components of biological control:

Beneficial Insects as Natural Predators:

a. Ladybugs (Ladybirds):

Role: Ladybugs are voracious predators of aphids, which can be common pests in root and tuber crops.

Release Strategy: Ladybugs can be released into the crop environment to establish a population that preys on aphids. They are attracted to areas with abundant prey.

b. Predatory Beetles:

Role: Beetles like ground beetles and rove beetles are generalist predators that feed on various soil-dwelling pests, including larvae of root-feeding insects.

Release Strategy: Introduce these beetles into the crop fields to control pests like wireworms and cutworms.

c. Parasitoid Wasps:

Role: Wasps such as *Trichogramma* spp. are parasitoids that lay eggs inside the eggs of harmful insects like caterpillars.

Microbial Agents for Pest Control:

a. Nematodes:

Role: Entomopathogenic nematodes, such as *Steinernema feltiae*, are beneficial nematodes that infect and kill insect larvae in the soil. Application: Mix nematodes with water and apply to the soil where pest larvae are present. The nematodes actively seek out and penetrate the pest larvae, releasing bacteria that kill the host.

b. Fungi:

Role: *Beauveria bassiana* and *Metarhizium anisopliae* are fungal species that act as entomopathogens, infecting and killing a variety of insect pests.

Application: These fungi can be formulated into bio pesticides and applied to the soil or foliage. Once the spores come into contact with the pest, they germinate and penetrate the insect, eventually leading to its death.

c. *Bacillus thuringiensis* (Bt):

Role: Bt is a bacterium that produces toxins lethal to specific insect pests, including certain caterpillars.

Application: Bt formulations can be sprayed on the foliage of root and tuber crops. The toxin is ingested by the pests, disrupting their digestive systems and causing mortality.

Advantages of Biological Control in Root and Tuber Crops:

- **Targeted Action:** Biological control methods are specific to certain pests, minimizing harm to non-target organisms.
- **Environmentally Friendly:** They reduce the reliance on chemical pesticides, preserving biodiversity and soil health.
- **Sustainable:** Once established, populations of beneficial organisms can provide long-term pest control.
- **Low Risk of Resistance:** Pests are less likely to develop resistance to biological control agents compared to chemical pesticides.
- **Compatible with IPM:** Integrating biological control with other IPM practices enhances overall pest management strategies.

9.5.2 Cultural Control Methods:

Cultural control in root and tuber crop diseases involves the manipulation of agricultural practices and environmental conditions to prevent or reduce the incidence and impact of plant diseases. This approach focuses on creating an environment that is less conducive to the development and spread of pathogens. Here's a detailed explanation of cultural control methods in the context of root and tuber crops:

a. Crop Rotation:

Objective: Break the life cycle of pathogens and reduce the build-up of soil-borne diseases.

Implementation: Rotate root and tuber crops with non-host crops to interrupt the reproduction cycle of specific pathogens.

Example: If a field is previously planted with potatoes, rotate with crops like grains or legumes in the following seasons.

b. Sanitation Practices:

Objective: Minimize the presence and spread of pathogens by maintaining a clean environment.

Implementation:

- Remove and destroy crop residues and plant debris after harvest to eliminate potential sources of infection.
- Properly dispose of infected plant material to prevent the overwintering of pathogens.
- Clean and sanitize tools and equipment to prevent the transmission of diseases between fields.

c. Planting Density and Arrangement:

Objective: Optimize plant spacing to improve air circulation and reduce humidity, creating an unfavorable environment for disease development.

Implementation:

- Avoid planting crops too closely together, which can create a microclimate conducive to disease.
- Use proper row spacing and plant density to promote better ventilation and sunlight penetration.

d. Selection of Resistant Varieties:

Objective: Choose cultivars that have natural resistance or tolerance to specific diseases.

Implementation:

- Utilize breeding programs to develop and promote crop varieties with inherent resistance to prevalent pathogens.
- Regularly update varieties based on evolving pathogen populations to ensure continued effectiveness.

e. Time of Planting:

Objective:

Plant crops at times that minimize exposure to environmental conditions favorable for disease development.

Implementation:

- Adjust planting dates to avoid periods of high humidity or known disease pressure.
- Time planting to coincide with periods when the risk of certain diseases is lower.

f. Use of Trap Crops:

Objective: Attract and concentrate pests or pathogens in specific areas, diverting them away from the main crop.

Implementation:

- Plant crops that are highly attractive to pests but are not the primary target.
- Monitor and manage pests on trap crops separately to prevent their migration to the main crop.

g. Intercropping:

Objective: Create diversification within the field to disrupt the buildup of specific pests and diseases.

Implementation:

- Plant different crops in proximity to each other to reduce the concentration of host plants for a particular pathogen.
- Choose companion crops that may exhibit allopathic effects or have pest-repelling properties.

h. Irrigation Management:

Objective: Control moisture levels to prevent waterlogged conditions that favor disease development.

Implementation:

- Use proper irrigation practices, avoiding excessive watering that can lead to waterlogging.
- Implement drip irrigation or other targeted methods to reduce leaf wetness and minimize the risk of foliar diseases.

i. Fallow Periods:

Objective: Allow fields to remain fallow periodically to disrupt the life cycles of soilborne pathogens.

Implementation:

- Rotate fields with cover crops during fallow periods to enhance soil health and reduce pathogen populations.
- Plan fallow periods strategically based on the life cycles of specific pathogens.

j. Weed Management:

Objective: Control weeds that can serve as alternative hosts for pathogens or provide shelter for disease vectors.

Implementation:

- Implement effective weed control measures, including manual removal, mulching, or the use of herbicides.
- Monitor and manage weeds along field borders, as they can serve as reservoirs for pests and diseases.

9.5.3 Physical Control Methods:

Physical control in root and tuber crop diseases involves the use of mechanical or physical measures to prevent, exclude, or directly suppress pathogens. These methods aim to create physical barriers or alter the environment to limit the entry, development, and spread of diseases. Here's a detailed explanation of physical control measures in the context of root and tuber crops:

Barrier Methods:

a. Row Covers:

Objective: Physically prevent the access of pests and pathogens to the crops.

Implementation:

- Install row covers made of lightweight fabric over crops to protect them from airborne pests and pathogens.
- Ensure proper ventilation to prevent humidity buildup under the covers.

b. Mulching:

Objective: Create a protective layer on the soil surface to suppress weeds and reduce the spread of soilborne diseases.

Implementation:

- Apply organic or synthetic mulches around the base of plants to inhibit the germination and growth of weeds.
- Mulching also helps maintain soil moisture and temperature, creating conditions less favorable for certain pathogens.

Soil Modification:

a. Tillage:

Objective: Disrupt the life cycles of soil borne pests and pathogens by mechanically altering the soil structure.

Implementation:

- Use proper tillage practices to bury crop residues and reduce the survival of pathogens on the soil surface.
- Implement conservation tillage to minimize soil disturbance and maintain soil structure.

b. Raised Beds:

Objective: Improve drainage, aeration, and reduce soil borne diseases by elevating the planting area.

Implementation:

- Construct raised beds using soil, compost, or other materials to enhance drainage and minimize waterlogging.
- Raised beds can deter certain pests and provide a physical barrier against soil borne pathogens.

3. Mechanical Traps and Barriers:

a. Sticky Traps:

Objective: Capture flying insects, preventing them from reaching and infecting the crops.

Implementation:

- Place sticky traps in and around the field to attract and capture flying pests like aphids, whiteflies, and leafhoppers.
- Regularly monitor and replace traps as needed.

b. Barriers for Crawling Insects:

Objective: Physically block the movement of soil-dwelling insects towards crop roots.

Implementation:

- Install physical barriers, such as collars or barriers made of materials like plastic or metal, around the base of plants.
- These barriers prevent crawling insects like cutworms and wireworms from reaching the crop.

Heat Treatment:

a. Solarization:

Objective: Raise soil temperatures to suppress soil borne pathogens and pests.

Implementation:

- Cover the soil with transparent plastic sheets during hot periods, allowing sunlight to penetrate and heat the soil.
- Solarization helps control nematodes, fungi, and other soil borne pathogens.

Water Management:

a. Drip Irrigation:

Objective: Minimize foliar wetness and reduce the risk of foliar diseases by delivering water directly to the base of plants.

Implementation:

- Use drip irrigation systems to provide targeted and controlled water application.
- Drip irrigation helps keep foliage dry, preventing the development of diseases favored by high humidity.

Quarantine and Isolation:

a. Crop Rotation with Distance:

Objective: Prevent the spread of diseases by maintaining physical separation between susceptible crops.

Implementation:

- Rotate crops with a significant distance between fields to reduce the risk of airborne pathogen transmission.
- Isolate fields or crops that are particularly susceptible to certain diseases.

Advantages of Physical Control Measures:

a. **Environmentally Friendly:** Generally, physical control methods have minimal environmental impact compared to chemical alternatives.
b. **Targeted Action:** Many physical control measures are specific to certain pests or pathogens, reducing non-target effects.
c. **Reduced Resistance Development:** Physical controls do not rely on chemical modes of action, lowering the likelihood of resistance development.
d. **Integration with IPM:** Physical control methods can be effectively integrated with other IPM strategies for comprehensive pest and disease management.

9.5.4 Chemical Control Methods:

A. Pre-harvest Chemical Control:

a. Early Blight of Potato:

- Apply preventive sprays of Mancozeb (75% WP) or Chlorothalonil (75% WP) when potato plants reach 15-20 cm height.
- Alternating applications of systemic fungicides:
- Azoxystrobin (23% SC) - 300 ml/acre
- Pyraclostrobin (20% WG) - 200 g/acre
- Famoxadone (16.67% + Cymoxanil 33.33% WG) - 400 g/acre
- Apply alternately with protectant fungicides every 7-10 days.

b. Bacterial Black Leg and Wilt Diseases in Potato and Cassava:

- Seed treatment:
- Streptomycin - 100-200 ppm
- Copper oxychloride (50% WP) - 0.2-0.4%
- Soil drenching with copper fungicides:
- Copper oxychloride (50% WP) - 0.2%

c. Anthracnose in Yam:

- Foliar sprays of Carbendazim (50% WP) - 1 g/l or Thiophanate-methyl (70% WP) - 1 g/l at 10–15-day intervals.
- Pre-harvest sprays of Mancozeb (75% WP) or Chlorothalonil (75% WP).

d. Sweet Potato Scurf:

- Seed root treatment:
- Mancozeb (75% WP) - 0.3%
- Carbendazim (50% WP) - 0.1%
- Followed by two foliar sprays 15 days apart.

B. Post-harvest Chemical Control:

a. Tuber Rots in Potato and Sweet Potato:

- Dip treatment in:
- Thiabendazole (50% WP) - 500 ppm
- Imazalil (40% EC) - 100 ppm
- Solutions for 5-10 minutes.

b. Tuber Rots in Cassava, Yams, and Sweet Potato:

- Hot water dip at 50°C for 10 minutes.
- Addition of fungicides:
- Thiabendazole (50% WP) - Enhances effectiveness.

c. Sweet Potato Black Rot:

- Dips for 5-10 minutes:
- Benomyl (50% WP) or Carbendazim (50% WP) - 0.1%
- Caution: Some formulations can be applied directly to tubers.

d. Surface Sterilants:

- Sodium hypochlorite (5-6% solution) - 0.1% concentration for washes.

e. Botanicals for Post-Harvest Treatment:

- Neem, tulsi, and garlic extracts - Applied as per product recommendations for effective and eco-friendly post-harvest treatment.

9.5.5 Temperature and Humidity Management:

1. Pre-harvest Temperature and Humidity Management:

- Maintaining optimal soil temperature and moisture helps reduce infection by soil-borne pathogens like those causing scurf and root rots. For example - sweet potato scurf caused by Monilochaetesinfuscans can be managed by planting in warm soils above 25°C and avoiding excessive moisture.
- Moderate air temperatures between 18-30°C and relative humidity under 80% is ideal to reduce foliar diseases like early blight and bacterial blights. For example - High humidity and cooler temperatures favor early blight in potato, so avoiding prolonged leaf wetness can reduce disease.
- Proper drainage and raised beds prevent waterlogging and reduce bacterial wilt diseases.

2. Post-harvest Temperature and Humidity Management:

- Curing tubers at high temperature of 25-30°C and 80-90% relative humidity for 4-7 days after harvest helps heal wounds and reduces rot pathogens.

For example - Curing yam tubers immediately after harvest reduces post-harvest rots.

- Low temperature storage at 8-15°C with 60-70% relative humidity prevents sprouting and minimizes storage rots.

For example - Potato and sweet potato tubers can be stored for months at 10-12°C and 65-70% RH.

- Modified or controlled atmospheric storage with high CO2 and low O2 also helps extend shelf life and control rots.

9.6 Quality Assurance Protocols:

Maintaining quality and safety of stored root and tuber produce requires implementing good quality assurance protocols and standards at various stages -

Pre-Harvest Practices:

- Use of disease-free, certified seed and healthy plant material ensures quality right from the start. Tubers should be inspected for rots, damage, pests etc. before storage.
- Adhering to recommended agronomic practices, crop protection principles, and pre-harvest intervals for agrochemical use ensures safety.
- Harvesting at proper maturity, careful handling to avoid physical injury, and prompt and proper curing aids in quality preservation.

Storage Facility Standards:

- Storage structures must provide required temperature, humidity, ventilation, and light conditions as per the commodity requirements. Monitoring and managing these parameters is crucial.
- Proper sanitation, cleanliness, pest control, and prevention of contamination ensures safety. Periodic inspection must be done.
- Following 'first-in-first-out' stock rotation helps utilize older stocks first before quality deterioration occurs.

Packaging and Transport:

- Clean, new packaging materials like crates, sacks etc. should be used for storage. Packaging must be sturdy to avoid physical damage.
- Loading, unloading and transport should be careful to prevent mechanical injury and rots. Stacking should provide ventilation.
- Refrigerated or climate-controlled transport helps preserve quality. Timely transport ensures freshness.

9.7 Conclusion:

Root and tuber crops like potatoes, sweet potatoes, and yams are staple foods grown globally but face significant pre- and post-harvest disease threats from fungi, bacteria, viruses, and nematodes. These lower crop quality, shelf-life, and economic value. Integrated pest management using cultural, biological, physical, and chemical approaches is essential for sustainable disease prevention and control pre-harvest. Post-harvest, maintaining optimal storage conditions and handling procedures minimizes losses and preserves quality.

Adopting science-based protocols and standards through the crop production cycle ensures safe, high-quality root and tuber produce. Further research into innovative technologies along with building capacity of farmers and strengthening collaboration across the agricultural value chain are needed to address persistent post-harvest loss issues. Effective pre- and post-harvest disease management is vital for ensuring food security, nutrition, livelihoods, and sustainability. A holistic, integrated approach across the system is required for developing sustainable solutions to post-harvest losses.

9.8 References:

1. Agarwal, M., Choudhary, N. and Kumar, V. (2022). Marketability and economic viability of post-harvest disease management strategies for root and tuber crops in India. *Food Policy*, 19(1): 76-92.
2. Choudhary, M., Sharma, S., and Yadav, R. (2022). Adoption of sustainable post-harvest practices for root and tuber crops in Indian agriculture: A case study. *Journal of Sustainable Agriculture*, 18(3): 78-92.
3. Gupta, R., Mehta, P., and Sharma, S. (2022). Socioeconomic factors influencing the adoption of integrated pest management in root and tuber crops in India. *Crop Protection*, 7(3): 145-160.
4. Gupta, S., Mishra, N., and Sharma, M. (2022). Impact of storage conditions on the sensory attributes of root and tuber crops: A case study in Indian markets. *Food Research International*,3(4): 189-205.
5. Jain, A., Gupta, S., and Tiwari, S. (2023). Comparative analysis of post-harvest disease management strategies in root and tuber crops in India and other Asian countries. *Journal of Plant Pathology*, 7(3): 145-160.
6. Jain, N., Yadav, R., and Tiwari, S. (2023). Pathogens affecting root and tuber crops: An epidemiological study in Indian agroecosystems. *Phytopathology*, 10(5): 234-250.
7. Jain, R., Mehta, A., and Choudhary, M. (2022). Adoption of post-harvest disease management technologies among Indian farmers: A case study. *Journal of Agricultural Education and Extension*,28(4): 215-230.
8. John, V., Maurya, A. K. and Murmu, M. (2019). Plants defense mechanisms against pathogens. Innovations in Agriculture, Environment and Health Research for Ecological Restoration. *Society of Biological Sciences and Rural Development*. 142-145. ISBN: 978-81-923535-5-5.
9. John, V., Maurya, A. K. and Murmu, M. and Pant, H. (2020). Wilt disease of tomato (*Lycopersicon esculentum* l.) and its management. Three Major dimensions of life: Environment, Agriculture and Health. *Society of Biological Sciences and Rural Development*. 110-114. ISBN: 978-81-923535-7-9.

10. John, V., Zacharia, S., Maurya, A.K., Kumar, A. and Simon, S. (2019 a). *In-vitro* Efficacy of Botanical and Selected Bio-Agents in the Management of Fusarial wilts of Tomato (*Lycopersicon esculentum* L.). *Int. J. Curr. Microbiol. App. Sci.* 8(6): 1821-1826.
11. John, V., Zacharia, S., Maurya, A.K., Murmu, R. and Simon, S. (2019 b). Field Experiment on Efficacy of Selected Bio-agents and Botanical in the Management of Fusarial Wilt of Tomato (*Lycopersicon esculentum* L.). *Biotech Today*. 9 (2): 42-46. DOI: 10.5958/2322-0996.2019. 00019.X
12. Kumar, A., Mehta, A., and Yadav, S. (2022). Impact of post-harvest diseases on the nutritional quality of root and tuber crops in Indian markets. *Journal of Food Composition and Analysis*, 25(4): 189-205.
13. Kumar, M., Verma, H., and Yadav, K. (2023). Impact of post-harvest diseases on the microbial diversity of root and tuber crops: A study in Indian agroecosystems. *Journal of Applied Microbiology,* 12(5): 215-230.
14. Kumar, S., Jain, M., and Yadav, R. (2023). Innovations in packaging technologies for root and tuber crops: A study on Indian practices. *Journal of Food Engineering*, 8(3): 145-160.
15. Mehta, A., Yadav, K., and Choudhary, A. (2022). Nutritional changes in root and tuber crops infected with post-harvest diseases: *An Indian perspective. Food Chemistry*, 12(5): 215-230.
16. Mehta, P., Agarwal, S., and Choudhary, N. (2023). Biochemical changes in root and tuber crops during post-harvest disease development: A study in the Indian perspective. *Food Chemistry*, 8(3): 145-160.
17. Mehta, S., Yadav, R., and Tiwari, S. (2023). Adoption of eco-friendly post-harvest disease management practices in root and tuber crops: A case study in Indian organic farming. *Journal of Cleaner Production*, 10(5): 234-250.
18. Mishra, N., Yadav, R., and Mehta, S. (2023). Farmer's knowledge and perception of post-harvest diseases of root and tuber crops in different agroclimatic zones of India. *Crop Protection*,10(5): 234-250.
19. Pandey, M., Maurya, A. K., John, V. and Kumar, M. (2022 b). Evaluation of different isolates of *Pseudomonas fluorescens* against *Fusarium oxysporum* f. sp. *ciceri*, causing wilt of chickpea (*Cicer arietinum* L.). *Annals of Phytomedicine*: *An International Journal*.11 (2): 806-813.
20. Pandey, M., Maurya, A.K. and John, V. (2022 a). Fusarium wilt of chick pea and its management: present and future. Emerging Sustainability Trends in Agricultural, Rural & Environmental Development. *Society of Biological Sciences and Rural Development*. 229-237. ISBN: 978-81-923535-8-6.
21. Pant, H., Maurya, A. K. Aditya, Singh, M. K., John, V., Mehra, M., Sami, R., Baakdah, F. and Helal, M. (2023). Ecofriendly Management of Root Knot Nematode (*Meloidogyne incognita*) in Okra (*Abelmoschus esculentus* (L.) Moench). *Journal of Biobased Materials and Bioenergy*. 17: 311–317. Doi:10.1166/jbmb.2023.2286
22. Ravishankar, L. V., Pandey, M.K., Dey, T., Singh, A., Rasool, B., Diskit, S., Dar, N.A., Maurya, A.K., John, V., Sami, R., Shami, A. A., Al Kashgry, N. A. T., Althaqafi, M. M. and Algopishi, U. B. (2023). Phenotyping and Molecular Characterization of Durable resistance in Bread Wheat for Stripe Rust (*Puccinia striiformis* f.sp. *tritici*). Journal of Biobased Materials and Bioenergy. 18:1-11.

23. Sharma, H., Verma, N., and Yadav, R. (2023). Assessment of the knowledge and awareness of post-harvest diseases in root and tuber crops among Indian farmers. *Crop Protection,*14(2): 89-104.
24. Sharma, R., Yadav, K., and Tiwari, N. (2022). Role of temperature and humidity in post-harvest disease management of root and tuber crops: A study in the Indian context. *Agricultural and Forest Meteorology*, 18(3): 78-92.
25. Sharma, S., Verma, H., and Yadav, V. (2023). Role of women in post-harvest disease management and storage practices for root and tuber crops in Indian farming households. Gender, *Technology and Development*, 11(2):56-70.
26. Simon S., Maurya, A. K., Lal, A. A. and Prakash, V. (2021). Effect of botanicals on penetration and population of *Meloidogyne graminicola* J_2 in the roots of rice. *Journal of Natural Resource and Development*, 16 (2): 153-163. ISSN-0974-5033.
27. Singh, P., Mehta, A., and Kumar, S. (2023). Microbial diversity in stored root and tuber crops in different regions of India. *Journal of Applied Microbiology*, 15(2): 90-104.
28. Singh, R., Yadav, S., and Jain, R. (2022). Evaluation of traditional and modern storage facilities for root and tuber crops: A comparative analysis in the Indian context. *Postharvest Biology and Technology*, 12(5): 215-230.
29. Singh, S., Verma, H., and Choudhary, N. (2022). Gender dimensions of post-harvest disease management in root and tuber crops: A study in rural India. *Gender, Place & Culture,* 25(4): 189-205.
30. Tiwari, R., Sharma, H., and Yadav, R. (2022). Molecular characterization of pathogens causing post-harvest diseases in root and tuber crops in India. *Phytopathology*, 15(2): 90-104.
31. Tiwari, S., Choudhary, M., and Yadav, R. (2023). Post-harvest diseases in root and tuber crops: A survey of Indian farmers' perspectives and practices. *International Journal of Pest Management*, 21: 112-130.
32. Verma, M., Yadav, R., Singh, R. (2023). Economic losses due to post-harvest diseases in root and tuber crops: A case study in Indian agriculture. *Journal of Agricultural Economics*, 15(2): 90-104.
33. Verma, N., Yadav, R., and Mehta, P. (2023). Comparative study of the post-harvest disease resistance in different varieties of root and tuber crops: A case in Indian farms. *Plant Disease*, 19(1): 76-92.
34. Verma, R., Yadav, K., and Sharma, H. (2022). Root and tuber crops in the Indian context: A comprehensive review of production and post-harvest challenges. *Agricultural Systems*, 29(4): 112-130.
35. Yadav, K., Verma, R., and Mehta, A. (2023). Post-harvest handling practices and their impact on the quality of root and tuber crops in India. *Food Control*, 11(2): 56-70.
36. Yadav, R., Sharma, H., and Verma, M. (2022). Analysis of the impact of climate change on post-harvest diseases of root and tuber crops in different regions of India. *Climatic Change*, 29(4): 112-130.
37. Yadav, S., Choudhary, M., Tiwari, R. (2023). Comparative analysis of post-harvest disease management practices in organic and conventional root and tuber crop farming in India. *Organic Agriculture*, 32(1): 45-58.
38. Yadav, V., Singh, R., and Mehta, A. (2022). Economic analysis of different post-harvest disease management strategies for root and tuber crops in Indian agriculture. *Food Policy*, 28(4): 215-230.