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Management of Postharvest Diseases of Vegetables in a Tropical and Sub-tropical Environment of the Kingdom of Eswatini

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Authors' contributions

This work was carried out in collaboration among all authors. Author DME designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MTM and BED managed the analyses of the study. Author KAN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Vegetables are important in human diets as a side dish eaten either cooked or raw as in salads. They are important for their nutritional contribution as major sources of minerals, vitamins, nine essential amino acids, beneficial phytochemicals, fibre and interesting colour from an aesthetic point of view. Despite the immerse health benefits offered by vegetables there are challenges encountered in their post-harvest handling and storage up to consumption. Challenges include post-harvest losses due to diseases. Some losses occur even at household level when vegetables are not stored appropriately when stored under the sink where humidity can be high leading to an environment which promotes diseases. Diseases in the post-harvest chain are caused by bacteria and opportunistic pathogenic fungi. Post-harvest losses of vegetables are not only a threat to

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nutritional security but a threat to food security as well. The aim of this research study was to document major post-harvest diseases of vegetables found in the Kingdom of Eswatini and to suggest appropriate management strategies or ways of alleviating them.

Keywords: Vegetables; health benefits; post-harvest diseases; losses; management; Sustainable Development Goals (SDGs).

1. INTRODUCTION

Eswatini is located in Southern Africa and is a member of the Southern African Development Community (SADC). To the North, West and South it is surrounded by South Africa while in the East it shares a boarder with Mozambique [1]. The Kingdom covers an area of 17, 364 square kilometres and has two major towns or cities of Mbabane (the capital city) and Manzini. The 2007 census put the population at 1.02 million with 0.54 million being female while 0.48 million being male. About 78 percent live in rural areas while 22 percent live in urban areas [2]. The country is landlocked and is divided into four agro-ecological zones which are the Highveld, Middleveld, Lowveld and Lubombo plateau. Each of these zones has a distinctive climate, rainfall and geography [3,4].

Vegetables are produced in all the four agroecological zones. Some vegetables are imported into the country. The importation or exportation of various agricultural products including vegetables is regulated by the National Agricultural Marketing Board (NAMBoard) [5,6].

After harvest however, vegetables which are still alive can suffer from various diseases leading to unwanted losses. This study aimed to document, discuss and to proffer solutions to various postharvest diseases of vegetables encountered in the Kingdom of Eswatini.

2. METHODOLOGY

The study was a qualitative one. Desk review of existing literature was done. Informal surveys were carried out. Observations of vegetables in the postharvest handling chain were made in both the formal and informal markets.

3. CATEGORIES OF VEGETABLES

3.1 Leafy Floral and Succulent Vegetables

These are vegetables whose edible portions consist of shoots, leaves buds or floral organs. Most leafy greens, immature flower heads and succulent crops are found in this category (Wang) [7] (Table 1). Taxonomically these vegetables come from a diverse number of families, however, most come from the Composita and Cruciferae [5] (Table 2).

3.2 Immature Fruit Vegetables

The important examples of vegetables for which the edible part is botanically an immature fruit are mostly cucurbits and legumes, along with a Solanaceous vegetable (eggplant, *Solanum melongena* L.), a member of the Malvaceae family [okra, *Abelmoschus esculentus* (L.) Moench, and monocotyledon (sweet corn, *Zea mays* L. Var. rugosa bonafel (M & B.] [8] (Table 3).

3.3 Mature Fruit Vegetables

Many vegetables are classified botanically as fruit, that is, as the product of ripening ovary and its associated tissue. Mature fruit vegetables are derived from taxonomically diverse families, however, the major mature vegetables are dominated by species from Cucurbitaceae (melons, pumpkins and winter squash) and Solanaceae (peppers, egg fruit and tomatoes) (Table 4) [9].

Table 1. Classification of leafy, floral and succulent vegetables on the basis of their primary edible plant part

Leaves and associated parts	Stems	Immature flowers
a. Leaf blade-chard, endive, leaf lettuce, spinach	a. Asparagus	a. Artichoke, broccoli, cauliflower
b. Petiole- celery, rhubarb		
c. Bud- Brussels sprouts, cabbage, head lettuce		
d. Shoot- green onion, leeks		

Source: [7]

Table 2. Taxonomic classification of some leafy, floral and succulent vegetables

Common name	Genus species
Amaryllidaceae family	
Green onion	*Allium cepa*
Leek	*Allium ampeloprasum*
Chenopodiaceae family	
Beet greens	*Beta vulgaris*
Spinach	*Spinacia oleracea*
Swiss chard	*Beta vulgaris* var. *cicla*
Asteraceae family	
Artichoke	*Cynara scolymus*
Chicory, Witloof chicory	*Cichorium intybus*
Endive and escarole	*Cichorium endive*
Lettuce	*Lactuca sativa*
Brassicaceae family	
Broccoli	*Brasscia oleracea* var. *botrytis*
Brussels sprouts	*Brasscia oleracea* var. *gemmifera*
Cauliflower	*Brasscia oleracea* var. *botrytis*
Cabbage	*Brasscia oleracea* var. *capitata*
Chinese cabbage	*Brasscia rapa* var. *pekinensis*
Collards and kale	*Brasscia oleracea* var. *acephala*
Kohlrabi	*Brasscia oleracea* var. *gongylodes*
Mustard greens	*Brasscia juncea*
Turnip greens	*Brasscia rapa* var. *rapifera*
Watercress	*Nasturtium officinale*
Apiaceae family	
Celery	*Apium graveolens* var. *ducle*
Parsley	*Petroselinum crispum*

Source: [7]

Table 3. Taxonomic classification of some immature fruit vegetables

Common name	Genus and species
Dicots	
Cucurbitaceae family	
Bitter gourd	*Momordica charantia* L.
Chayote	*Sechium edule* (Jacq.) Sw.
Cucumber	*Cucumis sativus* L.
Soft-rind or summer squash	*Cucurbita pepo* L.
Fabaceae family	
Broad bean	*Vicia faba* L.
Green or snap bean	*Phaseolus vulgaris* L.
Lima bean	*Phaseolus lunatus* L.
Garden pea	*Pisum sativum* L.
Snow pea	*Pisum sativum* L. var. *macrocarpom* Ser.
Malvaceae family	
Okra	*Abelmoschus esculentus* [L.] Moench
Solanaceae family	
Eggplant	*Solanum melongena* L.
Green pepper	*Capsicum annuum* var. *annuum*
Tomato	*Solanum lycopersicum*
Monocots	
Poaceae family	
Sweetcorn	*Zea mays* convar. *saccharata* var. *rugosa*
Baby corn	*Zea mays* L.

Source: [8]

Table 4. Taxonomic classification of some important mature fruit vegetables

Common name	Genus and species
Cucurbitaceae family	
Pumpkin, acron squash, ornamental gourds	*Cucurbita pepo*
Winter squashes and pumpkins (Boston marrow, hubbard, turks turban)	*Cucurbita maxima*
Winter squashes and pumpkins (green striped cushaw, Japanese pie, Tennessee sweet potato)	*Cucurbita argyrosperma*
Winter melons, casaba, honeydew	*Cucumis melo* var. *inodorous*
Netted muskmelon, cantaloupe, Persian melon	*Cucumis melo* var. *reticulatus*
Watermelon	*Citrullus lanatus*
Solanaceae family	
Pepper, sweet and punget (Ancho, bell, cayenne, chiltepin, Cuban, jalapeno, long wax, New Mexican, pimiento, Serrano)	*Capsicum annuum* var. *annuum*
Tomato	*Solanum lycopersicum*
Cherry tomato	*Solanum lycopersicum* var. *cerasiforme*

Source: [9]

3.4 Underground Storage Organs

These are commonly known as root crops where the edible portion is an underground storage organ (Table 5) [10]. However, the underground storage organs are taxonomically the most diverse group of vegetables, representing more than a dozen different families, including both monocotyledonous and dicotyledonous plants (Table 6) [10].

3.5 Fresh Cut Vegetables

Fresh cut also known as minimally or lightly processed vegetables are vegetables that have been cut into small size portions and are ready to eat [e.g. broccoli (*Brassica oleracea* L. *Botryt*is group), carrots (*Dacus carota* L.), Lettuce (*Lactuca sativa* L.) spinach (*Spinacia oleracea* L.) or to cook [e.g. artichokes (*Cynara scolymus* L.), broccoli, sweet corn (*Zea mays* L. Var rugosa bonafae) peeled potatoes (*Solanum tuberosum,* etc. (Tables 7, 8) [11-15]. The physiology of minimally or lightly processed vegetables is one of wounded tissue (Tables 7 and 8) and thus these vegetables are not only highly perishable but highly susceptible to disease infection through the wounds.

4. POSTHARVEST LOSSES

The magnitude of post-harvest losses in fresh fruits and vegetables is an estimated 5 to 25 percent in developed countries and 20 to 50 percent in developing countries [16] like Eswatini. Huge losses which were not quantified are reported to occur especially in the informal markets and even at household level. The Kingdom of Eswatini is a developing country with a vision of becoming a near developed country

Table 5. Classification of underground storage organ vegetables on the basis of their origin and primary edible plant part

I. Temperate origin
a. Roots (taproots and/or hypocotyl) - beet, carrot, celeriac, parsnip, radish, rutabaga, turnip
b. Tubers (underground stems) - Jerusalem artichoke
c. Bulbs (leaf bases) - garlic, onion, shallot
d. Corms (underground stems) - water-chestnut
e. Rhizomes (underground stems)- horse-radish
II. Subtropical origin
a. Roots - cassava, manioc, sweet potato, yam bean
b. Tubers (underground stems) -potato, yam
c. Corms (underground stems) taro, tannia, malanga
d. Rhizomes (underground stems)- ginger

Source: [10]

Table 6. Taxonomic classification of some underground storage organ vegetables

Common name	Genus and species
Amaranthaceae family	
Beet	*Beta vulgaris* L. spp. *Vulgaris*
Asteraceae family	
Jerusalem artichoke	*Helianthus tuberosum* L.
Convolvulaceae family	
Sweet potato	*Ipomoea batatas* (L.) Poir
Brassicaceae family	
Horse-radish	*Armoracia rusticana* P. Gaertn. [stn. *Nasturtium armonracia* (L.) Fries]
Radish	*Raphanus sativus* L. var. *radicula*
Rutabaga	*Brassica napus* L. var. *neobrassica*
Turnip	*Brassica rapa* L. var. *rapifera*
Euphorbiaceae family	
Cassava	*Manihot esculenta* Crantz.
Fabaceae family	
Jicama	*Pachyrhizus erosus* (L.) Urban
Solanaceae family	
Potato	*Solanum tuberosum*
Apiaceae family	
Carrot	*Daucus carota* L.
Celeriac	*Apium graveolens* L. var. *rapaceum* (Mill.) Gaud.
Parsnip	*Pastinaca sativa* L.
Amaryllidaceae family	
Garlic	*Allium sativum* L.
Onion	*Allium cepa* L.
Shallot	*Allium cepa* L.
Araceae family	
Malanga	*Xanthosoma* spp.
Taro	*Colocasia esculenta* (L.) Schott
Cyperaceae family	
Waterchestnut	*Eleocharis dulcis* (Burm.) Trin. Ex Hens.
Dioscoreaceae family	
Yam	*Dioscorea alata* L.
Zingiberaceae family	
Ginger	*Zingiber officinale* Roscoe

Source: [10]

by 2022. To reduce these losses, producers and handlers must (1) understand the biological and environmental factors involved in deterioration and (2) use post-harvest techniques that delay senescence and maintain the best possible quality [16].

5. BIOTIC FACTORS INVOLVED IN POSTHARVEST LOSSES

Biotic factors which cause diseases in plants include viruses, bacteria and fungi, [17,18,19,20].

Common postharvest diseases of vegetables are shown in Table 9.

5.1 Bacteria

The composition of the microbial ecosystem on vegetables in the field, at harvest and during the marketing and eventual consumption of the vegetable is unknown. During harvest and handling, vegetables receive various injuries that provide sites for colonisation by certain saprophytes as well as various post-harvest pathogens. How these new bacteria fare on the crop depends on the post-harvest environment and apparently on the existing ecosystem [18].

5.2 Bacteria Soft Rots

Most post-harvest soft rots of vegetables are caused by strains of pectolytic *Erwinia* spp or *Pseudomonads* spp. The “soft rot Erwinia group” includes *E. atroseptica* and *E. chrysanthemi*, whereas the pectolytic *Pseudomonas* include *Pseudomonas marginalis*, pectolytic strains of *P. fluorescens, P. viride flava* and *P. cepacia* [18]

Bacillus spp was associated with soft rot of potatoes at high temperatures above 30ºC [21,22]. *Xanthomonas* spp also caused soft rots in bell peppers, tomatoes, cucumber and papaya.

5.3 Discolouration, Slime and Stains

Many different bacteria appear to be capable of growing on vegetables in storage, particularly if the vegetable is wet, senescing or fresh cut [18]. Slime is caused by *L.euconostoc mensenteroides* while *Xanthomonas* spp or *Serratia marcescens* produce yellow or red colours respectively.

6. PATHOGENIC MICROORGANISMS IN FRESH VEGETABLES

These are various pathogens found on harvested vegetables which can potentially cause illness in humans.

6.1 *Escherichia coli*

This bacterium can cause diarrhoea and other illnesses in humans. Pathogenic strains of *E. coli* are classified as enterotoxic, enterohemorrhagic, enteroinvasive or entero-pathogenic [23].

6.2 *Listeria monocytogens*

Listeria can be found almost everywhere including water, decaying vegetation, sewage and animal excrement [24]. It can also be found on harvested vegetables and can potentially cause illness in humans. Recent outbreaks of listeriosis have been reported in Southern Africa [25].

6.3 *Salmonella*

Salmonella may cause diarrhea (salmonellosis) and may lead to death. Salmonella commonly occurs in eggs, raw poultry, beef and in unwashed vegetables. It has been reported that it can pose a health risk in vegetables from Mexico [26].

6.4 *Shigella* spp

Shigella bacteria causes shigellosis in humans this can as a result of consuming contaminated vegetable salads [26].

7. MANAGEMENT OF DISEASES IN HARVESTED VEGETABLES

Bacterial populations in harvested vegetables can be controlled in various ways which include modified/controlled atmosphere storage, refrigeration, chemical treatments and irradiation. Sanitation is also important in order to exclude microorganisms from harvested vegetables. There is need to follow hazard analysis critical control points (HACCP) [6,27,28,29].

7.1 Fungi

Of the more 70 000 fungal species that have been described, only a relatively small number

Table 7. Immediate physical effects caused by the preparation of fresh-cut vegetables

- Mechanical shock to tissue
  - Bruises, cracks, fractures, tears
    - Hydraulic shocks are dispersed or focused by reflective and refractive properties of non-homogenous tissues within the commodity
- Removal of protective epidermal layer
  - Alters gas diffusion
    - Water vapour, O_2, CO_2, C_2H_4
  - Provides entry for contaminants
    - Chemicals. micro-organisms
- Liquid on cut surface
  - Reduces gas diffusion
    - Elevates CO_2, C_2H_4
    - Reduces O_2
  - Accelerates water-loss
  - Provides substrate for microbes
- Liquid in tissue
  - Water in intracellular spaces causes translucent tissue
  - Changes density of the commodity

Source: [11]

Table 8. Physical effects caused by the preparation of fresh-cut vegetables

Elimination of natural barriers
Enhanced gas diffusion
Reduced CO_2, C_2H_4
Elevated O_2
Accelerated water-loss
Entry of contamination
Changes in appearance
White blush formation because of surface debris
Uneven surface resulting from uneven water loss by tissues
Splitting or fracturing resulting from different changes in turgor
Intrusion of water into intracellular spaces causing translucent tissue

Source: [11]

can be regarded as primary post-harvest pathogens of vegetables [19]. Most of these belong to Ascomycota or Deuteromycota, with a few species in the Basidiomycota (all true fungi) or Oomycota (Kingdom Chromista) [19,20]. Important genera of anamorphic post-harvest pathogens include *Penicillium*, *Aspergillus*, *Geotrichum*, *Dothiorella*, *Lasiodiplodia* and *Phomopsis* [17,19,20,29]. Fungal infection may occur in the field or after harvest.

7.2 General Management

There are various ways by which post-harvest diseases may be controlled. Choice of method of control is very important because it has implications on human health and the environment and thus subsequently on sustainable development goals (SDGs) pertaining to people and planet earth.

7.3 Preharvest Factors

There are factors before harvest which influence post-harvest diseases. These include the weather, locality, choice of cultivar, cultural practices (pesticide application, irrigation, fertilization, planting density, mulching, type of production – whether protected or in the open field etc.) and planting material [17,19,20,29]. These factors may have an indirect or direct influence on infection either in the field or after harvest. For example, the application of certain nutrients may improve the strength of the skin of the fruit vegetable so that it becomes less susceptible to injury and therefore less prone to invasion by wound pathogens.

7.4 Genetic Factors

The genetic makeup of an organism including that of vegetables influences its physiology as well as its predisposition to attack by pests. For example, common physiological disorders as affected by genotype, of various vegetables found in the Kingdom of Eswatini have previously been reviewed and ways of alleviating them suggested [30,31,32,33]. The physiological disorders of vegetables were influenced by the genotype and the environmental (GXE) conditions and subsequent predisposition of a given vegetable to post-harvest disease infection. On the other hand, genetic manipulation can influence a commodity's post-harvest shelf life. Genetic manipulation (GM) technologies which interfere with ethylene (C_2H_4) production, perception and action delays senescence and thus keep harvested fruits and vegetables in a state not prone to attack by opportunistic pathogens hence prolonged shelf life which is the utter most desirable goal in post-harvest technology of vegetables. The GM technologies reduce activities associated with cell wall degrading enzymes which prevent harvested fruits and vegetables from attack by post-harvest opportunistic diseases and insect pests [34,35]. Currently in addition to GXE there is GXEX management (GXEXM).

7.5 Injury Prevention

From harvesting through all the post-harvest handling stages up to use by the consumer injury must be prevented by any environmentally friendly means possible. As many post-harvest pathogens gain entry (ingress) through wounds or infect physiologically damaged tissue, prevention of injury at all stages during production, harvest and post-harvest handling is critical [17,19,20,29]. Injuries come in many ways. Injuries can either be mechanical (e.g. abrasions, cuts and bruises), chemical (e.g.burns), biological (e.g. bird, insect or rodent damage) or physiological (e.g. chilling injury, heat injury) [17,19,20,29]. There is need to prevent injury of vegetables along the post-harvest handling chain. Injuries can be minimised by careful harvesting and handling of produce, appropriate packaging of produce, controlling insect pests in the field, storing produce at the recommended temperatures and applying post-harvest treatments correctly [17,19,20,29]. There is need to expose wounded produce to environmental conditions or treatments that promote wound healing. The wound periderm serves as a barrier to prevent entry of disease causing pathogens. Wound healing has been shown to be associated with resistance to certain post-harvest diseases such as bacterial soft rot of potatoes caused by *Erwinia* spp [19,20,29].

7.6 Hygiene Practices

The practice of keeping the commodity clean from harvest along the post-harvest chain is crucial. The working environment must be maintained clean at all times. Good agricultural practices (GAPs) as prescribed in the Global-GAP must be maintained at all times [28]. Workers may be provided with work suits which are washed regularly and have their finger nails cut often so as to avoid wounding of commodities. Ablution facilities should be provided in the field at harvest and the grading and packaging shade. Inoculum for infections occurring after harvest commonly originates from the packing shade and storage environments [19,20,29]. There is need to disinfect equipment and material used in the post-harvest handling chain. Water used for washing or cooling (hydrocooling) produce can become contaminated with pathogen propagules if not changed on a regular basis and if disinfectant such as chlorine is not incorporated [19,20,29].

7.7 Use of Fungicides

The use of fungicides to prevent or control post-harvest diseases of vegetables has been practiced from the time particular fungicides were discovered. Timing of application and type of fungicide used depend primarily on the target pathogens and when infection occurs [20,29]. There is need for strategic or judicious use of protectant and systemic fungicides during the growing season.

7.8 Post-harvest Environment Manipulation

Manipulation of the post-harvest environment of vegetable commodities presents a great opportunity of preventing and controlling diseases. What can be controlled includes temperature and environmental modification. Temperature is perhaps the single most important factor influencing disease development after harvest [29,35]. Temperature not only influences the rates of pathogen growth but also fruit vegetable ripening. Low temperature storage of fruit vegetables is used extensively to delay ripening and the development of disease, although the temperatures commonly used for storage are not lethal to pathogens [29,35]. The ideal temperature for storage depends on the commodity's sensitivity to chilling injury (CI). For example, vegetables of the Solaneous family like tomatoes, egg fruit and peppers suffer from chilling injury if stored above 0^o and below 12.5^{o}C. Chilling injured vegetables are more susceptible to diseases than those that are not injured. The gaseous composition of storage environment can be modified. Modified atmosphere (MA) or controlled atmospheres (CA) mean removal or addition of gases resulting in an atmospheric composition around commodity that is different from that of air (78.08% N, 20.95% O_2, 0.03% CO_2). Usually this involves reduction of oxygen and/or elevation of carbon dioxide (CO_2) concentrations [29,35]. Atmospheric modification is supplement to temperature management. The potential benefits of CAs include retardation of senescence, reduction of fruit sensitivity to C_2H_4 action. Alleviation of certain physiological disorders, directly or indirectly affect post- harvest pathogens and consequently delay incidence and severity of diseases [16].

7.9 Heat Treatments

Physical treatments like heat treatment of harvested vegetable commodities have gained popularity in recent years in replacing the use of chemicals. Hot water or hot air may be used. Heat works by either killing the pathogen (and or its propagules) or by suppressing its rate of development following treatment [19,29]. The pre-requisite for heat treatment is that the commodity is not susceptible to heat injury. A combination of fungicides and heat treatment has proved to be effective in some commodities.

7.10 Radiation

Ionizing radiation is another physical treatment that can be used after harvest to reduce disease in some commodities, like heat, commodities must be able to tolerate dose of ionizing radiation required to achieve disease control [29]. However there are consumer concerns in acceptability of irradiated food.

Table 9. Examples of common post-harvest diseases and pathogens of vegetables

Disease	Pathogen	
	Anarmorph	**Teleomorph**
Vegetables		
Cucurbits		
Bacterial soft rots	Various *Erwinia* spp.	
	Bacillus polymyxa	
	Pseudomonas syringae	
	Xanthomonas campestris	
Grey mould	*Botrytis cinerea*	*Botryotinia fuckeliana*
Fusarium rot	*Fusarium* spp.	
Alternaria rot	*Alternaria* spp.	
Charcoal rot	*Macrophomina phaseolina*	
Cottony leak		*Pythium* spp.
Rhizopus rot		*Rhizopus* spp.
Tomato, Eggplant and Capsicum		
Bacterial soft rots	Various *Erwinia* spp.	
	Bacillus polymyxa	
	Pseudomonas spp.	
	Xanthomonas campestris	
Grey mould	*Botrytis cinerea*	*Botryotinia fuckeliana*
Fusarium rot	*Fusarium* spp.	
Alternaria	*Alternaria* spp.	
Cladosporium rot	*Cladosporium* spp.	
Rhizopus rot		*Rhizopus* spp.
Watery soft rot		*Sclerotinia* spp.
Cottony leak		*Pythium* spp.
Sclerotium rot	*Sclerotium rolfsii* (sclerotial state)	*Aethalium rolfsii*
Legumes		
Grey mould	*Botrytis cinerea* B. *fabae*	*Botryotinia fuckeliana*
White mould and watery soft rot		*Sclerotinia* spp.
Cottony leak		*Pythium* spp.
Sclerotium rot	*Sclerotium rolfsii* (sclerotial state)	*Aethalium rolfsii*
Brassicas		
Bacterial soft rots	*Various Erwinia spp.*	
	Bacillus spp.	
	Pseudomonas spp.	
	Xanthomonas campestris	
Grey mould	*Botrytis cinerea*	*Botryotinia fuckeliana*
Alternaria	*Alternaria* spp.	
Alternaria	*Alternaria* spp.	
Watery soft rot		*Sclerotinia* spp.
Phytophthora rot		*Phytophthora porri*
Leafy vegetables		
Bacterial soft rots	*Various Erwinia spp.*	
	Xanthomonas campestris	
	Pseudomonas spp.	
Grey mould	*Botrytis cinerea*	*Botryotinia fuckeliana*
Watery soft rot		*Sclerotinia* spp.
Onions		
Bacterial soft rots	Various *Erwinia* spp.	
	Pseudomonas spp.	
	Lactobacillus spp.	
Black mould rot	*Aspergillus niger*	
Fusarium basal rot	*Fusarium oxysporum* f.sp. *cepae*	

Disease	Pathogen	
	Anarmorph	**Teleomorph**
Smudge	*Colletotrichum circinans*	
Carrots		
Bacterial soft rot	Various *Erwinia* spp. *Pseudomonas* spp.	
Rhizopus rot		*Rhizopus* spp.
Grey mould	*Botrytis cinerea*	*Botryotinia fuckeliana*
Watery soft rot		*Sclerotinia* spp.
Sclerotium rot	*Sclerotium rolfsii* (sclerotial state)	*Aethalium rolfsii*
Chalara	*Chalara thielavioides*	
Thielaviopsis	*Thielaviopsis basicola*	
Potatoes		
Bacterial soft rot	*Erwinia* spp.	
Dry rot	*Fusarium* spp.	*Gibberalla* spp.
Gangrene	*Phoma exigua* var *exigua and* var *foveata*	
Black scurf	*Rhizoctonia solani* (sclerotial state)	*Thanatephorus cucumeris*
Silver scurf	*Helminthosporium solani*	
Skin spot	*Polyscytalium pustulans*	

Source: [29]

8. NOVEL TECHNOLOGIES FOR POST-HARVEST DISEASE CONTROL

New technologies for post-harvest disease control of vegetables have been developed to answer consumer concerns of the presence of pesticides in food commodities. A number of new approaches to control post-harvest diseases are currently under investigation, including biological control, natural fungicides and constitutive or induced host resistance.

8.1 Biological Control

Biological control can be defined as the control of one organism using another organism. In recent years, there has been considerable interest in the use of antagonistic microorganisms for the control of post-harvest diseases [17,19,29]. Antagonistic microorganisms can be isolated from their natural habitats like surface of leaves and fermented food products. Wound pathogens can be controlled by antagonistic microorganisms. To be effective against wound pathogens, an antagonist must be able to successfully colonise wound sites to the exclusion of the pathogen. Antagonists which act against post-harvest pathogens by competitive inhibition at wound sites include the yeasts *Pichia guilliermondii*, *Cryptococus laurentii* and *Candida* spp [17,19,29].

8.2 Natural Fungicides

Some compounds produced by plants themselves and microorganisms have antifungal properties. Chitosan, for example, it is not only an elicitor of host defence responses but also direct fungicidal action against a range of post-harvest pathogens. Various spp of *Trichoderma* produce antibiotics that have potent antifungal activity against *Botrytis cinerea*, *Corticium rolfsii* and other plant pathogens [17,19,29].

8.3 Constitutive and Induced Host Resistance

Naturally plants possess various morphological and biochemical mechanisms which are in place before arrival of the pathogen (i.e. constitutive resistance), while others are only activated in response to infection (i.e. induced resistance) [17,19,20,29]. Certain antipathogenic compounds which are high in growing vegetables decline after harvest. Levels of diene compounds can be increased by applying various treatments such as challenge inoculation with either pathogenic or non-pathogenic strains of *Colletotrichum* or by treatment with certain antioxidants or high concentrations of CO_2 [17,19,20,29]. Phytoalexins can be induced in various crops by non-ironizing ultra-C radiation. For example UV treatment of carrot slices induces production of 6-methoxymellen which is an inhibitor to *Botrytis cinerea* and *Sclerotinia sclerotiorum*. [17,29].

8.4 Genetic Manipulation

Genetic manipulation/ where permissible is the deliberate change of genetic makeup of an organism in order to obtain desired traits [34,35,36,37,38]. It has been done in vegetables to prolong shelf life after harvest. Ethylene (C_2H_4) apart from promoting ripening is known to hasten senescence. Senescing vegetables are more susceptible to opportunistic postharvest pathogens. Manipulation of C_2H_4 technologies in order to suppress its production, perception, signal transduction and action will reduce the rate of senescence of vegetables [39,40] and subsequently reduce relative susceptibility to pathogen attack. Suppression of gene expression through anti-sense technologies of cell wall degrading enzymes: pectin methyl esterase (PME) and polygalacturonase (PG) will help keep cell walls of vegetables intact [36,37,38,39]. Relatively more intact cell walls are less susceptible to postharvest diseases.

8.5 Processing of Vegetables

An opportunity of pocessing exists to avoid loss of vegetables due to spoilage by disease causing organisms. Processing can be done to avoid wastage. Several vegetables are harvested, handled and processed using indigenous knowledge systems (IKS) at household level. Due to unaffordability of freezing and chemical processing technologies for preservation, dring has been the predominant method for traditional vegetable preservation, where the dried product is known as *umfuso* in siSwati [41].

8.6 Nutritional and Food Security Issues

Food security, as defined by the United Nations' Committee on World Food Security, means that all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life (IFPRI) [42].

Reduction of the incidence and severity of postharvest diseases of vegetables has a direct and indirect effect on nutritional and food security in the Kingdom. Less use or judicious use, or avoidance of pesticides use on vegetables before and after harvest addresses some of the SDGs pertaining to planet earth and human health. On the other hand making vegetables available with a longer shelf life not only for consumption but until sold for income generation also helps address SDGs pertaining to food and nutritional security for the people in the Kingdom with the view of attaining 2022 vision in a climate smart way! With the aid of information and communication technologies (ICTs) harmony and prosperity may be attained for the people and their aspirations while also catering for future generations.

9. CONCLUSION

Postharvest diseases of vegetables are common in the Kingdom of Eswatini in both the formal and informal markets. Diseases cause loss of potential food items. Losses must be avoided by preventing or controlling diseases from the field, through postharvest handling, storage and marketing. Previously chemicals (fungicides and bactericides) were used to control diseases. However, in recent years there has been a shift to avoid use of pesticides on food items. Novel control methods are preferred these days such methods include physical methods and biological control which are environmentally friendly. Alternatively the usually highly perishable vegetables can be processed before spoilage caused by diseases.

10. RECOMMENDATION

There is need for constant monitoring of postharvest diseases of vegetables by all stakeholders in the Kingdom of Eswatini. At the border gates where vegetables come into the country there is need for phytosanitary experts to identify and block entry of diseased vegetables. Ultimately there may be need to develop a compendium of postharvest diseases for use in the country.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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