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Domestic quarantine: An introspection and future perspectives on biosecurity interventions to contain pathogen spread in vegetatively propagated spices in India

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Abstract

Safeguarding biodiversity poses a major challenge that warrants preventive legislative and regulatory frameworks to ensure biosecurity, preserve intrinsic biodiversity and mitigate risks from the invasion of exotic pathogenic microbes thereby sustaining agricultural productivity and food safety. The anthropogenic activities contribute enormously towards transboundary movement of invasive alien pathogens through trade and transport of seeds/propagation materials that need to be regulated by enacting appropriate laws and policy guidelines. Black pepper, cardamom, ginger, turmeric and vanilla are the major vegetatively propagated spices cultivated in India. Since primary spread of the major pathogens in these spices are mediated through planting materials, it is imperative to formulate guidelines for flawless and meticulous implementation of quarantine measures which are otherwise not adopted. This review discusses the significance of domestic quarantine in major vegetatively propagated spices with a comprehensive background on plant biosecurity and invasive plant pathogens which could pose threat to spice cultivation in India. It further illustrates the constraints and possible strategies to annihilate the cryptically disseminated pathogens through vegetative planting materials ultimately to safeguard our self-sustaining agricultural systems.

Keywords: biosecurity, invasive pathogens, legislation, quarantine, spices, vegetative propagation

Introduction

The Indian economy depends on agriculture, the mainstay of millions, assuring nutritional-cum-financial security and provides raw materials to several agro-based industries. Evolving varieties with high yield potential, desirable agronomic traits, resistance to various biotic and abiotic stresses assumes a critical role in scaling-up agricultural production. Over the years, countries pan globe have developed interdependency and sustenance on numerous vital resources for holistic development of economy and stabilizing agricultural production. Exchange/movement of planting materials as germplasm, genotypes, varieties, landraces and wild relatives across geographical boundaries of continents, countries and states for varied reasons might lead to inadvertent introduction and subsequent establishment of alien biotic agents which might pose a threat to biosecurity and biodiversity. In this context, protection of biodiversity by preventing invasion of exotic pathogens assumes paramount importance and highlights the need for enacting rules and regulations through legislation.

Plant biosecurity

Plant biosecurity, the ever increasing challenge across the globe, has far-reaching impacts on food safety/security, trade, market access/ development, production costs, profitability and sustainability of industries dependent on the agricultural sector. As a robust resourceful platform, it proficiently converges legislative and regulatory frameworks to analyze, interpret and manage risks related to biodiversity *in toto*, health and environment to ensure agricultural sustainability, food safety and environmental protection. Plant biosecurity is defined as a set of measures designed to protect a crop, crops or a subgroup of crops from emergency plant pests at national, regional and individual farm levels (McKirdy *et al*. 2008). It envisages comprehensive strategies to protect the country from alien pests during transboundary transit of commodities (through quarantine), evolving indigenous diseases, from genetically modified organisms (GMOs) and the deployment of pathogens/GMOs in bioterrorism/warfare. Some of the major sectors that have a profound influence on plant biosecurity are depicted in Fig. 1.

Ensuring biosecurity: Legislative measures

The majority of developing countries are hot spots of abundant genetic diversity with respect to major agricultural crops. Nevertheless, several resource less countries largely depends on exotic crops and introduced germplasm for research programmes, to ensure food/ nutritional security and comprehensive agricultural development. In the global scenario, no country is self-sufficient in the genetic repository to fulfil its requirement and have become highly interdependent on non-indigenous species leading to extensive movement of germplasm across the globe (Ghimiray & Vernooy 2017). The escalating global trade in agriculture-related commodities and large-scale transboundary movement of plant genetic materials led to the situations which warranted enacting stringent legislative measures and their flawless implementation to regulate trade/exchange. Transboundary movement of pathogens is principally effected through various channels *viz*., (a) host plant (b) inert materials such as packing material (c) birds and insect vectors (d) air currents and (e) deliberate, illegal introductions. The first two platforms of introduction lend themselves to restriction by adopting appropriate quarantine procedures. The succeeding two are the major limitations in enforcing pest control through exclusion and unfortunately beyond the capacities of human intervention wherein, diverse degrees of alertness and preparedness are required to tackle them (Khetarpal & Gupta 2007).

Rapid globalization and progress in transport, travel and tourism combined with liberalization of trade policies increase risks due to invasion of exotic and invasive pests having potentially devastating impacts on food security. Introduction of pathogens into new geographical regions and their switching to new/susceptible hosts through physiological adaptations is a major factor facilitating the emergence of novel virulent lineages that threaten food security. Unprecedented epiphytotic outbreaks, the resultant of a spatio-temporal synchronization of three vital pre-requisites *viz*., susceptible host, virulent pathogen and conducive environment could cripple the economy, paralyze the nation and devastate agriculture production scenario. Lack of awareness regarding seed/planting transmitted pathogens, their devastating potential, ambiguity on history of origin of planting materials and lack of sufficient certified accredited nurseries to cater the need of farming community still pose challenges to curtail the threats posed by invasive pests.

Plant quarantine is the legally enforced restriction on the movement of agriculture-related commodities which are intended for exclusion, prevention or delay in the establishment of invasive weeds, pests or pathogens in regions where they are absent

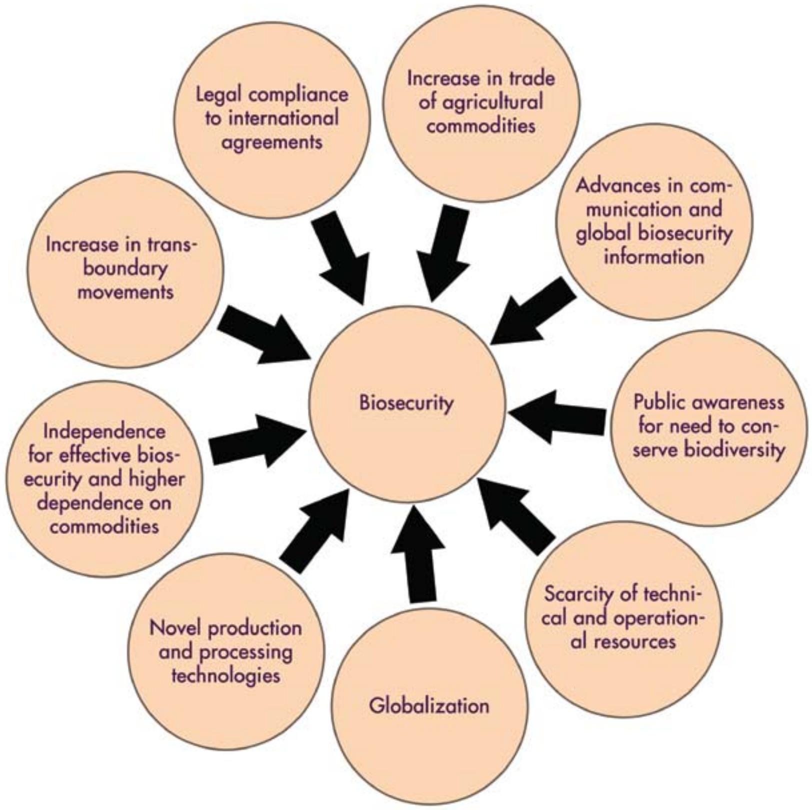

Fig. 1 Integrated framework of sectors relevant to biosecurity

or to impede their multiplication if already gained entry and established in new areas.

The devastating consequences of pest/disease introduction facilitated through international transport of planting materials, agricultural produce and products are documented in several instances. The historical famine that Ireland witnessed during 1845-1849 due to potato late blight pandemics introduced from Central America to Ireland is a classic example. In Sri Lanka, coffee was replaced by tea as a plantation crop due to the widespread epiphytotics of coffee leaf rust. Citrus fluted scale introduced from Sri Lanka (1928), San Jose scale infesting apple introduced during 1930s, banana bunchy top from Sri Lanka (1943), golden nematode infesting potatoes from the United Kingdom (1960s), the noxious weed, *Lantana camara* introduced from Central America, *Pyricularia oryzae* (*Magnaporthe grisea*) introduced from South East Asia and *Xanthomonas oryzae* pv. *oryzae* invaded from Philippines (1959) are some of the evident examples that undoubtedly demonstrated that introduction and establishment of pests of quarantine importance into new areas have adverse impacts on agricultural economy of a region/country. From the Indian perspective, detailed descriptions on invasive exotic insect pests and pathogens are narrated by Singh *et al*. (2016) and Singh *et al*. (2020).

India being a signee to three major agreements related to plant health management such as the International Plant Protection Convention, World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures and Convention on Biological Diversity, it is of paramount importance to assess the invasive pest/pathogen adopting appropriate Pest Risk Analysis (PRA) approach. Risk analyses on exotic pathogens in areas under threat depend on the occurrence of host species, inoculum potential and prevalence of conducive weather. Further, inherent features of invading pathogens including adaptable spore phases, wide host array, capability to tolerate the environment/microclimate, manifold reproductive styles and switching lifestyle patterns influence outbreak of a disease. The exotic pathogen (a) may be more or less damaging in a new environment (b) may rapidly acclimatize with the environment and inflict more damages and (c) may interbreed with other strains/species leading to the emergence of more virulent types (Giraud *et al*. 2010; Fisher *et al*. 2012).

Domestic quarantine regulations

The Destructive Insects and Pests (DIP) Act legislated by the Government of India during 1914 provide provisions for imposing domestic quarantine in order to check the movement of certain planting materials across different states. In 1984, a notification namely Plants, Fruits and Seeds (Regulation of Import into India) Order (PFS Order) was issued under this Act which was subsequently revised during 1989 consequent to the announcement of New Policy on Seed Development 1988 proposing major amendments for smooth implementation of quarantine policies. The Plant Quarantine (Regulation for Import into India) Order 2003 (https://www.fao.org/faolex/results/details/en/c/LEX-FAOC149142/) now supersedes this order formulated to address the issues pertaining to import of germplasm/ transgenic plant material/live insects/biocontrol agents/ genetically modified organisms etc. to satisfy India's legal obligations envisioned under international treaties.

Domestic quarantine envisages the measures to eradicate and hinder further spread of pathogens (both indigenous as well as introduced) with limited distribution within the country. In India, the awareness towards quarantine measures was initiated during 1906 in which the government ordered mandatory fumigation of imported cotton bales to prevent introduction of Mexican cotton boll weevil. During 1944, the central government issued first domestic quarantine notification against the fluted scale. Similar notifications were also issued to prevent the spread of bunchy top disease of banana from Assam, Kerala, Odisha and Tamil Nadu (1951), San Jose scale (1953), potato wart in which movement of potato from West Bengal was prohibited (1959) and apple scab in Himachal Pradesh in 1977. Other pests of quarantine importance include, codling moth, coffee berry borer and potato cyst nematode (Khan *et al*. 2017). Thomas *et al*. (2015) analyzed the possible pathways favouring transboundary movement of coconut root (wilt) disease through planting materials and suggested regulatory frameworks for preventing its introduction into disease-free regions. The entry, establishment and subsequent dissemination of the invasive alien species are mainly due to the lack of awareness among stakeholders, inadequate surveillance, containment as well as eradication programmes. It is highly indispensable to formulate guidelines to combat the possible threats from bio-invasion of pests. Developing comprehensive macro-level spatial designs encompassing maximum probable pathogens in the region and delineating areas climatically favouring the possible invasion are certain essential pre-requisites to formulate appropriate policies. There is also a need for capacity building to enhance sanitary and phytosanitary (SPS) compliance and competitiveness to augment market access in international trade. However, considering the genetic diversity, climatic variability prevalent over various agro-ecological zones which generally favour rapid spread and establishment of diseases in spice cultivating regions, domestic quarantine has not attracted sufficient attention of both scientific and policy making communities in India.

Black pepper (*Piper nigrum* L.), cardamom (*Elettaria cardamomum* Maton), ginger (*Zingiber officinale* Rosc.), turmeric (*Curcuma longa* L.) and vanilla (*Vanilla planifolia* Andrews) are the major vegetatively propagated spice crops cultivated in India (Fig. 2). The major production constraints in spices are diseases incited by oomycetes, fungi, viruses, bacteria and nematodes. Though the secondary spread of these pathogens is mediated through soil, water, wind, weeds, agricultural implements etc. the primary dispersal and dissemination occurs through planting materials which has serious implications on biosecurity. Propagation and large-scale multiplication

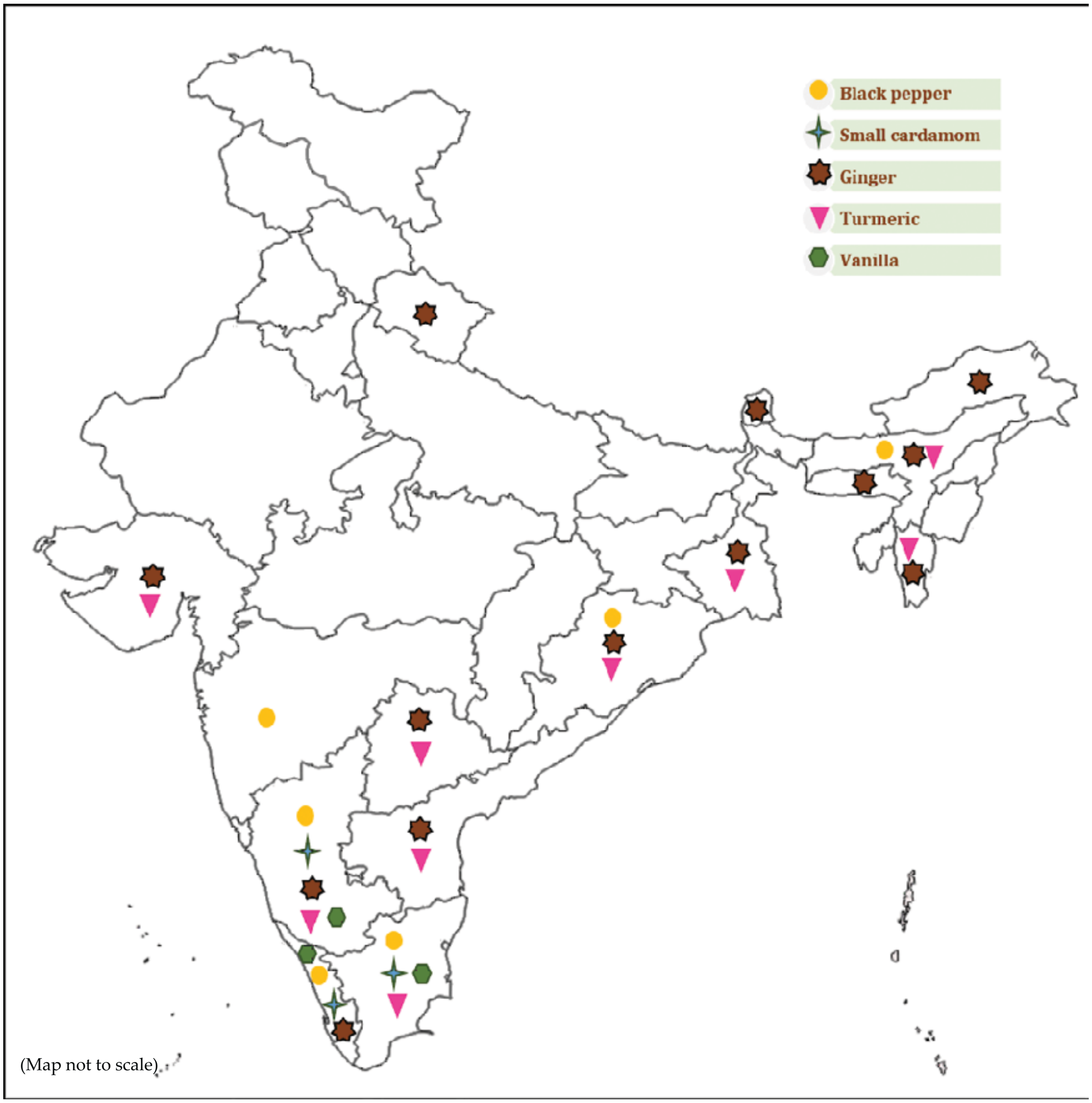

Fig. 2 Distribution of major vegetatively propagated spices in India

of major spice crops like black pepper, cardamom, ginger, turmeric and vanilla are effected through vegetative means. Hence, it is highly imperative to have a thorough insight into the pathogens associated with these principally vegetatively propagated spices. A comprehensive knowledge in this aspect also would help to formulate guidelines for the implementation of quarantine measures which are otherwise not adopted in spices. Some of the diseases presumably with domestic quarantine importance are depicted in Table 2.

Transboundary movement of plant pathogens in spices and aftermath

When plant pathogens are introduced into newer regions, they are likely to cause catastrophic epiphytotics compared to native pathogens. However, it is extremely challenging to accurately foresee whether an exotic organism will be able to establish and once established, become economically significant. Factors which influence entry and establishment of an organism includes hitchhiking potential compared with natural

Table 1. Occurrence and distribution of some important diseases of major vegetatively propagated spices

Crop	Disease/Pathogen	Country/Region	Reference
Occur in other countries and not in India			
Black pepper	Root rot and stem blight (*Fusarium solani* f. sp. *piperis*)	Brazil, Malaysia, Costa Rica, Vietnam	Duarte & Albuquerque (1991), Shahnazi *et al*. (2012), Thuy *et al*. (2013)
Cardamom	Erwinia rot (*Erwinia chrysanthemi*)	Papua new Guinea	Tomlinson & Cox (1987)
Ginger	Rhizome and stem rot (*Sclerotium rolfsii*)	Africa/Pacific Ocean Islands	Okwuowulu (2005)
	Rhizome rot (*Armillariella mellea*)	Africa/Pacific Ocean Islands	Okwuowulu (2005)
Occur in India and other countries			
Black pepper	Foot rot (*Phytophthora* spp.)	Indonesia, Malaysia, Brazil, Ethiopia	Holliday & Mowat (1963), Sarma *et al.* (1992), Kueh & Sim (1992), Manohara *et al.* (1992)
	Stunt disease/mosaic (cucumber mosaic virus and piper yellow mottle virus)	Brazil, Indonesia, Philippines, Sri Lanka, Malaysia, China, Vietnam	Duarte & Albuquerque (1991), Lockhart *et al.* (1997), de Silva *et al*. (2002), Che *et al.* (2021)
	Slow decline (*Radopholus similis* & *Meloidogyne* spp.)	Malaysia, Indonesia (as Yellows disease)	De Waard (1979), Zaragoza *et al.* (1991), Sitepu & Kasim (1991), Kueh & Sim (1992), Varughese & Anuar (1992)
	Anthracnose (*Colletotrichum* spp.)	Malaysia and Indonesia	Kueh *et al.* (1993), Anandaraj (2000)
Cardamom	*Katte*/mosaic	Guatemala	Gonsalves *et al*. (1986)
Ginger	Soft rot (*Pythium* spp.)	China, Bangladesh, Japan, Australia, Fiji, Hawaii, Korea, Taiwan, Malaysia, Nigeria, Sri Lanka	Meenu & Kaushal (2017)
	Bacterial wilt (*Ralstonia pseudosolanacearum*)	Australia, China, Ethiopia, Indonesia, Japan, Malaysia, Mauritius, Nigeria, South Korea, Thailand, Philippines, Hawaii	Prameela & Suseela Bhai (2020)
	Leaf spots (*Phyllosticta* and *Colletotrichum*)	China, Malaysia, Tanzania	Okwuowulu (2005), Xizhen *et al*. (2005)
	Fusarium yellows (*Fusarium oxysporum* f.sp. *zingiberis*)	Australia, Hawaii, South Africa	Trujillo (1963), Gupta & Kaushal (2017)

Table 2. Diseases of domestic quarantine importance in vegetatively propagated spices

Disease	Causal agent	Survival	Sources of primary spread	Secondary spread
Black pepper				
Foot rot	*Phytophthora* spp.	Chlamydospores and thickened mycelium in soil	Infected planting material, contaminated soil	Root contact, rain/ irrigation water, wind
Anthracnose	*Colletotrichum* spp.	Microsclerotia in the runner shoots/ infected leaves	Infected planting material, infected leaves of preceding season	Rain splash, wind
Stunt disease	Cucumber mosaic virus, piper yellow mottle virus	Infected planting materials	Infected planting materials, seeds (PYMoV)	CMV: Mechanical PYMoV: Mealybugs (*Ferrisia virgata* and *Planococcus citri*)
Cardamom				
Leaf blight	*Colletotrichum* spp.	Infected planting materials, crop debris	Infected planting materials, crop debris	Rain splash, wind
Stem lodging	*Fusarium oxysporum*	Infected planting materials, crop debris	Infected planting materials, crop debris	Rain splash, wind
Katte/mosaic	cardamom mosaic virus	Infected planting materials	Infected planting materials	Aphid (*Pentalonia caladii*)
Chlorotic streak	banana bract mosaic virus	Infected planting materials	Infected planting materials	-
Kokke kandu	cardamom vein clearing virus	Infected planting materials	Infected planting materials	Aphid (*Pentalonia caladii*)
Ginger				
Soft rot	*Pythium myriotylum, P. aphanidermatum, P vexans*	Infected rhizomes and contaminated soil	Infected rhizomes, contaminated soil	Root contact, rain, irrigation water
Bacterial wilt	*Ralstonia pseudosolanacearum*	Infected rhizomes and contaminated soil	Infected rhizomes, contaminated soil	Root contact, rain/ irrigation water
Leaf spot	*Phyllosticta zingiberi*	Infected rhizomes	Infected rhizomes	Rain splash, wind
Chlorotic fleck	ginger chlorotic fleck-associated virus-1 and ginger chlorotic fleck-associated virus-2	Infected rhizomes	Infected rhizomes	-

Turmeric				
Rhizome rot	*Pythium aphanidermatum, P. graminicolum*	Infected rhizomes	Infected rhizomes	Rain, irrigation water
Plant parasitic nematodes	*Pratylenchus* spp.	Infected roots and rhizomes	Infected seed rhizomes	Contaminated soil, water, farm implements
Vanilla				
Viruses	cucumber mosaic virus, cymbidium mosaic virus, odontoglossum ring spot virus, vanilla distortion mosaic virus, dasheen mosaic virus, bean common mosaic virus, bean yellow mosaic virus, ornithoglossum mosaic virus and watermelon mosaic virus 2	Infected planting materials	Infected planting materials	Aphids and other insect vectors

dispersal, ecological range, prevailing weather conditions, rapidity in colonization, reproductive potential and agricultural practices including pest management. Survival, dispersal, establishment and secondary spread are the basic interconnecting links in the life cycle of a pathogen and the intricate network leading to epiphytotics with the conjunction of susceptible host, virulent pathogen and favourable weather over a period of time with possible interventions of human beings (Agrios 2005). Articulating skilful management tactics warrants comprehensive analyses and in-depth understanding of these vital processes *vis-a-vis* host/weather and timely interventions with appropriate measures. The consequences of biosecurity breach with respect to major spices can be discussed from host, pathogen and environmental perspectives keeping aside the involvement of human component.

Host

Host plant resistance is the most economic and effective strategy for disease management owing to environmental, social and economical reasons. Genes conferring resistance to diseases can technically be considered as one among the valuable natural resources undoubtedly determining survival of mankind, whereas evolutionary potential of pathogens to conquer the gene and adapt to host resistance makes worthy stewardship critical to accomplish sustainable usage of this valuable resource (McDonald & Linde 2002; Mundt 2014). Majority of the economically important spice crops are vegetatively propagated which maintains desirable traits (genetic purity) of the mother progenitor. Large-scale cultivation of varieties with uniform genetic background (the at-risk population) invariably susceptible to major pathogens and lack of varietal diversity with multiple desirable traits invariably leads to epiphytotics (Nagarajan 1981). Expansion of area to new/non-conventional geographical regions is faster in ginger and turmeric that are highly vulnerable to majority of the seed-borne pathogens.

Pathogen

Plant diseases incited by diverse spectra of pathogens continuously tend to evolve through mutation/recombination, thereby generating new strains for survival in the ecosystem (Islam 2018). Long-distance dispersal of pathogens surpassing the natural barricades erected by nature is principally effected through movement of planting materials. Pathogens that invade vascular tissues and systemic pathogens like viruses surviving without inducing any apparent diagnostic visible symptoms might become seed-borne and later seed-transmitted. Pathogens may also be transmitted as a contaminant (without infecting the host tissues) as infective propagules on the surface of planting material or in the contaminated soil particles adhering to the propagation materials. The most striking feature of spice pathogens is that majority are endemic. However, extreme care should be taken to use disease-free planting material for replanting purpose and establishing cultivation so as to impede the entry and establishment of pathogenic microbes into new areas.

Most of the pathogens affecting major spices proliferate during monsoon which makes it difficult to adopt management measures once secondary spread occurs in the field. Possibility of introduction of pathogenic strains which might be more virulent/aggressive and possibly resistant to normal doses of plant protection chemicals. These strains might interbreed with the local strains leading to the emergence of super pathogens. The pathogens infecting major spices are endowed with certain intrinsic traits like highly proliferative, high reproductive potential, faster secondary spread through enormous propagative units or through insect vectors, high survival potential in soil and crop residues as perennating dormant structures, plasticity in incubation/latent period, highly virulent and host switching/adaptability. Emergence of a disease in a diverse crop ecosystem is greatly influenced by host range of the invading pest. The migrant pathogens can be demarcated either as specialists (narrow host range) or generalists (infect several unrelated host genera) (Barrett *et al.* 2009; Navaud *et al.* 2017). Host switching rather than co-speciation has been demonstrated as a dominant factor assuming a strategic role in diversified host-pathogen associations in which specialized pathogens ecologically embrace the sloppy fitness space thereby promoting migration towards new niches (Araujo *et al*. 2015).

Environment

Crop architecture and innate natural microclimate appear to be the determining factors that favour epiphytotics of various diseases in spice-based ecosystems. Besides the infectious biotic elements, the ever changing weather, often manifested as erratic precipitation and temperature instabilities over a time frame have unforeseen effects which may pose a threat to the agricultural system in which spices are cultivated either as principal or component crops. Climatic conditions directly influence longevity of perennating organs of the pathogens. In spices, most of the foliar and soil-borne diseases make its appearance during the monsoon. The conducive weather conditions including rainfall, rainy days, ambient temperature, air currents and relative humidity favour rapid multiplication and swift dissemination of the pathogen.

Symptomatology: The visual-based primary diagnostic tool

A compatible host-pathogen interaction triggers complex chain of physiological as well as structural responses at cellular level, externally manifested as symptoms, which is the oldest and traditional method employed for disease diagnosis effected through visual analysis. Accurate diagnosis of the disease is the most critical exercise so that specific need-based treatments to combat the pathogen(s) involved can be tailored. A comprehensive knowledge on the objective evidence of a disease, the symptoms is a pre-requisite during nursery and field examinations undertaken as a measure for selecting mother stocks/planting materials. The prominent diagnostic symptoms induced by various pathogens are summarized in Table 3.

Table 3. Diagnostic symptoms of major diseases in vegetatively propagated spices

Crop	Disease	Suspected Pest/ Pathogen	Symptoms
Black pepper	Foot rot	*Phytophthora capsici*, *P. tropicalis*	Blackish lesions with fimbriate margins on leaves, yellowing, defoliation, spike shedding, blackening of collar region, withering, necrosis of tender leaves and succulent shoot tips, wilting
	Slow decline	Plant parasitic nematodes	Persistent yellowing, wilting and decline, especially during summer months; lesions/galls, rotting of feeder roots
	Fungal *pollu*/ Anthracnose	*Colletotrichum syzygicola, C. queenslandicum, C. siamense, C. endophytica, C. guajavae*	Yellowish/dark brown circular spots with chlorotic halo (nursery) and circular/angular brownish lesions with yellow halo (field) on leaves, brown/ black necrotic lesions on shoots, spike shedding, brownish splits on mature berries
	Stunt disease	cucumber mosaic virus, piper yellow mottle virus	Mosaic, mottling, rough, leathery and narrow malformed leaves, stunting
Cardamom	*Chenthal*/ Leaf blight	*Colletotrichum karstii*, *C. gloeosporioides, C. siamense, C. syzygicola, C. guajavae, Neopestalotiopsis clavispora*	Water soaked lesions later turning yellowish brown to orangish-red streaks with necrotic center, withering of leaves
	Azhukal/Capsule rot	*Phytophthora meadii*	Water soaked lesions on young leaves and capsules, failure of immature unopened leaves to unfurl, shrivelling and shredding of leaves, rotting of capsules, panicles and rhizomes
	Phytophthora leaf blight	*Phytophthora nicotianae var. nicotianae*	Formation of water soaked patches on young and unopened leaves which turn necrotic and dries
	Stem lodging	*Fusarium oxysporum*	Pale discoloured patches on tillers leading to dry rot, breakage/toppling of tiller, withering of leaves and leaf sheaths
	Katte/mosaic	cardamom mosaic virus	Discontinuous yellowish stripes on leaves, mottling of leaf sheaths, short, slender tillers with few short panicles
	Chlorotic streak	banana bract mosaic virus	Spindle-shaped intravenous streaks along veins and midribs on leaves, spindle-shaped mottling on petiole and pseudostem
	Kokke kandu/ Cardamom vein clearing disease	cardamom vein clearing virus	Chlorotic veins, rosetting, loosening of leaf sheath and shredding of leaves, formation of hook-like tillers due to entangling of leaves, mottling on pseudostem, light green patches with shallow grooves on immature capsules

Ginger	Soft rot	*Pythium myriotylum, P. aphanidermatum, P vexans*	Yellowing, withering of leaves, pale translucent discolouration at basal portion, toppling of shoots, rhizomes decompose into putrefying tissue emitting foul smell
	Bacterial wilt	*Ralstonia pseudosolanacearum*	Yellowing, downward curling of leaves, wilting, rhizomes putrify emitting foul smell
	Phyllosticta leaf spot	*Phyllosticta zingiberi*	Spindle/oval/elongated spots with papery white center and dark brown margins with yellow halo on younger leaves, later forming shot-holes
	Fusarium yellows	*Fusarium oxysporum*	Premature drooping, marginal yellowing and drying of lower leaves, wilting and drying of aerial shoots, creamish/brown discolouration with shrivelling and vascular rotting of rhizomes
	Chlorotic fleck	ginger chlorotic fleck virus 1 and 2	Intravenous light green/yellowish discrete or coalescing streaks on foliage, pseudostem mottling
Turmeric	Rhizome rot	*Pythium aphanidermatum, P. graminicolum*	Rotting of collar region, water soaking of pseudostem extensive foliar yellowing, collapse of the aerial tillers and decay of rhizomes
	Lesion nematodes	*Pratylenchus* spp.	Stunting and yellowing of leaves, lesions and necrosis on roots and rhizomes
Vanilla	Virus diseases	cucumber mosaic virus, cymbidium mosaic virus, odontoglossum ring spot virus, dasheen mosaic virus, vanilla distortion mosaic virus, ornithoglossum mosaic virus, watermelon mosaic virus 2, bean common mosaic virus, bean yellow mosaic virus	Mosaic or mild mottling with chlorotic specks or streaks on the leaves and rarely on stems, stunting, sterility and leaf distortions

Significance of domestic quarantine in vegetatively propagated spices: Cardamom as a model system

Among the spices, alike black pepper, ginger, turmeric and vanilla, commercial and large-scale propagation of cardamom is effected through vegetative means. All the viral diseases and some fungal pathogens are primarily transmitted through the planting materials originating from endemic regions. Early and accurate diagnosis of diseases and subsequent rejection of the planting materials as well as omission of the hot spots from collecting planting materials are considered as tactical approaches to prevent dissemination of pathogenic microbes from one region to another. Survey and surveillance programmes supplemented with correct diagnosis of diseases and generating information on the endemic regions are essential for successful implementation of domestic quarantine in spices.

With respect to vegetatively propagated spices, as per Madras Pests and Diseases Act 1919, quarantine regulations were successfully enforced to curtail the spread of *Katte*/mosaic disease of cardamom from Anamalai to Nelliampatti (Thomas *et al*. 2015). Extensive surveys and surveillances undertaken in major cardamom cultivating regions have resulted in identifying endemic regions of certain diseases (Fig. 3). *Katte* caused by cardamom mosaic virus is a major production constraint and surveys conducted in 84 cardamom plantations in 44 locations of Karnataka and Kerala indicated that the incidence was in the range of 0 to 85% with the highest in Kodagu (Karnataka) while no incidence was recorded in Peermade (Kerala). In general, the incidence was higher in cardamom plantations of Karnataka (Biju *et al*., 2010). Whereas, the incidence of chlorotic streak caused by banana bract mosaic virus was in the range of 0 to 15% in major cardamom cultivating tracts of Kerala, Karnataka and Tamil Nadu. Among the 77 plantations representing 49 locations surveyed, highest incidence was recorded in Vythiri, Wayanad, Kerala (Siljo *et al*. 2012). On contrast to *Katte* and chlorotic streak, cardamom vein clearing, another disease of virus origin incited by cardamom vein clearing virus is confined and endemic only to a restricted tract in Sakleshpur and Sorsi regions of Karnataka (Bhat *et al*. 2020). Other pathogens with probable nature of transmission through the planting material include *Colletotrichum* spp. (leaf blight) and *Fusarium oxysporum* (stem lodging). Based on surveys conducted in cardamom plantations located in high ranges of Idukki, Kerala (Vijayan *et al*. (2013) reported the occurrence of rot disease (*Fusarium oxysporum*) affecting the pseudostem with an incidence of 10.6%. Chethana *et al*. (2016) reported the association of *C. karstii*, *C. gloeosporioides*, *C. siamense*, *C. syzygicola* and *C. guajavae* from the samples representing Kerala, Karnataka and Tamil Nadu. Unlike foliar disease incited by *Colletotrichum*, the virus diseases as well as stem lodging once introduced into a new region could pose threat to cardamom cultivation. The dormant survival structures of *Fusarium* (chlamydospores) would persist in soil or dead host residues for long periods and serve as source of inoculum aiding further spread of the disease. While virus diseases spread via vectors (aphids) within the plantation and also to adjacent locations.

A comprehensive information on the occurrence and distribution of diseases of economic significance is highly imperative in implementing domestic quarantine in spices. Based on the survey programmes undertaken to various spice cultivating regions of south India, the information generated on distribution pattern of various diseases are presented in Table 4. In general, the diseases incited by various phytopathogenic genera including *Phytophthora*, *Pythium*, *Ralstonia*, *Rhizoctonia*, *Colletotrichum*, *Phyllosticta*, *Taphrina* etc. are cosmopolitan in nature which may also be transmitted through planting materials. However, based on the information available, some regions that are endemic to certain diseases can be regularly monitored for temporal variations in disease dynamics. While collecting planting materials for large-scale establishment focus should to avoid endemic regions, identification of healthy disease-free mother stocks (indexing with sensitive and reliable nucleic acid tools may be resorted in case of nucleus materials of improved as well as farmer's varieties intended for establishing nurseries) and pre-transport treatment of the planting materials with recommended plant protection chemicals. Creating awareness among the stakeholders, especially the farming community is highly essential to execute domestic quarantine in spices as well as to prevent trans-boundary movement and introduction of diseases into new regions.

Nucleic acid-based diagnostics: Complementing the conventional diagnostic platforms

Symptomatology is undoubtedly considered as the primary tool for diagnosis of a disease. However, symptom-based diagnosis might create ambiguity in accurate identification due to mixed infections, uniformity in expression,

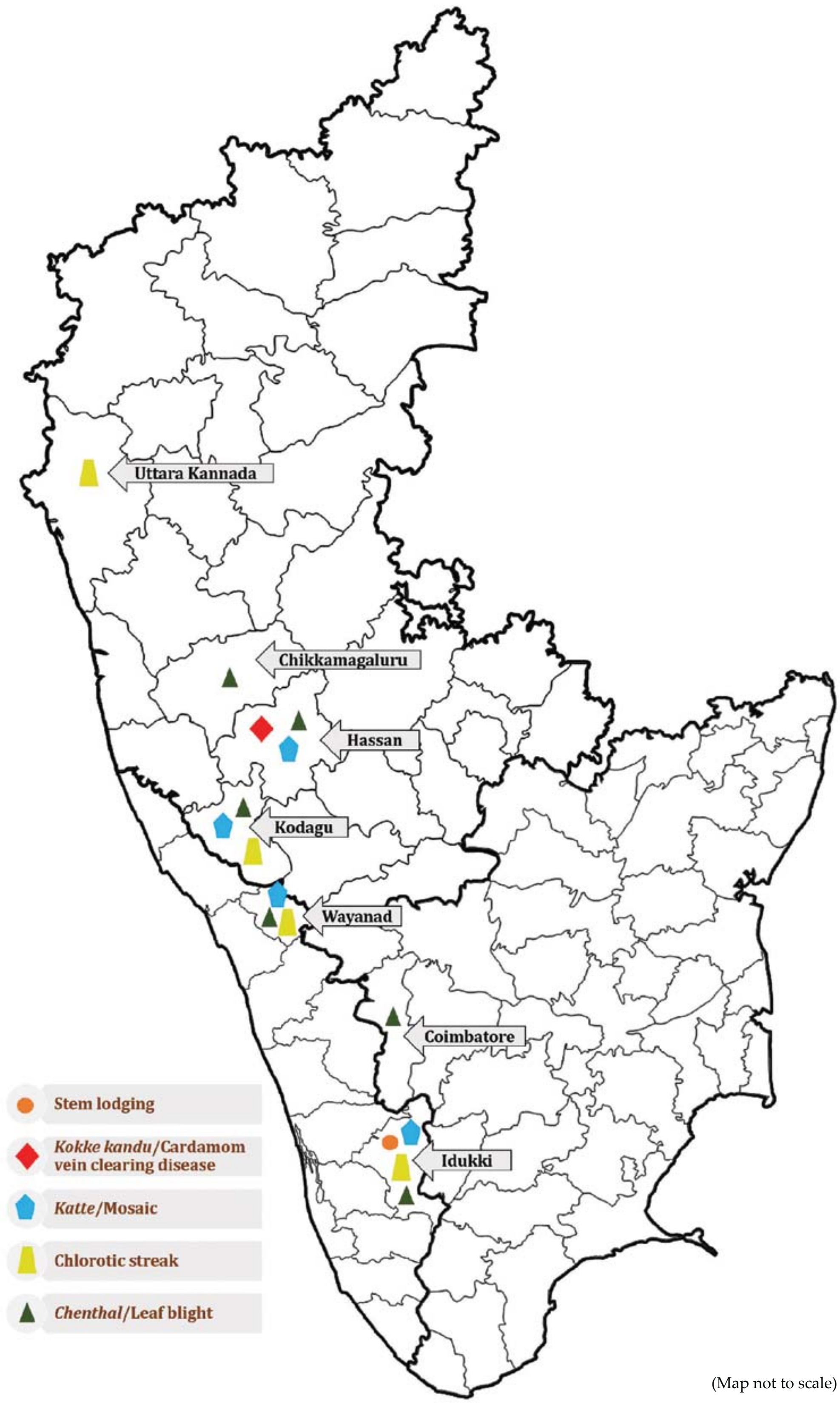

Fig. 3 Occurrence of important diseases of cardamom in major cultivating regions

Table 4. Distribution of important diseases of domestic quarantine significance in vegetatively propagated spices

Crop	Disease	State	District	Reference
Black pepper	Stunt disease	Karnataka	Hassan, Kodagu Uttara Kannada	Bhat *et al*. (2005)
		Kerala	Idukki, Kannur, Kasaragod, Kozhikode, Wayanad	
Cardamom	Stem lodging	Kerala	Idukki	Vijayan *et al*. (2013)
	Katte/Mosaic	Karnataka	Hassan, Kodagu	Biju *et al*. (2010)
		Kerala	Idukki, Wayanad	
	Chlorotic streak	Karnataka	Uttara Kannada, Kodagu	Siljo *et al*. (2012)
		Kerala	Idukki, Wayanad	
	Kokke kandu/Cardamom vein clearing disease	Karnataka	Hassan, Uttara Kannada	Bhat *et al*. (2020)
	Chenthal/Leaf blight	Karnataka	Chikkamagaluru, Hassan, Kodagu	Chethana *et al*. (2016)
		Kerala	Idukki, Wayanad	
		Tamil Nadu	Coimbatore	
Vanilla	Virus diseases	Karnataka	Dakshina Kannada, Udupi, Uttara Kannada	Bhat *et al*. (2004)
		Kerala	Idukki, Kozhikode, Wayanad	
	Other diseases (leaf rot, leaf axil rot, fruit rot, bean rot, stem rot, premature yellowing and bean shedding, yellowing and bean shedding)	Kerala	Kozhikode, Wayanad, Ernakulam, Malappuram	Suseela Bhai & Jithya Dhanesh (2008)
Turmeric	Lesion nematode	Andhra Pradesh	Guntur	Sellaperumal *et al*. (2021)
		Tamil Nadu	Erode, Coimbatore	

confusing with damages induced physiological alterations, nutrition deficiency, damage due to insect pests etc. It is also necessary to index the mother stock as the pathogens may be transmitted asymptomatically. The advent of molecular biology revolutionized diagnostic protocols leading to the development of reliable, rapid and reproducible nucleic acid-based diagnostic tools. Molecular diagnostics for the early detection of pathogens, particularly viruses have been developed and found promising (Table 5).

Need for nursery certification in spices

Authenticity and healthiness are of paramount importance for guaranteeing superior quality of planting materials. Establishment of nurseries with well-defined infrastructure complying the prescribed quality standards is imperative for large scale multiplication and distribution

Table 5. Protein and nucleic acid-based diagnostic tools for major diseases in vegetatively propogated spices

Crop	Disease/pathogen	Protein-based	Reference	Nucleic acid-based	Reference
Black pepper	Foot rot (*Phytophthora capsici* and *P. tropicalis*)			PCR qPCR LAMP RPA	Silvar *et al*. (2005); Aravind *et al*. (2011); Jeevalatha *et al*. (2019) Pandian *et al*. (2018) Yu *et al*. (2019) Jeevalatha *et al*. (2021)
	Slow decline (*Radopholus similis*)			PCR qPCR	Aravind *et al.* (2011) Krishna & Eapen (2019)
	Stunt disease (*Piper* yellow mottle virus)	ELISA	Bhadramurthy *et al*. (2008)	PCR LAMP qPCR RPA	Bhat *et al*. (2009) Bhat *et al*. (2013) Bhat & Siljo (2014) Mohandas & Bhat (2020)
	Stunt disease (cucumber mosaic virus)	ELISA	Bhat *et al*. (2004) Bhadramurthy *et al*. (2008)	RT-PCR qRT-PCR LAMP	Bhat & Siju (2007) Bhat & Siljo (2014) Bhat *et al*. (2013)
Cardamom	*Katte*/Mosaic (cardamom mosaic virus)			qRT-PCR RT-PCR	Siljo *et al*. (2014) Biju *et al*. (2010)
	Chlorotic streak (banana bract mosaic virus)			RT-PCR, qRT-PCR RT-LAMP	Siljo *et al*. (2014) Siljo & Bhat (2014)
	Katte/Mosaic (cardamom mosaic virus)	ELISA	Saigopal e*t al*. (1992)		
	Vein clearing (cardamom vein clearing virus)			RT-PCR, qRT-PCR RT-LAMP RT-RPA	Naveen & Bhat (2020)
Ginger	Bacterial wilt (*Ralstonia pseudosolanacearum*)	NCM-ELISA	Kumar *et al*. (2002)	PCR Real time-PCR LAMP	Kumar & Abraham (2008) Thammakijjawat *et al*. (2006) Prameela *et al*. (2017)
	Ginger chlorotic fleck (ginger chlorotic fleck-associated virus 1 and 2)			RT-PCR, qRT-PCR RT-LAMP RT-RPA	Naveen & Bhat (2020)
Vanilla	Cucumber mosaic virus, cymbidium mosaic virus, odentoglossum ring spot virus, vanilla mosaic virus, vanilla necrosis virus, bean common mosaic virus and bean yellow mosaic virus			RT-PCR	Bhat *et al*. (2006) Madhubala *et al*. (2005) Bhadramurhty *et al*. (2009) Bhadramurthy *et al.* (2011)

PCR, polymerase chain reaction; qPCR, quantitative PCR; RLAMP, loop-mediated isothermal amplification; RPA, recombinase polymerase amplification; RT-PCR, reverse transcription PCR of healthy, disease-free planting materials with assured genetic purity to cater the ever increasing needs of farming community. Meeting the standards that are obligatory in nature is highly essential and nursery accreditation programmes implemented by concerned organizations set up guidelines for ensuring supply of quality planting materials and stifle the dubious market players. The major advantage of nursery accreditation scheme includes; support from governmental machinery, advertisements in government websites creating market opportunities and increased sales, receiving free training on various crop production aspects and high quality propagation materials. In India, to guarantee quality of propagation materials used in Mission for Integrated Development of Horticulture (MIDH) programmes, the Government of India has made it obligatory that the planting materials intended for various schemes including rejuvenation/ replanting/area expansion should be procured from accredited nurseries. The Department of Agriculture, Cooperation and Farmer's Welfare, GOI, has accredited the Directorate of Arecanut and Spices Development (DASD), Kozhikode, Kerala to establish a "Nursery Recognition Regime for Spices" in order to establish a network of recognized model nurseries across the nation to serve as a reliable platform for the supply of authentic planting material of spices. The DAC & FW has also entrusted DASD for accrediting nurseries adopting the prescribed guidelines including infrastructure facilities, quality of planting materials and production systems adopted.

The general guidelines prescribed for accreditation encompasses (a) a well-defined block with authentic mother stock to ensure genetic purity of the planting materials produced (b) establishment of adequate infrastructure with potting media preparation facility, provisions to ensure irrigation and also with sufficient skilled/technical human resources for day-to-day maintenance (c) adopt flawless labelling/tagging procedures for the varieties/planting materials intended for propagation and sale (d) follow standard operating procedures/calendar of operations integrating recommended crop production as well as protection strategies (which shall be displayed in the nurseries as a flowchart) to produce pest/disease-free healthy planting materials (e) ensure documentation through stock registers reflecting the production status and sale along with receipts/bills (f) minimum connectivity to nursery by road or rail (Anonymous, 2021).

Limitations and constraints

Scrupulous implementation of legislative measures enacted to prevent the entry of pathogenic organisms encounters several stumbling blocks particularly with respect to domestic quarantine which may be attributed to vast geographical area of the country and unrestricted transit of plant materials from one region/state to another. As far as spice sector is concerned, enacting appropriate rules to enforce quarantine guidelines on international and domestic quarantine is the need of the hour. Some of the key issues related to spices which warrants domestic quarantine are:

- Lack of quarantine guidelines for spice sector, especially domestic quarantine.
- Lack of organized and coercive action to create awareness regarding the aftermath of post entry spread of biotic agents.
- Lack of plant quarantine check posts at interstate borders at railway and road links.
- Lack of initiatives to identify hot spots/ endemic regions of major diseases based on published information.

Possible remedies

- Establishment of disease-free mother gardens adopting prescribed guidelines with improved/high yielding varieties sourced from authenticated institutions for planting material production and implementation of mandatory certification programmes.
- Development of quick, sensitive and reliable field level diagnostic kits for early detection of pathogens.

- Developing strategies for production/ distribution or sale of healthy planting materials amalgamating all the authorized agencies within the country.
- Establishment of seed portals under the aegis of recognized organizations and mandatory certification of planting materials intended for large scale production. Materials before transit should be subjected to treatment with recommended plant protection chemicals to prevent possible dissemination of pathogens.
- Inspection and certification of nurseries undertaking planting material production through authenticated and certified officials for various pests and diseases at different stages to ensure early diagnosis of diseases.
- Formulating appropriate laws to enforce and enact domestic quarantine policies and also establishing quarantine check-posts at state/district boundaries as a measure to maintain constant vigil on the movement of pathogens of significance and planting materials.
- Issuance of mandatory phytosanitary clearance certificate at quarantine check-posts of state/district boundaries as a measure to prevent the movement of pests/ pathogens of significance through planting materials.
- Flawless implementation of regulatory frameworks at national or regional levels including mandatory seed certification programmes.
- Evolving early diagnosis/warning platforms and trained manpower to curtail dispersal/ eradicate recently introduced diseases in new areas and also to check their subsequent spread and establishment.
- Developing easily accessible and explicit knowledge platforms aligning various strategies for permeation of information on potentially devastating consequences of invasive pathogens and creating awareness on mitigation measures among the farming communities.
- Measures for safe transit of planting materials: (i) mandatory post-transit phytosanitation (ii) avoiding transit combination of collateral host species of pathogens and (iii) traceability of planting material.
- Necessary amendments in existing laws/ acts (if required) to include provisions envisioned to curtail international/interstate movement of invasive organisms thereby harmonizing the quarantine and Export-Import (EXIM) regulations for subsequent enactment.

Future perspectives

Plant biosecurity is vital for any nation in the world to safeguard its food security, ensure sustainability in agricultural production and protecting livelihood of the people. Though alien pest incursion into new regions is not a novel phenomenon, an increase in global trade facilitated rapid entry of obnoxious exotic pathogens to hitherto unknown areas. Perhaps, the inadvertent anthropogenic activities immensely contributed towards such movement of alien pathogens either directly through trade or indirectly by unscrupulous transport of seeds, propagation materials and agricultural commodities. Introduction of plant pathogens through inadvertent movement of plant materials pose a threat to biosecurity. Invasion of alien species possessing high pathogenic potential can pose serve threats due to large-scale cultivation of susceptible hosts and prevailing conducive environmental conditions. India is one among the twelve mega biodiversity hotspots in the world and perhaps highly vulnerable to invasive pathogens. The far reaching consequences of introduction, establishment and secondary spread of pathogens could pose a threat to several agro-ecological zones of India due to its inherent delicate biodiversity and primary dependence on agriculture for day-to-day sustenance.

India, considered as "The Homeland of Spices" is one among the largest producers, consumers and exporters of spices as well as spice products. The major spices such as black pepper, cardamom, ginger, turmeric and vanilla are of prime economic value, contributing considerably to agricultural exports both at global as well as national levels. Vegetative propagation forms the principal method of large-scale multiplication of black pepper, cardamom, ginger, turmeric and vanilla. A thorough analysis on the mode of dissemination of major pathogens associated with these crops is essential to formulate appropriate management strategies. Judicious amalgamation of various approaches including constant vigil through regular monitoring, adopting phytosanitation meticulously in nurseries and fields, insect proof nurseries, establishment of disease-free plantations with resistant varieties, timely adoption of cultural operations aimed to reduce residual/initial inoculum and minimize certain pre-disposing factors, management of vectors, destruction of collateral hosts, use of efficacious bioagents, reliable diagnostic tools and need-based application of plant protection chemicals are imperative to annihilate the pathogens that are cryptically carried in/on/with the vegetative planting material so as to safeguard our subsistence-oriented agricultural production system and to win battles against the invading lethal conquerors of plant life.

References

Anonymous 2021 https://www.spicenurseries.in.

Anandaraj M 2000 Diseases of black pepper. In: Ravindran P N (Ed) Black pepper (*Piper nigrum*). Harwood Academic Publishers. pp. 239–266.

Aravind R, Kumar A, Dinu A & Eapen S J 2011 Single tube duplex PCR for simultaneous detection of *Phytophthora capsici* and *Radopholus similis* infecting black pepper (*Piper nigrum*). Indian Phytopathol. 64: 353–357.

Araujo S B L, Braga M P, Brooks D R, Agosta S J, Hoberg E P, von Hartenthal F W & Boeger W A 2015 Understanding host-switching by ecological fitting. PLoS ONE. doi:10.1371/ journal. pone.0139225.

Barrett L G, Kniskern J M, Bodenhausen N, Zhang W & Bergelson J 2009 Continua of specificity and virulence in plant host-pathogen interactions: Causes and consequences. New Phytol. 183: 513–529.

Bhadramurthy V, Bhat A I, George J, Thankamani C K & Mathew P A 2008 Variation in the concentration and indexing black pepper plants for PYMoV and CMV through DAS-ELISA. J. Spices Arom. Crops. 17(2): 197–201.

Bhadramurthy V & Bhat A I 2009 Biological and molecular characterization of *Bean common mosaic virus* associated with vanilla in India. Indian J. Virol. 20: 70–77.

Bhadramurthy V, Bhat A I & Biju C N 2011 Occurrence and coat protein sequence based characterization of Bean yellow mosaic virus (BYMV) associated with vanilla (*Vanilla planifolia* Andrews) in India. Arch. Phytopathol. Plant Prot. 44: 1796–1801.

Bhat A I, Venugopal M N, Pant R P & Suseela Bhai R 2004 Occurrence and distribution of viral diseases of vanilla (*Vanilla planifolia* Andrews) in India. J. Spices Arom. Crops. 13(2): 143–148.

Bhat A I, Devasahayam S, Venugopal M N & Suseela Bhai R 2005 Distribution and incidence of viral disease of black pepper (*Piper nigrum* L.) in Karnataka and Kerala, India. J. Plant. Crops. 33(1): 59–64.

Bhat A I & Siju S 2007 Development of a single tube multiplex RT-PCR for the simultaneous detection of Cucumber mosaic virus and Piper yellow mottle virus associated with stunt disease of black pepper. Curr. Sci. 93: 973–976.

Bhat A I & Siljo A 2014 Detection of viruses infecting black pepper by SYBR Green based real-time PCR assay. J. Plant Pathol. 96: 105–109.

Bhat A I, Bhadramurthy V, Siju S & Hareesh P S 2006 Detection and identification of Cymbidium mosaic virus infecting vanilla (*Vanilla planifolia* Andrews) in India based on coat protein gene sequence relationships. J. Plant Biochem. Biotechnol. 15: 33–37.

Bhat A I, Faisal T H, Madhubala R, Hareesh P S & Pant R P 2004 Purification, production of antiserum and development of enzyme linked immunosorbent assay based diagnosis for Cucumber mosaic virus infecting black pepper. J. Spices Arom. Crops. 13: 16–21.

Bhat A I, Siljo A & Deeshma K P 2013 Rapid detection of Piper yellow mottle virus and Cucumber mosaic virus infecting black pepper (*Piper nigrum*) by loop-mediated isothermal amplification (LAMP). J. Virol. Methods. 193: 190–196.

Bhat A I, Siljo A, Jiby M V, Thankamani C K & Mathew P A 2009 Polymerase chain reaction (PCR) based indexing of black pepper (*Piper nigrum* L.) plants against Piper yellow mottle virus. J. Spices Arom. Crops. 18: 28–32.

Bhat A I, Pamitha N S, Naveen K P & Biju C N 2020 Identification and characterization of Cardamom vein clearing virus, a novel aphid transmitted *Nucleorhabdovirus* associated with vein clearing disease of cardamom. Eur. J. Plant Pathol. 156: 1053–1062.

Biju C N, Siljo A & Bhat A I 2010 Survey and RT-PCR based detection of Cardamom mosaic virus affecting small cardamom in India. Indian J. Virol. 21: 148–150.

Che H, Cao X, Liu P & Luo D 2021 Occurrence and characterization of virus species associated with black pepper (*Piper nigrum* L.) virus diseases in Hainan province, China. J. Phytopathol. 169(4): 247–252.

Chethana C S, Chowdappa P, Biju C N, Praveena R & Sujatha A M 2016 Molecular and phenotypic characterization revealed six *Colletotrichum* species responsible for anthracnose disease of small cardamom in South India. Eur. J. Plant Pathol. 146(3): 465–481.

Fisher M C, Henk D A, Briggs C J, Brownstein J S, Madoff L C, Mc Craw S L & Gurr S J 2012 Emerging fungal threats to animal, plant and ecosystem health. Nature. 484: 186–194.

Ghimiray M & Vernooy R 2017 The importance and challenges of crop germplasm interdependence: the case of Bhutan. Food Secur. 9: 301–310.

Giraud T, Gladieux P & Gavrilets S 2010 Linking the emergence of fungal plant diseases with ecological speciation. Trends Ecol. Evol. 25: 387–395.

Gonsalves D, Trujillo E & Hoch H C 1986 Purification and some properties of a virus associated with cardamom mosaic, a new member of the potyvirus group. Plant Dis. 70: 65–69.

Gupta M & Kaushal M 2017 Diseases infecting ginger (*Zingiber officinale* Roscoe): A review. Agric. Rev. 38(1): 15–28.

Husain H K, Verma S S, Saleem M, Verma S K, Usmani T A, Naz H & Naz A 2017 Role and history of plant quarantine in India-A review. Int. J. Chem. Stud. 5(6): 2034–2037.

Islam W 2018 Plant disease epidemiology: Disease triangle and forecasting mechanisms in highlights. Hosts and viruses. 5(1): 7–11.

Jeevalatha A, Biju C N & Suseela Bhai R 2021 Ypt1 gene based recombinase polymerase amplification assay for *Phytophthora capsici* and *P. tropicalis* detection in black pepper. Eur. J. Plant Pathol. 159: 863–875.

Jeevalatha A, Sruthi M & Biju C N 2019 Detection and differentiation of *Phytophthora* spp. causing foot rot disease in black pepper. International conference on Plant Protection in Horticulture: Advances and challenges, 24–27 July 2019, ICAR-IIHR, Bengaluru, India.

Khetarpal R K & Gupta K 2007 Plant Biosecurity in India-Status and Strategy. Asian Biotechnol. Dev. Rev. 9(2): 83–107.

Krishna P B & Eapen S J 2019 Development of a real-time PCR based protocol for quantifying *Radopholus similis* in field samples. J. Spices Arom. Crops. 28(1): 52–60.

Kueh T K, Fatimah O & Lim J L 1993 Management of black berry disease of black pepper. In: Ibrahim M Y, Bong C F J & Ipor I B (Eds.) The Pepper Industry: Problems and Prospects (pp. 162–168). Universiti Pertanian Malaysia, Sarawak, Malaysia.

Kumar A & Abraham S 2008 PCR based detection of bacterial wilt pathogen, *Ralstonia solanacearum* in ginger rhizomes and soil collected from bacterial wilt affected field. J. Spices Arom. Crops. 17(2): 109–113.

Kumar A, Sarma S & Priou S 2002 Detection of *Ralstonia solanacearum* in ginger rhizomes using post-enrichment NCM-ELISA. J. Spices Arom. Crops. 11(1): 35–40.

Madhubala R, Bhadramurthy V, Bhat A I, Hareesh P S, Retheesh S T & Bhai R S 2005 Occurrence of Cucumber mosaic virus on vanilla (*Vanilla* *planifolia* Andrews) in India. J. Biosci. 30: 339–350.

McDonald B A & Linde C 2002 Pathogen population genetics, evolutionary potential, and durable resistance. Annu. Rev. Phytopathol. 40: 349–379.

McKirdy S, Shea G, Hardie D & Eagling D 2008 Why plant biosecurity?. In: Palta J A & Berger J B (Eds.) Lupins for health and wealth. Proceedings of the 12th International Lupin Conference, 14–18 September 2008, Fremantle, Western Australia.

Mohandas A & Bhat A I 2020 Recombinase polymerase amplification assay for the detection of Piper yellow mottle virus infecting black pepper. Virus Dis. 31: 38–44.

Mundt C C 2014 Durable resistance: A key to sustainable management of pathogens and pests. Infect. Genet. Evol. doi.org/10.1016/j.meegid.2014.01.011.

Nagarajan S 1983 Plant Disease Epidemiology. Oxford and IBH Publishing Company, New Delhi. 267p.

Navaud O, Barbacci A, Taylor A, Clarkson J P & Raffaele S 2018 Shifts in diversification rates and host jump frequencies shaped the diversity of host range among Sclerotiniaceae fungal plant pathogens. Mol. Ecol. 27: 1309–1323.

Naveen K P & Bhat A I 2020 Development of reverse transcription loop-mediated isothermal amplification (RT-LAMP) and reverse transcription recombinase polymerase amplification (RT-RPA) assays for the detection of two novel viruses infecting ginger. J. Virol. Methods. 282: doi.org/10.1016/j.jviromet.2020.113884.

Naveen K P & Bhat A I 2020 Reverse transcriptase loop-mediated isothermal amplification and reverse transcriptase recombinase amplification assays for rapid and sensitive detection of cardamom vein clearing virus. 3 Biotech. 10: doi.org/10.1007/s13205-020-02238-w.

Okwuowulu P A 2005 Ginger in Africa and the Pacific Ocean Islands. In: Ravindran P N & Nirmal Babu K (Eds.) Ginger-The genus *Zingiber*. (pp. 279–303). Hardwood Academic Publishers.

Pandian R T P, Bhat A I, Biju C N & Sasi S 2018 Development of diagnostic assays for rapid and sensitive detection of *Phytophthora* infecting major spices and plantation crops. J. Spices Arom. Crops. 27(2): 119–130.

Perumal C, Santhosh J Eapen & Praveena R 2021 Root lesion nematodes (*Pratylenchus* spp.) emerge as a serious soil-borne pest across turmeric growing states of India. SYMSAC X 2021, International Symposium on Spices as Flavours, Fragrances & Functional Foods, 9–12 February 2021, ICAR-IISR, Kozhikode, Kerala, India.

Prameela T P, Suseela Bhai R, Anandaraj M & Kumar A 2017 Development of real-time loop-mediated isothermal amplification for detection of *Ralstonia pseudosolanacearum* race 4 in rhizomes and soil. Australas. Plant Pathol. 46: 547–549.

Prameela T P & Suseela Bhai R 2020 Bacterial wilt of ginger (*Zingiber officinale* Rosc.) incited by *Ralstonia pseudosolanacearum*-A review based on pathogen diversity, diagnostics and management. J. Plant Pathol. doi.org/10.1007/s42161-020-00487-5.

Saigopal D V R, Naidu R & Joseph T 1992 Early detection of '*Katte*' disease of small cardamom through Enzyme Linked Immunosorbent assay (ELISA). J. Plant. Crops. 20: 73–75.

Shahnazi S, Meon S, Vadamalai S Ahmad K & Nejat N 2012 Morphological and molecular characterization of *Fusarium* spp. associated with yellowing disease of black pepper (*Piper nigrum* L.) in Malaysia. J. Gen. Plant Pathol. 78: 160–169.

Siljo A, Bhat A I, Biju C N & Venugopal M N 2012 Occurrence of *Banana bract mosaic virus* on cardamom. Phytoparasitica. 40: 77–85.

Siljo A & Bhat A I 2014 Reverse transcription loop mediated isothermal amplification assay for rapid and sensitive detection of Banana bract mosaic virus in cardamom (*Elettaria cardamomum*). Eur. J. Plant Pathol. 138: 209–214.

Siljo A, Bhat A I & Biju C N 2014 Detection of Cardamom mosaic virus and Banana bract mosaic virus in cardamom using SYBR Green-based Reverse Transcription-Quantitative PCR. Virus Dis. 25: 137–141.

Silvar C, Duncan J M, Cooke D E L, Williams N A, Dı´az J & Merino F 2005 Development of specific PCR primers for identification and detection of *Phytophthora capsici* Leon. Eur. J. Plant Pathol. 112: 43–52.

Singh S, Pandey A K, Singh B K & Rajak D C 2016 Impact of exotic pests on agro-biodiversity and their management: A review. Bio Bulletin. 2(1): 58–73.

Singh S, Sharma J H, Udikeri A & Ansari H 2020 Invasive insects in India. doi: 10.5772/intechopen.91986.

Suseela Bhai R & Jithya Dhanesh 2008 Occurrence of fungal diseases in vanilla (*Vanilla planifolia* Andrews) in Kerala. J. Spices Arom. Crops. 17(2): 140–148.

Thammakijjawat P, Thaveechai N, Kositratana W, Chunwongse J, Frederick R D & Schaad N W 2006 Detection of *Ralstonia solanacearum* in ginger rhizomes by real time PCR. Can. J. Plant Pathol. 28(3): 391–400.

Thomas R J, Rajkumar A J, Shareefa M & Babu M 2015 Domestic quarantine umbrella to prevent spread of root (wilt) disease to be strengthened. Indian Coconut J. 4: 32–35.

Thuy T T T, Chi N T M, Yen N T, Anh L T N, Te L L & De Waele D 2013 Fungi associated with black pepper plants in Quang Tri province (Vietnam), and interaction between *Meloidogyne incognita* and *Fusarium solani*. Arch. Phytopathol. Plant Prot. 46(4): 470–482.

Tomlinson D L & Cox P G 1987 A new disease of cardamom (*Elettaria cardamomum*) caused by *Erwinia chrysanthemi* in Papua New Guinea. Plant Pathol. 36: 79–83.

Trujillo E E 1963 Fusarium yellows and rhizome rot of common ginger. Phytopathology. 53(11): 1370–1371.

Vijayan A K, Sithara L, Joseph Thomas, Thomas J, Misra R S & Saju K A 2013 Molecular characterisation of *Fusarium oxysporum* causing rot diseases in small cardamom (*Elettaria cardamomum* Maton). Arch. Phytopathol. Plant Prot. doi:10.1080/03235408.2013.792582.

Xizhen A, Jinpeng S & Xia S 2005 Ginger production in South East Asia. In: Ravindran P N & Nirmal Babu K (Eds.) Ginger-The genus *Zingiber*. (pp. 241–278). Harwood Academic Publishers.

Yu J, Shen D, Dai T, Lu X, Xu H & Dou D 2019 Rapid and equipment free detection of *Phytophthora capsici* using lateral flow strip-based recombinase polymerase amplification assay. Lett. Appl. Microbiol. 69: 64–70.