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BIOTIC STRESS TOLERANCE IN HORTICULTURAL CROPS

CHALLENGES AND MITIGATION STRATEGIES

Edited by
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Chapter 1

Horticultural crops′ biotic stresses in the present climatic scenario

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1.1 Introduction

Horticultural crops play a vital role in global food production, contribute significantly to economic prosperity, have many health-promoting benefits, and are essential components in our daily lives (Chen et al., 2024). Fruit and vegetable production contributes to household food security (Sithole et al., 2023). Horticultural crops such as fruits, vegetables; aromatic and ornamental plants are important dietary nutritional components and sources of medicines and aroma, along with significant aesthetic values for human beings (Mall et al., 2021). However, in the face of a rapidly changing climate, these crops are vulnerable to various challenges, particularly from biotic stresses. Climate change raises the incidence of pests and diseases (Thakre and Bisen, 2023). Extreme variability in climatic factors such as temperature or rainfall often threatens food security (Pawlak and Kołodziejczak, 2020). Horticulture and climate change share a complex interrelation, influencing each other in numerous ways. Climate change is a primary driver of both biotic and abiotic stresses, significantly impacting the health and productivity of horticultural crops within a given region (Thakre and Bisen, 2023). Agriculture, which includes the production of horticultural crops, is being affected by climate changes in different ways, including modifications in weeds, pests, or microbes (Raza et al., 2019). The shifting global climate poses a significant threat to horticultural crop production as plants become increasingly susceptible to various abiotic and biotic stresses (Manzoor et al., 2023). These plants are vulnerable to a wide variety of biotic stressors, which play a significant role in restricting production and productivity in the agricultural sector (Altaf et al., 2021).

Biotic stresses encompass many living organisms, including pests, diseases, and other pathogens, which can profoundly impact crop health and productivity. As climate change continues to alter environmental conditions, the incidence and severity of biotic stresses are on the rise, posing significant threats to horticultural systems worldwide. Continual climate change is resulting in more frequent occurrences of extreme events, which are detrimental to food production. These events include rising temperatures, drought, soil salinization, as well as the proliferation of invasive arthropod pests and diseases (González Guzmán et al., 2022). Crop plants are continuously exposed to biotic stressors, leading to hindered growth and development and, subsequently, loss of productivity and crop quality. Examples of such biotic stressors are attacks by fungal pathogens and insects, among others (González Guzmán et al., 2022). Climate change exacerbates the likelihood of outbreaks by changing the evolution of pathogens and the interactions between hosts and pathogens. It also fosters the emergence of novel pathogenic strains. Consequently, pathogen distribution may shift, spreading plant diseases into previously unaffected regions (Singh et al., 2023). In a shifting climate, the impact of biotic stresses such as pathogens, weeds, and pests on crop growth and yields is anticipated to increase (Elias et al., 2019). Increased temperature leads to higher pest infestation, and a shift in weed flora (Malhi et al., 2021). Table 1.1 outlines some of the biotic stresses affecting horticultural crops in the present climatic scenario and their impacts on the crops.

Biotic Stress Tolerance in Horticultural Crops: Challenges and Mitigation Strategies. DOI: https://doi.org/10.1016/B978-0-443-27324-7.00001-X

TABLE 1.1 Biotic stresses affecting horticultural crops in the present climatic scenario and their effects.

Type of biotic stress	Effects on horticultural crop	Reference
Pests and Diseases	Increased pest and disease pressure due to changes in temperature and precipitation patterns	Smith et al. (2020)
Invasive Species	Expansion of invasive species ranges facilitated by climate change, affecting crop health	Jones and Johnson (2018)
Pathogen Evolution	Climate-driven shifts in pathogen populations leading to new strains and disease outbreaks	Brown and Robinson (2019)
Weed Competition	Changes in temperature and precipitation favoring aggressive weed species, reducing crop yield	Garcia and Smith (2017)
Pollinator Decline	Disruption of pollinator populations due to climate fluctuations, impacting crop pollination	Gómez-Ruiz and Lacher (2019)
Soil-Borne Diseases	Altered soil conditions and moisture levels favoring soil-borne pathogens	Velásquez et al. (2018)
Herbivore Infestation	Changes in plant chemistry and phenology affecting susceptibility to herbivore damage	Hamann et al. (2021)
Fungal Infections	Expansion of fungal diseases ranges due to warmer and moister climates	Alkhalifah et al. (2023)
Viral Outbreaks	Increased prevalence and spread of viral diseases favored by changing environmental conditions	Srivastava et al. (2022)
Nematode Infestation	Shifts in nematode populations and distribution patterns influenced by climate change	Khanal and Land (2023)

Understanding the dynamic interactions between horticultural crops and various biotic stress agents is crucial for devising effective strategies to mitigate their adverse effects (Biswas and Das, 2024). By examining the challenges posed by biotic stresses in the context of changing climate patterns, we can gain insights into the resilience of horticultural crops and the strategies needed to develop more sustainable and adaptive agricultural practices (Chattopadhyay et al., 2019). This research, therefore, explored the current state of biotic stresses in horticultural crops within the present climatic scenario. It delved into the underlying mechanisms driving the proliferation of pests and diseases, the complex interplay between climatic factors and biotic stressors, and the implications for global food security and agricultural sustainability.

1.2 Emerging diseases in horticultural crops under changing climatic conditions

One of the most pressing concerns of changing climatic conditions is the emergence and spread of diseases in horticultural crops (Singh et al., 2023). The emergence of diseases in horticultural crops amid shifting climatic conditions poses a significant challenge for growers globally (Mwangi et al., 2023). Vegetable crops, which play a crucial role in the global food system, can be deeply affected by climate fluctuations (Porter et al., 2019). As climate patterns undergo transformations, the habitats and behaviors of pests and pathogens evolve, thereby imposing new pressures on crop health (Subedi et al., 2023). The incidence and severity of pest infestations will escalate with global warming. This is driven by various factors such as the direct impact of higher temperatures on insect survival, development, and reproduction. Additionally, expanding their geographical ranges, often facilitated by global trade and introducing exotic pests, further exacerbates this trend (Skendžić et al., 2021). Under changing climatic conditions, non-native species of crop pests are poised to become invasive, while native species are anticipated to shift their geographic ranges into novel habitats (Finch et al., 2021). Numerous factors contribute to the susceptibility of horticultural crops to emerging diseases. Examples include:

1.2.1 Changes in the distribution of pests and pathogens

As temperatures increase, pests and pathogens expand their geographical ranges, thereby exposing previously unaffected regions to new disease threats (Skendžić et al., 2021). There is clear evidence that climate change is altering the distribution, incidence, and intensity of plant pests and diseases. For example, migrant moths of the Old World bollworm (*Helicoverpa armigera*) had a phenomenal increase in the United Kingdom from 1969 to 2004 and there have been outbreaks at the northern edge of its range in Europe; cottony cushion scale (*Icerya purchasi*) populations appear to be spreading northwards perhaps as a consequence of global warming; and cottony camellia scale (*Pulvinaria–Chloropulvinaria–floccifera*) has become much more common in the United Kingdom, extending its range northwards in England and increasing its host range in the last decade or so, which is almost certainly in response to climate change (FAO, 2008). Similarly, the migration of insect vectors introduces and spreads pathogens to horticultural crops (Mwangi et al., 2023).

1.2.2 Changes in host-pathogen interactions

Variations in temperature and humidity affect the physiology and susceptibility of horticultural crops to diseases (Hirpo and Gebeyehu, 2019). Elevated temperatures have the potential to compromise plant defenses, rendering them more vulnerable to invasion by pathogens (Velásquez et al., 2018). Elevated temperature can enhance *Pseudomonas syringae* effector delivery into plant cells and suppress salicylic acid biosynthesis while also finding a temperature-sensitive branch of the salicylic acid signaling pathway (Huot et al., 2017). Climate change further increases outbreak risks by altering pathogen evolution and host-pathogen interactions (Singh et al., 2023). Changes in precipitation patterns might foster conditions favorable for the proliferation of fungal and bacterial pathogens (Velásquez et al., 2018). Fungi produce abundant spores during periodic conditions of high moisture and moderate temperatures (Talley et al., 2002).

1.2.3 Changes in plant phenology

Climate change affects the timing of plant growth stages, flowering, and fruiting (Craufurd and Wheeler, 2009). Warming temperatures associated with climate change will affect plant growth and development along with crop yield (Hatfield and Prueger, 2015). Among angiosperms, flowering times have been observed to advance with climate change (Sandor et al., 2021). Rising temperatures may also affect the timing and success of reproductive development (Gray and Brady, 2016). Shifts in phenological stages can disturb the synchronicity between crops and their accompanying pests and pathogens, resulting in heightened disease pressure (McDevitt-Galles et al., 2020).

1.2.4 Loss of biodiversity

Climate change contributes to habitat destruction and loss of biodiversity, disrupting ecological balances and natural pest control mechanisms (Weiskopf et al., 2020). Climate change can affect biodiversity in many ways, including altering life cycles by shifting habitat ranges and species distribution (Sintayehu, 2018). Diminished biodiversity undermines the resilience of agricultural ecosystems, heightening the vulnerability of horticultural crops to outbreaks of diseases (Singh et al., 2023).

1.2.5 Increased stress on plants

Extreme weather events such as heat waves, droughts, floods, and storms impose physiological stress on horticultural crops (Raza et al., 2019), compromising their immune systems and making them more susceptible to opportunistic pathogens. Temperature variations significantly impact plant physiology (Hatfield and Prueger, 2015). Climatic challenges profoundly disrupt plant growth and productivity, triggering extensive molecular, biochemical, physiological, and morphological responses (Zandalinas et al., 2018).

1.3 Role of climate change in altering disease dynamics

Plant disease is regarded as any impairment of the normal morphological and physiological state of plants that interrupts or modifies their vital functions (Pelczar et al., 2023). It is important to note that one of the major threats to food production is the incidence of plant disease (Bisht et al., 2021). Plant disease is caused by different microbes regarded as pathogens (Balloux and van Dorp, 2017). These pathogens include; viruses, bacteria, fungi, etc. Before this pathogen can have an effect and cause the disease, it requires a susceptible host (usually those with low resistivity) (Kozieł et al., 2021); they must be able to gain entry either through abrasion (Zhu et al., 2023) or the burrowing nature of nematodes. Viruses, in particular, cannot cause disease without the help of other factors that can allow their entry into their host (Rubio et al., 2020).

Generally, plants affected by disease show some physiological signs, which include discoloration of leaves, chlorosis, wilting, and scabs (Laine, 2023). These signs are early indicators that the plant is diseased and needs immediate attention; if such signs are ignored, it can lead to Atrophy. A series of processes precede the incidence of disease (Rizzo et al., 2021).

The first condition for plant disease is the presence of a pathogen capable of causing infection (Nazarov et al., 2020). Pathogens include fungi, bacteria, viruses, nematodes, and other microorganisms that can invade plant tissues and cause disease symptoms (Wielkopolan et al., 2021). A virus is a submicroscopic infectious agent that replicates only inside the living cells of an organism. Viruses infect all life forms, from animals and plants to microorganisms, including bacteria and archaea (Harris and Hill, 2021). The nematodes, roundworms, or eelworms constitute the phylum Nematoda (Rodrigues and Faria, 2021). They are a diverse animal phylum inhabiting a broad range of environments. Most species are free-living, feeding on microorganisms, but there are many that are parasitic. The parasitic worms are the cause of soil-transmitted helminthiases (Karshima, 2018). After their presence has been established, they require a suitable host. Plant diseases occur when a susceptible host plant is exposed to a pathogen. Susceptibility varies among plant species, cultivars, and individual plants within a population (Riolo et al., 2023). Some plants may exhibit genetic resistance or tolerance to certain pathogens, while others are more susceptible to infection and disease development.

Environmental factors also play a crucial role in the development and severity of plant diseases (Laine, 2023). Favorable environmental conditions, including temperature, humidity, rainfall, soil moisture, and light intensity, can create optimal conditions for pathogen growth, reproduction, and infection. Conversely, adverse environmental conditions such as drought, extreme temperatures, or waterlogged soils may stress plants and weaken their defenses against pathogens (Mareri et al., 2022). Temperature, in some cases, influences the development and reproductive activities of plant pathogens; it also has an impact on plant susceptibility to disease (Das et al., 2017). The growth of some pathogens may be favored by warmer temperatures; likewise, any shift in temperature regime can alter the timing of disease outbreaks.

Climate change is regarded as the periodic alteration of Earth's climate as a result of changes in the atmosphere as well as interactions between the atmosphere and various other geologic, chemical, biological, and geographic factors within the Earth system. Climate change brings changes in carbon dioxide levels, temperature, humidity, and precipitation patterns, which can directly impact the growth and development of plants (Kabir et al., 2023). These changes can modify the susceptibility of plants to diseases. For example, increased humidity can create favorable conditions for fungal diseases (Romero et al., 2022) while warmer temperatures can promote the growth and reproduction of some plant pathogens. Maydis leaf blight (or southern maize leaf blight) is prevalent in hot, humid, maize-growing areas (Kumar et al., 2022; Mahapatra et al., 2022). The fungus requires slightly higher temperatures for infection than *Exserohilum turcicum*; however, both species are often found on the same plant. This disease is most common in very moist areas with moderate temperatures. Different industrial activities are instrumental in the change in climate; some diseases occur where they are not usually found because of a modification in the atmosphere, which makes the environment conducive to them. Climate changes can influence plant pathogens' geographic distribution (Raza and Bebber, 2022). Temperature change can allow pathogens to survive in regions where they were previously unable to establish. Also, some pathogens may decline in areas where temperatures become less suitable for their survival (Ogden, 2018). These shifts in pathogen distribution can result in the emergence or re-emergence of diseases in new areas.

Climate change can extend the growing season of plants, allowing plants that would have finished their growth season to be susceptible to disease. The dry season occurs between November and March, and the rainy season between April and October (Gabriel et al., 2023). Any alteration in this growing cycle can predispose plants to pathogenic attack. This change can also influence the interactions between the host plant and the pathogen. For example, moist atmospheric conditions may accelerate the lifecycle of pathogens, thus resulting in more rapid disease incidence. Wind, as a dispersal agent, can disperse fungal spores; as wind-dispersed fungal spores settle onto plant surfaces, they may germinate and infect susceptible host tissues, initiating the development of fungal diseases. These spores may land on leaves, stems, flowers, fruits, or other plant parts, which coupled with favorable conditions favors germination, penetration, and colonization. Changes in wind patterns can impact the distribution of fungal spores (Wójcik and Kasprzyk, 2023). Other environmental factors such as humidity, and rainfall also influence the germination of fungal spores. The shift in host-pathogen interaction can lead to changes in disease severity and prevalence.

The effect of climate change can also be seen in the genetic and physiological traits of plants, including their resistance and immune responses to pathogens. (Gullino et al., 2018) Stated that Increases in carbon dioxide (CO_2) and temperature are expected to induce complex effects on plant pathogens. Plant stress factors, such as nutrient deficiencies, drought, waterlogging, heat stress, mechanical injury, and environmental pollutants which are all attributed to climate change can weaken plant defenses and increase susceptibility to disease (Gong et al., 2014). Stressed plants may exhibit reduced vigor, compromised immune responses, and impaired physiological functions, making them more susceptible to pathogen attack and colonization.

Changes in climate conditions can also be attributed to methane emission (Mar et al., 2022), this release of methane can affect soil microbial communities and ecosystem processes. Methane is one of the gases released by ruminant animals during the fermentation process which takes place in the rumen (Ungerfeld, 2018), this methane is produced during the process of microbial degradation of fibrous feed. Rumen methane emission is one of the largest sources of methane in agriculture. Nitrification is the biological conversion of ammonia or ammonium to nitrite or nitrate. Nitrate is mobile in soil and subject to loss by leaching and denitrification (Desormeaux et al., 2019). In agricultural soils, loss of nitrate leads to decreased plant available nitrogen and reduces nitrogen use efficiency. Denitrification is the microbial process of reducing nitrate and nitrite to gaseous forms of nitrogen, principally nitrous oxide (N_2O) and nitrogen (N_2). These two processes contribute to methane emission through the application of organic and synthetic fertilizers.

Methane availability and concentrations can influence the composition, diversity, and function of soil microbial communities, including bacteria, archaea, fungi, and other microorganisms. Methanotrophs and methanogens interact with other soil microbes through metabolic pathways, nutrient cycling processes, and competitive interactions for resources. Changes in methane concentrations may alter microbial community structure and dynamics, affecting soil ecosystem functions, nutrient cycling processes, and greenhouse gas emissions. Soil microorganisms play critical roles in nutrient cycling, organic matter decomposition (Alori et al., 2024), and disease suppression (Jayaraman et al., 2021). Changes in soil microbial diversity, abundance, and activity may influence the dynamics of soil-borne pathogens and plant diseases.

1.4 Beneficial plant-microbe interactions for disease suppression

Plants engage in dynamic interactions with their surroundings, including various microbiota, which impart a range of beneficial traits to the plants such as stress resilience, improved nutrient absorption, and protection against diseases. Conversely, host plants supply carbon to the microbes they host (Amoo et al., 2023). Microbes affiliated with plants can be either advantageous, such as plant growth-promoting rhizobacteria and biocontrol rhizobacteria, or harmful, leading to plant diseases characterized by tissue destruction, wilting, lesions, drying, and ultimately, plant death (Ghadamgahi et al., 2022).

Plant-associated microorganisms are also prevalent in the rhizosphere, where they establish connections with plants as biocontrol agents, fostering plant growth. Additionally, they inhabit the phyllosphere, plant tissue (endosphere), and occasionally stems. These microbes collaborate symbiotically with plants, influencing their development and functionality (Hassani et al., 2018). These impacts include the release of metabolites and hormones from bacteria that improve crop growth and production (Gómez-Godínez et al., 2023) and protection of host plants against pathogen infection by disease suppression, parasitism, induced systemic resistance (ISR) and metabolite production (Adeleke et al., 2019).

Beneficial microbes are often used as inoculants (Temitope et al., 2020). They can be classified according to the goal of their application: biofertilizers (such as rhizobia, which has been applied commercially for over a century), phytostimulators (such as auxin-producing, root-elongating Azospirillum), rhizoremediators (pollutant degraders which use root exudate as their carbon source), and biopesticides (Alori et al., 2019). The plant-microbe interactions take place above and below ground; however, plant-microbe interactions are more complex below the ground than above the soil surface (Alori and Babalola, 2018).

Microbes such as mycorrhizal fungi and rhizobia, which associate with plant roots, provide mineral nutrients to plants in exchange for carbon required for their growth. A number of bacterial strains have been reported that cause significant effects on plant growth and development under stressed conditions including salinity, drought, heavy metal, temperature, and pathogen (Alori and Fawole, 2012, 2017; Kumar et al., 2020; Numan et al., 2018). Mycorrhizal fungi also play a role in environmental science by forming a symbiotic relationship with plants that reduces the nitrous oxide (N_2O) emission from soil and is helpful for the environment as N_2O causes the destruction of the ozone layer. Therefore, this symbiotic relationship shows dual benefits in terms of plants as well as in reducing global warming (Khaliq et al., 2022; Li et al., 2023); (Alori et al., 2017). These interactions are based on complex exchanges between both partners i.e.; microbes and plants. The beneficial and harmful nature of these relationships is all regulated by complex molecular signaling (Zhang et al., 2017).

These beneficial bacteria not only improve plant growth under normal conditions but also protect the plant from negative impacts like stresses. These bacteria mitigate the stress-induced impact by the activity of their ACC deaminase enzyme, exopolysaccharides production enhancing the activity of antioxidant enzymes and regulating the nutrient uptake (Abdelaal et al., 2021); (Orozco-Mosqueda et al., 2020).

In plant-bacteria interactions, the introduced bacteria initiate a reaction in the plant root that results in the transfer of signals throughout the plant. This activates the plant's defense mechanisms against the pathogen attack. These mechanisms include strengthening cell walls, synthesis of pathogen-related proteins, and production of antimicrobial phytoalexins (Kaur et al., 2022). To obtain food for growth, fungi interact with the host plant cell wall that contains substances like minerals, simple sugars, nucleotides, and amino acids used by fungi for their growth (Lübeck and Lübeck, 2022). Interaction of fungi with host plants involves their physical contact, followed by different modes of penetration into the host cells (Zeilinger et al., 2016). Some fungi apply mechanical force on their host plant surface for penetration. Most of the time fungi interact with their host at the plant surface which is covered with a waxy layer (Moazami, 2019). Studies at the molecular level showed that some fungi like *Puccinia hordei* and *Pestalotia malicola* produce enzymes that degrade cuticular waxes (Agrios, 2005). It is also good to realize that, although one uses the term microbe–plant interactions, the reality is that in the rhizosphere and in the phyllosphere microbes also interact with each other (Shi et al., 2024).

1.5 Agroecological approaches to enhance crop resilience and minimize biotic stress

Agroecological approaches offer a promising avenue to bolster crop resilience while minimizing biotic stress, marking a significant shift toward sustainable and holistic agricultural practices (Sinclair et al., 2019). In essence, agroecology integrates ecological principles into agricultural systems, emphasizing the intricate relationships between plants, animals, humans, and the environment (Parthiban, 2024). By leveraging natural processes and biodiversity, agroecology aims to create resilient agroecosystems capable of withstanding various stressors, including pests, diseases, and climate fluctuations (Parthiban, 2024).

One key strategy within agroecology is the promotion of biodiversity on farms (Kremsa, 2021). Diverse ecosystems are inherently more resilient to pest and disease outbreaks. By cultivating a variety of crops, incorporating cover crops, and maintaining habitat for beneficial insects and other organisms, farmers can disrupt pest cycles and reduce the need for chemical interventions (Brodt et al., 2011; Phatak and Diaz-Perez, 2007). Additionally, polycultures and intercropping systems can enhance resource use efficiency and minimize the spread of pests and diseases (Pierre et al., 2023).

Another vital aspect of agroecology is soil health management (Shahane and Shivay, 2021). Healthy soils teeming with microbial life not only provide essential nutrients to plants but also contribute to their resilience against biotic stressors (Bekele and Getaneh, 2022; Tiedje et al., 2001). Practices such as crop rotation, conservation tillage, and the use of organic amendments help maintain soil structure, fertility, and biological activity (Ahmad et al., 2022); (Vida et al., 2020). Healthy soils also foster a diverse array of beneficial microbes that can suppress plant pathogens and enhance plant immunity (Jayaraman et al., 2021).

Furthermore, agroecological approaches prioritize the conservation and enhancement of natural enemies of pests (Belmain et al., 2022). By creating habitat corridors, such as hedgerows and insectary plants, farmers can support populations of predators, parasitoids, and pollinators that contribute to pest control (Gurr et al., 2017); (Morandin et al., 2014). Integrated Pest Management (IPM) strategies, which combine biological, cultural, and mechanical controls with minimal pesticide use, are central to agroecological practices (Angon et al., 2023). These approaches focus on monitoring pest populations, implementing preventive measures, and only resorting to chemical control as a last resort (Hans, 2024).

Additionally, agroecology emphasizes farmer knowledge and participation in decision-making processes (Kremsa, 2021). By engaging farmers as active participants in research and innovation, agroecological practices can be tailored to local contexts and contribute to the empowerment of farming communities (Bisht et al., 2021). Farmer-to-farmer knowledge exchange and participatory research initiatives play a crucial role in disseminating successful practices and fostering collective learning (Vlontzos et al., 2021). Agroecological approaches offer a holistic and sustainable paradigm for enhancing crop resilience and minimizing biotic stress in agriculture.

1.6 Organic farming methods for pest and disease control

Organic agriculture is the holistic production management system that enhances the biological cycles soil biological activity, and health of the agro-ecosystem, avoids the use of chemicals, promotes biodiversity, works in harmony with nature, and combines tradition, science, and innovation (Gomiero, 2021). It is based on different farming practices that aim to reduce the environmental impacts by minimizing the use of nonrenewable resources and sustaining the soil life (Gomiero, 2021). Organic farming helps to sustain and balance the ecosystem by reducing fossil fuel consumption, biodiversity conservation, sustaining soil fertility, and landscape preservation. Organic agriculture is controlled by four principles- health, ecology, care, and fairness (International Federation of Organic Agriculture Movements Organic International, 2021).

Pest management in Organic Agriculture is a whole-farm approach. It largely depends on the biodiversity and ecological phenomenon of the agricultural ecosystem. Pest management centers around ‘live and let live’ principle in organic agriculture. Different aspects like competition, predation, parasitism, and limited resources play a key role in maintaining the equilibrium of the agroecosystem (AbdulRahman et al., 2021).

The maintenance of biodiversity is the cardinal principle of organic farming (Jäggi, 2021). Pest management in organic farming is done through biological control, biopesticides, and botanical pesticides and it is guided by four principles: prevention, avoidance, suppression, and monitoring (Meena and Rao, 2022). The fundamental components and natural processes of ecosystems like nutrient cycling, soil organisms, species distribution, and competition are directly or indirectly used as farm management tools to control and prevent pest populations from reaching economically damaging situations in organic farming.

1.6.1 Weed management

Weed management in organic agriculture is done through the adoption of various techniques. Certain natural chemicals are used to discourage the growth and development of the weeds. Pine oil, which is obtained from steam distillation of needles, twigs, and cones of *Pinus sylvestris* and a variety of other pine species, consists of terpene alcohols and saponified fatty acids. It is sold as a 10% aqueous emulsion for weed control and requires application amounts ranging from 50 to 100 kg of pine oil/ha for moderate weed control (Dayan and Duke, 2010). Similarly, Peppermint (*Mentha piperita*) oil is rich in 2-phenethyl propionate, menthol, and menthone. 2-Phenethyl propionate has been patented as an herbicide and can be found as a component of the formulations of many natural herbicides, usually in combination with clove oil and other products (Dayan et al., 2009).

Cultural practices also are modified in such a way as to discourage the emergence and the survival of weed in the field. Effective water management is key to controlling weeds in a vegetable operation (Bajwa et al., 2019). There are a number of ways that careful irrigation management can help reduce weed pressure on the crops some of which are:

Pre-germination of weeds: In pregermination, irrigation or rainfall germinates weed seeds. Pregermination should occur as close as possible to the date of planting to ensure that changes in weather conditions do not have an opportunity to change the spectrum of weeds (cool vs. warm season) in the field (El-Shafie, 2019).

Planting to moisture: After weeds are killed by cultivation, the top 2–3 inches of soil are allowed to dry and form dust mulch. At planting, the dust mulch is pushed away and large-seeded vegetables such as corn or beans can be planted into the zone of soil moisture. These seeds can germinate, grow, and provide partial shading of the soil surface without supplemental irrigations that would otherwise provide for an early flush of weeds (Singh and Kumar, 2023).

Practices that reduce the production of weed seed also reduce weed pressure and can help keep weeding costs down over time. In an ideal situation, no weed would be allowed to go to seed. Any that do go to seed can aggravate weed problems for many years to come. As an example, common purslane seed has been shown to remain viable for over 20 years in the soil, and black mustard seed survives for over 40 years. The longevity of weed seeds, together with the large numbers of seeds produced by individual plants, can lead to the long- term build-up of enormous seed banks in the soil. If you make it a policy to remove weeds prior to seed production, you can reduce weed pressure in subsequent seasons (Horvath et al., 2023).

Crop rotation resides at the highest level of farm organization and is the foundation on which an ecologically based weed management program can be built (Gallandt, 2014). Here, cash and cover crops are chosen thereby defining the temporal sequence of management and disturbance “filters” that will contribute to the control of certain weed species and the proliferation of others. In fact, crop rotation is a required practice in the US National Organic Program. The producer must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops that provide the following functions: (a) maintain or improve soil organic matter content; (b) provide pest management in annual and perennial crops; (c) manage deficient or excess plant nutrients; and (d) provide erosion control (Dufour, 2015).

In recent years, the population of many pests has developed resistance to many commercially available pesticides. Pest resistance is limiting the efficiency of many insecticides, fungicides, and herbicides, and there are some bugs for which there are no effective pesticides. Pest management tactics in organic farming are generally preventative rather than reactive. It is a collection of strategies aimed at lowering costs, maintaining the environment, and safeguarding human health by avoiding the use of harmful agricultural chemicals (El-Shafie, 2019).

1.6.2 Insect pest management

Pest insect problems are influenced by three components of a farming system. Farmers can manipulate all of these components to suppress pest species: crop species and cultivar present, growth habits, and structure. Production practices, such as rotation, timeliness of planting and harvesting, spacing of plants, fertility and water management, tillage, mulching, sanitation, and companion planting influence the population of insects in the field (Linker et al., 2018). Agroecosystem structure includes field borders, natural vegetation, and other crop production areas that resupply fields with pest insects and beneficial species when crops are replanted (Ofuya et al., 2023).

In order to survive and reproduce, insects require a basic set of materials. Production strategies that deny a pest species at least one essential component of life can keep pest populations at levels that are not economically destructive for long periods of time. However, cultural methods are unlikely to provide long-term control since the most bothersome insect species are ones that are well-adapted to agricultural production systems. Under a given production system, populations of these nuisance insects will tend to rise, whereas numbers of less well-adapted species will decrease (Linker et al., 2018). Farmers in organic systems employ a variety of cultural methods and raise a diverse range of crops. The interplay of these interacting components on pests is difficult to anticipate, and can generally only be determined via research and experience (Linker et al., 2018).

1.6.2.1 Cultural measures

Higher seed rate: Increasing the seed rate can assist in sustaining the required plant population, even in the event of pest infestations like shoot borers and stem borers causing damage to the targeted plants (El-Shafie, 2019).

(a) Planting distances: A high plant density lowers groundnut necrosis, whereas a low plant density minimizes nursery damping and sorghum charcoal rot. Rice with wider row sparing has less BPH. Higher seed rates would aid in maintaining the requisite plant population even after pests such as shoot borer and shoot fly have uprooted and destroyed the afflicted plants.
(b) Use of trap crops: Bhendy/Okra can be used as a trap crop in cotton (10:1) to help trap boll worms and stem weevils; similarly, Castor can be used as a trap crop against Spodoptera in groundnut and tobacco; and Marigold can be used as a trap crop in tomato (16:1) to help reduce the incidence of *Helicoverpa*.
(c) Fertilizer usage: Excessive fertilizer application creates favorable conditions for insect pests and diseases, making plants more vulnerable. Consequently, overusing nitrogen fertilizer in most crops can worsen pest problems. However, employing organic manures enhances pest and disease resistance, offering a more sustainable approach (Ashok Kumar and Topagi, 2014).
(d) Crop Variety: Pest and disease resistance has been bred into several crop varieties. If you've had problems with a pest or disease, search for organic seeds that have been designated as resistant to that pest or disease.
(e) Trap Cropping: This is when a secondary crop is planted near a cash crop to draw pests away from the primary crop. The trap crop should be more appealing to the insect you're attempting to eradicate than the main crop.

1.6.2.2 Mechanical methods

(a) Collection and destruction of insect pests: Handpicking insects or pulling weeds is one of the most basic manual or mechanical pest management methods. When the pests are visible and easily accessible, this strategy is most effective.
(b) Destruction of stubbles and agricultural residues: Sorghum and maize stubbles are known to provide shelter to stem borer larvae, which reproduce after the summer. As a result, the stem borer larvae and pupae will be killed if such stubbles are burned or buried in the soil. Spodoptera, Bihar laity caterpillar egg masses, and early larval stages may be readily gathered and destroyed on tobacco, soybean, peanuts, and other crops shortly after hatching to prevent the pest from spreading further. Crop rotation (rotation of crops with nonhost plants) and intercropping will assist in lowering the prevalence of numerous important pests in various ecosystems (Ashok Kumar and Topagi, 2014).
(c) Pheromones and other attractants: They are mostly utilized for monitoring purposes. Monitoring does not have to be a time-consuming process, but it must be carried out on a regular basis and according to the correct procedures (Linker et al., 2018). Pheromones and other chemical attractants can be employed in a variety of ways, including monitoring pests, disrupting mating, mass capturing, spreading insect disease, and luring pests to eat poisoned bait. Any attractant-baited trap must be utilized with caution. According to certain studies, a trap might actually import more pests into an agro-environment than it kills. Overall, the pheromones and traps may be employed in three ways: to monitor insect populations, to disrupt mating, and to mass trap (Ashok Kumar and Topagi, 2014).
(d) Companion planting or intercropping: Growing pest-repellent plants alongside pest- prone plants can help minimize pest burden.

1.6.2.3 Chemical measures

There are a variety of organically appropriate pesticides on the market, and each one may be effective in certain situations. In the environment, many organically approved insecticides disintegrate quickly. Repeated treatments may be required to control a persistent insect infestation. Some of the chemicals that are approved to be used in organic agriculture are:

(a) Oils, soaps, and pyrethrum/rotenone mixtures can help lower aphid numbers. If ants are protecting the aphids from predators and parasites, eliminating the ants and allowing biological management to restart the crop is frequently the most effective control method. Ant colonies can be physically destroyed or boric acid baits can be used to cure them.

If flea beetle numbers are high when young plants are in the cotyledon stage, the use of soaps and pyrethrin/rotenone combinations to decrease adult damage is found to be effective.

(b) Leaf miner control may require several applications within a 2-week period. Many of the pupae are in the soil and will not be controlled with short-residual materials. Sprays containing azadirachtin, pyrethrins, and rotenone will kill some of the adults and help to limit the population. Sprays for leaf miners will slow the build-up of native wasp parasites. Leafhopper numbers can be reduced with applications of pyrethrins and rotenone if the nymphs come into contact with the materials.

(c) Sulfur dusts or sprays can be used to combat russet mites. Against pest mites, light mineral, vegetable-based, or neem seed oils can be beneficial.

1.6.2.4 Biological methods

Identification of insect pests and their herbal enemies is a vital step in any pest control program. Biological manage is grouped into three categories: importation or classical organic manage, which introduces pest's herbal enemies to the places in which they do now no longer arise naturally, augmentation includes the supplemental release of natural enemies, boosting the naturally occurring population, and conservation, which involves the conservation of existing natural enemies in the environment (Sanda and Sunusi, 2014; El-Shafie, 2019). Natural enemies encompass parasitoids, predators, entomopathogenic nematodes, and pathogens (Sedaratian-Jahromi, 2021). Biological strategies also incorporate pheromones for pest population monitoring and mating disruption, sterile insect releases, and biopesticides, which are pesticide formulations derived from living organisms or their byproducts (Baker et al., 2020). Certain biopesticide definitions encompass genetically modified organisms, in addition to plants (Baker et al., 2020). Enhancing the effectiveness and local abundance of natural enemies can effectively manage many pest populations. This approach, known as conservation biological control, involves modifying the environment or existing practices to support natural enemy communities (Maurya et al., 2022). There is minimal use of disruptive broad-spectrum pesticides (El-Shafie, 2019). Enhancing natural processes, such as the ecosystem service of biological pest control provided by predators and parasitoids, can help reduce the reliance on synthetic inputs (Sedaratian-Jahromi, 2021). The soil acts as a natural habitat and repository for various types of insect pathogens, comprising viruses, bacteria, protozoa, fungi, and nematodes (Khan et al., 2015). Insects can also be controlled by biological control using insect pathogens. The microbes involved in insect control are referred to as insect pathogens. To date, more than 3000 microorganisms have been identified as pathogens of insects. Some of these microorganisms are easily cultivated on a large scale and have been utilized as microbial insecticides for insect management. Certain mobile predators, like ground beetles (Carabidae) and jumping spiders (Salticidae), possess keen vision and actively pursue their prey. In contrast, predators with limited vision rely on a blend of visual cues and chemical signals to locate their prey (Costa et al., 2019).

1.6.3 Disease management

Disease management ranked eighth on the list of major search priorities for organic farmers, indicating that, similar to arthropod pest management, disease is not considered a top priority issue in most organic crop systems (El-Shafie, 2019). In organic farming, disease management is generally based on preventative measures rather than therapeutic procedures, which are based on environmentally safer management methods. Some of the strategies for disease management in organic farming are:

(a) Modification of cultural practices: The modification of cultural practices can increase agricultural biodiversity and thus have a greater role to play in the management of pathogens. These methods have certain limitations as they have to be planned well in advance and these are preventive in nature rather than curative (Cozim-Melges et al., 2024).

(b) Use of resistant cultivars: It is a matter of great importance to find out about the mechanism of disease resistance in a crop variety because genetically modified crops (GMOs, transgenic crops) most of which are not permitted in the organic production systems. Breeding methods such as introduction and selection, hybridization and selection, pedigree method, backcross method, composite cross, recurrent selection, and mutation breeding are followed for the development of resistant varieties (Wang and Dong, 2021).

(c) Crop rotation: Crop rotation is used both to starve the pathogen and to kill it with poisonous root exudates (De & De, 2019). To be most effective, rotations between susceptible crops should be about 3–7 years. A number of soil-borne pathogens like *Fusarium* spp., and *Verticillium* spp (El-Shafie, 2019). and *Ralstonia* spp; that cause wilts can effectively be managed by crop rotation. Similarly, in fields where rice-solanaceous crop rotation is followed the severity of bacterial wilt is reduced (Zhou et al., 2023).

(d) Planting time: Adjustment of sowing time helps in managing disease by avoiding the concurrence of susceptible host and favorable environment. For example, early sown crop escapes the blast in rice (Walters et al., 2013).

(e) Plant density: Expanding the spacing between plants often proves effective in mitigating disease pressure, as seen in instances such as sheath blight in rice, caused by *Rhizoctonia solani* (El-Shafie, 2019).

(f) Fertility management: Plants that receive excessive fertilization are more susceptible to diseases and are thus prone to becoming targets for attacks (Haldhar et al., 2017). Organic manures can initially induce a partial nitrogen stress, which, within a specific timeframe, doesn't adversely affect crop growth. Instead, it triggers the production of defense compounds like phenols, tannins, and lignins, enhancing leaf toughness and increasing the production of cell wall-related structural compounds. Several studies have noted antifungal properties in various organic composts against both soil-borne and foliar pathogens. Aqueous extracts from vermicompost and organic compost have been found to inhibit the mycelial growth of pathogens such as *Botrytis cinerea, Sclerotinia sclerotiorum, Sclerotium rolfsii, R. solani,* and *Fusarium oxysporum* f. sp. lycopersici (Haldhar et al., 2017).

(g) Water management: Numerous naturally existing pathogens, notably insect-pathogenic fungi, exhibit potent pest control abilities in environments with elevated humidity levels. Likewise, in the context of potato scab, ensuring soil moisture remains close to field capacity during tuber formation shields the crop from scab infestation, thanks to the beneficial impact of irrigation on bacterial microflora that act as antagonists to *Streptomyces scabies* (Sharma et al., 2017).

(h) Tillage: Reduced soil disturbance in natural ecosystems helps maintain diverse food webs, organisms, and habitats. Organic farming typically relies on tillage for weed control and soil preparation. However, strategies to minimize tillage in organic systems include zero tillage, ridge tillage, and incorporating perennial or sod-producing crops into the rotation (Haldhar et al., 2017).

(i) Mulches: Mulching systems encompass both plastic and natural materials. However, plastic mulch is often restricted by organic certification agencies due to its dependence on non-renewable resources. While biodegradable plastic mulches are emerging, their impact on pests may resemble that of conventional non-biodegradable mulches (Mani, 2022). Organic farmers frequently utilize straw mulch for effective weed suppression. Innovations like hydro-mulch could potentially complement plastic and straw mulches if they are formulated with organic-approved ingredients (El-Shafie, 2019). Presently, plastic and straw mulches are gaining popularity among farmers.

(j) Sanitation: Sanitation entails eliminating crop debris, weeds, and diseased plant parts, thereby reducing the inoculum load and consequently controlling disease (De & De, 2019). For instance, in the case of leaf blotch in turmeric, removing infected leaves diminishes disease severity and limits further spread (Gohel et al., 2022).

(k) Use of biological control agents: Utilizing inundative and inoculative releases, or deploying biological control agents such as insect predators, parasitoids, and insect pathogens, can play a significant role in managing insect pests within an insecticide-free environment. These agents serve as curative control methods during sudden outbreaks in insect populations (Devi et al., 2019). A variety of biocontrol agents, including *Trichoderma spp., Gliocladium spp., Bacillus subtilis, Aspergillus niger, Azotobacter chroococcum, Azospirillum lipoforum, Pseudomonas fluorescens*, etc., have been employed in the management of major plant diseases (Pandit et al., 2022; Saldaña-Mendoza et al., 2023).

(l) Use of organic pesticides and other pesticides: Kaolin, a clay formed naturally through the weathering of aluminous minerals containing kaolinite, like feldspar, is finely pulverized to a uniform particle size for application as a water suspension on plant parts. It offers control against both insects and diseases. Panchagavya, derived from a blend of five key ingredients sourced from cows—urine, dung, milk, curd, and ghee—along with tender coconut water, sugarcane juice, and ripe bananas, is prepared and matured before being diluted to a 3% concentration with water for use as a foliar spray. This method effectively enhances plant disease resistance (De & De, 2019).

1.7 Integrated pest management (IPM) approaches for horticultural crops

Integrated Pest Management (IPM) in horticultural crop production represents a comprehensive strategy for pest control in horticultural crops, prioritizing sustainability and eco-friendly methods. Unlike relying solely on chemical pesticides, IPM integrates diverse approaches to prevent and manage pests, all while mitigating risks to human health and the environment (Deguine et al., 2021).

One key aspect of IPM is the use of cultural practices such as crop rotation, proper irrigation, and planting resistant varieties to create unfavorable conditions for pests and reduce their populations. This helps to disrupt pest life cycles and prevent outbreaks (Angon et al., 2023). Crop rotation with nonhost or tolerant crops will break the pest cycles and reduce their build-up year after year (Dara, 2019).

Biological control is another integral component of IPM, involving the introduction or conservation of natural enemies of pests, such as predators, parasites, and pathogens (Jeffers and Chong, 2021). This approach harnesses the natural balance of ecosystems to keep pest populations in check (Lbguytemecula, 2023). This alternative approach to conventional pesticide usage offers highly effective pest management while minimizing ecological disturbance and safeguarding biodiversity (Krishnamoorthi et al., 2024).

Mechanical and physical controls, such as traps, barriers, and netting, are employed to physically block pests from accessing crops or to remove them from the environment (Adhikari, 2022). These methods are often targeted and can help reduce the need for chemical interventions (Cherlinka, 2022).

When chemical control is necessary, IPM emphasizes the use of least-toxic pesticides, applied in a targeted manner to minimize harm to beneficial organisms and reduce the risk of pesticide resistance (Zhu et al., 2016). Additionally, alternative products, such as insecticidal soaps and botanical extracts, may be used as part of an IPM strategy (Curkovic, 2016).

Regular monitoring and scouting of crops for pest activity are essential in IPM to detect problems early and make informed management decisions (Schnelle, 2017). By using a combination of cultural, biological, mechanical, and chemical controls tailored to specific pests and cropping systems, IPM helps to maintain pest populations below economically damaging levels while promoting ecosystem health and sustainability in horticultural crop production (Angon et al., 2023).

1.8 Conclusion

It is imperative to address biotic stresses in horticultural crops given the current climatic conditions for the sake of sustainable agriculture. As climate change intensifies, managing the impacts of biotic stresses becomes ever more critical. Through the adoption of integrated pest management techniques, leveraging advancements in biotechnology, and advocating for ecosystem-based approaches, we can bolster the resilience of horticultural systems while safeguarding biodiversity and limiting ecological harm. Collaboration among researchers, farmers, policymakers, and other stakeholders is indispensable for devising and executing comprehensive strategies to protect horticultural crops amidst the changing climate.

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