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Physiology of crops under biotic stress

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Abstract

In general, plants can undergo stress condition which may either biotic or abiotic. Biotic stress factors mostly includes pest and diseases. It directly affects plant growth or has an indirect effects on photosynthesis. Pest affects plant physiology by influencing its water balance, sucking of plant sap from phloem elements, altering the sink demand and has autotoxic effects. Mostly sucking pest such as aphids, plant bugs affects the plant physiology more compared to other pest. Similar to pest pathogen also influence plant physiology to a greater extent. They has detrimental effects on photosynthesis, translocation of water and nutrients, upward movement of water, increase in leaf temperature due to reduced transpiration rate, clogging of phloem elements by pathogen particles which results in improper transport of water and wilting. Although biotic stress affects plant physiology, there are certain adaptive mechanisms that help in plants mitigating such stress. It includes signalling mechanism, systemic acquired resistance (SAR), role of plant growth regulators like salicylic acid, jasmonic acid and judicial application of mineral nutrients in the form of fertilizers.

Keywords: biotic stress, pest, disease, photosynthesis, SAR, salicylic acid

Introduction

Several stresses can be involved during the life of plants. One of the major stresses is caused by tissue damage. Tissue damage in plants is most often associated with insect herbivore infestation. On average, herbivores remove approx. 15 % of primary production in terrestrial ecosystems. Herbivore damage is assessed by surveying the amount of tissue removed from foliagein agricultural fields. Many types of insect damage affect photosynthesis in undamaged tissues, and these ‘indirect’ effects on photosynthesis may be considerably greater than the direct removal of leaf area (Pessarakli, 2016) [13].

Plant bugs penetrate epidermal cells and ingest cell contents, aphids suck mainly from the sap flow in phloem sieve elements. Spittlebugs and cicadellinine leafhoppers often tap the xylem (Thompson, 1994) [17]. Phloem-feeding whitefly and aphid cause small wounds in plant foliage that are perceived as pathogens by the plant’s defense system and activate the SA-dependent and JA/ET-dependent signalling pathways (Walling, 2000) [19]. Some leaf-mining insects that live and feed during their larval stage between the upper and lower epidermis of leaf blade and damage the parenchymal tissues.

Similar to pest, pathogens also infect plants in the course of obtaining food for themselves, depending on the kind of pathogen and on the plant organ and tissue they infect, pathogens interfere with the different physiological function(s) of the plant and lead to the development of different symptoms. Fungal plant pathogens, infection and diseases they cause in host plants can result in various stressful conditions. As a result, serious stressful conditions may be induced in plants.

Detrimental Effects of Insect Herbivores to Plants:

1. Effects on Photosynthesis

Over 50% of all plant–insect interactions resulted in a loss of photosynthetic capacity.Insect herbivory, whether defoliation or by feeding on specific tissues (e.g., phloem or xylem), triggers a complex and interacting array of molecular and physiological responses in plants. These responses potentially reduce the photosynthetic capacity in remaining leaf tissues to a greater extent than the direct removal of photosynthetic surface area. For example, the removal of only 5% of the area of an individual wild parsnip leaf by caterpillars reduced photosynthesis by 20% in the remaining foliage (Zangerl *et al.*, 2002) [20].

1.1 Direct Reduction of Photosynthetic Capacity

The removal of leaf tissue by herbivores represents a “direct” reduction of photosynthetic capacity (Nabity *et al.*, 2009).

1.2 Indirect Reduction of Photosynthetic Capacity

In addition to directly damaging photosynthetic tissue, herbivores may indirectly affect remaining leaf tissue by diverting resources to defense or disrupt the transport of nutrient and water. The insect attack to xylem or phloem may alter water transport, stomatal aperture, and sucrose transport and loading, thereby reducing photosynthesis in remaining leaf tissue. Severing tissue vasculature alters leaf hydraulics and, subsequently, nutrient transport. If insect feeding is subtle enough to avoid outright cell rupture, modulation of nutrients sequestered by feeding will alter plant osmotica or sink/source relationships (Aldea *et al.*, 2005) [3]. These effects also may be mediated by the plant’s response. Insect infestation, or even the perception of attack, can induce a myriad of defense-related responses while concomitantly reducing the expression of photosynthesis-related genes.

Indirect effects of herbivory were assigned to four classes: severed vasculature, altered sink demand, defense-related autotoxicity, and defense-induced down-regulation of photosynthesis (Nabity *et al.*, 2009).

2. Alteration of Photosynthesis and Water Balance

Damage to leaf venation provoked by insect infestation alters leaf hydraulic conductance thereby reducing stomatal conductance and photosynthesis (Nabity *et al.*, 2009). If there are not alternative pathways for water transport, the consequences of damage to venation can persist for weeks after the initial injury and lead to leaf desiccation. The foliage damage injury, which severs venation indiscriminately or feeding on specific tissues, may physically obstruct fluid flow with insect mouthparts (stylets) or cell fragments and alter photosynthesis and water balance in remaining leaf tissue (Fig1).

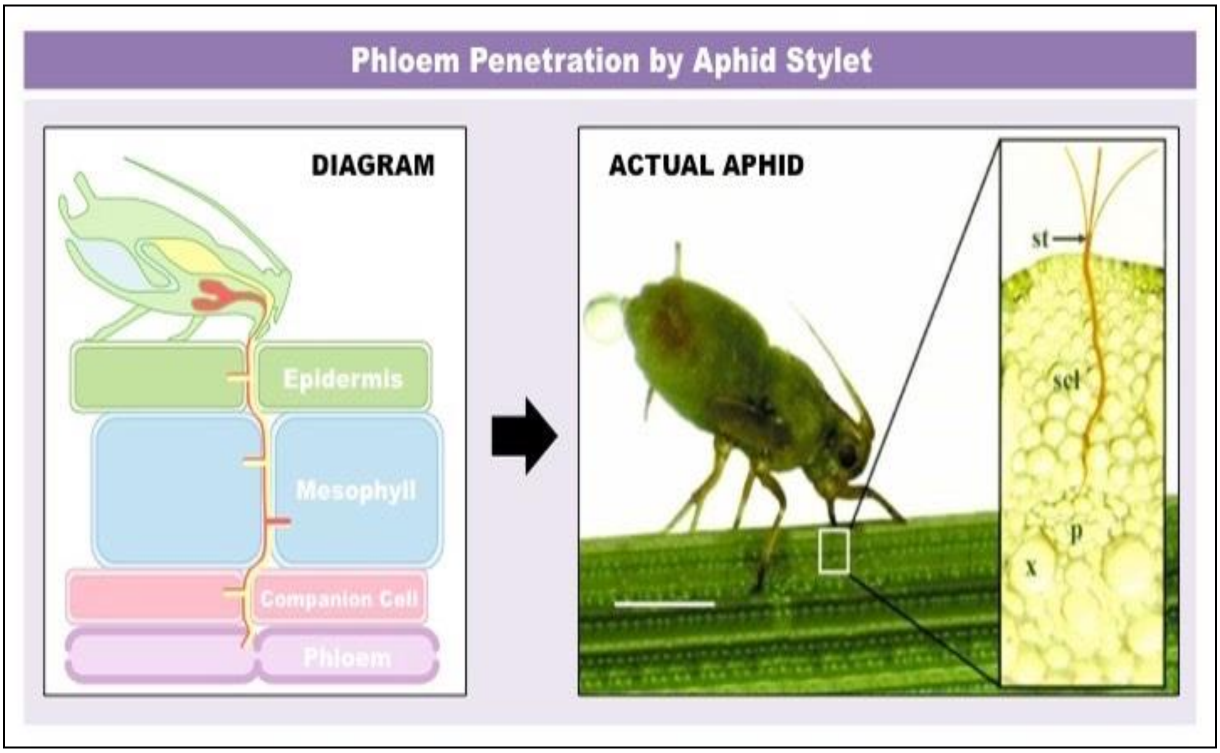


Fig 1: Phloem penetration by Aphid stylet

Skeletonizing of soybean leaves by Japanese beetles increased water loss from the cut edges. Damaging the interveinal tissue increased transpiration by 150% for up to 4 days post-injury, and this uncontrolled water loss had no detectable effect on CO$_2$ exchange, severed vasculature induced for 2 days increase in photosynthetic efficiency in undamaged tissue of damaged leaves (Aldea *et al.*, 2005; Nabity *et al.*, 2009) [3].

The effects of defoliation on photosynthesis seem to be less predictable than damage caused by other feeding guilds. In hardwoods, leaf gall and fungal damage consistently reduced photosynthetic efficiency at distances ≥1 cm from the point of direct damage, whereas defoliation resulted in only highly local reductions (<1 mm) in photosynthetic efficiency (Aldea *et al.*, 2006).

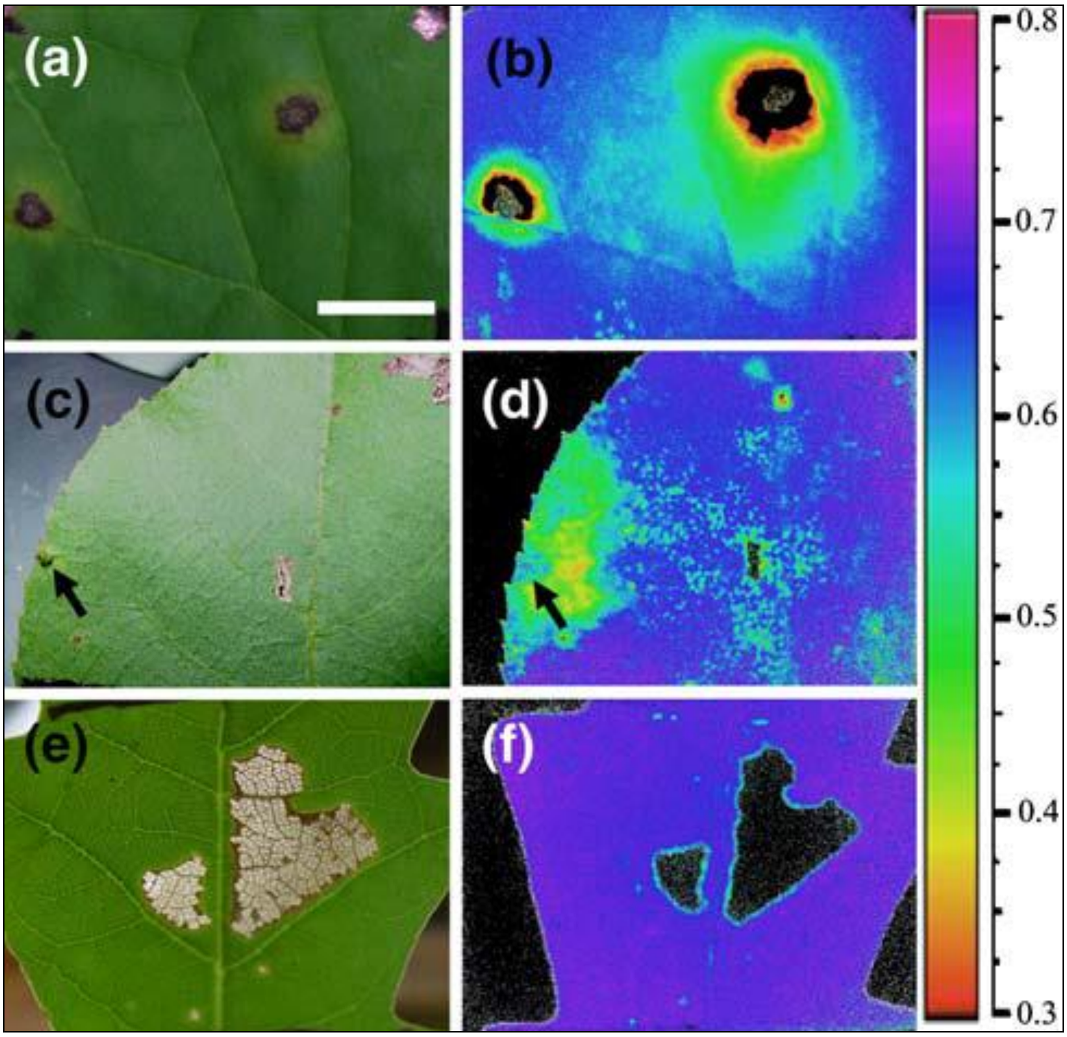
3. Alteration of Sink Demand

Plants respond to herbivory with increased CO$_2$ uptake and the mechanism typically is linked to compensation or an increase in the sink demand within the leaf (Nabity *et al.*, 2009).

Phloem feeding increased whole-canopy photosynthesis in beech trees, perhaps through a reduction in photosynthatebuildup; however, the mechanism remains unclear and may be as simple as herbivore preference for hosts with higher rates of photosynthesis. Gall formation in red maple, pignut hickory, and black oak reduced photosynthetic efficiency, but increased non-photochemical quenching, indicating a down-regulation of the photosystem II reaction centers in the area around galls (Aldea *et al.*, 2006).

Depending on the type of damage and tree species, biotic damage caused a decrease in the operating efficiency of photosystem II (ϕPSII) at considerable distance away from the zone of visible damage (Fig 2). Fungal infections on *C. canadensis*and galls on *C. glabra*reduced ϕPSII by 22 and 33%, respectively, andthe damage extended up to 14mm away from the tissueaffected visibly.

A decline in leaf temperature near galls suggests that transpiration was greater and fluid and nutrient transport increased near the point of damage (Macfall *et al.*, 1994) [9]. Defoliation, as well as removal of reproductive and other vegetative sinks, may improve photosynthesis in remaining leaf tissue by increasing carboxylation efficiency and the rate of ribulose-1,5-bisphosphate regeneration (Thomson *et al.*, 2003) [18].

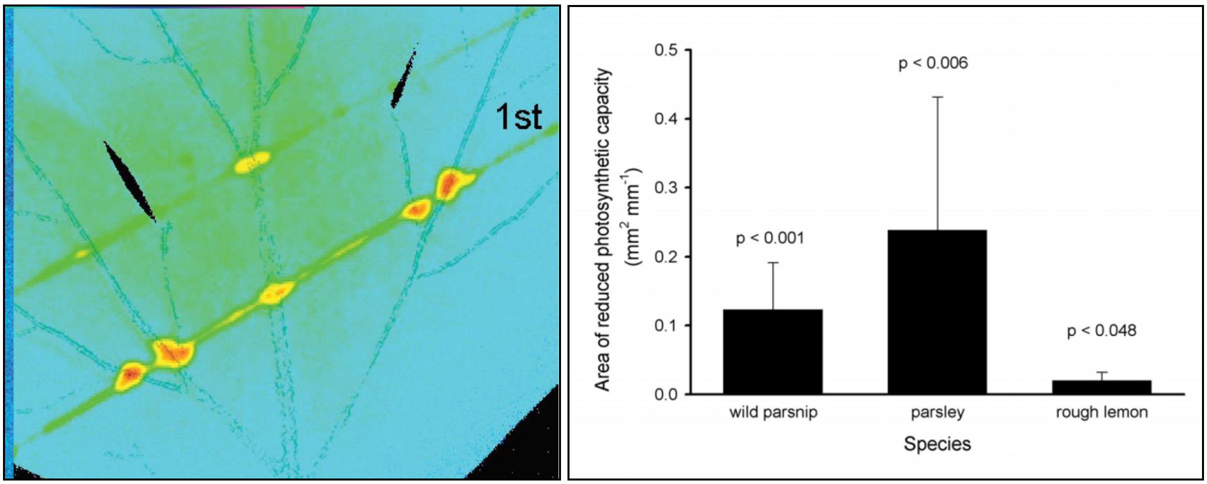


(Aldea *et al.*, 2006)

Fig 2: (a, b) fungal infection of a *Cercis Canadensis*; (c, d) leaf damage caused by *Caryomyia*midge galls on a *Caryaglabra*leaf; (e, f) skeletonizer damage to a *Quercusalba*leaf

4. Autotoxic Effect of Defensive Compounds on Photosynthesis

Plants run the risk of autotoxicity because of the biocidal properties of many secondary compounds. The autotoxic effect of defensive compounds on photosynthesis is highly species-specific. The secondary compound may reduce the photosynthesis as reported for the wild parsnip (*Pastinacasativa*). Wild parsnip contains an arsenal of defense compounds including furanocoumarins, which are photoactivatedand biocidal against a variety of organisms (Gog *et al.*, 2005) [7]. Furanocoumarins are contained in oil tubes under positive pressure and bleed profusely from the wounding site (Fig 3-4).



(Gog *et al.*, 2005) [7]

Fig 3 & 4: Effect of razor cut on reduction in photosynthetic capacity of wild parsnip, parsley and rough lemon

During feeding, leaf-chewing insects are likely to release essential oils. The effect of insect-feeding may be even more dramatic, however, if oils transferred to the mandibles of an insect are secondarily transferred to other tissues. Although the spatial impact on photosynthesis of releasing endogenous oils was small, leaf-chewing insects frequently produce collections of irregular-shaped holes within a single leaf, leaving far more extensive networks of cut edges. Thus, the post-attack cost of autotoxicity may be substantial for plants that rely on monoterpenes for defense (Gog *et al.*, 2005) [7].

5. Down-Regulation of Photosynthesis-Related Genes

Photosynthetic proteins are often down-regulated by insect attack. Jasmonates play a central role in regulating plant defense responses to herbivores, but while jasmonatesinduce defenses, they also inhibit growth and photosynthesis (Giri *et al.*, 2006). Transcriptional analysis of plant–herbivore interactions revealed that photosynthesis-related genes are down-regulated after infestation.

Partial defoliation of individual leaves by herbivores largely increases evapotranspiration via enhanced water loss from cut edges and produces leaf dehydration (Aldea *et al.*, 2005) [3], reduces photosynthesis by causing stomata to close, and also by initiating senescence signalling. It has been suggested that the slower growth and down-regulation of photosynthetic-related genes by herbivore elicitation may be required to free up resources for defense-related processes.

Detrimental Effects of Pathogen to Plants

1. Effect of pathogens on photosynthesis

Pathogens do interfere with photosynthesis is obvious from the chlorosis they cause on many infected plants, from the necrotic lesions or large necrotic areas they produce on green plant parts, and from the reduced growth and amounts of fruits produced by many infected plants (Agrios, 2005) [1].

In leaf spot, blight, and other kinds of diseases in which there is destruction of leaf tissue, e.g., in cereal rusts and fungal leaf spots, bacterial leaf spots (Fig5A-D), viral mosaics and yellowing and stunting diseases (Fig5E-F), or in defoliations, photosynthesis is reduced because the photosynthetic surface of the plant is lessened (Guo *et al.*,2005) [8].

Even in other diseases, however, plant pathogens reduce photosynthesis, by affecting the chloroplasts and causing their degeneration (Guo *et al.*, 2005) [8]. The overall chlorophyll content of leaves in many fungal and bacterial diseases is reduced, but the photosynthetic activity of the remaining chlorophyll seems to remain unaffected.

In some fungal and bacterial diseases, photosynthesis is reduced because the toxins, such as tentoxin and tabtoxin, produced by these pathogens inhibit some of the enzymes that are involved directly or indirectly in photosynthesis. In plants infected by many vascular pathogens, stomata remain partially closed, chlorophyll is reduced, and photosynthesis stops even before the plant eventually wilts (Sampol *et al.*, 2003) [14]. Most virus and nematode diseases also induce varying degrees of chlorosis and stunting. In the majority of such diseases, the photosynthesis of infected plants is reduced greatly (Agrios, 2005) [1].

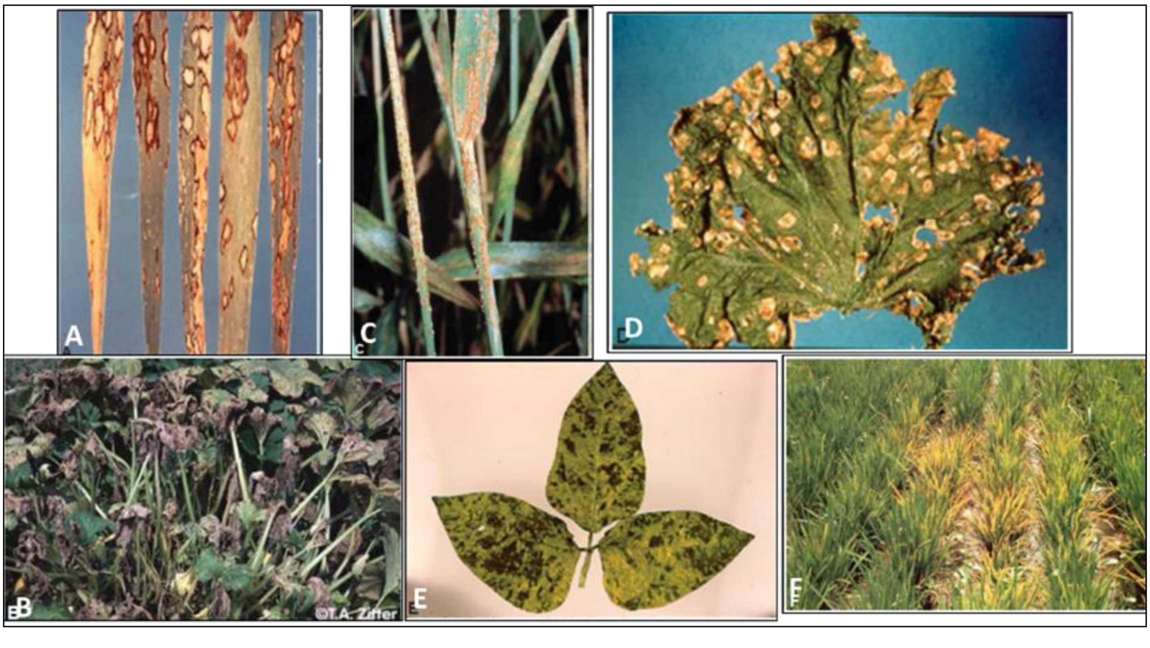


Fig 5: A) Spots on barley leaves caused by the fungus *Rhynchosporium sp*. (B) Pumpkin leaves infected heavily with the downy mildew caused by *Pseudoperonosporacubensis*. (C)Wheat plant infected with the stem rust fungus *Pucciniagraminisf.sp. tritici.* (D)Angular leaf spots on cucumber leaf caused by the bacterium *Pseudomonas lacrymans*. (E) Reduced chlorophyll in yellowish areas of virus-infected cowpea with *cowpea chlorotic mottle virus* or (F) Stunting and yellowing of rice plants infected with the *rice tungro virus*.

2. Effect of pathogens on translocation of water and nutrients in the host plant

When a pathogen interferes with the upward movement of inorganic nutrients and water or with the downward movement of organic substances, diseased conditions result in the parts of the plant denied these materials. The diseased parts, in turn, will be unable to carry out their own functions, thus causing disease of the entire plant. For example, if water movement to the leaves is inhibited, the leaves cannot function properly, photosynthesis is reduced or stopped, and few or no nutrients are available to move to the roots, which in turn become starved and diseased and may die.

2.1 Interference with Upward Translocation of Water and Inorganic Nutrients

Many plant pathogens interfere in one or more ways with the translocation of water and inorganic nutrients through plants. Some pathogens affect the integrity or function of the roots, causing them to absorb less water; other pathogens, by growing in the xylem vessels or by other means, interfere with the translocation of water through the stem; and, in some diseases, pathogens interfere with the water economy of the plant by causing excessive transpiration (Guo *et al*., 2005) [8] through their effects on leaves and stomata.

2.2 Interference with Absorption of Water by Roots

Many pathogens, such as damping-off fungi (Fig6A), root-rotting fungi and bacteria (Fig6B-C), most nematodes (Fig7B), and some viruses, cause an extensive destruction of the roots before any symptoms appear on the aboveground parts of the plant. Some bacteria and nematodes (Putten*et.al*, 2004) cause root galls or root knots (Fig7A), which interfere with the normal absorption of water and nutrients by the roots. Root injury affects the amount of functioning roots directly and decreases proportionately the amount of water absorbed by the roots. Some vascular parasites, along with their other effects, seem to inhibit root hair production, which reduces water absorption (Agrios, 2005) [1].

Fig 6: (A) Destruction of roots of young seedlings by the damping-off oomycete *Pythium sp*.(B) Roots and stems of pepper plants killed by *Phytophthora sp*. (C) Infection of crown and roots of corn plant with the fungus *Fusarium*.

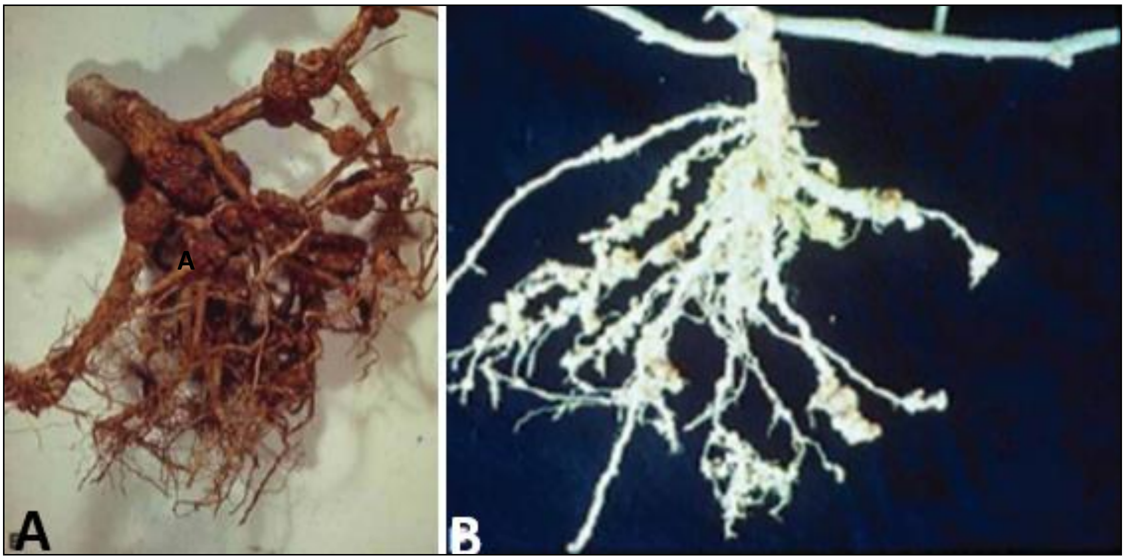


Fig 7: (A) Numerous galls caused by the bacterium *Agrobacterium tumefaciens*on roots of a cherry tree. (B) Root knot galls caused by the nematode *Meloidogyne sp*. on roots of a cantaloupe plant.

2.3 Interference with Translocation of Water through the Xylem

Fungal and bacterial pathogens that cause damping off, stem rots, and cankers may reach the xylem vessels in the area of the infection and, if the affected plants are young, may cause their destruction and collapse.

Cankers in older plants, particularly older trees, may cause some reduction in the translocation of water, but, generally, do not kill plants unless the cankers are big or numerous enough to encircle the plant (Fig8A-B). In vascular wilts, however, reduction in water translocation may vary from little to complete (Fig9A-D). In many cases, affected vessels may be filled with the bodies of the pathogen and with substances secreted by the pathogen or by the host in response to the pathogen and may become clogged (Sharma *et.al*, 2013) [15].

Whether destroyed or clogged, the affected vessels cease to function properly and allow little or no water to pass through them. Certain pathogens, such as the crown gall bacterium (*Agrobacterium tumefaciens*), the clubroot protozoan (*Plasmodiophorabrassicae*), and the root-knot nematode (*Meloidogyne*sp.), induce gall formation in the stem, roots, or both. The enlarged and proliferating cells near or around the xylem exert pressure on the xylem vessels, which may be crushed and dislocated, thereby becoming less efficient in transporting water (Agrios, 2005) [1].

Fig 8: (A) The stem of a cantaloupe plant infected with the fungus *Phomopsis*sp. (B) Canker on an almond tree caused by the fungus *Ceratocystisfagacearum.*

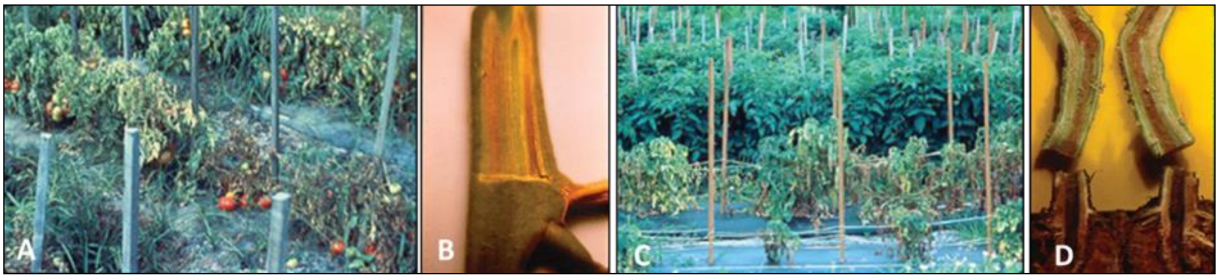


Fig 9: (A) Vascular wilt of tomato caused by the fungus *Fusarium.* (B) Discoloured vascular tissues of a tomato stem infected with the same fungus. (C) Wilted tomato plants infected with the vascular bacterium.

Ralstoniasolanacearum. (D) Discoloured vascular tissues of a tomato plant infected with the same bacterium.

The pathogens invade the xylem of roots and stems and produce diseases primarily by interfering with the upward movement of water through the xylem. In many plants infected by these pathogens the water flow through the stem xylem is reduced to a mere 2 to 4% of that flowing through stems of healthy plants. The pathogen can reduce the flow of water through its physical presence in the xylem as mycelium, spores, or bacterial cells and by the production of large molecules (polysaccharides) in the vessels (Fig10A-C).

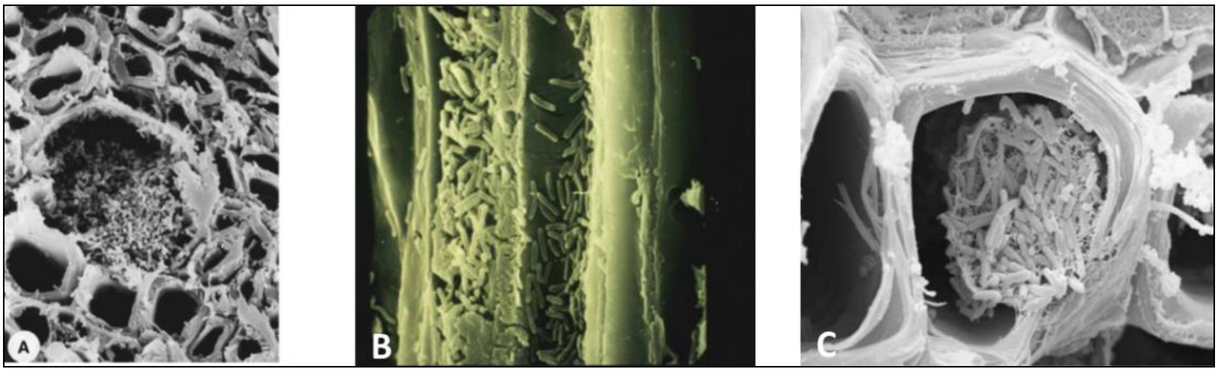


Fig 10: Microscopic images: (A) *Pseudomonas* bacteria clogging a xylem vessel of a young plant shoot. (B) Bacteria of the xylem-inhabiting *Xylellafastidiosa*in a vessel of a grape plant. (C) *Xylella* bacteria in a cross section of a xylem vessel of an infected grape leaf.

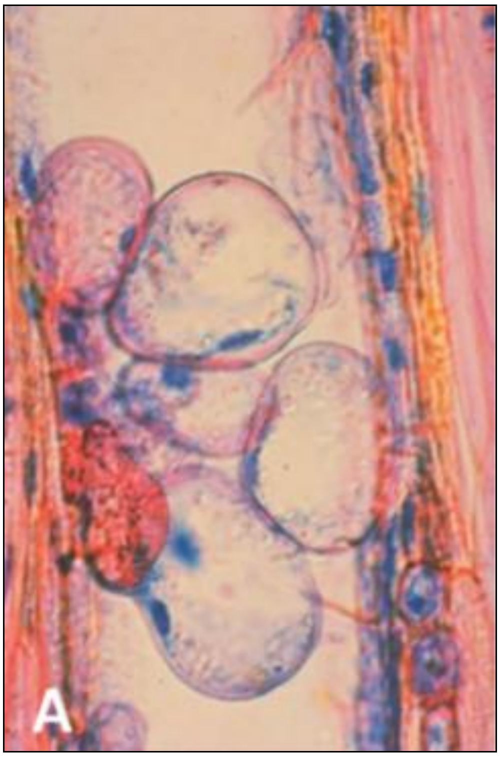


Fig 11: (A) Tyloses in a xylem vessel.

2.4 Interference with Transpiration

In plant diseases in which the pathogen infects the leaves, transpiration is usually increased. This is the result of destruction of at least part of the protection afforded the leaf by the cuticle, an increase in the permeability of leaf cells, and the dysfunction of stomata.

In diseases such as rusts, in which numerous pustules form and break up the epidermis, in most leaf spots, in which the cuticle, epidermis, and all the other tissues, including xylem, may be destroyed in the infected areas (Fig12A-B), in the powdery mildews, in which a large proportion of the epidermal cells are invaded by the fungus (Fig12C) and in apple scab, in which the fungus grows between the cuticle and the epidermis (Fig12D)-in all these examples, the destruction of a considerable portion of the cuticle and epidermis results in an uncontrolled loss of water from affected areas. If water absorption and translocation cannot keep up with the excessive loss of water, loss of turgor and wilting of leaves occur (Fig12E).

The suction forces of excessively transpiring leaves are increased abnormally and may lead to collapse or dysfunction ofunderlying vessels through the production of tyloses (Fig11A) and gums.

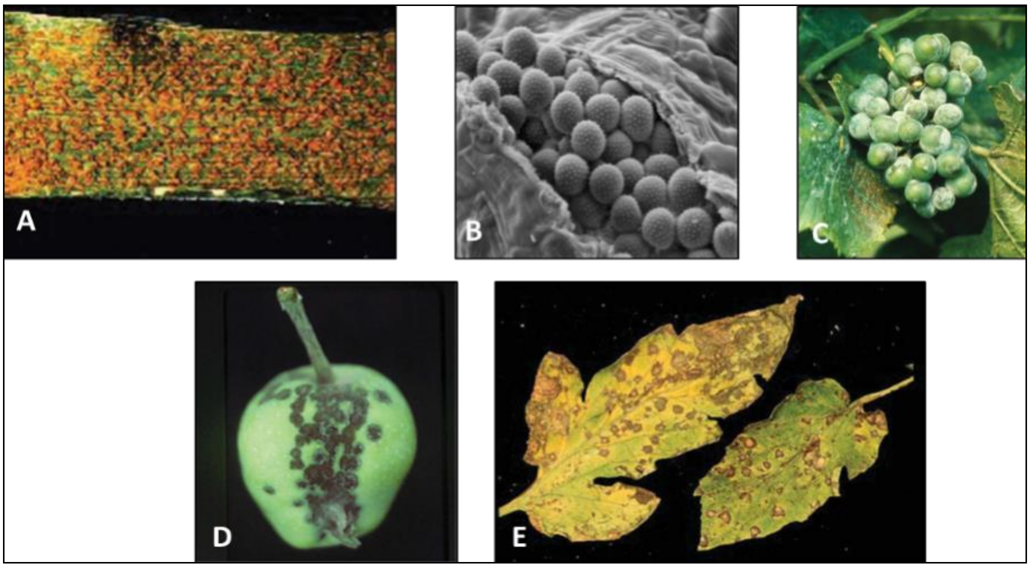


Fig 12: (A) The wheat leaf rust pathogen *Pucciniarecondita*produces innumerable lesions (uredia) on wheat leaves. (B) Uredospores breaking the epidermis and emerging from the surface of an infected leaf. (C) Grape berries infected with the powdery mildew fungus *Uncinulanecator* (D) The apple scab fungus *Venturiainaequalis*grows between the cuticle and the epidermis, causing the cuticle to, allowing transpiration to occur. (E) Tomato leaves with numerous lesions caused by the fungus *Septoria sp.* and through which excessive transpiration occurs.

2.5 Interference with Translocation of Organic Nutrients through the Phloem:

Plant pathogens may interfere with the movement of organic nutrients from the leaf cells to the phloem, with their translocation through the phloem elements, or, possibly, with their movement from the phloem into the cells that will utilize them (Fig13A).

Obligate fungal parasites, such as rust and mildew fungi, cause an accumulation of photosynthetic products, as well as inorganic nutrients, in the areas invaded by the pathogen. In these diseases, the infected areas are characterized by reduced photosynthesis and increased respiration. However, the synthesis of starch and other compounds, as well as dry weight, is increased temporarily in the infected areas, indicating translocation of organic nutrients from uninfected areasor from healthy leaves toward the infected areas (Agrios, 2005) [1].

In stem diseases of woody plants, the pathogen attacks and may destroythe phloem elements in that area, thereby interfering with the downward translocation of nutrients (Fig13B-C). In diseases caused by phytoplasmas, as well as in diseases caused by phloem-limited fastidious bacteria, they exist and reproduce in the phloem sieve tubes, thereby interfering with the downward translocation of nutrients. In several plants propagated by grafting a variety scion onto a rootstock, infection of the combination with a virus (e.g., infection of an apple or stone-fruit rootstock with *tomato ringspot virus*) leads to formation of a necrotic plate at the points of contact of the hypersensitive scion variety with the rootstock, which leads to the death of the scion.In some virus diseases, particularly the leaf-curlingtype and some mosaic diseases, starch accumulation inthe leaves is mainly the result of degeneration (necrosis)of the phloem of infected plants, which is oneof the first symptoms.

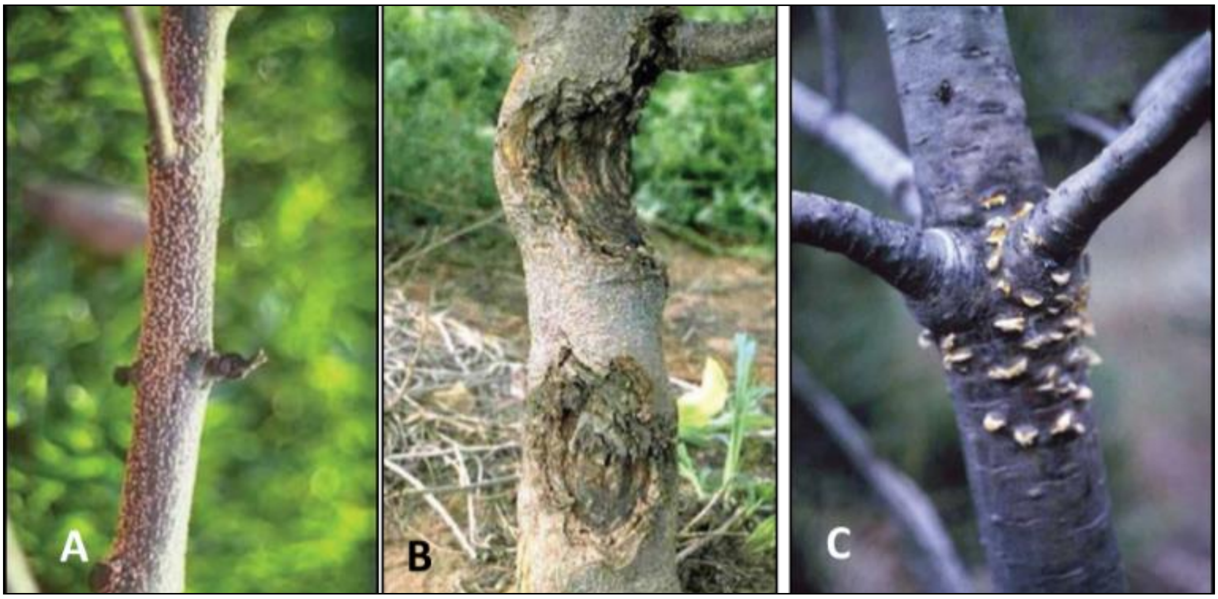


Fig 13: (A) Young canker caused by the fungus *Nectria*in the bark of the branch. (B)Two advanced *Nectria*cankers in which both the xylem and the phloem. (C) Blister canker on a pine tree in which the bark and phloem have been killed by the fungus *Cronartiumribicola.*

3. Effect of pathogens on host plant respiration:

When plants are infected by pathogens, the rate of respiration generally increases. This means that affected tissues use up their reserve carbohydrates faster than healthy tissues. The increased rate of respiration appears shortly after infection, certainly by the time of appearance of visible symptoms and continues to rise during the multiplication and sporulation of the pathogen.

Several changes in the metabolism of the diseased plant accompany the increase in respiration after infection. Thus, the activity or concentration of several enzymes of the respiratory pathways seems to be increased. The accumulation and oxidation of phenolic compounds, many of which are associated with defense mechanisms in plants, are also greater during increased respiration. Increased respiration in diseased plants is also accompanied by an increased activation of the pentose pathway, which is the main source of phenolic compounds. Increased respiration is sometimes accompanied by considerably more fermentation than that observed in healthy plants, probably as a result of an accelerated need for energy in the diseased plant under conditions in which normal aerobic respiration cannot provide sufficient energy (Agrios, 2005) [1].

4. Effect of pathogens on plant reproduction

Pathogens that attack various organs and tissues of plants weaken and often kill these organs or tissues, thereby weakening the plants. As a result, such plants remain smaller in size, may produce fewer flowers, and may set fewer fruit and seeds; the latter may be of inferior vigour and vitality and, therefore, if planted, they may produce fewer and weaker new plants (Agrios, 2005) [1]. In addition to these indirect effects of pathogens on plant reproduction, many pathogens have a direct adverse effect on plant reproduction because they attack and kill the flowers, fruit, or seed directly, or interfere and inhibit their production, or the pathogens interfere directly or indirectly with the propagation of their host plant (Fig14A-D).

Fig 14: (A)The flowers of apricot tree which have been killed by the brown rot fungus *Moniliniafructicola*.(B) A mixture of barley kernels (whitish-yellow) and ergot sclerotia (the larger black bodies) produced by the ergot fungus *Clavicepspurpurea*(C) A mixture of intact healthy wheat kernels and somewhat darker, broken wheat kernels filled with spores of the common bunt (covered smut) fungus *Tilletia*sp.(D) Ear of corn having some of the corn kernels replaced by galls containing spores of the fungus *Ustilagomaydis*.

Biotic and abiotic stress - Interaction

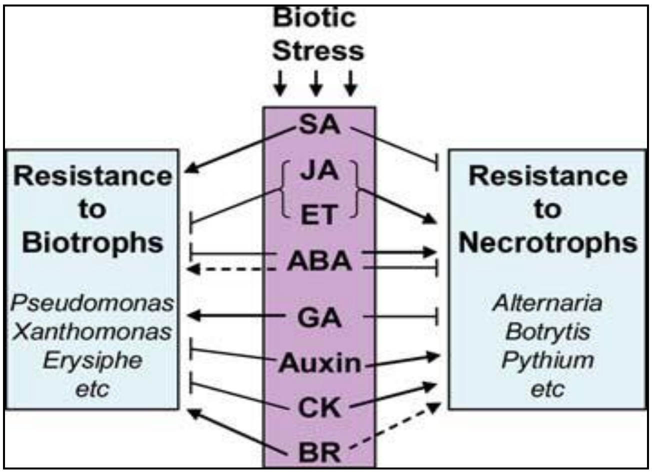
Based on the number of interacting factors, stresses can be grouped into three categories: single, multiple individual, and combined stresses. A single stress represents only one stress factor affecting plant growth and development, whereas multiple stress represents the impact of two or more stresses occurring at different time periods without any overlap (multiple individual) or occurring concurrently with at least some degree of overlap between them (combined). The co-occurrence of drought and heat stresses during summer is an example of a combined abiotic stress, whereas a bacterial and fungal pathogen attacking a plant at the same time represents a case of combined biotic stress (Pandey *et.al*, 2017) [12].

One of the important diseases known to be aggravated by high temperature and water deficit conditions is dry root rot (DRR), caused by a necrotrophic fungus R. bataticola. Sharma and Pande (2015) have shown the interaction between *R. bataticola* and drought stress in laboratory conditions by infecting *C. arietinum*plants grown at different soil moisture contents with this fungi. This study showed that the disease incidence was the highest at 40% soil moisture content. Less disease incidence at high soil moisture content was attributed to the inability of the fungal sclerotia to survive under wet soil conditions.Long periods of drought accompanied with warm days andcool nights generally favour powdery mildew in *Beta vulgaris* (sugar beet) caused by the fungus *Erysiphebetae*.Drought stress accompanied by high soil temperature has been correlated with increased charcoal stalk rot development, caused by *M. phaseolina*, in *S. bicolor*.

Role of mineral nutrients and Plant Growth Regulators in mitigating Biotic Stress:

1. Role of Plant Growth Regulators in mitigating Biotic Stress

Plant hormones play important roles in regulating developmental processes and signalling networks involved in plant responses to a wide range of biotic and abiotic stresses. Plant defense mechanisms are usually complex and composed of multiple layers of defense that are effective against diverse array of pathogens. Plants utilize preformed physical and chemicalbarriers that hinder pathogen entry and infection. In addition, plants have evolved a wide variety of inducible defense mechanisms that are triggered upon pathogenrecognition. These inducible defenses include multifaceted molecular, biochemical, and morphological changes, suchas oxidative burst, expression of defense-related genes, production of antimicrobial compounds, and/or programmedcell death. Plants produce a wide variety of hormones, which include auxins, gibberellins (GA), abscisic acid (ABA), cytokinins (CK), salicylic acid (SA), ethylene (ET), jasmonates (JA), brassinosteroids (BR) and peptide hormones (Fig15).

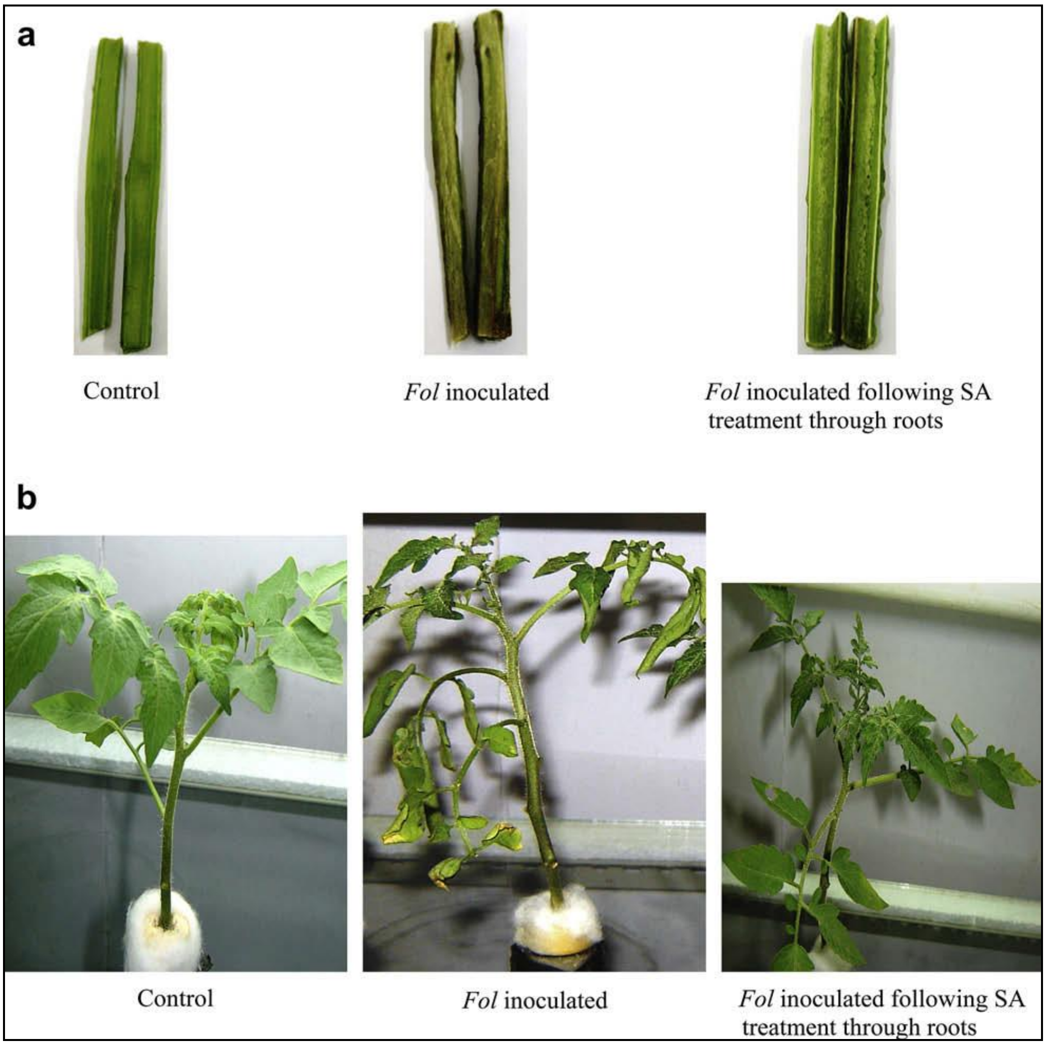


(Bari *et.al*, 2009) [5]

Fig 15: Plant Growth Regulators in mitigating Biotic Stress

Three phytohormones—SA, JA and ET, are known to play major roles in regulating plant defense responses against various pathogens, pests and abiotic stresses such as wounding and exposure to ozone. SA plays a crucial role in plant defense and is generally involved in the activation of defense responses against biotrophic and hemi-biotrophic pathogens (Fig15) as well as the establishment of systemic acquired resistance (SAR).SA levels increase in pathogenchallengedtissues of plants and exogenous applicationsresult in the induction of pathogenesis related (PR) genesand enhanced resistance to a broad range of pathogens (Bari *et.al*, 2009) [5].

Exogenous application of 200 µM salicylic acid through root feeding and foliarspray could induce resistance against *Fusariumoxysporum f. sp. Lycopersici* (Fol) in tomato (Fig16). (Mandal *et al*.,2009) [10]



(Mandal *et al*., 2009) [10]

Fig 16: a) Vascular browning (b) Leaf yellowing wilting

By contrast, JA and ET are usually associated withdefense against necrotrophic pathogens and herbivorous insects (Fig15). Although, SA and JA/ET defense pathways are mutually antagonistic, evidences of synergistic interactions have also been reported. This suggests that the defense signalling network activatedand utilized by the plant is dependent on the nature of thepathogen and its mode of pathogenicity. In addition, thelifestyles of different pathogens are not often readilyclassifiable as purely biotrophic or necrotrophic (Bari *et.al,* 2009) [5]. Therefore, the positive or negative cross talk between SA and JA/ETpathways may be regulated depending on the specificpathogen.

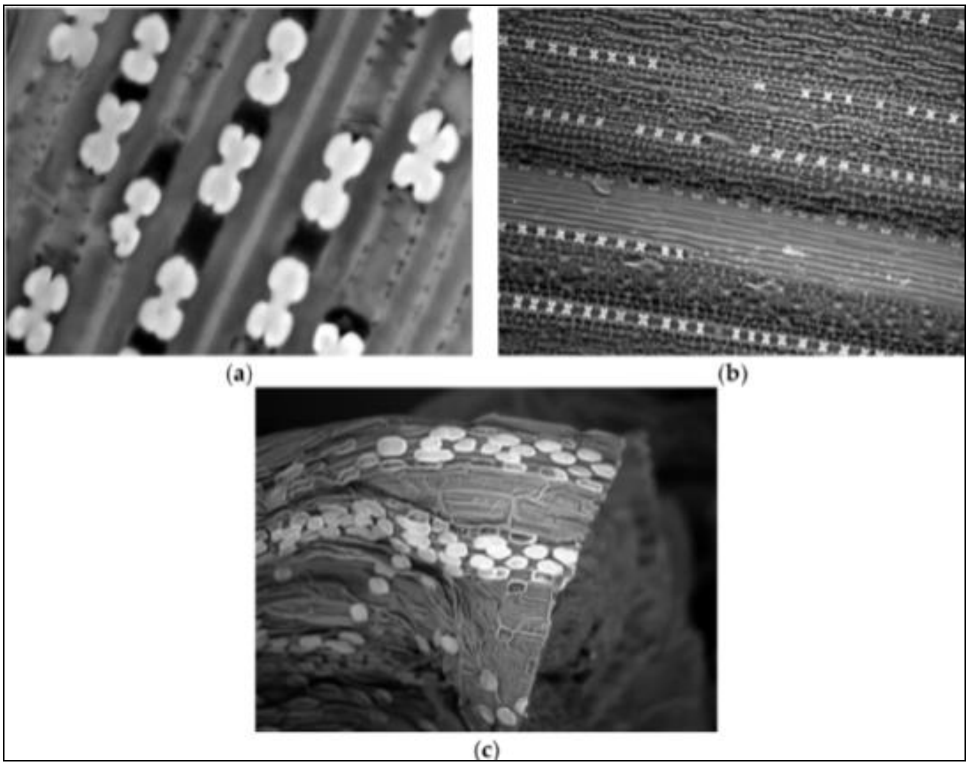
2. Role of mineral nutrients in mitigating Biotic Stress

Nutrients are important for growth and development of plants and also microorganisms, and they are important factors in control of disease. There is no general rule, as a particular nutrient can decrease the severity of a disease but can also increase the severity of the disease incidence of other diseases or have a completely opposite effect in a different environment. Despite the fact that the importance of nutrients in disease controlhas been recognized for some of the most severe diseases, the correct management of nutrients in order to control disease in sustainable agriculture has received little attention (Dordas, 2008) [6].

Nitrogen (N) is the most important nutrient for plant growth and there is an extensive literature about the effect of N on diseases, because its role in disease resistance is quite easily demonstrated. Despite the fact that N is one of the most important nutrients for plant growth and disease development, there are several reports of the effect of N on disease development that are inconsistent and contradict each other, and the real causes of this inconsistency are poorly understood. Potassium (K) decreases the susceptibility of host plants up to the optimal level for growth: beyond this point, there is no further increase in resistance which can be achieved by increasing the supply of K and its contents in plants. Application of K can decrease helminthosporium leaf blight severity and increase grain yields in wheat (Sharma *et al*., 2005) [16]. Phosphorous (P) has been shown to be most beneficial when it is applied to control seedlings and fungal diseases where vigorous root development permits plants to escape disease. Phosphate fertilization of wheat can have a significant effect and almost eliminate economic losses from pythium root rot. Similarly, in corn P application can reduce root rot, especially when it is grown on soils deficient in P, and in other studies it can reduce the incidence of soil smut in corn. Calcium (Ca) is another important nutrient that affects the susceptibility to diseases in two ways. First, Ca is important forthe stability and function of plant membranes. Second, Ca is an important component of the cell wall structure as calcium polygalacturonatesare required in the middle lamella for cell wall stability. When Ca concentration drops, there is an increased susceptibility to fungi which preferentially invade the xylem and dissolve the cell walls of the conducting vessels, which leads to wilting symptoms. Ca treatment of fruits before storage is therefore an effective procedure for preventing losses both from physiological disorders and from fruit rotting.

Systemic acquired resistance (SAR) may be involved in the suppression of plant diseases by micronutrients. Reduction in disease severity has been reported in other crops after a single foliar application of H_3BO_3, $CuSO_4$, $MnCl_2$ or $KMnO_4$, which provided systemic protection against powdery mildew in cucumber plants. Manganese controls lignin and suberin biosynthesis through activation of several enzymes of the shikimic acid andphenylpropanoid pathways. Both ligninand suberin are important biochemical barriers to fungal pathogen invasion. Boron promotes stability and rigidity of the cell wall structureand therefore supports the shape and strength of the plantcell. Silicon (Si) show an improved growth, higher yield, reduced mineral toxicities and better disease and insect resistance (Alhousari *et.al*, 2018).

It is believed that Si creates a physical barrier which can restrict fungal hyphae penetration, orit may induce accumulation of antifungal compounds suchas flavonoid and diterpenoidphytoalexins which can degrade fungal and bacterial cell walls (Fig17). In addition, a high silica content in plant tissue reduces its digestibility and palatability, consequently slowing the insect growth rate.



(Alhousari*et.al*, 2018)

Fig 17: Scanning electron micrographs of maize (a), rice (b) and wheat (c) sheath surfaces showing silica cell form and deposition.

Conclusion

Abiotic stress conditions such as drought, high and low temperature and salinity are known to influence the occurrence and spread of pathogens, insects, and weeds. Biotic stress in plants affects photosynthesis, respiration, translocation of nutrients and water. There is an increased respiration rate and decreased photosynthesis, water & nutrient transport in both pest and disease attack. Some traits for screening genotypes for tolerance to pathogen are Root System Architecture, Leaf Pubescence, Cuticular wax. Further, Plant traits that confer herbivore resistance typically prevent or reduce herbivore damage through expression of traits that deter pests from settling, attaching to surfaces, feeding and reproducing, or that reduce palatability to be improved.

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