Global Scenario of Natural Products for Sustainable Agriculture

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Abstract

Agronomic practices and agricultural goods can be only compete with growing populations. Better crop productivity as well as transparency in market are essential for any farmer's business model. In modern agriculture system, the use of chemicals to fertilize soils and plants is widespread. Such compounds are also used to kill phytopathogens and several plant pests that are limiting factors to optimum productivity. There is an estimation of the increasing world population expected to be approximately 10 billion in the coming three to four decades for fulfilling the demands of growing populations; it needs to improve the agronomic products as well as agriculture practices to encounter the demand of this growing population. Apart from this, another focusing area is to increase agricultural products with high quality. Generally, significant damage to crop production is carried out by many diseases caused by several groups of phytopathogens, namely, bacteria, fungi, viruses, etc., which mutually epitomize a substantial encumbrance of the production of crops. The problem gets more aggravated with the evolution of resistant phytopathogenic microbes which causes even more severe threat to the crops as well as stored plant products and leads to severe damage to the production and storage of crops. In recent times, the use of natural entities such as plants metabolites, microbes, nanomaterials, and viruses against these pathogens reduces the loss of crop productivity and storage damage. The commonly used approach is to introduce the biological compounds to food directly or indirectly, which further shows antimicrobial activity. To avoid undesirable inactivation, application of these natural compounds in the form of

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fabricated nanoparticles seems to be more productive. Biologically synthesized nanoparticles can also be acceptable nowadays to control plant pathogens as antibacterial agents. These too can enhance seed germination and increase growth parameters. Bacteriophages can be used potently to control bacterial diseases. Phages are newly used to manage the pathogenic bacterial population and provide a promising tool to cope with bacterial diseases instead of antibiotics. Bacteriophages have a unique property where they feed on specific bacteria only. This specification makes them future antibacterial agents. Still, there is a need to work on several experiments regarding the use of bacteriophages as antibacterial agents. The present chapter is promising and focusing one to reveal the new options and trends in agriculture.

Keywords
Bactericides · Sustainable farming · Natural compounds · Nanoparticles · Antimicrobial

14.1 Introduction

During recent centuries, a significant loss in productivity leads to constructing calamitous and causes drastic hunger globally. Due to limited disease control methods in some of the less developed countries, an annual loss of 30–50% of major crops was recorded. This type of forfeiture of diseases in agro-plants affects global hunger and famishment. These pests and diseases move rapidly to threaten neighboring countries and continents. A total crop failure is the severe effect of such conditions. There is annually around US$220 billion losses in agro-economics which estimates 20–40% of agro-products due to global diseases and pest infections (FAO 2017).

14.1.1 Historical Use of Botanical Products in Antimicrobials

As mentioned earlier, the population of plant species were reported with approx. 2.5 to 5.0 lakh species present globally (Cowan 1999), but the humans and other land dwellers consumed only a minute fraction. There are so many possibilities of development of phytomedicines using plants (Moerman 1996). Most of the European countries now using botanicals act as another option from mainstream medicinal practices because the present allopathic system has side effects and other reactions. Plant products are used at a greater extent now in mainstream medicine too, because of the ineffectiveness of traditional antibiotics. The rate of extinction of plant species was hastened during the past 20 years. Several microbiologists have a belief that the assemblies of active phytoconstituents having the configurations, manufactured chemically, have a risk to extinct permanently (Borris 1996).

14.1.2 Bacterial Diseases

Around 200 species of bacteria are known for their phytopathogenic nature. These bacterial pathogens may be associated with either parasitic or superficial plants. Occasionally they are present in dead plant debris or found in soils mixed with decaying organic matters. Spreading of bacteria can be proficient by numerous means. It is very important to know the endurance physiognomies of phytopathogenic bacteria as fewer can subsist on inanimate substances, in water or inside creepy-crawlies. Sometimes infected seeds and transplants create a cradle of a banquet. For the entry into host tissue, bacteria require an opening (either artificial or natural). For the establishment of a bacterial colony, they need warm and moist conditions. A high velocity of wind-blown soil and sand causes wounds in a plant which provide a platform for bacterial infection. Bacteria get nutrition from leaked nutrients of intercellular space and colonize themselves inside the host. They may also grow within the vascular tissue of the plant. Bacterial species usually produce and release enzymes that cause alteration in the normal physiology of plant (Abdallah 2011).

14.1.3 Diagnosis of Plant Bacterial Diseases

Indications of bacterial infection and fungal infection in plants are almost similar. Some bacteria-associated plant diseases are as follows (Cooper and Gardener 2006).

14.1.3.1 Bacterial Spots

Leaf spots are the best and typical example of bacterial disease. These spots may give the impression on all parts of plant, namely, leaves and surface of fruits and speedily extend throughout the area then the disease is well-thought-out blight. In the leaves of dicotyledonous plants, spots show a foul or fishy order. These are water-soaked and are initially found in the veins and veinlets with angular appearance. The presence of bacterial exude is the diagnostic feature for bacterial infection. Many times it is observed that infected leaf possesses a chlorotic halo near the bacterial lesion. Leaf spots may amalgamate causing large areas of necrotic tissue. But on a monocot plant, bacterial spots will give the impression as streaks or stripes. Bacterial canker generally appears on stems and branches. The brownish color cortical tissue appeared, and gum was produced in the cankered branches and twigs. Those spotted regions mainly diseased with canker are sour and have odor with soft and sunken appearance if they do not produce any gums. These stems or twigs were concluding dieback of the portion of the tree distal to the canker (Cooper and Gardener 2006).

14.1.3.2 Bacterial Galls

Gall or tumors are caused by bacteria, namely, *Rhodococcus*, *Agrobacterium*, *Arthrobacter*, and *Pseudomonas*. Galls in more than 390 genera of plants worldwide have been caused by several species of genera *Agrobacterium* and generally called as crown gall or root gall. In most of the agricultural soil, members of

Agrobacterium species with other microbes present in the soil. Damage caused by gall may be benign to fatal. The orange-brown color was observed due to the infection of *A. tumefaciens*. Gummosis can be caused due to infection of *Pseudomonas* sp. (Cooper and Gardener 2006).

14.1.3.3 Bacterial Vascular Wilts

Herbaceous plants are attacked by pathogen bacteria to cause vascular wilt. Xylem and phloem were accountable for the ascent of sap and translocation of solutes, respectively. Hence, the causal pathogen moves through the xylem vessels of the host plant and multiply themselves. They can interfere in the transportation of water and minerals by developing gum in vessels of xylem (Cooper and Gardener 2006).

14.1.3.4 Bacterial Soft Rots

Several species of *Bacillus*, *Pseudomonas*, *Clostridium*, and *Erwinia* causes rot tissue of plants. Some of the saprophytes which are non-phytopathogenic bacteria may cause soft rots. Soft rots are known to be corpulent and have spongy structure in plant tissue (Cooper and Gardener 2006).

14.1.3.5 Bacterial Scabs

Underground parts of the plants show infection in this type of disease. The most common example of this category is potato. Scab disease is mostly caused by *Streptomyces* sp. in potato. In this case, lesions occurring in scabs appear in the superficial surface. Below and around the lesion, a typical corky tissue will appear. Some of the pathogens like rot pathogens can enter through these lesions into the host plant tissue and degrade the host (Cooper and Gardener 2006).

14.2 Vectors of Pathogens

Vectors of pathogens are categorized as fastidious vascular-colonizing bacteria shown in Table 14.1 and non-fastidious bacteria shown in Table 14.2 (Mitchell 2004).

14.2.1 Fastidious Vascular-Colonizing Bacteria

Fastidious colonizing bacteria (FVC) are constrained to elements of xylem or phloem. These bacteria are rod-shaped with cell-walled structure. Spittlebugs and sharpshooters are xylem feeders and known as the best vector for fastidious xylem-limited bacteria (Fletcher et al. 1998). Bacteria get accumulated in the

Table 14.1 List of vectors of fastidious vascular-colonizing bacteria

Vector species	Plants	Plant disease	Descriptions
Anasa tristis	Cucurbits	Yellow wine	Noncirculative
Piesma quadratum	Beet	Latent rosette	Persistent, propagative

Source: Mitchell (2004)

Table 14.2 List of vectors of non-fastidious vascular-colonizing bacteria

Vector species	Plants	Plant disease	Phytopathogens	Descriptions
Hypselonotus fulvus	Cotton	Boll rot	*X. campestris malvacearum*	Transmission
Lygus lineolaris	Potato	Ring rot	*Clavibacter michiganensis sepedonicus*	Associated
Lygus lineolaris, *L. elisus*, *Adelphocoris rapidus*, *Campylomma verbasci*, *Heterocordylus malinus*, *Lygidea mendax*, *Lygocoris communis*	Potato and family Solanaceae	Fire blight	*Erwinia amylovora*	Associated
Lygus lineolaris	Celery	Soft rot	*Erwinia carotovora*	Vector associated with punctures
Lygus rugulipennis, *Orthotylus flavosparsus*	Beet	Beet bacterial disease	*Pseudomonas syringae aptata*	Associated
Pseudatomoscelis seriata, *Helopeltis* sp., *Taylorilygus vosseleri*	Cotton	Bacterial blight of cotton, angular leaf spot	*X. campestris malvacearum*	Transmission, associated
Nezara viridula	Cowpea	Stem canker	*X. campestris phaseoli*	Transmission
Nezara viridula	Soybean	Leaf spot and vein necrosis	*Pseudomonas* spp., *Curtobacterium* spp.	Isolated
Nezara viridula, *Edessa meditabunda*, *Dysdercus fasciatus*, *D. honestus*, *D. intermedius*, *D. mendesi*, *D. nigrofasciatus*, *D. ruficollis*	Cotton	Cotton ball rot	*Xanthomonas campestris malvacearum*	Transmission, associated

Source: Mitchell (2004)

foregut of the insect and are ingested into the host. Several times in *Xylella fastidiosa*, the transmission is noncirculative. *Serratia marcescens* is reported to cause yellow wine disease in several cucurbits (Bruton et al. 2003). Transmission of *S. marcescens* has been carried out by vector *Anasa tristis*, known as the squash bug (Mitchell 2004).

14.2.2 Non-fastidious Bacteria (NFVC)

Insects as a vector is not an essential part of the transmission of the majority of pathogenic bacteria. Bacteria cannot protrude inside the plant tissue directly.

They penetrate via stomata or by small wounds (Goto 1992). Thus, a bacterial infection is mainly facilitated when the insect feeds on plant parts and causes feeding punctures (Mitchell 2004).

14.3 Natural Products as Bactericides

Majority of the aromatic compounds have phenolic components (Geissman 1963). Most of the aromatic compounds are secondary metabolites, of which approx. 12,000 have been isolated. Still, the total counts are less than 10% and need to enlighten on plant-based natural products (Schultes 1978). Plant extract compositions were produced in the response of stress and work in plant defense mechanisms. These metabolites provide defense against pathogens and pests. In comparison to all metabolites, terpenoids produce odors, whereas quinones and tannins were responsible for the synthesis of phyto-pigments. Various biological active components are used as a flavoring agent, for example, capsaicin (terpenoid) produced from *Capsicum* sps. Useful medicinal compounds can also be extracted from the various herbs and many spices.

14.3.1 Phenolics and Polyphenols

These are simple biologically active phytoconstituents with a single phenolic ring. For example, Cowan (1999) reported that cinnamic acid and caffeic acids partake phenyl-propane-derived compounds and have maximum oxidation property. Brantner and his coworkers (1996) extracted the caffeic acid from tarragon and thyme plants and showed prominent antibacterial activity. Both have 2- and 3-hydroxyl group, respectively, in their structure and found that these groups increased in number and cause toxicity to many microbes, namely, bacteria, fungi, etc. (Geissman 1963). Phenolics were reported as highly oxidized and showed maximum toxicological effects (Scalbert 1991). These oxidized phenols and hydroxylated compounds believed to interact either with groups of hydrosulfide or nonspecific with the proteins and lead to cause an inhibitory effect on the enzymatic mechanism (Mason and Wasserman 1987). Eugenol found in clove showed the best example for enzymatic inhibition and proved to be good bacteriostatic against bacteria (Fig. 14.1).

14.3.2 Quinones

These compounds are a major cause to form browning color after reaction on the cut or injured fruits and vegetables (Schmidt 1988). These were also present in the henna plant by which gives its dying property (Fessenden and Fessenden 1982).

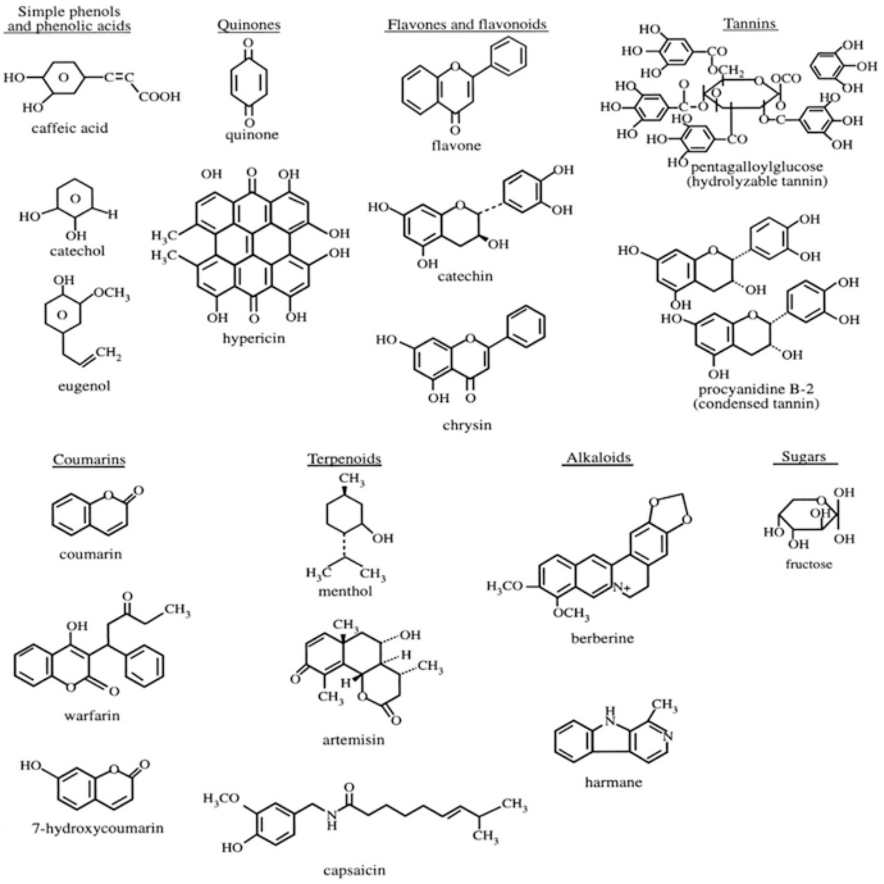

Fig. 14.1 Examples of some biologically active compounds. (Source: Cowan 1999)

14.3.3 Flavones and Its Derivatives

Flavones contain one carbonyl group, and flavonols have an additional 3-hydroxyl group (Fessenden and Fessenden 1982). Flavonoids have aromatic rings linked with C3–C6 unit. Dixon and his coworkers (1983) reported that flavonoids synthesized in the plants have antimicrobial activity. Tsuchiya and his colleagues (1996) found that these flavonoids can penetrate into the cell wall and disrupt microbial membranes by changing the internal chemical environment. Toda et al.'s (1989) reports suggested that reduced form of flavonoid was catechins found in tea plants which have high antimicrobial property.

14.3.4 Tannins

Tannins are polymeric phenolic compounds used for tanning of leather or hastening gelatin from a solution called as astringency. These were found almost in all plants with various ranges of molecular weights (Scalbert 1991). They are mainly found in two forms, namely, hydrolysable and condensed tannins. The monomeric type of flavonoid produces the condensed tannins (Geissman 1963).

14.3.5 Essential Oils

These were hydro-distillate constituents of plants and have great fragrances. They are also called terpenoids when contains additional elements usually oxygen atom. These have antibacterial properties (Amaral et al. 1998; Chaurasia and Vyas 1977).

14.3.6 Alkaloids

These were firstly reported in opium plant named morphine (Fessenden and Fessenden 1982). There are many more now known alkaloids, and they have high antimicrobial activity and used widely in medical practices to prevent disease-causing microbes.

14.3.7 Simple Polypeptides and Lectins

Balls and his colleagues (1942) reported that peptides had antimicrobial activity. They contain disulfide bonds with a positively charged skeleton. The acting mechanism of peptides is still to be discovered, but some reported showed that they interact with microbial cell membrane cytosolic constituents and form ion channels (Zhang and Lewis 1997). Contemporary research findings showed biological activity of several extracted metabolites, and their specific constituents have antifungal and antibacterial properties (Kumar and Malik 2011; Bajpai et al. 2008). These are used as food or plant sample preservations against various fungal and bacterial pathogens. Phytochemical analysis revealed that plants synthesized these bioactive compounds during stress conditions, evincing to have many inhibitory activities against microbes, pests, and herbs (Matos and Ricardo 2006).

14.3.8 Plants with Antibacterial Properties

Since forever, plants were used for curing the bacterial infections, and till today a majority of the plants are known to have antibacterial properties. Several plants were investigated and found that all plants aqueous and ethanolic extracts were effective against various phytopathogenic bacteria (Ghosh et al. 2000; Krupinski and Sobiczewski 2001).

Table 14.3 List of peptide-based antimicrobial components

Targeted plant pathogens	Antimicrobial peptides
Erwinia amylovora	Pseudopeptides
Erwinia carotovora	Cyclopeptides
Clavibacter michiganensis	Peptaibols
Pseudomonas syringe	Cyclopeptides
Rhodococcus fascians	Cyclopeptides

Source: Dubey (2011)

14.3.8.1 Phyto-protein

Several reports suggest that some proteins synthesized by plants showed immune response to various diseases and took part in defense mechanisms of plants. Thus, scientists were focused on inducing or enhancing the production of these protein molecules to increase the phyto-resistivity against phytopathogens (Dubey 2011).

14.3.8.2 Antimicrobial Peptides

Some plants were found to produces defensive peptides to cope with several diseases (Table 14.3). These peptides were small in size by which they can easily penetrate inside the microbial cell membrane and disrupt their cytoplasmic constituents and lead to killing these pathogens (Park et al. 2009). Biologically synthesized peptides were having pesticidal as well as antimicrobial activity as these inhibited the nucleic acid and protein synthesis. These were also found to inhibit enzymatic pathways (Huang 2000).

14.4 New Approach of Agricultural Bactericides

14.4.1 Phytoalexins and Phytoanticipins

Phytoalexins are the antimicrobial compounds which are expressed by the enzymes when elicitation occurs (Grayer and Kokubun 2001). Therefore once pathogen was detected, plants initiate the transcriptional and translational process for phytoalexins synthesis. Many pieces of evidence prove that these antimicrobial compounds which were formed due to induction and also autonomous process comprise resistivity to several diseases (Lamothe et al. 2009).

14.4.2 Response by Phytoanticipins

Saponins glycosylated phytoanticipins which were widely present in many plants. These compounds have impressive antimicrobial activity. The saponins were studied very well concerning plant defense molecule, and majority are avenacin and α-tomatine. The major avenacin, that is, avenacin A-1, was confined in layers of an epidermal cell of the oat root tip and makes an appearance in the form of lateral root initials and form a chemical blockade (Osbourn et al. 1994). Furthermore, the ability of *Gaeumannomyces graminis* var. *aveanae* to suppress the toxic effects of avenacin A-1 was compulsory for interaction with oat. Excitingly avenacin biosynthetic pathway mediates callose accumulation in oat root tip which is known for defense mechanism and indicates the role of phytoanticipin in several defense responses (Mylona et al. 2008). All healthy plants contain phytoanticipin in biologically active form. Excitingly the degraded product of α-tomatine was capable in restriction of defense response (Bouarab et al. 2002).

14.4.3 Phytoalexins: Some Biological Examples

Phytoalexin plays a role in defense mechanism in rice and crucifers. Also, it showed the biological processes present in the root emission. Valle and his coworkers (1997) reported that the important phytoalexins in tobacco are the hydroxyl-coumarin scopoletin (6-methoxy-7-hydroxycoumarin) having antimicrobial properties. Tissues near necrotic lesions appeared bright blue in color under UV radiation due to phytoalexins (Costet et al. 2002; Chong et al. 1999). A forager of ROS produced in abundance after stimulating the hypersensitive response (Lamothe et al. 2009).

Camalexin was not metabolically synthesized by deforming of mutant pad3 in its last step of the synthesis, which leads to accumulating in mutant pad3 (Rogers et al. 1996). Camalexin was only known phytochemical to disturb the permeability of bacterial plasma membrane at lower concentration. Due to this property of camalexin, it is involved in the defense metabolism of plants against bacterial infections (Lamothe et al. 2009).

14.5 Mechanism of Bioactive Components

Sikkema and his colleagues in 1995 found that the biological metabolism of terpenes and its mode of action are still unknown, but some hypothesis was given as it disrupts the lipophilic components of the microbial cell. The oils of the tea plant are capable of interfering the penetrability barrier of plasma membrane structure and conduct damage of chemiosmotic mechanism leading to cause the death of *Candida albicans* and *E. coli* (Cox et al. 2000). The susceptibility to lysis of bacterial cells showed that oil extracted from tea plant interferes in the membrane cytosolic constituents (Carson et al. 2002) (Fig. 14.2).

Chemical analysis showed that antimicrobial phytochemicals contain phenolic structures connected with –OH. Diallyl thiosulfonate (allicin) found in garlic having the antimicrobial properties. Low doses of allicin (0.2–0.5 mM) showed high efficacy of bacteriostatic on the growth of several bacterial pathogens that was due to the action of suppression and inhibition of DNA and protein (Rasmussen et al. 2005). Allicin also inhibits quorum sensing in bacteria (Bazaka et al. 2015).

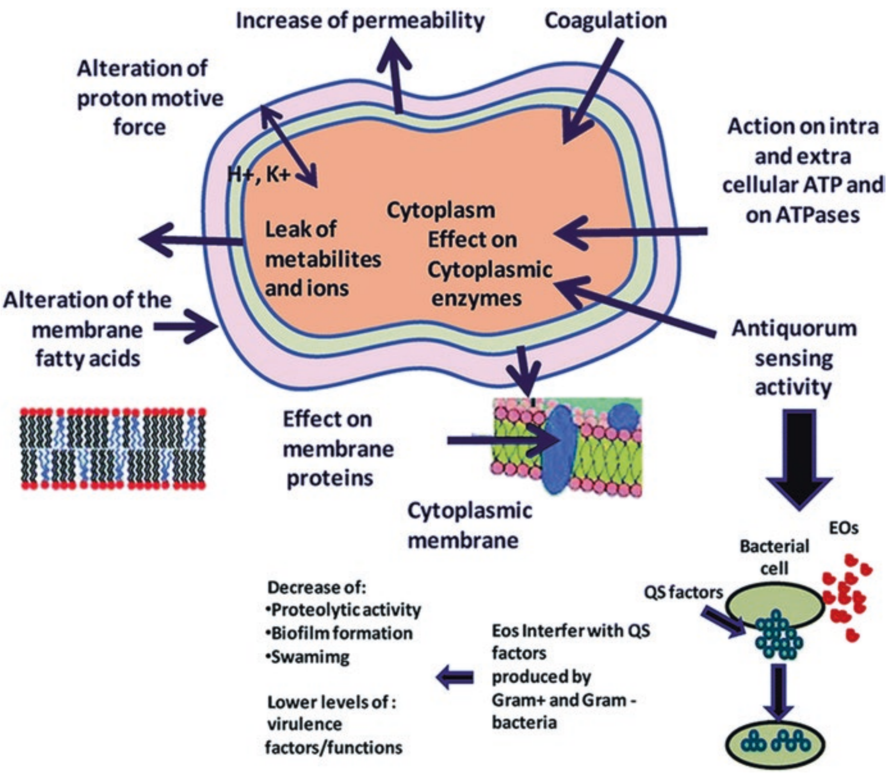

Fig. 14.2 Regulation of bio-constituents and its antimicrobial activity (Bazaka et al. 2015)

14.6 Nanoparticles as Bactericides

Nanotechnology application in agriculture sectors allows more well-organized and sustainable agriculture by plummeting the probabilities of enhancement resistant to various diseases and pests (Nair and Kumar 2013). Some of the important uses of nanomaterials are in sewage treatment, purification of water, remediation of toxic heavy metals in soil and water, packaging and processing of food materials, coating of capsules and other pharmacological activity and household purposes (Huang et al. 2015).

All the approaches of recent researches were mainly focusing on the application of agricultural practices and improving crop quality and productivity. Nanomaterials were further approaching toward the agriculture sector and in the protection and storage of crops (Sharon et al. 2010). The toxicological efficacy of several nanoparticles was tested against various pathogens (bacteria and fungi) and showed high antimicrobial activity (Huang et al. 2015).

14.6.1 Metal, Metalloid, and Nonmetal NPs

NP of Ag was the first NP which was investigated for different aspects of plant disease management. The efficacy of Ag NPs against bacteria has been studied by many researchers (Park et al. 2016; Ocsoy et al. 2013).

But more investigation about NP of Ag is needed as its exact function about defense mechanism and activity of ionic Ag is not clear. Copper nanoparticles are used as antimicrobial agents (Evans et al. 2007). Biologically as well as chemically synthesized Cu NP in controlled concentration showed great inhibitory impact on microbes without affecting plants. Several scientific reports showed the antimicrobial properties of Zn NPs (Indhumathy and Mala 2013). Recently, many zinc-based nanoproducts were used in controlling various bacterial diseases such as Zinkicide used for bacteria *Xanthomonas citri* causing canker disease in lemons (Young et al. 2017). Zinkicide was showed high effectiveness during field trials as compared with chemical bactericides in scab disease in lemons.

Many investigations showed that a wide range of bacterial and fungal pathogens can be controlled by nanoparticles of Zn, Au, Ti, Fe, Si, etc. (Czajkowski et al. 2015). A piece of proper information about working mechanism and efficacy must be needed as many of the reports have arisen from a single study. NP of Si has received more attention as it shows some consequences on plant health when supplied continuously. To maintain the plant defense system, a continuous and constant supply of NP of Si is needed. The use of NP Al_2O_3, MgO, NP TiO_2, NP S, and NP CeO_2 showed effectiveness against several phytopathogens, namely, fungi and bacteria (Mallmann and Hemstreet 1924; Czajkowski et al. 2015) (Fig. 14.3).

14.7 Bacteriophages in Crop Production

Bacteriophages were used as an alternative for pesticides as well as potent bactericide. The antibacterial activity was first reported by Twort (1915) and further confirmed in 1917 by Felix D’Herelle. Both experimentally found antibacterial properties done by these phages and found more specific to host bacteria, that is, *Xanthomonas campestris*, which caused rot disease in cabbage. Phages showed no negative effects on cabbage plants (Svircev et al. 2018).

14.7.1 Blight and Bacterial Wilt

Phages belong to Myoviridae used as biocontrol agents in controlling the soft rot in potato. These phages inhibit the growth of *Dickeya solani* and *Pectobacterium* spp. causing rot disease in the storage of potato (Svircev et al. 2018).

Phages were singly or consortia treated on *Xanthomonas perforans* and *Pseudomonas syringae* on potato and tomato plants, respectively. These phages were found to have potent inhibitory effects on these two pathogens which are

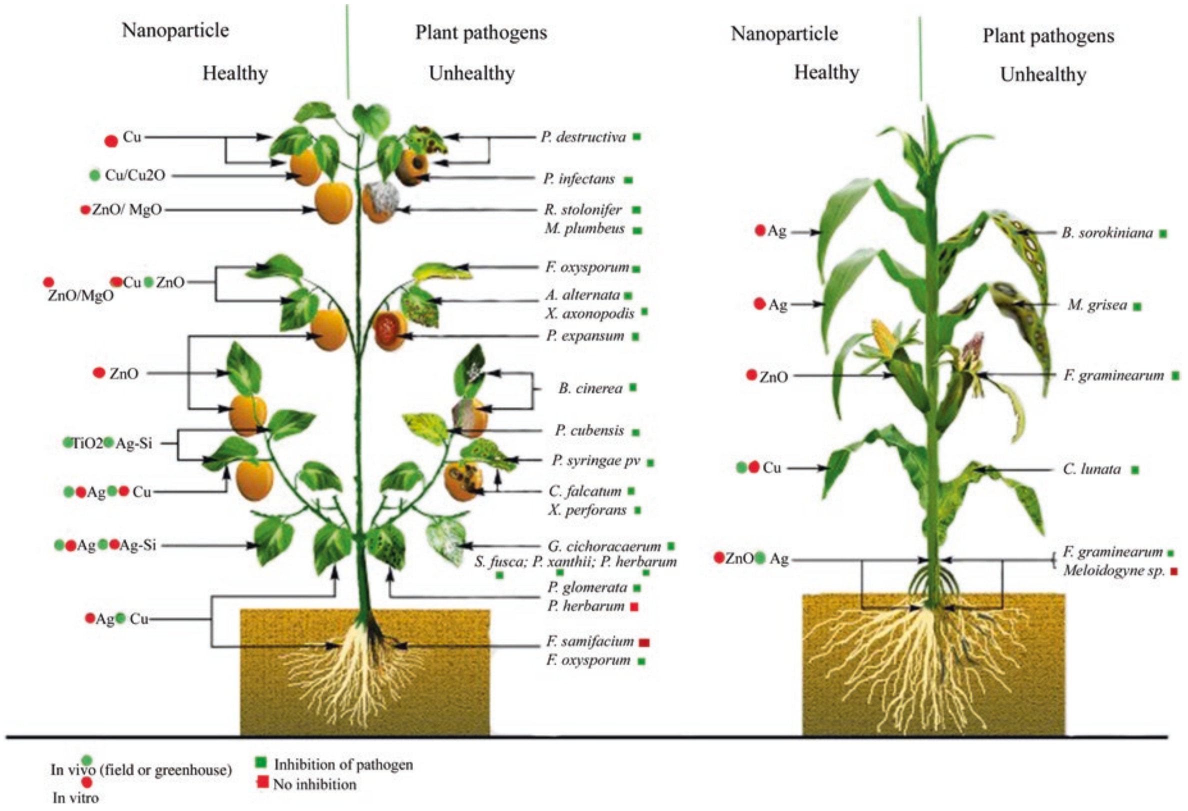

Fig. 14.3 Interaction and antibacterial activity against some bacteria on the plant (Elmer et al. 2018)

responsible for serious threat to plant disease and cause significant damage to potato and tomato production (Hirano and Upper 1990).

Recently, one experimental study revealed that phages also control the growth of *P. syringae* pv. *actinidae. P. syringae* causes blight disease on plants and causes severe loss in kiwi and leek production every year (Lehman 2007). These phages proved to be potentially used to control phytopathogens (Di Lallo et al. 2014).

14.7.2 Citrus Bacterial Canker and Spot

Recent investigation found that these phages also showed inhibitory activity against several bacterial species which causes bacterial canker and spot diseases in grape plants.

14.8 Conclusion and Future Prospects

There is ruthless demand for crops as population increases. It is very unfortunate that the demand still does not achieve the satisfaction point. Major causes are disease in crops and ill storage strategy. In agriculture, the bacterial disease causes severe loss after fungal diseases. Recently the world focused on natural bactericides and also developing hybrids that are genetically disease resistant. The secondary metabolites from plants, namely, oil, terpenoids, alkaloids, etc., are potent bactericidal.

The world introduces a new concept of biologically synthesized nanoparticles used to control bacterial diseases. They have very high potential to alter the mechanism in growth and also inhibit the wide range of phytopathogens. Some researchers found that use of viruses like bacteriophage can be one of the excellent tools to tackle bacterial and fungal pathogens. Instead of using chemicals or other expensive tools and techniques, agronomic practices must be more natural and biological. Natural and phyto-products must be used as bactericides. There is the only one way to develop a safe and healthy environment for agriculture and society and strengthen the base of sustainable agriculture.

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