



REVIEW ARTICLE

Discussion on the consequences of chickpea wilt and management through induced resistance

Sumanth Reddy¹, Adesh Kumar¹, Sakshi Sharma¹, Chandrapati Akhilesh¹, Ranjna Kumari² & Vipul Kumar¹*

¹Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara (Punjab)-144411, India

²Department of Botany, School of Bioengineering and Biosciences, Lovely Professional University, Phagwara (Punjab)-144411, India

*Email: vipul.19845@lpu.co.in



ARTICLE HISTORY

Received: 09 February 2023 Accepted: 17 June 2023

Available online

Version 1.0 : 30 August 2023 Version 2.0 : 01 October 2023



Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS,UGC Care etc. See https://horizonepublishing.com/journals/ index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an openaccess article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (https://creativecommons.org/licenses/by/4.0/)

CITE THIS ARTICLE

Sumanth R, Adesh K, Sakshi S, Akhilesh C, Ranjna K, Vipul K. Discussion on the consequences of chickpea wilt and management through induced resistance. Plant Science Today. 2023; 10(4): 78–87. https://doi.org/10.14719/pst.2324

Abstract

Chickpea (Cicer arietinum L.) is a crucial source of dietary protein and accounts for 18% of global legume production. However, the crop faces a variety of biotic and abiotic constraints, with fusarium wilt being the most common soil-borne disease. This disease poses a significant threat to chickpeas, leading to yield losses of up to 80% worldwide. Fusarium wilt pathogens exhibit host specificity and characteristic symptoms in mature plants include brown to black discoloration of the xylem vessels, wilting, and leaf burning caused by phytotoxins produced by the pathogen. To combat this fungal disease, several cultural, biological, and chemical methods have been extensively employed. While chemical control methods have proven to be highly effective and widely adopted by growers, they come with several adverse consequences for humans, the environment, soil, and water. Moreover, improper and excessive use of fungicides can lead to the development of resistance in plant pathogens. Thus, there is a pressing need for an environmentally friendly approach that promotes plant resistance. One such approach is induced resistance, which involves enabling plants to build their own resistance mechanisms. Induced resistance can take different forms, such as systemic acquired resistance based on the salicylic acid pathway, and induced systemic resistance based on the jasmonic acid pathway.

Keywords

Fusarium wilt; chickpea; systemic induced resistance; systematic acquired resistance; bio-control

Introduction

Chickpea (*Cicer arietinum* L.) is a self-pollinated, annual diploid plant that is also known as Bengal gram or garbanzo bean. In Asia, Africa, Central America, and South America, chickpea is a significant grain legume crop (1). Leguminaceae is the family of legumes that includes chickpeas. Chickpeas are cool-season legumes that can be found in tropical, subtropical, and temperate climates (2). Chickpea is known as the "poor man's meat" because it offers a high-protein and low-cost alternative to animal protein. After dry beans (*Phaseolus vulgaris* L.) and dry peas (*Pisum sativum* L.), chickpea is the world's third most significant pulse crop. Chickpea is a legume that originated in the Middle East and is now grown in 45 nations. India is the world's largest producer of chickpeas. India produces 67.32% of chickpeas, Pakistan 6.19%, and Australia 5.72% (3). Chickpea production reached 73.3 million tonnes in 2011-2013. In India, 9.2 million tonnes were

produced, with an average yield of 920 kg/ha. Madhya Pradesh ranked first in production (40.60%). Maharashtra ranked second in terms of area (16.57%) and third in terms of production (13.07%). Rajasthan ranked second in production (14.09%). Andhra Pradesh recorded the highest yield (1522 kg/ha) (4).

Unsaturated lipids containing acids like linoleic acid and oleic acid, as well as protein (18–22%), carbohydrates (6–62%), fat (4.5%), calcium (280 mg/100 g), iron (112.3 mg/100 g), and phosphorus (301 mg/100 g) are present in chickpea. Because of its nutritional worth, the market is crowded (5). Among pulses, chickpea proteins have a higher glutelin content (6). The most common fungal diseases that affect chickpeas are fusarium wilt (*Fusarium oxysporum* f. sp. *ciceri*), aschochyta blight (*Aschochyta rabiei*), dry root rot (*Rhizoctonia bataticola*), and wet root rot (*R. rolfsii*), as well as viral diseases including the beet western yellow virus, bean leaf roll virus, soybean dwarf virus, pea seed-borne virus, and the chlorotic stunt virus (Table 1) (7).

Table 1. Yield loss in chickpea crop

Disease	Yield loss	Year	References
Fusarium wilt	80-100%	2016	(11)
Aschochyta blight	25-50%	2020	(3)
Botrytis grey mould	50-60%	2006	(12)
Dwarf chlorotic virus	nearly 100 %	2009	(17)
Dwarf chlorotic virus	75-90%	2009	(17)
Luteovirus	50-60%	2008	(13)
Faba bean necrotic yellow virus	40-50%	2008	(13)

Fusarium spp. was identified as the cause of chickpea wilt by Prasad and Padwick. Padwick later gave the fungus its name. Synder and Hansen renamed F. orthoceras var. ciceri as F. oxysporum f. sp. ciceri which is now widely accepted (8). Wilt is one of the most common diseases that affect chickpea plants. It is a seed and soilborne disease (3). Wilt lowers chickpea output by reducing seed yield and weight. In India, annual output losses from the disease were estimated at 10-15%, but severe outbreaks account for 70% of overall crop yield losses (9). F. oxysporum is a widespread soil fungus found all over the

world in cultivated soil. Some occur only as saprophytes in the rhizosphere of plants. Based on their host plant species and plant cultivars, there are more than 53 forms, and 29 varieties, respectively (10).

The use of resistant cultivars in the disease management strategy of fusarium wilt is both practicable and effective globally (11). It is difficult to understand why it has taken so long for the scientific community and agrichemical industry to recognize the hazards to human health and the environment of the increased dependence on pesticides, acknowledge the potential of induced systemic resistance in plants, and appreciate its significance to fundamental science and as a technology for plant disease control (12). The wilt is treated with four fungal bioagents (Trichoderma harzianum, T. viride, T. hamatum and Gliocladium virens) and two bacterial bioagents (Pseudomonas fluorescens and Bacillus subtilis) (Table 2). The ability of these fungicides, including carbendazim 50wp, dividend star, aliette 80wp, copper oxychloride, defeater 20wp, ridomil gold, and thiowet jet 80wp, to prevent the growth of F. oxysporum colonies was investigated using the poisoned food approach.

Geographical Distribution of Chickpeas

Chickpeas are the third-largest pulse produced globally, with a yearly production of 11.67 million tonnes. This ranking places chickpea behind beans (25.66 million tonnes) and peas (11.69 million tonnes) with a mean annual production of 11.67 million tonnes from 2004 to 2017 (Table 3). These three types of pulses beans, peas, and chickpeas account for more than 70% of all pulse production worldwide, with chickpeas contributing over 17%. Chickpea is third among the most popular pulses consumed (13).

Table 3. Mean annual global production of pulse crops 2004–2017 (54)

Pulse	Production (tons)
Beans	25,657,833
Peas	11,691,517.3
Chickpeas	11,672,579
Cowpeas	6,498,236.8
Faba beans	4,468,240.1
Lentils	4,990,522.6
Pigeon peas	4,449,435.9
Other pulses	6,254,656.9
Total pulses	75,683,021.6

Table 2. Control of chickpea wilt by biological control and within induced resistance

Antagonists	Nature of disease control	Year	Reference
Salicylic acid + Pseudomonas fluorescens	Bacterium induced resistance and reduced wilt by 26-50%. Salicylic acid reduced wilt by 52-64 %. Reduction in disease with combined application.	2005	(40)
Bacillus subtilis	Seed coating significantly reduced wilt by 30-40.8%	2014	(47)
Trichoderma viride + T.harzianum			(48)
Non-pathogenic Fusarium oxysporum			(28)
P.fluorescens	Seed treatment with culture suspension reduced pre and post emergence losses by 40%.	2007	(10)

From 1961 to 2013, the harvested area used to produce chickpeas varied from 8.9 million ha in 1981 to 13.5 million ha in 2013 (Fig. 1). In terms of harvested area, earlier production trends from 1961 to 2001 were largely stable or slightly dropping. However, starting in the late 1900s, yield gains started to have an effect on overall production. Production began to rise steadily in the early 2000s and has been doing so ever since, especially after 2004. Over 50 nations produce chickpeas, with India being the largest producer and accounting for more than 70% of global production. India's dominance in chickpea production and the relative importance of the next-largest producers, Pakistan and Iran, contribute 10% and 5% of global production, respectively. Ethiopia, which has significantly boosted output in recent years and currently contributes over 2% of global production, is followed by other important producing nations like Turkey and Australia, which account for 4 and 3% of global production, respectively. Malawi, Mexico, Morocco, and Syria are also significant producers. Mean chickpea yields have a wide range in producing nations, varying from relatively low yields of 500-600 kg/ha in Syria, Pakistan, Malawi, Morocco, and Iran to comparatively high yields in Mexico and Ethiopia. The largest producer, India, consistently achieves mean yields of 900 kg/ha. The peak yields in Mexico are primarily due to the majority of the crop being grown during the chilly winter weather (14).

Biology

Chickpea is an herbaceous annual plant that branches from the base. It is almost a small bush with diffused, spreading branches. The plant is mostly covered with glandular or non-glandular hairs, but some genotypes do not possess hair.

Based on seed size and colour, cultivated chickpeas are of two types (14).

Macrosperma (kabuli type)

The seeds of this type are large (100-seed mass >25 g), round or ram head-shaped, and cream-colored. The plant is medium to tall in height, with large leaflets and white flowers, and does not contain anthocyanin.

Microsperma (desi type)

The seeds of this type are small and angular in shape. The seed colour varies from cream, black, brown, yellow, to green. There are 2-3 ovules per pod, but on an average 1-2 seeds per pod are produced. The plants are short, have small leaflets and purplish flowers, and contain anthocyanin.

Symptomatology of Fusarium Wilt

Chickpea wilt is caused by Fusarium species, according to Prasad and Padwick. Padwick later named the fungus in 1940 (15). Early wilt symptoms include flaccidity of individual leaves, dull green discolouration, desiccation, and plant collapse. These symptoms appear in the flowering stage following a 6-week seeding in Arizona during the months of October and November (9). Late wilt causes the dropping of petioles, rachis, leaflets, and foliage, which are noticeable at the podding stage in the months of March and April (9). Chickpea wilt is a vascular disease that causes browning or blacking of the xylem. All phases of the crop are affected. Two pathotypes have been identified, which cause unique yellowing and wilting syndromes with brown vascular discoloration in susceptible chickpeas. The yellowing syndrome is characterized by slow and progressive foliar yellowing and late plant death. The wilting syndrome is marked by rapid and severe chlorosis, flaccidity, and premature plant death (9). To date, eight races of Fusarium oxysporum f. sp. ciceris have been reported from India, Spain, and the United States (0, 1A, 1B/C, 2, 3, 4, 5, and 6) (16).

Source: FAOSTAT (Aug 20, 2022)

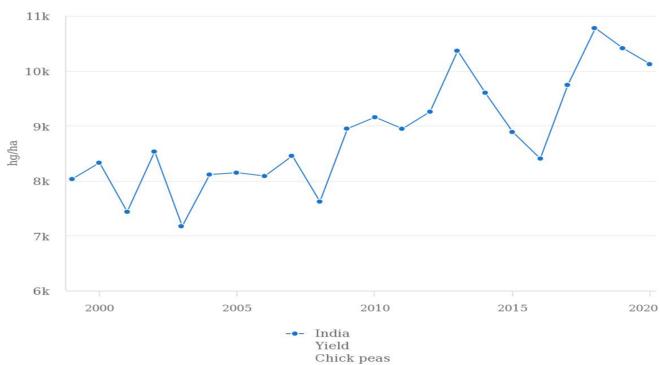


Fig.1. Yield of chickpea in India (54, 55)

Survival and Primary Infection

The pathogen's primary inoculum is responsible for the formation of fusarium wilt in chickpeas, which is a monocyclic disease. Macroconidia, microconidia, and chlamydospores are the three types of asexual spores produced by the common soil inhabitant *Fusarium oxysporum* (17). The macroconidia have three or four septa, a tapering and curved apical cell, and a foot-shaped basal cell. They are generally straight to slightly curved, slender, and thin-walled (2). Infected seeds and plant debris can spread the disease. Chlamydospores are the principal source of wilt infection. The fungus may live for at least 6 years in soil and chickpea trash as a result of the presence of chlamydospores (9).

Disease Cycle

The fungus can be spread by seed and lives on plant debris in the soil. Free chlamydospores were discovered in soil, seed hilums, cotyledons, and axis. Chlamydospores are the main source of infection. The pathogen can live for up to 6 years without a host. Microconidia and macroconidia exist in chlamydospores. The mycelium takes up residence in the host plant. The fungus remains dormant as chlamydospores in plant debris until stimulated to germinate, once carbohydrates are released from decaying plant tissue or from roots. After the chlamydospores germinate, conidia and chlamydospores may be formed, as well as hyphae. Following germination, a thallus is produced, from which conidia form in 6-8 h, and chlamydospores in 2-3 days if conditions are favourable. Invasion of the roots is followed

by the penetration of the epidermal cells of the host or the non-host (18) and the development of a systemic vascular disease in host plants. Mycelium spores penetrate the root through the cortex, epidermis, and xylem vessels. Penetration occurs when a wound is pierced (19).

Mycelium proliferates rapidly in xylem tissues, causing xylem vessels to become blocked. As a result, the plant wilts and dies. The roots do not appear to be decaying on the outside and appear to be in good health, but when split vertically from the collar region downward, the internal tissues, namely the pith and xylem, reveal a dark discoloration. Similarly, early wilting reduced the seed number/plant and caused more yield losses than late wilting. Disease is more severe in light sandy soil than heavy clay (20). At 20 °C, wilt incidence was higher than at 25°C. At 15°C, plant vascular discoloration and leaf chlorosis did not occur (21). Chauhan reported that the disease intensity increases with decreasing pH, with considerably low intensity at a pH of 9.2. A pH of 5.2 was found to be optimum (22) (Fig. 2).

Agronomic Practices

Diseases are more prevalent in early-planted crops. Several studies have found that delaying the planting of crops results in improved yield and disease control, primarily due to the cold weather. Plants planted at a spacing of 7.5 cm show less wilt compared to plants spaced at 15-20 cm apart (23). When crops such as wheat, linseed, mustard, and barley are inter-cropped or mixed-cropped with chickpea, wilt is mostly reduced in linseed.

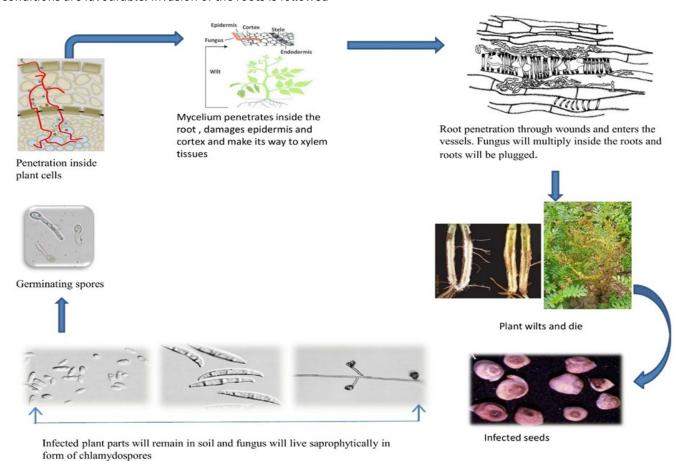


Fig.2. Disease cycle of Fusarium oxysporum f. sp. ciceris (9)

Control using plant extracts, such as plant-derived fungicides, is environmentally friendly and non-toxic. Farmers can easily prepare these extracts. In an in vitro investigation, four plant species were identified: Azadirachta indica A. Juss, Datura metel L. var Ocimum sanctum L., and Parthenium hysterphours L. methanolic extracts from these four plants were found to be efficient in controlling the mycelium proliferation of Fusarium oxysporum ciceri at a concentration of 40%. The germination of pathogen spores was completely prevented by a leaf extract of A. indica at a concentration of 100%. Researchers studied the effect of aqueous garlic leaf extract on F. oxysporum f. sp. ciceri and found that 7000 and 5000 ppm of the extract reduced wilt and fungal growth (24). To manage pests and diseases, synthetic fungicides should be employed. In many areas where chickpeas are grown, diseases caused by F. oxysporum and Meloidogyne Javanica (MJ) co-occur. When chickpea plants are infected by both of these pathogens simultaneously, the severity of fusarium wilt is increased (25).

Chemical Control

Chemical control has been widely used in the past and present to control chickpea wilt disease. The sensitivity of twenty-seven isolates of Fusarium oxysporum f. sp. ciceris against 10 fungicides (Antracol, Captan, Benlate, TopsinM, Cobox, Dithane M-45, Acrobat, Ridomil, Vitavax and Daconil) (Table 4) was studied based on their sensitivity to fungicides at a concentration of 100 ppm using the poison food technique. After autoclaving, each fungicide was added to the Waksman agar medium. A 20 ml mixture of altered and unamended media was poured into petri plates. Using a sterile cork-borer, a 4 mm agar plug of the fungus was cut from the cultured plate and placed in the center of each petri plate as it solidified. After seven days of incubation at 26±20°C, the infected petri-plates were measured for radial colony growth (mm) of mycelium. Isolates with radial growth of the fungus greater than 35

mm, were classified as nonsensitive "N" while those with radial growth less than 35 mm were classified as sensitive "S" (26).

Induced Resistance

A physiological "state of heightened defensive capacity", known as "induced resistance", occurs when a plant's intrinsic defenses are strengthened against subsequent biotic and abiotic factors. This improved state of resistance works well against a variety of parasites and pathogens (21). Systemic acquired resistance (SAR) and induced systemic resistance (ISR), which can be distinguished based on the type of elicitor and the regulatory mechanisms involved, are the two forms of induced resistance that are most thoroughly defined (27).

Plant growth-promoting rhizobacteria (PGPR), which colonise the root surface and the tightly adherent soil interface, are extensively researched PGPR in the rhizosphere. Competition for an ecological niche is the commonly acknowledged mechanism of bio-control mediated by PGPR. The development of systemic resistance (ISR) in host plants to a range of diseases is facilitated by PGPR as well as the production of inhibitory allelochemicals (28). SAR can be induced in plants by exposure to virulent microbes that are non-pathogenic or avirulent. The accumulation of proteins involved in pathogenicity (such as chitinase and glucanase) and salicylic acid occurs after a specific period of time, depending on the plant and elicitors. The most wellknown approach for increasing ISR is the use of plant growth-promoting rhizobacteria, specifically Pseudomonas strains that do not have an obvious effect on the plant roots (29). Unlike SAR, ISR does not involve the accumulation of pathogenesis-related proteins or salicylic acid, but instead relies on pathways controlled by jasmonate and ethylene, which can be differentiated based on the nature of the elicitor and the regulatory pathways involved (Fig. 3) (30).

Table 4. List of fungicides used for the determination of variability in chickpea isolates of Fusarium oxysporum f. sp. ciceri (57)

Sr. No.	Common Name	Trade Name	Chemical Name	Mode of Action	Formulation	Manufacturer
1	Copper- oxychloride	CupravitCobox (1965), cobox, Vitigran Blue (1988), Cuprasan (1992)	Copper Oxychloride	Contact	50%WP	Agricide (Pvt) Ltd.
2	Metalaxyl	Ridomil Gold (1996)	Methyl-N- (2- methoxyacetyl)-N- (2,6) xyls	Contact	60%WP	Novartis (Pvt) Ltd
3	Benomyl	Benlate, Sunlate, Benlate (1980)	Methyl-1- (butylcabamonyl)- 2- benzinidazol	Systemic	50%WP	R.B. Avari Entreprises Ltd.
4	Captan	Orthocide, Captane, Marpan, Vondcaptan (1986)	N- Trichloromethyl thio)-3a, 4,7,7a tetrahydrophthalimide	Contact	50%WP	ICI (Pvt) Ltd.
5	Propineb	AntracolMenizeb (1974)	Zinc Prophylenebisdithio carbamate	Contact	80%WP	Bayer (Pvt) Ltd
6	Carboxin	Vitavax, DCMO (1975)	5,6 dihydro-2- methyl,1,4 oxathin, 3 Carboxanilide	Systemic	75%WP	Longxiang Chem. Co. Ltd
7	Acrobat	Arbotect, Comfuvaz, Mertect, Mycozol (1962)	2-(4-Thiazolyl) benzimidazole	Contact	40-60%WP	Merck & Co.
8	Dithane M- 45	Mancozeb	16%Mn, 2%Zn, 62% Ethylenebisdithiocarbama	Contact	80% WP	Rohm & Hass Ltd
9	Thiophanat e methyl	Topsin-M (1979)	1,2-di (3- ethoxycarboxyl) – 2- thioureido benzene	Systemic	70%WP	Pennwalt corp.
10	Chlorothal onil	Daconil, Bravo, Termil, Nopocide (1982)	Tetrachloroisophthalonitrile	Contact	75%WP	Uniroyal Crop Div.

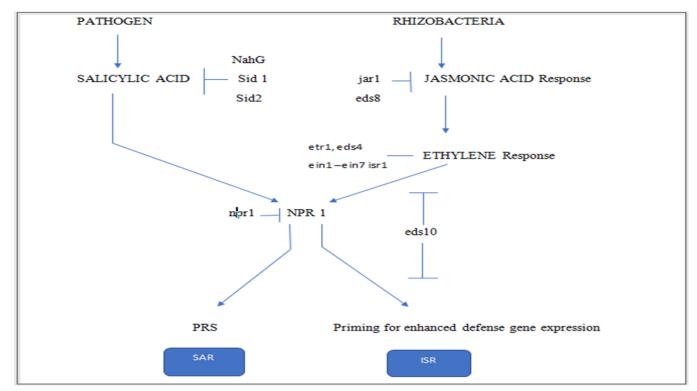


Fig. 3. The pathogen-induced SAR and the rhizobacteria mediated ISR signal transduction pathways in Arabidopsis (21)

The rhizosphere microflora is crucial for plant growth and their adaptation to external challenges. Rhizobacteria that promote plant growth can also prevent disease by developing a systemic resistance in bacteria that combat soil-borne pathogens (31). Combining ISR and SAR can enhance protection against infections resistant to both pathways individually and extend protection to a wider range of pathogens compared to ISR or SAR alone (32). In Arabidopsis, three generally accepted pathways of induced resistance exist, two of which are associated with the direct production of pathogenesis-related (PR) proteins. One pathway typically triggers the production of PR proteins in response to attacks by pathogenic microorganisms, while the other is triggered by wound or necrosis-inducing plant pathogens. However, both pathways have alternative mechanisms for inducing resistance.

The wounding-induced pathway typically involves jasmonic acid (JA) as the signaling molecule, whereas the pathogen-induced pathway typically involves salicylic acid (SA), which is produced by the plant (33). When administered exogenously, these substances and their equivalents produce comparable effects, and there is undoubtedly significant cross-talk between the pathways (34). The JA-induced pathway is referred to as induced systemic resistance (ISR), which is also associated with various processes initiated by rhizobacteria. The pathways triggered by salicylate and jasmonate involve the production of a series of PR proteins, including antifungals (glucanases and chitinases), oxidative enzymes (such as peroxidases, thaumatins, polyphenol oxidases, and lipoxygenases) (35), and antibacterial low-molecularcompounds. Additionally, weight characteristics (phytoalexins) can assemble. Rhizobacteria-induced systemic resistance (RISR), also known as non-pathogenic root-associated bacteria, is a third type of induced

resistance that contributes to the widespread evolution of plant disease resistance. When a plant is attacked by a pathogen, the plant's defenses are enhanced, and the severity of the disease is reduced. As the usual protein cascade induced by salicylate is absent in RISR, it potentiates plant defense responses.

Role of Induced Systemic Resistance (ISR)

It is expected that plant roots in suppressive soils are connected to microbial populations that generally promote plant health. As a matter of fact, a number of biocontrol PGPRs induce ISR in the host plant, allowing plants to survive pathogen attacks on leaves or roots without providing complete protection (36). ISR is elicited by several powerful biocontrol PGPR, regardless of antibiotic production (37). Transcriptome analysis of plants with roots colonized by different strains of Pseudomonas spp. (P. fluorescens WCS 417r, P. thivervalensis, and P. fluorescens CHA0) has revealed how these strains mediate ISR in Arabidopsis thaliana. Studies with mutant A. thaliana plants have shown that the salicylic acid (SA)-inducible route is involved in systemic acquired resistance, while the jasmonic acid (JA)/ethylene-inducible defense pathway is crucial for ISR (38). Hexenal, a volatile antifungal chemical, and the expression of enzymes involved in hexenal synthesis were increased in bean plants when ISR was induced by P. putida strain.

In order to address the issue of iron non-availability, particularly in calcareous soils, researchers have explored the role of siderophores, one of the factors of ISR, in influencing plant nutrition. This is achieved by incorporating strains of fluorescent pseudomonads that produce siderophores (FLPs) (39). A pot experiment using Fe-citrate, Fe-EDTA, and Fe(OH)₃ in varying concentrations was conducted to evaluate the effect of microbial siderophores on the iron nutrition of mung beans using the siderophores-producing bacterium *Pseudomonas*

strain GRP3. The chlorotic symptoms of the plants decreased, and their chlorophyll levels increased when the plants were infected with the bacteria. The peroxidase activity in the roots increased, while the catalase activity decreased. Moreover, both total and physiologically available iron increased significantly. Researchers have provided detailed information on the function of siderophores. This approach to siderophore production has the potential to increase iron availability to plants and reduce the need for fertilizers (40). Choudhary et al. (41) showed the effectiveness of a bacterial isolate to guard against pathogen infestation in both naturally occurring (Pythium and Phytophthora spp.) and artificially constructed (*Phytophthora* spp.) vegetable nurseries. After 21 days after seeding, tomato and chile plants were harvested, and their peroxidase and phenylalanine ammonia lyase (PAL) activity (ISR responsive proteins, not SAR-responsive proteins) were examined (42). Ganeshan et al. (43) discovered that the Pseudomonas sp. strains FQP-PB-3, FQP-PB-3, and GRP3 were the most effective in promoting shoot length and increasing PAL and peroxidase activity, which are well-known indicators of an active lignification process (44).

Consequences of Management of Wilt

The current scenario is that a large number of chemicals are employed to treat ailments, but this has the unintended consequence of harming the ecosystem and endangering human health. Chemicals can also be used to develop disease resistance in plants. Induced systemic resistance is the name given to this form of resistance (ISR). Production of PAL, TPC, PO, and PPO occurs through many methods (45). Plants may fight disease caused by a range of pathogens through a number of processes that might be local or systemic, inducible or constitutive (46). Plant-derived bio-active substances can be used safely and successfully against disease. Due to their anti-bacterial activity against plant diseases, essential oils (EOs) and their derivative chemicals have attracted a lot of attention in recent years (47). The chemical makeup and anti-fungal activity of six plant EOs against Fusarium oxysporum f. sp. ciceri are investigated by the studies of (48), as well as the impact of essential oils on reducing the severity of fusarium wilt in chickpeas and their role in fostering systemic resistance by regulating phenolic and flavonoid compounds. ISR is used in a variety of microorganisms (Trichoderma spp., Pseudomonas fluorescence, Bacillus spp., and Rhizobacteria) as well as by products (seaweed, vermicompost, and vermiculite). Application rhizobacteria-mediated induced systemic resistance of Pseudomonas spp. is capable of initiating plant-mediated resistance in above-ground plant sections (49). Plants that have been previously infected by a disease become more resistant to infection. This is referred to as acquired systemic resistance (49). Both local resistances mediated by key genes and systemic induced resistance generated after initial pathogen attacks are influenced by salicylic acid. SAR is aided by salicylic acid rather than ISR (50).

Plants treated with *P. fluorescence* showed a significant increase in shoot and root length. Wilt disease

was reduced by 26-50%. Vitamin B2 (riboflavin) is a coenzyme that is created by plants and microorganisms and is used in a variety of physiological activities in plants, microbes, and animals. It also plays a role in both antioxidation and peroxidation (51). Non-Pathogenic strains isolated from suppressive soil strains had many modes of action against pathogenic strains and were used as biocontrol agents. Non-pathogenic strains fight for nutrients in the soil, limit chlamydospore germination, compete for infection sites on the root, and generate systemic resistance in plants that infiltrate host plant species before the pathogen (52). Biocontrol agents and chemical inducers worked best together to lessen the degree of damping off, root rot, or wilt and improve plant fresh weight (53). Saikia et al. (40) examined the effectiveness of P. fluorescence with or without modification in chickpea against fusarium wilt infection.

Jahan et al. (41) discovered that the Bacillus subtilis isolate k18 was an efficient wilt pathogen antagonist. Biochar is an excellent bio-fertilizer, bio-pesticide, and rhizobacteria carrying material. Chickpea output can be boosted by combining Mesorhizobium ceceri with a biochar amendment, which boosts growth and increases nodulation weight and number in the face of fungi like F. oxysporum. Biochar-treated plants produce more nodules and boost legume crop yields through heat tolerance, which is achieved by increasing the soil's water holding capacity and growing hostile microbial colonies (54). Biocontrol agents such as Trichoderma harzianum, Aspergillus niger, B. subtilis, P. fluorescence, Rhizobium spp., and Azospirillum spp. can be used to control chickpea wilt. In dual culture, the bio control microorganisms such as P. fluorescence inhibit the pathogen (F. oxysporum f.sp. ciceri) growth by 70.94%, followed by T. harzianum (63.95%), Rhizobium spp. (60.79%), and B. subtilis (63.95%) (Table 4). Because wilt is a soil-borne pathogen, it is mostly controlled through chemical fumigation, such as methyl bromide, which has been outlawed due to health concerns, and then through the use of resistant types (42). However, in order to execute biological control commercially on a practical level, a better understanding of biocontrol agents' ecology and interactions with host plant pathogens, as well as the surrounding soil and rhizosphere, is required. Induced resistance has been proposed as a mechanism for non-pathogenic F. oxysporum-induced disease management.

Studies by Bekkar et al. (43) showed that tomato plants cultivated in suppressive soil had increased levels of hydrolytic enzymes associated with the PR protein. The use of rhizobacteria, combined with resistant cultivars and appropriate planting dates, may help manage fusarium wilt in chickpeas. Paenibacillus spp. and Pseudomonas spp. strains have demonstrated potential in reducing fusarium wilt infections in other crops, including chickpea, cotton, and radish (55). The induction of systemic resistance by plant growth-promoting rhizobacteria (PGPR) is dependent on the plant hormones jasmonic acid and ethylene. Various inorganic and organic compounds, as well as extracts from plants and microorganisms, have been reported to induce disease resistance in plants,

including INA (2, 6-dichloro-isonicotinic acid) and BTH (benzo 1, 2, 3) under the trademark BION.

Chemicals like salicylic acid, 2, 6-dichloroisonicotinic acid (INA), and non-pathogenic bacteria can all cause systemic resistance. Chitosan, a polysaccharide, has been found to protect plants from diseases and can be used as soil additive, seed, and foliar spray (45). The accumulation of phenolic acid is linked to enzymes like polyphenol oxidase (PPO) and phenylalanine ammonium for pathogen attack (PAL) (Table 3). Chitosan significantly reduced the seed borne infection which ranged from 59 to 23 % (56). Gas chromatography identified six cinnamic acids, eight benzoic acids, and one cinnamic acid ester, as well as an increase in lignin concentration in chitosantreated seeds. Biocontrol agents have been genetically modified through physical and chemical means to develop biocontrol agents with better toxicant tolerance, improved enhanced antagonistic potential, survivability in the agro environment (47).

Seeds were treated with benzo (1, 2, 3)-thiadiazole-7-carbothioic acid S-methyl ester (Bion), salicylic acid, and di-potassium hydrogen phosphate to induce systemic resistance in chickpeas against wilt disease caused by *F. oxysporum* f. sp. *ciceri* (K₂PHO₄). Both seed dressing and soaking methods resulted in a reduction in infection. The highest reduction in wilt disease, 63%, was induced by bion dressing, followed by salicylic acid at 40% and K₂PHO₄ 30%. Bion and salicylic acid showed a 41 and 24% reduction in the disease, respectively, and K₂PHO₄ soaking indicated a reduction of 30% (48) (Table 5).

Conclusion

Wilt disease is a serious problem in many crop plants as the pathogen has a high competitive saprophytic ability, allowing it to survive in the soil for extended periods. In recent years, biological control of fusarium wilt infections has been a major consideration in disease management. Induced resistance plays a significant role in suppressing wilt disease from a crop protection standpoint. To develop viable bio-control techniques for commercial situations, it is essential to have a better understanding of the mechanisms involved in the protection of plants by biocontrol agents. Improved forecasting of disease development and more effective utilization of biocontrol agents for managing fusarium wilt can be achieved by understanding how the inoculum density of *F. oxysporum* f. sp. ciceri affects disease development. Directly promoting plant growth, biological control, and developing systemic resistance in host plants are some of the advantageous impacts of PGPR. Certain strains of PGPR can induce ISR against multiple diseases affecting the same crop. The use of PGPR significantly reduces insect and nematode damage in addition to disease control. Therefore, in the present scenario, an alternative eco-friendly module for managing the disease and sustainable crop production is very much needed. Induced resistance is a healthy method of controlling the disease as it strengthens the host plant by increasing its resistance. Induced resistance through PGPRs, Pseudomonas, Bacillus, Trichoderma spp., and the use of salicylic acid as an inducer, are effective ways to prevent and suppress fusarium wilt chickpea.

Acknowledgements

The authors are grateful to Dr. Ramesh Kumar, Dean, School of Agriculture, Lovely Professional University, Phagwara, Punjab for providing their necessary support and encouragement.

Authors' contributions

AK conceived the idea of writing the review and designed the content. VK and SR collected the literature and prepared the article. All authors contributed to the content of the manuscript and approved the final version.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

Table 5. Control of chickpea wilt by chemical control and within induced resistance

Chemicals	Nature of disease control	Year	Reference
Bavastin 0.5g/kg of seed	Improved germination and disease control of wilt by 23.7%	2011	(46)
Benalate 0.15% (S.T)	Destroy seed borne inoculum completely	2011	(46)
Benomyl (soil drench)	Very effective in controlling wilt	2011	(46)
Bavistin + Thiram (2.5g/kg seed)	Decreased disease and increased yield under field condition	2009	(44)
Chitosan	Seed treatment at 0.3 and 1 % .Wilt symptoms reduced by 45-59% and prevented plant mortality. Enhanced polyphenol oxidase, pero-oxidase and phenylalamine ammonia lyase activities usually associated with defense.	2007	(21)
Salicylic acid	Seed soaking at 1.0 and 1.5 mM conc.	2003	(45)
Bion	Seed soaking at 0.3 and 0.4mM conc. Wilt was reduced in all treatments	2005	(34)

References

- Pande SK, Siddique KH, Kishore GK, Bayaa B, Gaur PM, Gowda CL, Bretag TW, Crouch JH. Ascochyta blight of chickpea (*Cicer arietinum* L.): A review of biology, pathogenicity and disease management. Aust J Agric. 2005;56(4):317-32. https://doi.org/10.1071/AR04143
- Abed H, Rouag N, Mouatassem D, Rouabhi A. Screening for Pseudomonas and Bacillus antagonistic rhizobacteria strains for the biocontrol of Fusarium wilt of chickpea. Eurasian J Soil Sci. 2016;5(3):182-91. https://doi.org/10.18393/ejss.2016.3.182-191
- Rani U, Singh S, Basandrai AK, Rathee VK, Tripathi K, Singh N, Dixit GP, Rana JC, Pandey S, Kumar A, Singh K. Identification of novel resistant sources for ascochyta blight (*Ascochyta rabiei*) in chickpea. Plos one. 2020;15(10):e0240589. https:// doi.org/10.1371/journal.pone.0240589
- Eyidogan F, Öz MT. Effect of salinity on antioxidant responses of chickpea seedlings. Acta Physiologiae Plantarum. 2007;29:485-93. https://doi.org/10.1007/s11738-007-0059-9
- Poddar RK, Singh DV, Dubey SC. Management of chickpea wilt through combination of fungicides and bioagents. Indian Phytopathol. 2004;57(1):39-43.
- Chang YW, Alli I, Konishi Y, Ziomek E. Characterization of protein fractions from chickpea (*Cicer arietinum* L.) and oat (*Avena sativa* L.) seeds using proteomic techniques. Food Res Int. 2011;44 (9):3094-104. https://doi.org/10.1016/j.foodres.2011.08.001
- 7. Damte T, Ojiewo CO. Current status of wilt/root rot diseases in major chickpea growing areas of Ethiopia. Arch PhytopatholPflanzenschutz. 2016;49(9-10):222-38. https://doi.org/10.1080/03235408.2016.1180925
- Kaur R, Kaur J, Singh RS. Non-pathogenic Fusarium as a biological control agent. Plant Pathol J. 2011;9(3):79-91. https:// doi.org/10.3923/ppj.2010.79.91
- Jendoubi W, Bouhadida M, Boukteb A, Béji M, Kharrat M. Fusarium wilt affecting chickpea crop. Agriculture. 2017;7 (3):23.https://doi.org/10.3390/agriculture7030023
- Kaur R, Singh RS. Study of induced systemic resistance in *Cicer arietinum* L. due to non-pathogenic *Fusarium oxysporum* using a modified split root technique. Plant Pathol J. 2007;155(11-12):694-98. https://doi.org/10.1111/j.1439-0434.2007.01300.x
- 11. Damte T, Ojiewo CO. Current status of wilt/root rot diseases in major chickpea growing areas of Ethiopia. Arch PhytopatholPflanzenschutz. 2016;49(9-10):222-38. https://dx.doi.org/10.1080/03235408.2016.1180925
- Honnareddy N, Dubey SC. Pathogenic and molecular characterization of Indian isolates of *Fusarium oxysporum* f. sp. ciceris causing chickpea wilt. Curr Sci. 2006;10:661-66.
- Kumari SG, Makkouk KM, Loh MH, Negassi K, Tsegay S, Kidane R, Kibret A, Tesfatsion Y. Viral diseases affecting chickpea crops in Eritrea. PhytopatholMediterr. 2008;47(1):42-49.10.14601/ Phytopathol_Mediterr-2543
- Singh F, Diwakar B. Chickpea Botany and Production Practices, Skill Development Series no. 16. ICRISAT, Patancheru. 1995;502:324.
- Singh KB, Ocampo B, Robertson LD. Diversity for abiotic and biotic stress resistance in the wild annual *Cicer* species. Genet Resour Crop Evol. 1998;45(1):9-17. https://doi.org/10.1023/ A:1008620002136
- Millan T, Clarke HJ, Siddique KH, Buhariwalla HK, Gaur PM, Kumar J, Gil J, Kahl G, Winter P. Chickpea molecular breeding: new tools and concepts. Euphytica. 2006;147(1):81-103. https://doi.org/10.1007/s10681-006-4261-4
- 17. Chand H, Khirbat SK. Chickpea wilt and its management-A review. Agric Rev. 2009;30(1):1-2.
- 18. Maheswari TU, Sharma SB, Reddy DD, Haware MP. Interaction of

- Fusarium oxysporum f. sp. ciceri and Meloidogyne javanica on Cicer arietinum. J Nematol. 1997;29(1):117.
- 19. Sugha SK, Kapoor SK, Singh BM. Factors influencing *Fusarium* wilt of chickpea (*Cicer arietinum* L.). Indian Journal of Mycology and Plant Pathology (India). 1994
- Ahmad MA, Iqbal SM, Ayub N, Ahmad Y, Akram A. Identification of resistant sources in chickpea against *Fusarium* wilt. Pak J Bot. 2010;42(1):417-26.
- Choudhary DK, Prakash A, Johri BN. Induced systemic resistance (ISR) in plants: mechanism of action. Indian J Microbiol. 2007;47 (4):289-97. https://doi.org/10.1007/s12088-007-0054-2
- Haas D, Keel C, Reimmann C. Signal transduction in plant-beneficial rhizobacteria with biocontrol properties. Anton Leeuw Int J G. 2002;81(1):385-95. https://doi.org/10.1023/A:1020549019981
- van Loon LC, Glick BR. Increased plant fitness by rhizobacteria. In Molecular ecotoxicology of plants. Springer, Berlin, Heidelberg. 2004;pp. 177-205. https://doi.org/10.1007/978-3-662-08818-0_7
- Choudhary DK, Prakash A, Johri BN. Induced systemic resistance (ISR) in plants: mechanism of action. Indian J Microbiol. 2007;47 (4):289-97. https://doi.org/10.1007/s12088-007-0054-2
- Haas D, Défago G. Biological control of soil-borne pathogens by Pseudomonas fluorescent. Nat Rev Microbiol. 2005;3(4):307-19. https://doi.org/10.1038/nrmicro1129
- Harman GE, Howell CR, Viterbo A, Chet I, Lorito M. *Trichoderma* species—opportunistic, avirulent plant symbionts. Nat Rev Microbiol. 2004;2(1):43-56. https://doi.org/10.1038/nrmicro797
- Pieterse CM, Van Loon LC. Salicylic acid-independent plant defence pathways. Trends Plant Sci. 1999;4(2):52-58. https:// doi.org/10.1016/S1360-1385(98)01364-8
- Ongena M, Duby F, Rossignol F, Fauconnier ML, Dommes J, Thonart P. Stimulation of the lipoxygenase pathway is associated with systemic resistance induced in bean by a nonpathogenic *Pseudomonas* strain. Mol Plant Microbe Interact. 2004;17(9):1009-18.https://doi.org/10.1094/MPMI.2004.17.9.1009
- Verhagen BW, Glazebrook J, Zhu T, Chang HS, Van Loon LC, Pieterse CM. The transcriptome of rhizobacteria-induced systemic resistance in *Arabidopsis*. Mol Plant Microbe Interact. 2004;17(8):895-908. https://doi.org/10.1094/MPMI.2004.17.8.895
- 30. Iavicoli A, Boutet E, Buchala A, Métraux JP. Induced systemic resistance in *Arabidopsis thaliana* in response to root inoculation with *Pseudomonas fluorescens* CHA0. Mol Plant Microbe Interact. 2003;16(10):851-58. https://doi.org/10.1094/MPMI.2003.16.10.851
- 31. Mukhtar T, Khalid A, Jahan MS, Inam-ul-Haq M. Biochar effect to enhance nodulation and suppress root pathogenic fungi in chickpea. Mycopath. 2019;15(2). http://l11.68.103.26/.../671
- 32. Choudhary DK, Prakash A, Johri BN. Induced systemic resistance (ISR) in plants: mechanism of action. Indian J Microbiol. 2007;47 (4):289-97. https://doi.org/10.1007/s12088-007-0054-2
- Ganeshan G, Manoj Kumar A. Pseudomonas fluorescens, a potential bacterial antagonist to control plant diseases. J Plant Interact. 2005;1(3):123-34. https://doi.org/10.1080/17429140600907043
- 34. Sarwar N, Ch MZ, Haq I, Jamil FF. Induction of systemic resistance in chickpea against *Fusarium* wilt by seed treatment with salicylic acid and Bion. Pak J Bot. 2005;37(4):989.
- Saikia R, Yadav M, Varghese S, Singh BP, Gogoi DK, Kumar R, Arora DK. Role of riboflavin in induced resistance against *Fusarium* wilt and charcoal rot diseases of chickpea. J Plant Pathol. 2006;22(4):339-47. https://doi.org/10.5423/PPJ.2006.22.4.339
- Moutassem D, Belabid L, Bellik Y, Ziouche S, Baali F. Efficacy of essential oils of various aromatic plants in the bio control of Fusarium wilt and inducing systemic resistance in chickpea seedlings. Plant Prot Sci. 2019;55(3):202-17. https://

doi.org/10.17221/134/2018-PPS

- Sarwar NI, Zahid HC, Haq I. Seed treatments induced systemic resistance in chickpea against *Fusarium* wilt in wilt sick field. Pak J Bot. 2010;42(5):3323-26.
- Sharma M, Sengupta A, Ghosh R, Agarwal G, Tarafdar A, Nagavardhini A, Pande S, Varshney RK. Genome wide transcriptome profiling of *Fusarium oxysporum* f sp. *ciceris* conidial germination reveals new insights into infection-related genes. Sci Rep. 2016;6(1):1-1. https://doi.org/10.1038/srep37353
- El-Mohamedy RS, Shafeek MR, Fatma AR. Management of root rot diseases and improvement growth and yield of green bean plants using plant resistance inducers and biological seed treatments. J Agric Sci Technol. 2015;11(5):1219-34.
- Saikia R, Srivastava AK, Singh K, Arora DK, Lee MW. Effect of iron availability on induction of systemic resistance to *Fusarium* wilt of Chickpea by *Pseudomonas* spp. Mycobiology. 2005;33(1):35-40. https://doi.org/10.4489/MYCO.2005.33.1.035
- 41. Jahan MS, Shazad U, Naqvi SA, Tahir I, Abbas T, Iqbal M. Effects of *Mesorhizobiumciceri* and Biochar on the growth, nodulation and antifungal activity against root pathogenic fungi in chickpea (*Cicer arietinum* L.). J Plant PatholMicrobiol. 2020;11:520.
- Sharma P, Sharma M, Raja M, Shanmugam V. Status of Trichoderma research in India: A review. Indian Phytopathol. 2014;67(1):1-9.
- 43. Haware MP, Nene YL, Natarajan M. The survival of *Fusarium oxysporum* f. sp. *ciceri* in the soil in the absence of chickpea. Phyto pathologia mediterranea. 1996;9-12.
- 44. Shah TM, Atta BM, Mirza JI, Haq MA. Screening of chickpea (*Cicer arietinum*) induced mutants against *Fusarium* wilt. Pak J Bot. 2009;41(4):1945-55.
- 45. Singh UP, Sarma BK, Singh DP. Effect of plant growth-promoting rhizobacteria and culture filtrate of *Sclerotium rolfsii* on phenolic and salicylic acid contents in chickpea (*Cicer arietinum*). CurrMicrobiol. 2003;46(2):0131-40. https://doi.org/10.1007/ s00284-002-3834-2
- 46. Muhammad NS, Shahbaz TS, Safdar H, Anser A, Javaid I, Kiran H. Evaluation of various fungicides for the control of gram wilt caused by *Fusarium oxysporum* f. sp. *ciceris*. Afr J Agric Res. 2011;6(19):4555-59.

- Ritika B, Utpal D. An overview of fungal and bacterial biopesticides to control plant pathogens/diseases. Afr J Microbiol Res. 2014;8(17):1749-62. https://doi.org/10.5897/ AJMR2013.6356
- 48. Akram W, Anjum T, Ali B, Ahmad A. Screening of native *Bacillus* strains to induce systemic resistance in tomato plants against *Fusarium* wilt in split root system and its field applications. Int J Agric Biol. 2013;15(6).
- 49. Landa BB, Navas-Cortés JA, Hervás A, Jiménez-Díaz RM. Influence of temperature and inoculum density of Fusarium oxysporum f. sp. ciceris on suppression of Fusarium wilt of chickpea by rhizosphere bacteria. J Phytopathol. 2001;91(8):807-16. https://doi.org/10.1094/PHYTO.2001.91.8.807
- Benhamou N, Lafontaine PJ, Nicole M. Induction of systemic resistance to *Fusarium* crown and root rot in tomato plants by seed treatment with chitosan. J Phytopathol. 1994;84(12):1432-44. https://doi.org/10.1094/Phyto-84-1432
- 51. Jakab G, Cottier V, Toquin V, Rigoli G, Zimmerli L, Métraux JP, Mauch-Mani B. β-aminobutyric acid-induced resistance in plants. Eur J Plant Pathol. 2001;107(1):29-37. https://doi.org/10.1023/A:1008730721037
- 52. Nikam PS, Jagtap GP, Sontakke PL. Management of chickpea wilt caused by *Fusarium oxysporumf*. sp. *ciceri*. Afr J Agric Res. 2007;2(12):692-97.
- Bekkar AA, Zaim S, Belabid L. Induction of systemic resistance in chickpea against *Fusarium* wilt by *Bacillus* strains. Arch PhytopatholPflanzenschutz. 2018;51(1-2):70-80. https:// doi.org/10.1080/03235408.2018.1438819
- Faostat F. FAOSTAT statistical database. Publisher: FAO (Food and Agriculture Organization of the United Nations), Rome, Italy. 2019
- Verhagen BW, Glazebrook J, Zhu T, Chang HS, Van Loon LC, Pieterse CM. The transcriptome of rhizobacteria-induced systemic resistance in *Arabidopsis*. Mol Plant-MicrobeInteract. 2004;17(8):895-908. https://doi.org/10.1094/MPMI.2004.17.8.895
- Cachinero JM, Hervas A, Jiménez-Díaz RM, Tena M. Plant defence reactions against *Fusarium* wilt in chickpea induced by incompatible race 0 of *Fusarium oxysporum* f. sp. *ciceris* and non host isolates of *F. oxysporum*. Plant pathology. 2002;51(6):765-76. https://doi.org/10.1046/j.1365-3059.2002.00760.x