Integrated Disease Management of Fusarium Wilt Pigeon Pea

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CHAPTER- 14

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Abstract

Pigeon pea, also known as *Cajanus cajan*, ranks as the fifth most crucial grain legume globally and represents a valuable protein source for vegetarians. However, the inconsistency in its yield is a persistent challenge, primarily stemming from its vulnerability to various pests and diseases. One of the most devastating among these adversaries is Fusarium wilt, which can result in staggering yield losses of up to 100% and can afflict pigeon pea crops across all growing seasons. Compounding the problem, the pathogen responsible for Fusarium wilt is soil-borne, capable of enduring in the soil for extended periods, rendering it a formidable and persistent threat to pigeon pea cultivation.

In the context of this book chapter, our aim is to delve into the present state of knowledge regarding Fusarium wilt in pigeon pea, the characteristics and behaviour of the pathogen responsible, and to explore strategies that can effectively mitigate yield losses. To address this challenge comprehensively, we propose a multifaceted approach that combines various agronomic practices, the development and utilization of resistant pigeon pea varieties, the intentional deployment of biocontrol agents, reduced reliance on chemical fungicides, and the exploration of innovative disease management techniques. By amalgamating these approaches, we aim to provide a holistic framework for effectively managing Fusarium wilt in pigeon pea crops, ultimately ensuring more stable and productive harvest.

Introduction

Pigeon pea (*Cajanus cajan* L.) is a prominent leguminous crop mainly grown in semi-arid tropical zones, with India being the leading global producer and consumer, along with Myanmar, contributing to about 85% of the worldwide yield. Other significant pigeon pea cultivation areas include Malawi, Tanzania, Kenya, and Uganda (FAO 2021). Pigeon pea is rich in proteins and essential nutrients like calcium, manganese, magnesium, phenylalanine, aspartic acid, glutamic acid, leucine, lysine, folate, and vitamin B6. India dominates pigeon pea cultivation, with substantial production also seen in Malawi. However, pigeon pea cultivation faces various biological and environmental challenges that impact its yield potential. Biological challenges include fungal, bacterial, and viral infections, nematode infestations, and mycoplasma-like agents, with notable economic consequences. Fusarium wilt, caused by *Fusarium udum*, is a significant economic issue in pigeon pea cultivation, particularly in India and South Asian and African regions, resulting in substantial yield losses of 470,000 tons in India and 30,000 tons in Africa (Reddy *et al.*, 1990; Saxena *et al.*, 2017).

History

Fusarium udum Butler, a harmful fungus, was first noted in Indian pigeon pea farming in 1906 by E.J. Butler in Bihar. This discovery led to the formal naming of the fungus. Subsequently, *Fusarium udum* Butler was found in several countries across Africa, South Asia, and Europe (Karimi *et al.,* 2012). The hyphal configurations, described by Butler (1910), display translucence and slightness with extensive ramifications and limited aerial extension. The pathogen can generate three spore variants: Macroconidia, Microconidia, and Chlamydospores. Microconidia are aseptate, elliptical, and diaphanous, visible as a salmon pink hue when aggregated, measuring 6-11 x 2-3 µm. Macroconidia, measuring 15-15 x 3–5 µm, are translucent, three to five septate, curved, and possess a well-defined basal cell and a tapered apical cell. Chlamydospores, oval or spherical, are either solitary or in chains, with a diameter of about 5-10 µm (Holliday, 1980). Padwick (1940) and Snyder and Hansen (1940) assigned names *F. oxysporum* f.sp. *cajani* and *F. oxysporum* f.sp. *udum* respectively. However, Booth (1971) favoured *F. udum* due to the significant apical hook in macroconidia. Rai and Upadhyay (1981) discovered the perfect stages of *F. udum*, naming it *Gibberella indica*. Singh (1980) also discovered the perfect stage, naming it *Gibberella udum*.

Disease Symptoms

In pigeon pea, Fusarium infection heightens vulnerability, causing gradual or sudden wilting. This infection primarily shows as wilting, followed by yellowing, desiccation, and eventual foliage loss. Plants may wither entirely or in select branches (Singh, 1973). Prior to this, signs like reduced leaf turgidity, interveinal clearing, and chlorosis appear. Affected plant clusters during flowering and pod-bearing stages signal early onset. Mature plants exhibit a distinctive trait: a purplish band from the stem base, clearly distinguishing them from healthy plants. The soil-borne pathogen infiltrates the taproot system, resulting in comprehensive plant wilt. Longitudinal stem dissection shows characteristic browning of vascular tissues, particularly within the xylem (Reddy *et al.,* 1990; Reddy *et al.,* 1993).

Management of Disease

The management of Fusarium wilt disease is difficult to manage because of the complex soil environment of physical, chemical and biological origin, not only in pigeon pea crops but in every plant species and relies on the integration of different disease management approaches. Pathogen elimination and the reduction of the amount and viability of the fungal inoculum are the main targets of the disease control measures (Jiménez-Díaz *et al.,* 2015).

Cultural and Physical Approach

Cultural control in agriculture modifies the farming environment non-mechanically to boost crop yields and reduce the impact of pests and diseases (Islam *et al.,* 2001). Techniques include altering practices to deter disease-causing pathogens and pests during planting, growth, and cultivation. Effective implementation can improve soil structure and decrease disease occurrence (Neshev *et al.,* 2008). For Fusarium wilt in pigeon pea, strategies involve intercropping, crop rotation, and biomass management to minimize disease incidence (Natarajan *et al.,* 1985). Crops like sorghum, castor, maize, and groundnut can suppress *F. udum* population in the soil (Hemavathy *et al.,* 2001). Intercropping with tobacco and careful biomass management post-harvest can also reduce wilt incidence (Bose, 1938; Reddy *et al.,* 1994). Root exudates from intercropped crops and green manuring show promise in reducing wilt incidence by limiting the pathogen population or enhancing soil microbe antagonism.

Use of Bio Control Agents

Biological control in plant pathology uses introduced or native organisms, alongside disease-resistant host plants, to manage plant pathogens (Pal and Gardener, 2006). Enhancing rhizosphere colonization by beneficial agents like Trichoderma fungi and bacteria effectively controls Fusarium wilt. Arbuscular mycorrhizal fungi (AMF) and bacterial Rhizobium species also confer resistance against soil-borne diseases. Non-pathogenic *Fusarium* spp. compete for resources and induce resistance, acting as biocontrol agents. Understanding biocontrol mechanisms, including antibiosis, nutrient competition, mycoparasitism, hydrolytic enzymes, systemic resistance induction, and rhizosphere competence, is vital for effective implementation (Compant *et al.,* 2010). Antifungal compound action is extensively studied (Haas and Keel, 2003). Antagonistic organisms like *Aspergillus niger, Rhizopus* *nigricans*, and *Bacillus subtilis* play a role in disease incidence, shown in soil sterilization studies (Vasudeva and Roy, 1950; Vasudeva and Govindaswami, 1953). We also added a few lists of biocontrol agents that are effective against the pigeon pea wilt pathogen (Table: 1)

Table:1- List of biocontrol agents found effective against wilt causing *F. udum* in Pigeon pea.

S.no	Microorganism	Biocontrol Agent	Main Result	Reference
1.	Bacteria Antagonist	*Pseudomonas fluorescens*	Application of *P. fluorescens* reduced the wilt incidence in the field.	Siddiqui *et al.*, 1998
		Bacillus brevis	*In vitro*, it is found that *B. brevis* releases antifungal compounds that causes swelling and distortion of conidial spores of *F. udum*.	Bapat *et al.*, 2000
		B. subtilis AF1	Gave better management of wilt disease in pigeon pea.	Manjula and Podile, 2001
		Bacillus licheniformis	Under *in vitro* block the growth of *F. udum* and in field condition reduces the wilt infestation and improve the plant growth.	Singh *et al.*, 2002
		P. aeruginosa PNA 1	*P. aeruginosa* application in the field protects pigeon pea from wilt infection.	Anjaiah *et al.*, 2003
		Bacillus spp. and *fluorescent pseudomonas* spp.	Four isolates (Pa116, P324, B18 and B160) showed antifungal activities against *F. udum*.	Siddiqui *et al.*, 2005
		Fluorescent *Pseudomonas* spp.	Among four isolates, Pf605 gave best result under both in vitro and pot condition against the *F. udum*	Siddiqui and Shakeel, 2006
		Pantoea dispersa	*P. dispersa* shown antifungal activity against *F. udum*, under pot and filed conditions.	Maisuria *et al.*, 2018
		Pseudomonas sp. NS 1 and *Bacillus* sp. NS 22	Both biocontrol agent was found to be potential in prevent *F. udum infection and* induced systemic resistance in plant.	Dukare *et al.*, 2021

		Trichoderma harzianum, T. viride, Gliocladium virens and *Coniothy rium minitans*	Following biocontrol agents were utilized and shows the effective management of wilt disease in plot experiment.	Whipps and Lumsden, 2001
		T. harzianum	*T. harzianum* was applied for seed and soil treatment for the management of *F. udum.*	Prasad *et al.*, 2002
2.	Fungal Antagonist	*Aspergillus flavus, A. niger;G. virens, Penicillium citrinum,* and *T' harzianum*	*In vitro* inhibit the mycelium growth of *F. udum* and also under the field conditions reduces the wilt infection.	Singh *et al.*, 2002
		Trichoderma spp.	Talc-based formulation of *Trichoderma* spp. gave the highest wilt disease reduction in the field.	Patel *et al.*, 2011
		T. atroviride, T. harzianum, T. viride, A. flavus, A. niger	All are found as potent biocontrol agents which inhibit the growth of the *F. udum.*	Panwar *et al.*, 2016
		Trichoderma asperellum	Out of twelve isolates, two (IIPRTas-6 and IIPRTas-11) gave the best antifungal activity against *F. udum* under *in vitro.*	Mishra *et al.*, 2017
		Trichoderma spp.	A total 17 Trichoderma strains were utilized and they show excellent bio-control by inducing synthesis of defence-related enzymes against *F. udum.*	Mishra *et al.*, 2023

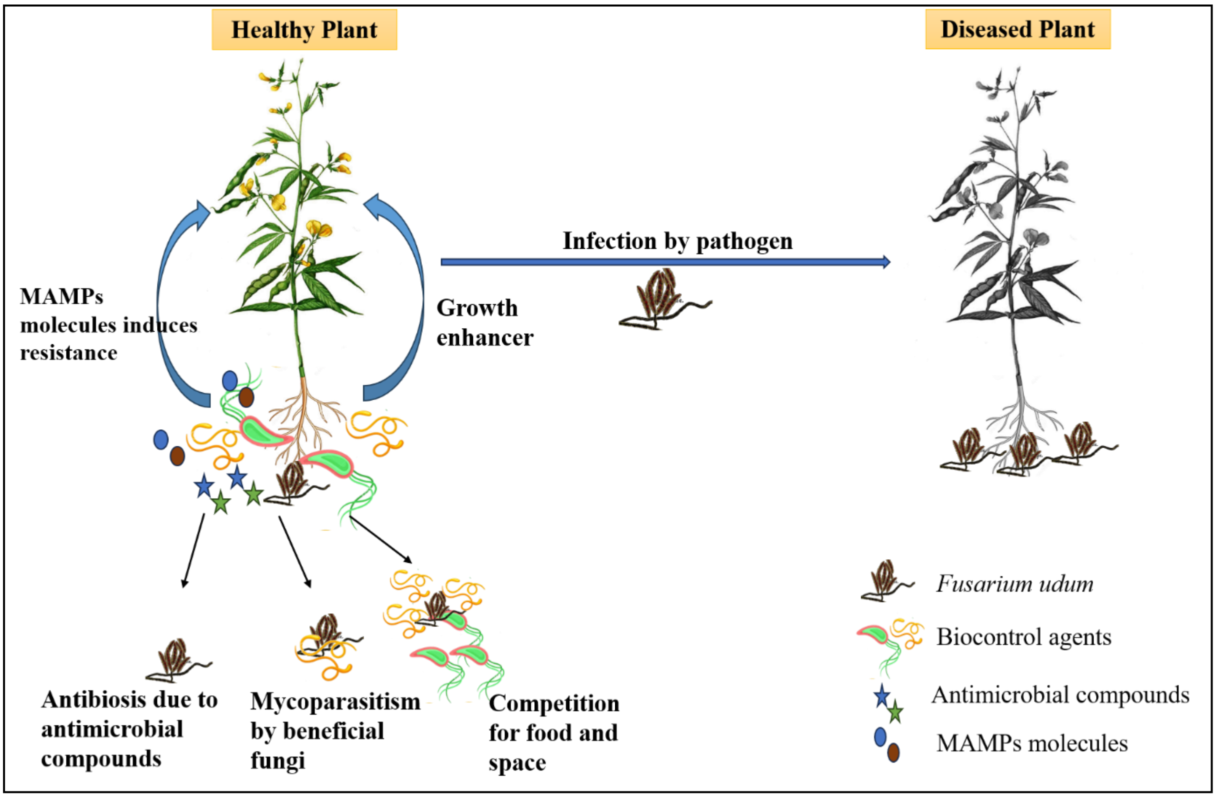

Figure 1: Primary mechanisms of action employed in the biological management of plant fungal diseases by biocontrol agents (Source- Thambugala *et al.*, 2020)

Host Plant Resistance Improvement

Control of Fusarium wilt with chemicals is hindered by environmental hazards linked to fungicides, making host plant resistance the most reliable, cost-effective, and eco-friendly approach for managing Fusarium wilt in grain legumes (Saxena, 2008; Jain *et al.*, 2015). Pigeon pea has seen success with resistant cultivars, utilizing conventional and modern breeding methods, such as quantitative trait loci-based and molecular-assisted breeding. Resistance sources have been identified in wild relative species and different cultivars. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has made significant progress in understanding host resistance improvement and incorporating them into breeding programs (Park *et al.*, 2008). However, the genetic variability within the *F. udum* population poses challenges for deploying resistant varieties against vascular wilt (Kumar and Upadhyay, 2014). ICP 9145 cultivar was a widely adopted wilt-resistant cultivar in Africa during the mid-1990s, constituting about a 20% increase in pigeon pea production.

The quest for wilt resistance in pigeon pea dates back to 1905 in India, involving screening efforts across various locations. Resistant or tolerant pigeon pea lines have been identified through extensive evaluations. Several wilt-resistant genotypes have been found, but a deeper understanding of resistance inheritance is necessary, considering varying resistance levels under field conditions. While new resistance sources have been reported, there is still ample opportunity to discover improved germplasm or native genotypes through systematic searching, collection, and evaluation, following established inoculation methods (Rispail *et al.,* 2013). Extensive testing of germplasm and advanced breeding lines in pigeon pea has identified promising lines for regular use in breeding programs, underscoring the importance of host plant resistance. Here, we have listed a few wilt resistance varieties that are being cultivated in India that are developed by various agricultural research institutions (Table: 2)

Table: 2- List of pigeon varieties resistant to Fusarium wilt cultivated in India.

S. no.	Institution	Variety	Year of released
1.	BARC, Trombay, Mumbai	TT 401	2007
2.	IGKV, Raipur	IC-550413	2007
3.	JNKVV, Jabalpur	Jawahar Tur JKM-189	2007
4.	NGRAU	Lam-41	2007
5.	RARS, Palem	PalemKhandi (PRG-158)	2007
6.	MPKV, Rahuri.	Vipula, Phule T 0012	2007, 2012
7.	VPKAS, ICAR, Almora	VL Arhar-1	2007
8.	ARS Gulbarga	TS 3R	2010
9.	IGKVV, Raipur	Rajeev Lochan	2011
10.	ARS, Warangal	WRG-65	2012
11.	ARS, Badnapur	BDN 711	2012
12.	ARS Tandur	RGT-1 TDRG 4	2012 2015
13.	RAK College Sehore	ICPH 2671	2013

14.	IIPR, Kanpur	IPA 203	2014
15.	JAU, Junagrh	GJP-1	2015
16.	ICRISAT	ICPH 2740	2015
17.	UAS, Bangalore	BRG 5, BRG 3	2015, 2018
18.	RARS, Lam	LRG 52	2015
19.	Dr. RPCA, Pusa, Bihar	Rajendra Arhar-1	2015
20.	SDAU SK Nagar	GT 103	2015
21.	ARS Gulbarga	GRG 881	2016
22.	ARS Badnapur	BDN 716	2016
23.	NAU Navsari	GNP-2 (BP-06-33)	2016
24.	RARS, ANGRAU	Tirupati Kandi 59 Krishna (LRG 105)	2020, 2020
25.	IGKV, Raipur	Chhattisgarh Arhar-1 (RPS 2007-10)	2020

Source: i) Project Coordinator's Report 2018-19 AICRP, ICAR, IIPR, Kanpur

ii) **www.seednet.gov.in**

Chemical-Based Approach

Chemical control is one of the disease management strategies used to deal with soil-borne diseases. Chemical control strategy has significant downsides, including economic, environmental, and public health concerns. Until the 1986 Montreal Protocol, which attempted to protect the ozone layer, methyl bromide was a frequently used fumigant due to its outstanding efficacy against soil-borne diseases but later it was banned (Gullino *et al.,* 2003). Alternative fumigants like as carbendazim, dazomet, chloropicrin, and 1,3-dichloropropene are now more often used in the fight against Fusarium wilt. Chemical like chloropicrin and dazomet efficiently prevented pea wilt in strongly infected soils (Ebbels *et al.,* 1967). However, various studies found that their widespread and indiscriminate use not only alters the composition of soil microbial communities but also poses risks to aquatic ecosystems and can even promote the development of fungicide resistance (Panth *et al.,* 2020; Zhao *et al.,* 2017). Use of chemical fungicide increases environmental concerns, there is growing agreement on the need to investigate more environmentally friendly techniques to disease control. For example, the European Union has adopted various directives aimed at decreasing the use of phytochemicals in agricultural systems (Barzman *et al.*, 2015).

Novel Approaches

Innovative plant disease management strategies include Bio-fumigation, incorporating fresh organic matter into the soil and covering it with plastic mulches, inducing anaerobic conditions and toxic metabolites to neutralize phytopathogenic fungi (Blok *et al.,* 2000). Another approach involves utilizing antagonistic microorganisms from suppressive soils to combat fungal pathogens. Fungi, among these microorganisms, have shown notable efficacy in pathogen control (Cha *et al.,* 2016). Botanical fungicides, like essential oils from various plants, exhibit antifungal properties, prolonging agricultural produce shelf life and preventing mycotoxin production (Shuping *et al.,* 2017). Nanotechnology offers a nanoscale-based solution, employing inorganic and organic antimicrobial particles to combat pathogens. "Green synthesis" of nanoparticles using biological materials is a cost-effective, environmentally friendly approach (Morones *et al.,* 2005; Begum *et al.,* 2020). These approaches hold promise for sustainable and effective plant disease management in agriculture.

Conclusion and Future Prospects

Collaborative efforts among diverse scientific teams have made significant strides in advancing sustainable crop enhancement and agricultural technologies, particularly to meet the growing demand for pulses. National and international research institutions have taken the lead in driving pulse improvement programs, resulting in a remarkable pulse production record exceeding 20 million tonnes. This endeavour has been pivotal in addressing protein malnutrition, especially in low-income households, given that pulses offer not just protein but also vital minerals and nutrients. However, considering forthcoming challenges in food and nutritional security, we must address several vital issues: rapid characterization of germplasm accessions for desirable traits using advanced phenotyping tools, reassessment of pathogen physiological specialization and the potential deployment of genetic variability in diverse agroecological regions, development and promotion of crop management practices tailored to resource-scarce conditions to mitigate biotic stresses like wilts, consideration of climate change and extreme weather events' potential impact on host-pathogen interactions, necessitating comprehensive research in specialized facilities, in-depth investigation into mutualistic interactions between wilts and other diseases, particularly root rots, utilization of whole-genome sequencing tools to unveil genes and transcription factors associated with wilt resistance, requiring innovative bioinformatic approaches, and evaluation of novel management techniques at various research stations through trials, with subsequent introduction of these techniques to farmers' fields based on the results. Addressing these challenges is paramount for augmenting pulse production, combating wilts, and ensuring global food security.

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