



Status and Characterization of Slow Wilt (*Fusarium oxysporum*) and Basal Wilt (*Sclerotium rolfsii*) Pathogens from Different Pepper Ecosystems of Tamil Nadu, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Black pepper (*Piper nigrum* L.) is grown extensively across many parts of Tamil Nadu. Pepper production is greatly affected by the fungal wilt complex diseases. In this study, the major pepper growing regions of Tamil Nadu were surveyed for two wilt complex diseases viz., slow wilt and

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basal wilt and the pathogens responsible for slow wilt (*Fusarium oxysporum*) and basal wilt (*Sclerotium rolfsii*) were isolated. The morphological and molecular characterization of the pathogens was performed to confirm their identities. The DNA sequence alignment with other sequences from the NCBI GenBank® database and the BLAST results indicate 97-98% similarity with reported *F. oxysporum* and *S. rolfsii*. The phylogenetic tree dendrograms were generated for both *F. oxysporum* and *S. rolfsii* using the MEGA 11 software and their relative similarities with known sequences were compared to identify the genetic linkage. Detailed investigations are necessary to get more knowledge on the epidemiology and economic importance of slow wilt and basal wilt diseases in black pepper.

Keywords: Pepper; slow wilt; basal wilt; *Fusarium oxysporum*; *Sclerotium rolfsii*.

1. INTRODUCTION

Black pepper (*Piper nigrum* L.), widely recognized as the “King of Spices” or black gold is a perennial climbing vine belonging to the family Piperaceae [1]. The presence of two alkaloids oleoresin and piperine contributes to the aroma and pungency of black pepper. In addition to cooking, black pepper is also used as therapeutic and preservative agent [2]. Worldwide, black pepper is grown in over 26 countries and nearly 3.2 lakh tonnes of black pepper is produced every year [3]. In India, pepper is cultivated in 2.78 lakh ha with a total production of 64000 tonnes per year. Among the states, Karnataka is the largest producer of pepper in India followed by Kerala and Tamil Nadu. In Tamil Nadu, the total area under black pepper cultivation is 6098 ha, with a total production of 2000 MT/year. India is exporting about 41,000 tonnes of black pepper earning a foreign exchange of ₹2.4 billion every year [4].

The major challenges to profitable black pepper cultivation in India are the fungal wilt complex diseases. They include quick wilt incited by *Phytophthora capsici*, slow wilt caused by *Fusarium oxysporum* and basal wilt due to *Sclerotium rolfsii* (Teliomorph: *Athelia rolfsii*). These diseases contribute to nearly 30% production losses in pepper cultivation [5].

Slow wilt is a debilitating disease of black pepper which was first reported by Van der Vecht in 1932 as “geelziekte” from Bangka, Indonesia. The affected plants, in general, will often survive for several years. The affected plants exhibit necrosis of roots, yellowing and flaccidity of lower leaves with upward progression, followed by defoliation, die-back and canopy reduction. The disease progresses gradually and the pepper vines deteriorate slowly over a period of 3-4 years before complete death of plants, giving the characteristic name slow wilt or slow decline.

Scientific evidences show that the slow wilt infestation weakens the pepper plants bringing down the life span of infected plants from 20 years to 6-8 years and reducing the per vine berry yield from 3.0 kg to 1.5 kg [6].

Similarly, the basal wilt of pepper caused by *S. rolfsii* is highly prevalent in the nurseries and poorly maintained plantations. It was first reported by S. Choudhury from Assam in 1943. The symptoms include chlorosis of leaves and development of grayish white mycelia and numerous mustard-like sclerotial bodies resulting in rotting and wilting of the pepper seedlings [7].

Several works have been confined to the pepper quick wilt disease, while information on slow wilt and basal wilt is limited. The yield losses in pepper is not the outcome of quick wilt incidence alone; slow wilt and basal wilt diseases also contribute significantly to yield reduction in Tamil Nadu and wherever pepper is cultivated. Hence, to ascertain the status of less studied wilt diseases, a survey was conducted in major pepper growing areas of Tamil Nadu, India and the causative fungal pathogens were isolated and characterized. This article reports the morphological variability and genetic relatedness of *F. oxysporum* and *S. rolfsii* in pepper ecosystems of Namakkal, Salem, Dindigul, Coimbatore and The Nilgiris districts of Tamil Nadu.

2. MATERIALS AND METHODS

2.1 Survey

During 2023, a roving survey was conducted in randomly selected villages of Kolli Hills (Namakkal district), Thadiyankudisai (Dindigul district), Yercaud (Salem district), Kallar and Valparai (Coimbatore district) and Gudalur (The Nilgiris district) of Tamil Nadu, India to identify the prevalence and incidence of slow decline and

basal wilt diseases in pepper plantations (Table 1). As the wilt disease complex is systemic in nature, the occurrence of the wilt diseases was expressed in terms of Percent Disease Incidence (PDI), which was calculated using the following formula according to Wheeler [8] and Oljira and Berta [9].

$$\text{PDI} = \frac{\text{Number of pepper vines infected}}{\text{Total number of pepper vines observed}} \times 100\%$$

2.1.1 Sample collection

Plant tissues (infected plant parts) were collected from symptomatic vines from different pepper growing regions of Tamil Nadu. In case of slow wilt (*F. oxysporum*) disease, the root tissues and collar region of the pepper vines presenting yellowing and wilting symptoms were collected. Similarly for basal wilt disease (*S. rolfsii*), infected stem and collar regions showing grayish white mycelial outgrowth were collected.

2.2 Isolation of the Pathogens

The infected plant samples were cut into small pieces of 3-5 mm size using a sterile scalpel. Then the excised tissues were surface sterilized by dipping them in 1.0% sodium hypochlorite solution for 1- 2 min, followed by dipping in 70% ethanol for 30 s. The tissues were then washed with sterile distilled water for 2-3 times to remove the traces of surface sterilizing agents. After that, the tissues were kept on sterile blotting papers to remove the excess moisture. Finally the tissues were placed on sterile Petri plates containing potato dextrose agar (PDA) medium amended with streptomycin sulphate, an antibiotic compound capable of inhibiting bacterial contamination. The Petri plates were then incubated at 26±2 °C for *F. oxysporum* isolation and 25±1°C for *S. rolfsii* isolation. The whitish mycelial growth appeared after 48 h on PDA plates. Actively growing mycelial discs were made using a sterile cork borer and sub-cultured on to PDA medium, as described by Shahidan and Kwan [10]. Finally the pure cultures of *F. oxysporum* and *S. rolfsii* were obtained using the single hyphal tip method.

2.3 Morphological Characterization

The purified cultures were examined for the mycelial characters, colony morphology, production of resting structures (sclerotia) and pigmentation produced by the pathogens. The

conidial morphology and conidiophore characteristics were examined under the compound microscope.

2.4 Molecular Characterization

The fungal genomic DNA was extracted using the CTAB method [11]. The fungal mycelia obtained from PDA medium were ground with CTAB extraction buffer and incubated at 65 °C for 30 min for digestion. After 30 min, an equal volume of phenol:chloroform:isoamyl alcohol (25:24:1) mixture was added to remove the protein fractions and other impurities. After centrifugation at 12,000 rpm for 10 min, the aqueous phase was carefully collected in to a new Eppendorf tube and then the DNA was precipitated by adding equal volume of ice-cold isopropanol [12]. The precipitated DNA was washed twice with 70% ethanol, followed by air-drying. Finally the DNA pellet was dissolved in 1X Tris-HCL buffer (0.5 M Tris-base, pH7.6) and stored at 4 °C for further applications.

2.4.1 DNA amplification

The genomic DNA extracted from the pure cultures of the isolated fungal pathogens (*F. oxysporum* and *S. rolfsii*) was used for molecular analyses. The internally transcribed spacer (ITS) region of ribosomal DNA were amplified using the fungi specific universal primers ITS-1 (5'-TCC GTAGGTGAACCTGCGG-3') and ITS-4 (5'-TCCTCCGCTTATTGATATGC-3') through polymerase chain reaction (PCR) in a thermocycler (QIAGEN QIAmplifier 96, New Delhi, India). All the PCR reactions were performed in 20 µL volume containing 2 µL of 10X PCR buffer [100 mM Tris-HCl (pH 8.3), 500 mM KCl, 20 mM MgCl₂], 2 µL of dNTP mixture (2.5 mM each), 2 units of Taq DNA polymerase (5 U/µL), 10 pmol each of forward and reverse primers and 1µL (100 ng) of template DNA. The temperature profile used for the DNA amplification consists of initial denaturation at 95 °C for 5 min, denaturation at 95°C for 1 min, annealing at 58 °C for 1 min, extension at 72 °C for 1 min and a final extension at 72°C for 10 min [10]. The PCR products along with 100 bp marker were resolved on 1% agarose gel by electrophoresis using 1X TBE (0.13 M Tris, 7.6, 45 mM Boric acid and 2.5 mM EDTA) as the electrode buffer. The fractionated DNA fragments were stained with Ethidium bromide and visualized using DNA gel documentation system (Gel UVITEC, UK).

2.4.2 DNA sequencing and analysis

The amplified DNA products of both *F. oxysporum* and *S. rolfsii* were sequenced with the commercial sequencing services offered by Biokart India Pvt. Ltd, Bangalore, India and the sequence details were submitted in the National Centre for Biotechnology Information (NCBI) DNA database (GenBank®, National Library of Medicine, USA) under the accession Nos. OR360870 (*F. oxysporum*) and OR167040 (*S. rolfsii*). The DNA sequences were then aligned with known gene sequences in the GenBank® database using BLAST network services for comparison. The ClustalW tool was used to analyze the ITS sequence data and Phylogenetic trees were generated using the Neighbourhood Joining (NJ) technique with a bootstrap value of 1000 replicated algorithmic searches using the MEGA 11 software [13].

3. RESULTS AND DISCUSSION

3.1 Survey

The data collected during the survey to assess the incidence of slow wilt (*F. oxysporum*) and basal wilt (*S. rolfsii*) in major pepper growing regions of Tamil Nadu indicated prevalence of slow wilt incidence from 10.12% to 42.83% while, basal wilt incidence ranged from 3.54% to 22.74% in different districts of Tamil Nadu (Table 1). The highest incidence of slow wilt was found in Thaiyankudisai (42.83%) followed by Kolli hills (40.00%) while, Kallar showed the highest incidence (22.74%) of basal wilt (Table 1). In general, higher wilt incidence was noticed during the monsoon period (data not shown).

Duarte et al., [14] reported that the pathogen responsible for pepper wilting in Brazil was *Fusarium oxysporum*. Edward et al., [15] isolated *F. oxysporum* from the infected pepper vines from Sarawak. In contrary, according to studies by Shahnazi et al., [12], *Fusarium solani* was identified as the causal agent of wilting on pepper vines in Malaysia.

3.2 Pathogen Isolation

From the diseased pepper plants collected during the survey, five distinct isolates each of *F. oxysporum* and *S. rolfsii* were recovered on PDA medium, according to Dutta et al., [16]. The *F. oxysporum* isolates were designated as FMKH 1, FMKH 2, FMK 3, FMYC 4, FMTK 5 (Table 2) and

S. rolfsii isolates were denoted as KSR 1, KHSR 2, KHSR 3, YCSR 4 and PRSR 5 (Table 3).

3.2.1 Morphological characterization

The morphological characters of each isolate of *F. oxysporum* were different from one another. Colour of the aerial mycelium varied from white to dull white while, the pigmentation varied from yellowish orange to brown (Table 2; Fig. 1). Similarly, the micro conidia, macro conidia and chlamydospore (vegetative spore) characteristics also differed between each isolate (Fig. 2A-C). The length of the micro conidia measured around 0.186 mm while, the macro conidia and chlamydospores measured 0.663 mm and 0.141 mm respectively. Two out of five isolates showed terminal chlamydospores while, other two isolates showed intercalary chlamydospores and one isolate (FMKR 3) did not put forth the vegetative spore (Table 2; Fig. 2E). Similar kind of results was obtained by Shahiden and Kwan [10,16], wherein 22 species of *Fusarium* isolates were isolated from pepper ecosystem and observed orange yellow to pink pigmentation and varying pattern of conidial morphology. Shango et al., [17] described different *F. oxysporum* isolates according to their mycelial and conidial characteristics.

In case of *Sclerotium rolfsii*, the mycelial characteristics varied from white to hyaline with cottony growth (Fig.1B) and took 6-8 d for the formation of golden brown to brownish black sclerotia (Table 2; Fig. 2F-G). The length of immature sclerotium measured around 0.048 mm (Fig.2G). Prajapati et al., [18] isolated *S. rolfsii* from chilli and observed similar kind of morphological characteristics.

3.3 Molecular Characterization

To avoid the misconceptions through morphological confirmation of the pathogens, molecular characterization is warranted. The PCR and DNA sequence based analysis have become as routine tool for early detection, identification, and phylogenetic classification of many plant pathogens up to species or strain level [19]. Hence, to check the genetic relatedness and identity of the fungal wilt complex pathogens, PCR analysis was performed with all the isolates of *F. oxysporum* and *S. rolfsii* using the universal primers ITS-1 and ITS-4, as described elsewhere. The products were fractionated on agarose gel through electrophoresis.

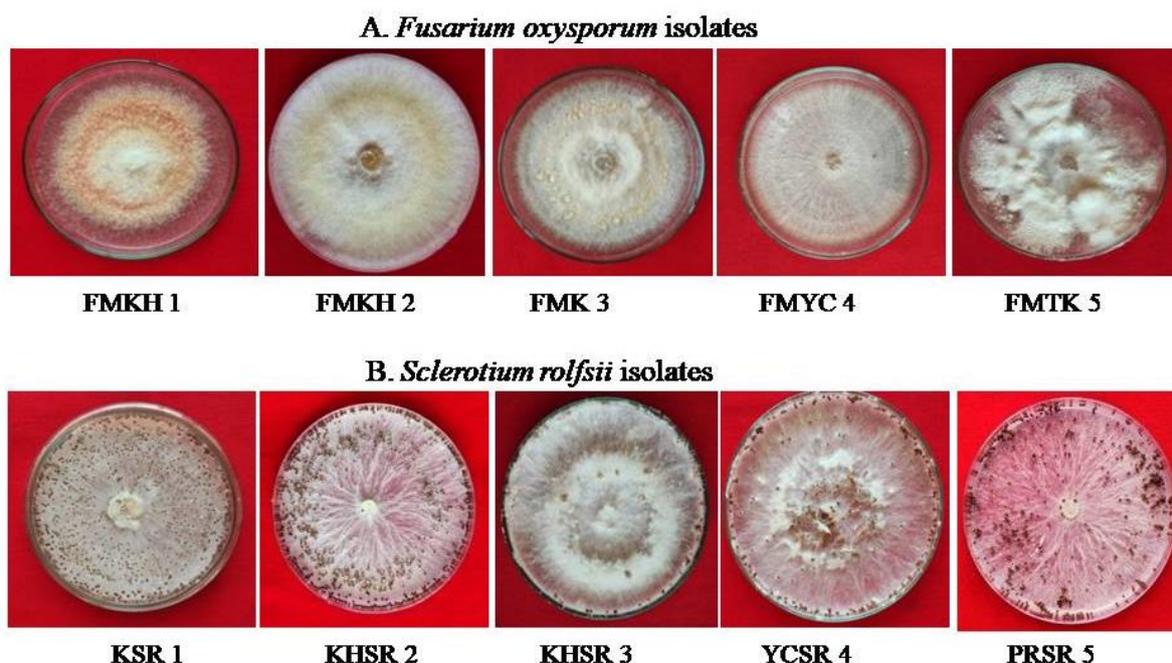


Fig. 1. Morphological characteristics of *F. oxysporum* (A) and *S. rolfsii* (B) isolates

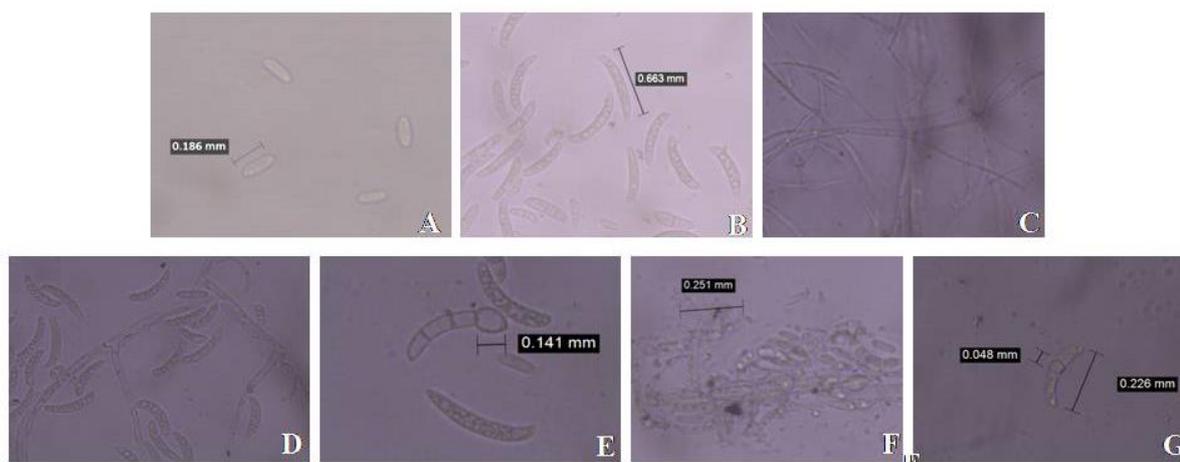


Fig. 2. Morphological characteristics slow wilt and basal wilt pathogens. A. Micro conidia, B. Macro conidia, C. Mycelium, D. Macro conidia and E. Chlamydospores of *F. oxysporum*. F. Early sclerotium induction and G. Immature sclerotium of *S. rolfsii*.

3.3.1 DNA sequencing and analysis

The fungus specific ITS primers, amplified a 550 bp DNA fragment both in *F. oxysporum* and *S. rolfsii* (Figs. 3 & 4). The amplified DNA fragments were purified and sequenced. The sequences obtained (query sequences) were analysed using the BLAST software and matched with NCBI GenBank® database for confirmation. The BLAST search showed nearly 97-98% homology with previously reported sequences of *F. oxysporum* and *S. rolfsii*, thus confirming its

identity. The matching accession numbers are presented in Fig. 5. After the confirmation, the sequence details were deposited under the accession numbers OR360870 for *F. oxysporum* isolate FMKH 1 and OR167040 for *S. rolfsii* isolate KSR 1 respectively. Elanchezhiyan et al., [20] confirmed the identity of *Fusarium oxysporum* f.sp. *lycopersici* by PCR amplification of 18S-28S rRNA region using fungal universal primers ITS 1 and ITS4. Mahadevakumar et al., [13] employed the similar molecular tools to confirm the identity of *S. rolfsii* isolated from

Cucurbita maxima with online DNA database. Shahidan and Kwan [10] obtained a single amplicon of 550 bp size with the universal fungus specific primers and constructed a Neighbourhood phylogenetic tree with the related sequences of *F. oxysporum* causing slow decline in black pepper.

3.3.2 Phylogenetic analysis

To further the knowledge on the genetic relatedness of the isolated pathogens, the

isolated query DNA sequences were aligned with known sequences in the GenBank® database by the ClustalW software and the phylogenetic dendrograms were generated using the MEGA 11 software (Fig. 5). The analysis showed that the sequences of *F. oxysporum* isolate FMKH 1 and *S. rolfsii* isolate KSR 1 shared 97-99% similarities with the accession numbers MW513788.1 and KJ546416.1 respectively in the NCBI GenBank® database, both forming a single cluster (Fig. 5).

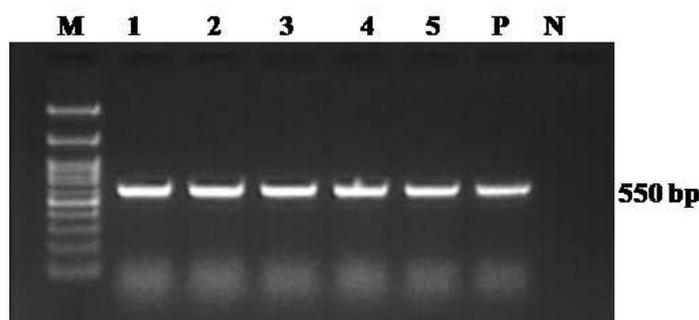


Fig. 3. PCR analysis of *Fusarium oxysporum* isolates. M. 100 bp marker, 1. FMKH 1; 2. FMKH 2; 3. FMK 3; 4. FMYC 4; 5. FMTK 5; P. Positive control (*Fusarium oxysporum* isolate FGS1) and N. Negative control

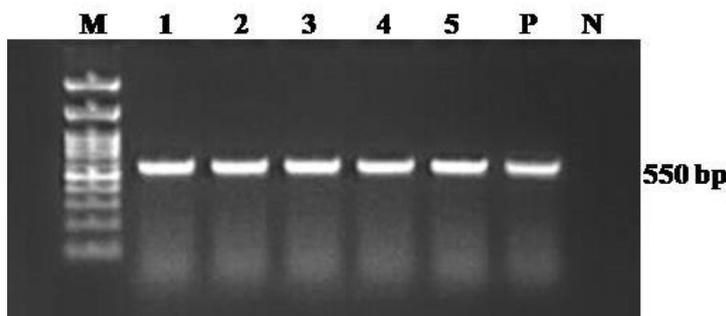


Fig. 4. PCR analysis of *Sclerotium rolfsii* isolates. M. 100 bp marker, 1. KSR 1; 2. KHSR 2; 3. KHSR 3; 4. YCSR 4; 5. PRSR 5; P. Positive control (*Athelia rolfsii* isolate ARG1) and N. Negative control

Table 1. Survey for slow wilt and basal wilt in major pepper growing districts of Tamil Nadu

S.No.	District	Location/ Villages	Geological Coordinates		PDI	
			Latitude	Longitude	SW	BW
1.	Namakkal	Karavalikombai	11.30275584°	78.34885688°	40.00	9.86
2.	(Kolli Hills)	Valavanthinadu	11.28407583°	78.35097889°	38.59	16.85
3.	Coimbatore	Kallar	11.33605301°	76.80065064°	10.12	22.74
4.		Vaalparai	11.33624777°	76.86169548°	16.47	3.54
5.	The Nilgris	Naduhatty	11.422832°	76.833792°	13.43	4.67
6.	Dhindugal	Thaiyankudisai	11.786541°	76.328755°	42.83	15.88
7.	Salem	Anthiyur	11.79417°	78.211476°	33.45	10.74
8.	(Yercaud)	Kombaikkadu	11.782627°	78.202198°	30.90	7.58

Table 2. Morphological Characteristics of *Fusarium oxysporum* isolates from Pepper ecosystem

Sl. No.	Isolates	Mycelial Pattern	Pigmentation	Microconidia	Macroconidia	Chlamydo spores
1.	FMKH 1	Flaccose, thick mycelia	Orange	Abundant, Oval, aseptate	Falcate, pointed ends, 3-5 septate	Terminal
2.	FMKH 2	Soft Cottony	Yellow	Sparse, oval, septate	Falcate, pointed ends, 3-4 septate	Intercalary
3.	FMK 3	Fluffy aggregates in centre with water droplets	Yellow	Sparse, ellipsoid, septate	Falcate to straight, blunt ends, 2-3 septate	Absent
4.	FMYC 4	Sparse thin concentric mycelia	Brown	Abundant, oval, aseptate	Falcate, pointed ends, 3-4 septate	Terminal
5.	FMTK 5	Scattered fluffy mycelia	No pigmentation	Abundant, ellipsoid, septate	Straight, blunt ends, 2-3 septate	Intercalary

Table 3. Sclerotial characteristics of *Sclerotium rolfsii* isolates from Pepper ecosystem

Sl. No.	Isolates	Mycelial Characters	Sclerotial Characters			
			Colour	Size (mm)	Arrangement	Days for sclerotium formation
1.	KSR 1	Whitish cottony mycelia	Brown	0.8- 1.0	Scattered equally	6 d
2.	KHSR 2	Hyaline to white	Golden brown	1.2	Arranged regularly in outer circle	8 d
3.	KHSR 3	White with cottony aggregates at centre	Brown	1.2 -1.4	In the corner of the plates	8 d
4.	YCSR 4	Fluffy cottony white mycelia	Dark brown	1.0-1.2	In the centre and in the corner	7-8 d
5.	PRSR 5	Hyaline mycelia	Brownish black	1.4- 2.0	Scattered irregularly	7 d

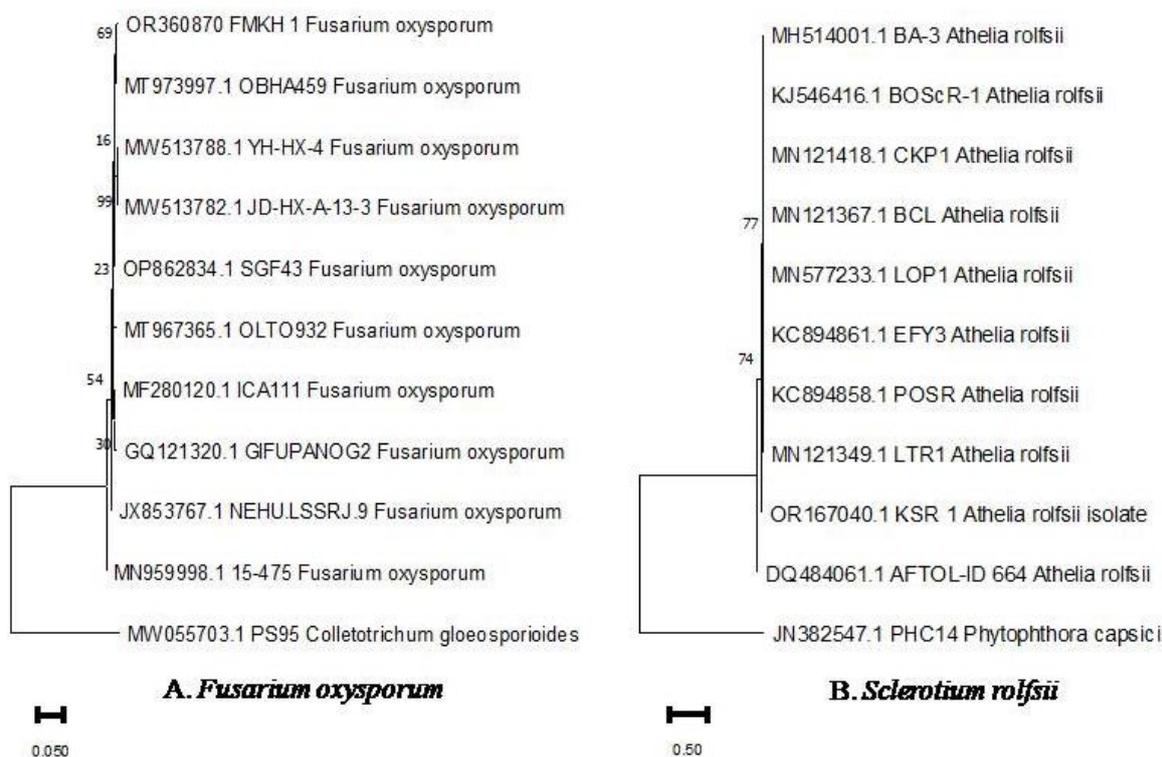


Fig. 5. Phylogenetic analysis of *F. oxysporum* isolate FMKH 1 and *S. rolfsii* isolate KSR 1

4. CONCLUSION

Our study reports for the first time, the presence of two less studied wilt diseases in different pepper growing areas of Tamil Nadu. Though considered minor when compared to quick wilt, the survey data shows the wider distribution of slow decline/wilt and basal wilt diseases in pepper plantations and the serious challenges faced by black pepper growers to prevent economic losses. With the recent developments in agriculture, infectious plant pathogens have become an increasingly significant factor contributing to crop and yield loss. The proliferation and development of new pathogenic strains are very common under intensive cropping system. Hence, to mitigate the losses from these diseases, a clear knowledge on various diseases, the causative pathogens, their distribution and mode of spread and symptomatology are to be studied in detail. The present study provides information regarding the status of *Fusarium oxysporum* and *Sclerotium rolfsii* in Tamil Nadu, their abundance and distribution, the morphological and molecular traits. These findings are important to strategize effective disease management practices for safeguarding black pepper plantations before the potential outbreak of disease(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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