FINAL REPORT OF RESEARCH PROJECT

Characterization, epidemiology and management of *Colletotrichum* spp. infecting black pepper, cardamom and turmeric

PRINCIPAL INVESTIGATOR

DR. BIJU.C.N.

INDIAN INSTITUTE OF SPICES RESEARCH, CARDAMOM RESEARCH CENTRE, APPANGALA, KODAGU, KARNATAKA

RPF – III

PROFORMA FOR SUBMISSION OF FINAL REPORT

OF RESEARCH PROJECTS

Part – I: General Information

800 Project Code: Path XVII (813)
8001 Institute Project Code No. : Path XVII (813)
8002 ICAR Project Code No.

801 Name of the Institution and Division
8011 Name and address of Institute: Indian Institute of Spices Research,
Calicut – 673 012, Kerala
8012 Name of Division/ Section: Division of Crop Protection
8013 Location of the Project: IISR, Cardamom Research Centre, Appangala,
Heravanadu Post, Madikeri, Kodagu (Dist.), Karnataka

802 Project Title: Characterization, epidemiology and management of *Colletotrichum* spp. infecting black pepper, cardamom and turmeric
803 Priority Area: Crop Protection
8031 Research Approach:

Applied Research	Basic Research	Process/Technology Development	Transfer of Technology
√	√	-	-

804 Specific area: Characterization and management of *Colletotrichum* spp.
805: Duration of the Project: 4 years.
8051 Date of start: May 2006
8052 Date of completion: March, 2010
806 Total cost/ Expenditure Incurred: Rs. 13, 64, 000/-
(Give reasons for variation, if any from estimated cost)
The project was extended for one year.
807 Executive Summary

Leaf blight and anthracnose/ spike shedding incited by *Colletotrichum gloeosporioides* are wide spread and economically important diseases of cardamom and black pepper, respectively. Characterization, epidemiology and management of diseases incited by *Colletotrichum* in cardamom, black pepper and other component crops grown in cardamom – black pepper cropping system are essential, as the diseases are widespread and associated with

these crops wherever they are grown and may assume epiphytotic proportions, if remained unchecked. In the present investigation, *Colletotrichum* spp. infecting cardamom, black pepper and other crops which are grown in the cropping system of the principal crops were collected from different geographical locations and characterized. *Colletotrichum gloeosporioides* is consistently isolated from anthracnose infected black pepper and leaf blight samples of different regions of Karnataka and Tamil Nadu. High degree of variability was observed in the isolates of *C. gloeosporioides* obtained from different regions of anthracnose infected black pepper and leaf blight infected cardamom and different hosts of same region. Studies on survival and carry over of black pepper anthracnose pathogen revealed that, the pathogen survives in the debris and rain splash plays the major role in rapid spread of disease to tender parts of the vine.

Pot experiments to study the survival of *Colletotrichum* spp. infecting cardamom, black pepper and turmeric indicated that, *C. gloeosporioides* infecting black pepper survived for 90 and 105 days at 30 and 0 cm depths respectively. *C. gloeosporioides* infecting cardamom survived for 90 and 105 days at 30 and 0 cm, respectively. In comparison with *Colletotrichum* infecting black pepper and cardamom, survivability of *C. capsici* infecting turmeric was found to be low both at 0 cm and 30 cm depths. Pathogenicity studies using different isolates and varieties of cardamom, black pepper and turmeric indicated that, the *Colletotrichum* isolates infecting black pepper, cardamom and turmeric have the potential to infect the varieties/ cultivars of crops other than their natural host. Compatibility studies (selfing and crossing) of predominant *Colletotrichum* isolates infecting black pepper, cardamom and turmeric indicated that, the isolates were either compatible (merging reaction) or incompatible (barrage reaction). The isolates exhibited differential sensitivity towards two fungal and two bacterial antagonists evaluated. Field experiments to manage anthracnose of black pepper with fungicides and biocontrol agents indicated that, treatment with basal application of *T. harzianum* and aerial spray with 1% Bordeaux mixture was superior over other treatments.

808 Key words: Anthracnose pathogen diversity, management, black pepper, turmeric, cardamom

Part – II Investigator Profile
(Please identify clearly changes, if any in Project Personnel)

810 Principal Investigator:

8101	Name	: *Dr. C. N. Biju
8102	Designation	: Scientist (Plant Pathology)
8103	Division/Section	: Crop protection/ Plant Pathology
8104	Location	: IISR, Cardamom Research Centre, Appangala
8105	Institute Address	: Indian Institute of Spices Research, Cardamom Research Centre, Appangala, Heravanad (P), Kodagu, Karnataka, 571 201

* Dr. M.N. Venugopal, Principal Scientist (Plant Pathology) acted as the PI of the project from May, 2006 to October, 2009.

Dr. D. Prasath, Senior Scientist (Crop Improvement and Biotechnology) acted as the Co-PI of the project from May, 2006 to April, 2007.

Dr. C.N. Biju was made as the PI of the project as Dr. Venugopal superannuated in the month of October, 2009 (as per the decision taken in the midterm IRC meeting, IISR, Calicut held during 8th to 9th December, 2009).

Part III – Technical Details

820: Introduction and Objectives:

8201: Project Objectives:

(i) To characterize *Colletotrichum* spp. infecting black pepper, cardamom and turmeric
(ii) To analyze pathogen diversity of *Colletotrichum* spp. infecting black pepper, cardamom and turmeric
(iii) To study the survival of the pathogen and disease spread
(iv) To study the sensitivity of *Colletotrichum* spp. to different biocontrol agents
(v) To identify resistant sources
(vi) To manage the disease by laying out field trials in hot spots/ sick plots using biocontrol agents and fungicides

8202: Background information and importance of the project

Anthracnose and spike shedding of black pepper in high altitudes and leaf blight in cardamom are major problems faced by the farmers. Studying etiology of the disease, diversity of the pathogen, survival and carry over of the pathogen, identification of resistant sources are indispensable in evolving integrated management strategies. The project was formulated with objectives to study the diversity, survival, identification of resistant sources and evolving a viable strategy to manage the disease economically and effectively.

821 Project Technical Profile

8211 Technical programme

(Indicate briefly plan of procedure, techniques, instruments and special material, organisms, special environments etc.)

1. Survey and collection of *Colletotrichum* isolates infecting cardamom, black pepper and other component crops from different geographical locations.
2. Isolation of pathogen using specific and general isolation media.
3. Studying the growth and morphological characters under controlled conditions.
4. Studying survival of the pathogen.
5. Screening of elite selections/ cultivars of cardamom and black pepper under field and controlled conditions.
6. Studying the sensitivity of the isolates to promising biocontrol agents.
7. Laying out field trial in hot spots using fungicides and biocontrol agents.

8212 Total man months involvement of component project workers

a) Scientific: 22
b) Technical: 04
c) Supporting: 12

822 Final Report on the Project

8221 Achievements in terms of targets fixed for each activity

(I) <u>Characterization and analysis of pathogen diversity of *Colletotrichum* spp. infecting black pepper, cardamom and turmeric</u>

Collection of samples

To collect the samples, surveys were undertaken in the major cardamom and black pepper growing tracts belonging to different altitude and rainfall regions of Kodagu and Hassan districts of Karnataka (Table 1). The isolates were collected from both monocropping and mixed cropping systems of cardamom and black pepper. Samples were also collected from other crops which were grown as component crops along with the principal crops. A total of 16 locations were surveyed and samples were collected from 21 crops. The samples were primarily composed of leaves exhibiting typical leaf spot or anthracnose symptoms. Isolation of the pathogen was carried out by following standard isolation procedures. The cultures were identified by comparing the colony and conidial morphology with published literature and photographs. The identified cultures were subsequently pure cultured and maintained for further studies.

Isolation and identification of isolates

The field symptoms observed on 21 different hosts is presented in Table 2 and Plate 1. The symptoms recorded on Panniyur – 1 variety of black pepper and CCS – 1 of cardamom in different locations did not reveal any variation.

The identification of *Colletotrichum* was done by comparing all the results of colony morphology, conidial size and shape as well as appressorial characteristics with the published reports. All the isolates from black pepper and cardamom were identified as *C. gloeosporioides* and the *Colletotrichum* sp. from the turmeric isolate was identified as *C. capsici*. Among the 24 isolates from other hosts of cardamom ecosystem the *Colletotrichum* infecting chilli (Appangala and Sampaje isolates) were identified as *C. capsici* and the remaining 22 *Colletotrichum* sp. were identified as *C. gloeosporioides.* Forty-five isolates of *C. gloeosporioides* and three isolates of *C. capsici* were obtained from 21 hosts.

Growth characteristics of black pepper isolates

Out of 13 *Colletotrichum gloeosporioides* isolated, eight were of dark type, three were light types and two were white types (Table 3). The diameter of the growth on seventh day varied for different isolates, in which larger growth diameter was found in black pepper isolate from Avemaria and the least was *C. gloeosporioides* from Sakleshpur. Clear variations were observed in the morphology of isolates (Plate 2).

Growth characteristics of cardamom and turmeric isolates

The isolates differed in many colony characters like growth, colour and texture. Among the ten *C. gloeosporioides* isolates from cardamom, five dark types, four light type, and one white type colony were observed (Table 4). The maximum growth was observed in *C. gloeosporioides* from Hakathur with 8.6 cm diameter on seventh day and the diameter (5.8cm) of the Siddapur cardamom isolate was less when compared to others. The colony of *C. capsici* from turmeric was of dark type and this attained a growth of 8.3 cm diameter on seventh day (Plate 3).

Growth characteristics of *Colletotrichum* species from other host plants of cardamom and pepper ecosystem

Thirteen dark type, nine light type, two white types were found in the *Colletotrichum* sp. from other hosts of cardamom ecosystem (Table 5). *Colletotrichum* sp. from sapota (Appangala isolate) obtained maximum growth of 8.8 cm diameter and the *Colletotrichum* from chilli

(Sampaje isolate), showed minimum growth of 5.8 cm diameter when compared to other isolates (Plate 4).

Conidial characteristics of black pepper isolates

The conidia were harvested from the exudations developed in the colony (Plate 5). The conidia from all the isolates were cylindrical with obtuse ends (found in six isolates), cylindrical with slightly tapered base and obtuse apex (found in four isolates) and cylindrical (found in only one isolate) (Plate 6). The length of the conidia varied from 10.31 µm to 17.81 µm and the width varied from three to 4.5 µm. The length of the conidia was high in the *Colletotrichum* isolated from Byakaravally having a width of 3.93 µm. Maximum width was found in Thithimathi with 15.75-µm length (Table 6).

Conidial characteristics of cardamom and turmeric isolates

Conidia of different shape such as cylindrical with obtuse end, cylindrical with obtuse ends with narrowing the centre (peanut pod shape), Ovid, cylindrical with a slightly tapered base and obtuse apex, cylindrical with obtuse ends were observed (Plate 7). The size of the conidia varied from 12.56 µm (Nelliahudikeri isolate) to 17.25 µm (Byakaravally cardamom isolate). The width range observed is 3.3 µm to 4.5 µm (cardamom isolate of Nelliahudikeri). The conidia of turmeric were sickle shaped having 19.5-µm lengths and 3.37-µm width (Table 7).

Conidial characteristics of *Colletotrichum* species from other host plants of cardamom ecosystem

Different conidial shapes recorded were ovoid (present in six isolates), cylindrical with obtuse ends with narrowing the centre (peanut pod shape, present in two isolates), cylindrical with obtuse ends (found in twelve isolates), cylindrical with a slightly tapered base and obtuse apex (found in two isolates) and sickle shaped conidia recorded in two isolates (Plate 8). The *Colletotrichum* observed from both the Appangala and Sampaje isolate isolated from chilli were of sickle shaped. The data on the size of conidia are presented in Table 8. The length of the conidia, other than chilli isolates varied from 12 µm (*Colletotrichum* isolate from bell pepper, Appangala) to 16.87 µm (*Colletotrichum* isolate from tomato Appangala). The width varied from 3.4 (isolate from arecanut, Appangala) µm to 4.37 µm (papaya, Appangala).

Appressorial characteristics of black pepper isolates

The appressorial characteristics presented in Table 9 clearly reveal the variation in appressoria formation. Unlobed, slightly lobed and multi lobed types of appressoria were observed in different *Colletotrichum* isolates from black pepper. Some of the multi lobed appressoria formed 2-3 lobes and in some, number of lobes varied from 3-4 lobes. Out of the thirteen isolates, nine isolates formed multi lobed appressoria, two formed slightly lobed appressoria, and only one of the isolate from Nelliahudikeri developed unlobed appressoria (Plate 9).

Appressorial characteristics of cardamom and turmeric isolates

The appressorial characters presented in Table 10 clearly reveals the variation in appressorial formation. Unlobed and multi lobed appressoria types were formed by the *Colletotrichum* isolates from cardamom. Out of ten *Colletotrichum* isolates, two formed multi lobed appressoria with 2-3 lobes, five formed multi lobed appressoria with 3-4 lobes, unlobed appressoria were formed by three *Colletotrichum* isolates from cardamom. The *Colletotrichum* isolate from the turmeric formed unlobed appressoria (Plate 10).

Appressorial characteristics of *Colletotrichum* species from other host plants of cardamom ecosystem

The appressorial characters presented in Table 11 clearly reveals the variation in appressorial formation. The different types of appressoria formed were unlobed, slightly lobed and multi lobed. The multilobed appressoria were again divided into four types, those which are formed with 2-3 lobes (in six *Colletotrichum* isolates), 3 - 4 lobes (in three *Colletotrichum* isolates), 3 - 5 lobes (in one *Colletotrichum* isolate) and 4-8 lobes (in one *Colletotrichum* isolate) (Plate 11). The *Colletotrichum* isolate from the betel vine formed appressoria in which the number of lobes varied from four to eight.

Table : 1 Crops and locations of *Colletotrichum* isolates

Hosts	Place of collection	Rainfall (mm)	Altitude (m)
Cocoa	1) Appangala, Madikeri Taluk, Kodagu District 2) Sampaje	3000 4,100	940 275
Tomato	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Anthurium	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Cucumber	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Chilli	1) Appangala, Madikeri Taluk, Kodagu District	3000	940

	2) Sampaje	4,100	275
Mango	1) Appangala, Madikeri Taluk, Kodagu District 2) Sampaje	3000 4,100	940 275
Strawberry	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Black pepper	1) Appangala, Madikeri Taluk, Kodagu District 2) Donigal 3) Pollibetta 4) Thithimathi, Virajpet Taluk, Kodagu District 5) Kodlipet 6) Green field of Kodagu, Chettalli, Somwarpet, Kodagu 7) Hakathur 8) Siddapur 9) Magalu, Sakleshpur, Hassan District 10) Cooverkolly, Somwarpet, Kodagu 11) Byakaravally, Sakleshpur, Hassan 12) Halery 13) Avemaria Estate, Sakleshpur, Hassan District	3000 3200 2100 1600 2000 2000 2800 2000 2500 2800 2960 2450 4200	940 1000 950 800 790 850 920 850 770 1050 800 1000 550
Cardamom	1) Appangala, Madikeri Taluk, Kodagu District 2) Donigal 3) Pollibetta, Virajpet Taluk, Kodagu 4) Siddapur, Virajpet Taluk, Kodagu 5) Green field of Kodagu, Chettalli, Somwarpet, Kodagu 6) Nelliahudikeri, Siddapur 7) Hakathur 8) Byakaravally, Sakleshpur Hassan 9) Avemaria Estate, Sakleshpur, Hassan District 10) Halery	3000 3200 2100 2025 2000 2000 2800 2960 4200 2450	940 1000 950 900 850 850 920 800 550 1000
Pomegranate	1) Appangala, Madikeri Taluk, Kodagu District 2) Kandanakolly	3000 2100	940 900
Bell pepper	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Basale	1) Appangala, Madikeri Taluk, Kodagu District 2) Donigal	3000 3200	940 1000
Brinjal	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Papaya	1) Appangala, Madikeri Taluk, Kodagu District 2) Donigal	3000 3200	940 1000
Bird's eye chilli	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Cashew nut	1) Sampaje	4100	275
Turmeric	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Betel vine	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Arecanut	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Sapota	1) Appangala, Madikeri Taluk, Kodagu District	3000	940
Cinnamon	1) Appangala, Madikeri Taluk, Kodagu District	3000	940

Table: 2 Field symptoms observed on cardamom, black pepper and other hosts	
Hosts	**Symptoms**
Black pepper	Numerous circular brown spots, with prominent dark brown margin encircling them were found throughout the leaf surface. Some spots were coalesced to form irregular patches with yellowish margins around them. Spike shedding and lesions on runners were also observed.
Cardamom	The spots appeared as the superficial discolouration, which later developed into circular brown coloured spots. Adjacent spots coalesced and formed elongated patches with a pale yellow halo.
Turmeric	Circular and oval spots on the upper surface. Yellow halo was noticed around each spots.
Bell pepper	Leaf spots, which were circular to irregular in shape, were observed. Smaller and larger spots. Dark brown marginal ring and grayish center with numerous black acervuli arranged in concentric rings.
Chilli	Irregular brown patches on the leaves. A large number of black dots were seen scattered all over the affected twigs. Black circular spots on the skin of the fruits.
Mango	Smaller leaf spots, which were circular to irregular with a narrow yellow halo.
Strawberry	Small brown coloured spots on the leaves with prominent dark margin. The spots were numerous on the margin of the leaves. Root necrosis, anthracnose on fruit, crown rot was also observed.
Cucumber	Many light brown spots, which later coalesced and occupied a large area. The spots were surrounded by a yellow halo. The leaves were distorted and the lesion centers were cracked.
Brinjal	Circular to irregular larger spots with yellow halo. The spots had dark brown margin.
Tomato	Brown coloured circular and irregular spots surrounded by yellow halo. Many spots coalesced to form patches. Black coloured acervuli of the fungus were observed on the coalesced spots.
Papaya	Brown and yellow coloured superficial discolouration of the leaves. Necrotic spots were seen on the leaves. Coalesced lesions were also observed.
Anthurium	Brown irregular spots all over the surface of the leaves. Yellow superficial discolouration on the leaves.
Cashew	Numerous irregular brown spots on the leaf surface. Spots were coalesced to form large patches.
Cocoa	Leaf spot, pod rot, brown coloured irregular spots were observed on the fruits.
Arecanut	Large, irregular, grayish spots outlined with the brown halo were observed on the leaves.
Betel vine	Small circular brown spots with the distinct dark brown margin. The spots were surrounded by yellow halo.
Bird’s eye chilli	Small gray spots on the leaves with brown margin.
Cinnamon	Small circular, distinct spots with gray center on the leaves
Sapota	Minute brown coloured spots on the leaves. Spots coalesced to form patches.
Basella	Large brown spots, which enlarge up to 1cm diameter. Dark brown margin around each spot. Spots coalesced to form lesions.
Pomegranate	Small regular dark brown spots on the leaves, which were surrounded by reddish brown margin. On the fruits, dark brown, depressed spots were observed.

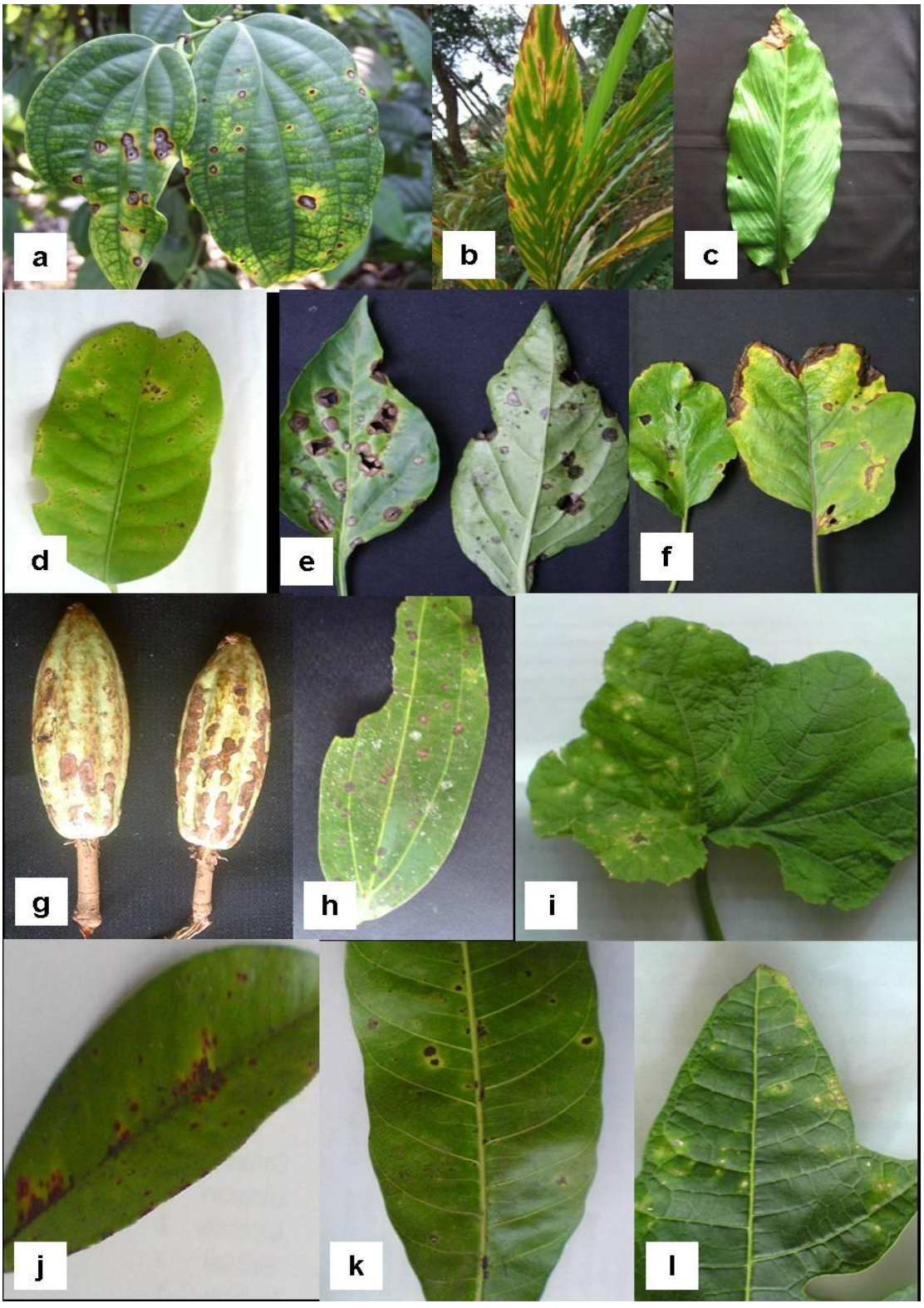

Plate – 1: a – black pepper, b – cardamom, c – turmeric, d – cashew, e – chilli, f – brinjal, g – cocoa, h – cinnamon, i – cucumber, j – sapota, k – mango, l - papaya

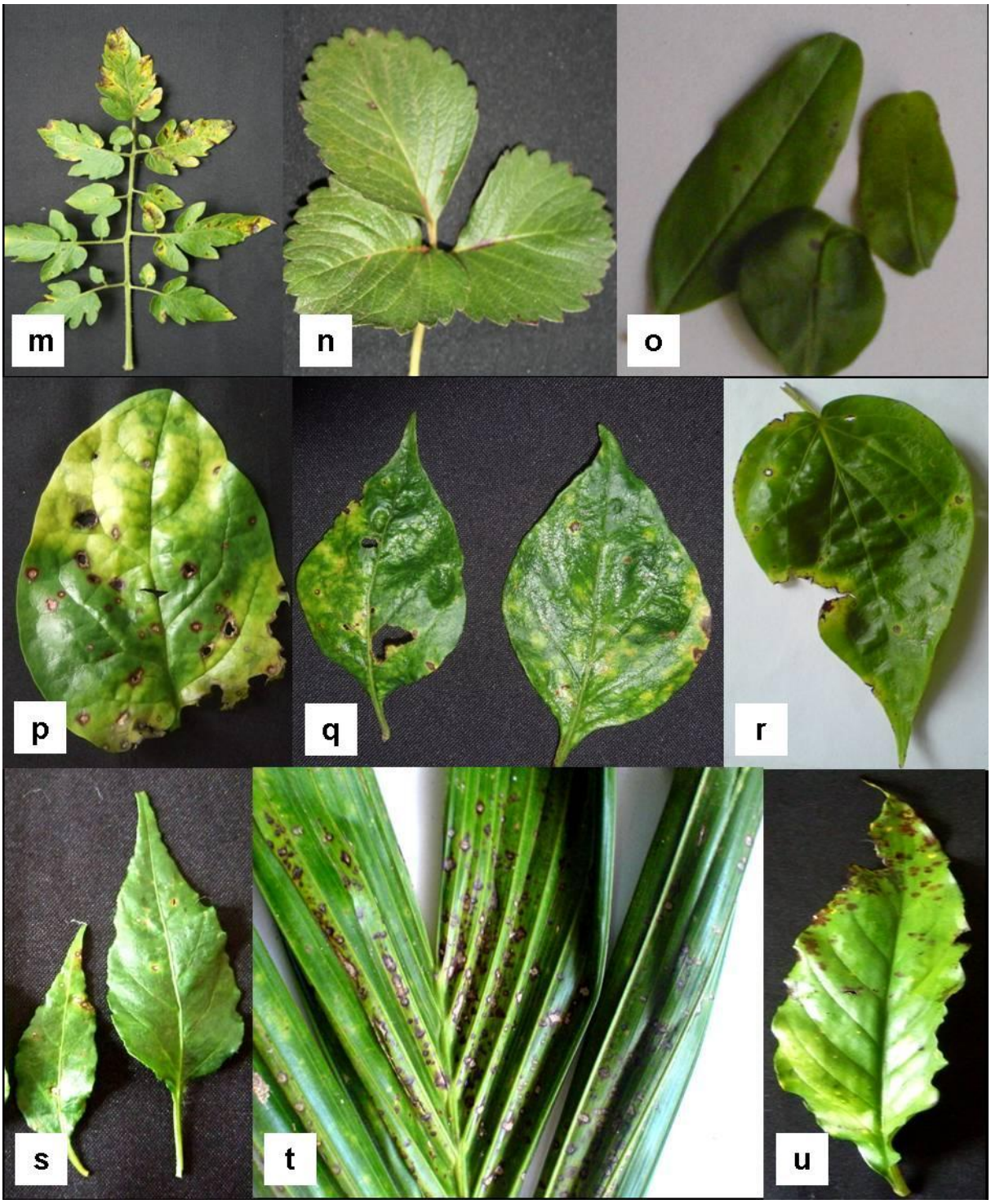

Plate – 1: m – tomato, n –strawberry, o – pomegranate, p – basale, q – bell pepper, r – betelvine, s – bird's eye chilli, t – arecanut, u - anthurium

Table: 3 Growth characteristics of black pepper isolates of *Colletotrichum gloeosporioides* on PDA					
Place of collection	**Colony diameter on 3rd day (cm)**	**Colony characters on third day**	**Colony diameter on 7th day (cm)**	**Colony characters on 7th day**	**Type of the colony**
Nelliahudikeri	2.8	Dark gray center with yellow slime and white margin, puffy Reverse is black and cream coloured	7.8	Gray coloured, with orange slime, back side of the Petriplates is black	Dark type
Magalu	3.1	White mycelium with light gray center. Reverse is dark gray with white margin	8.0	White and dark gray mycelium	Dark type
Avemaria	3.6	White cottony colony with orange slime, backside is cream, orange and gray	8.4	White and light gray with orange slime. Reverse orange center region surrounded by black region	Dark type
Appangala	3.2	Center 1.5 cm diameter forms dark gray coloured mycelia with narrow white margin. Back side is dark gray and cream coloured	7.3	Dark gray puffy mycelium. Back side is black and dark gray	Dark type
Hakathur	3.4	Light gray and white mycelia	7.6	Dark gray mycelia with a narrow white margin, Reverse is black and dark gray	Dark type
Cooverkolly	3.8	White cottony mycelium with orange coloured slime. Reverse is cream coloured	6.7	White mycelium with orange slime. Reverse is cream colour with light gray colour spots	White type
Kodlipet	2.9	White mycelia, reverse is cream coloured	8.0	White and light gray	Light type

Halery	3.2	White and gray with orange slime	8.1	Gray coloured with a narrow cream-coloured margin. Back side is black coloured	Dark type
Byakaravally	3.6	Light gray puffy mycelium, reverse is dark gray and cream	7.9	Dark gray and the reverse is black	Dark type
Sakleshpur	2.9	White puffy mycelium, cream coloured back.	6.6	White and orange	White type
Thithimathi	4.1	White and gray reverse is white and dark gray	6.9	Gray colour and backside is dark gray	Dark type
Pollibetta	3.1	White, gray and orange slime	8.1	Light gray mycelium back orange coloured	Light type
Chettalli	2.7	White and orange slime	7.8	White, gray, and orange and the reverse is gray	Light type

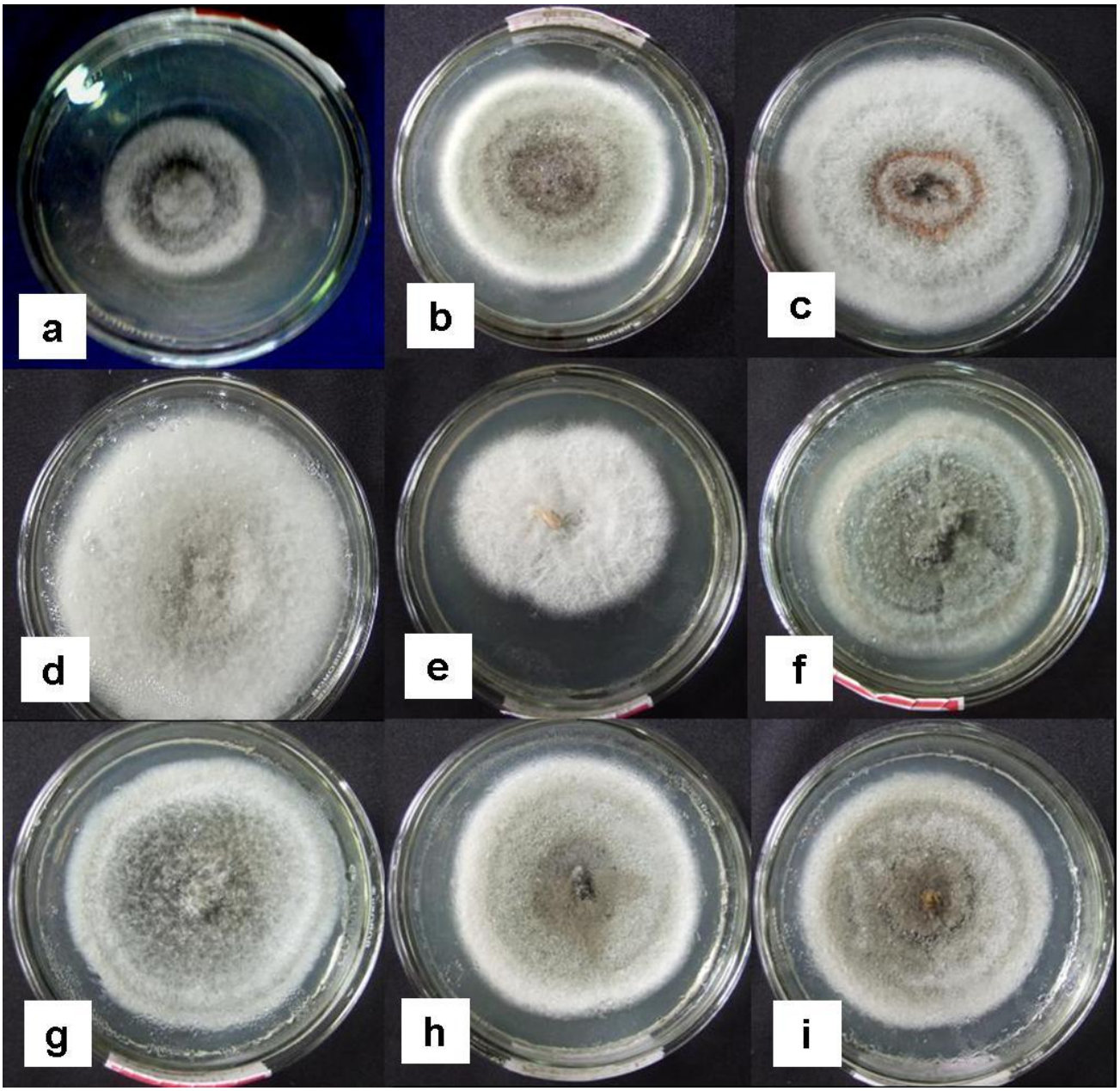

Plate – 2: a – Appangala, b – Thithimathi, c – Avemaria, d – Byakaravally, e – Cooverkolly, f – Hakathur, g – Lakshmi, h – Magalu, i - Nelliahudikeri

Table: 4 Growth characteristics of cardamom and turmeric isolates of *C. gloeosporioides* and *C. capsici*

Hosts	Place of collection	Colony diameter on 3rd day	Colony characters on 3rd day	Colony diameter on 7th day	Colony characters on 7th day	Type of colony
Cardamom	Appangala	5.0	White and orange colony, reverse is white	6.4	White, light gray and orange slime, reverse is cream coloured	Light type
Cardamom	Sakleshpur	3.0	White and gray with pink coloured slime	6.2	Dark gray with white margin with pink coloured slime	Dark type
Cardamom	Pollibetta	2.5	White with gray center, puffy mycelium, backside is dull white.	5.1	White and gray, reverse is cream and orange coloured	Light type
Cardamom	Siddapur	2.3	White and black with orange slime all over the mycelium. Reverse is cream and black	5.8	White and black with orange slime, reverse is black	Dark type
Cardamom	Chettalli	3.3	Gray and orange, reverse is gray and cream	6.8	Dark gray and orange, reverse is black	Dark type
Cardamom	Nelliahudikeri	4.1	White and gray mycelia with orange slime in the center. Black with a narrow white border	5.5	Gray and orange slime	Dark type
Cardamom	Hakathur	4.5	Center 2cm area is light gray coloured with orange slime. Sub epidermal black acervuli are also present. Back side is	8.6	White and light gray mycelia with light orange slime in the center	Light type

			cream coloured with dark gray and black spots			
Cardamom	Byakaravally	3.9	White puffy mycelia, back side is cream coloured	8.1	White puffy mycelia with light gray coloured spots	White type
Cardamom	Avemaria	2.7	White and light gray puffy colony. Reverse is cream and gray colour.	7.8	Gray and orange	Light type
Cardamom	Halery	3.4	White and light gray, Backside is cream	8.2	White and dark gray and reverse is dark gray and cream	Dark type
Turmeric	Appangala	4.1	Light gray and white with orange slime dots in the center of the colony	8.3	Light gray and white with orange slime. Back side is dark gray with white margin	Dark type

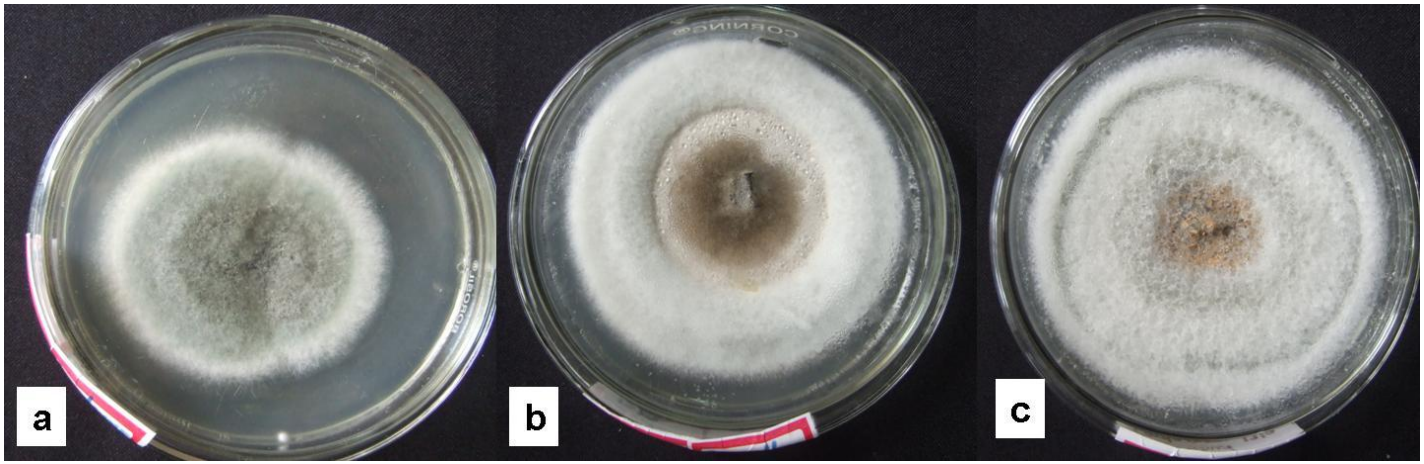

Plate –3: a – Avemaria, b – Byakaravally, c – Hakathur

Table: 5 Growth characteristics of *C. gloeosporioides* and *C. capsici* isolates from other hosts of cardamom ecosystem						
Host	**Place of collection**	**Colony diameter on 3rd day**	**Colony characters on 3rd day**	**Colony diameter on 7th day**	**Colony characters on 7th day**	**Type of colony**
Pomegranate	Appangala	3	White and gray, Back side is black and cream colour	6.4	White and gray reverse is black	Dark type
Pomegranate	Kandanakolly	5.9	White and gray, reverse is cream coloured with black coloured acervuli on the colony	7.9	Gray coloured	Light type
Bell pepper	Appangala	4.1	White and gray with acervuli on the surface, Cream coloured back with gray spots	5.6	Gray and orange	Light type
Basella	Sakleshpur	2.1	White puffy appearance	5.9	White puffy appearance, with orange slime, reverse is orange coloured.	White type
Basella	Appangala	2.3	White with slightly pink slime, backside is cream coloured	6.4	White with pink slimes in the middle of the colony, reverse is light gray and slightly pinkish	Light type
Brinjal	Appangala	4.7	Centre 3.2 cm diameter area is dark gray with orange slime. The marginal mycelia are white coloured. The backside of the Petri plate appears as black, dark gray and cream	7.9	Gray colony with cream border. Backside is black	Dark type

			colour			
Papaya	Sakleshpur	3.8	Gray mycelium with a narrow white border, reverse is gray	7.2	Dark gray mycelium with orange coloured slime in the center	Dark type
Papaya	Appangala	5	Centre 3cm diameter is light gray coloured mycelia with orange coloured slime covered it. Black coloured acervuli are also present. Gray area is surrounded by white margin	8.4	Gray front and dark gray back.	Dark type
Bird's eye chilli	Appangala	3.8	Centre 0.8cm diameter area is dark gray surrounded by white puffy mycelia	6.9	Dark gray and back side is black	Dark type
Cashew	Sampaje	3.5	White with orange slime layer. Back side is cream and light orange	6.9	White and orange, reverse is light orange with light gray	Light type
Betel vine	Appangala	3.9	Dark gray with white margin reverse is dark gray and white	6.8	Dark gray colony and the backside is black.	Dark type
Areca nut	Appangala	4.3	White puffy growth. Centre of the growth forms orange coloured slime. Back side is white	8.4	White and light gray with center orange slime. Reverse is dark gray and cream with pinkish border	Dark type
Sapota	Appangala	4.8	White, light gray with orange slime.	8.8	Light gray colony having orange slime all over the surface of the colony.	Light type

Cinnamon	Appangala	4.1	White colony. Backside is cream coloured	7.3	White and gray.	Light type
Cocoa	Sampaje	4	Dark gray and white, back side is black in colour	6.8	Gray with orange slime and black dots	Dark type
Cocoa	Appangala	3.7	White and gray, reverse is black.	8.1	Gray colony having orange slime in the center.	Dark type
Tomato	Appangala	3.1	Gray and white	7.4	Black and white. Reverse is black and cream coloured.	Dark type
Caladium	Appangala	3.5	The mycelia are white with dark gray center. The reverse is dark gray and dull white	6.8	Gray colony	Dark type
Cucumber	Appangala	7	White colony	8.4	White with orange slime	White type
Chilli	Appangala	4.7	White and light gray with oranges slime. Reverse is dark gray and cream	8.1	Gray colony with orange slime on the surface	Dark type
Chilli	Sampaje	2.1	White colony. Reverse is cream coloured	5.8	White and light gray	Light type
Mango	Sampaje	3.6	White puffy colony, with orange slime in a concentric manner.	5.6	Cream, gray with orange slime, reverse is cream and light gray	Light type
Mango	Appangala	4.3	White mycelium	7.4	White and gray	Light type
Strawberry	Appangala	2.8	White and gray	5.9	White and black colony. Backside is black with a narrow cream-coloured border.	Dark type

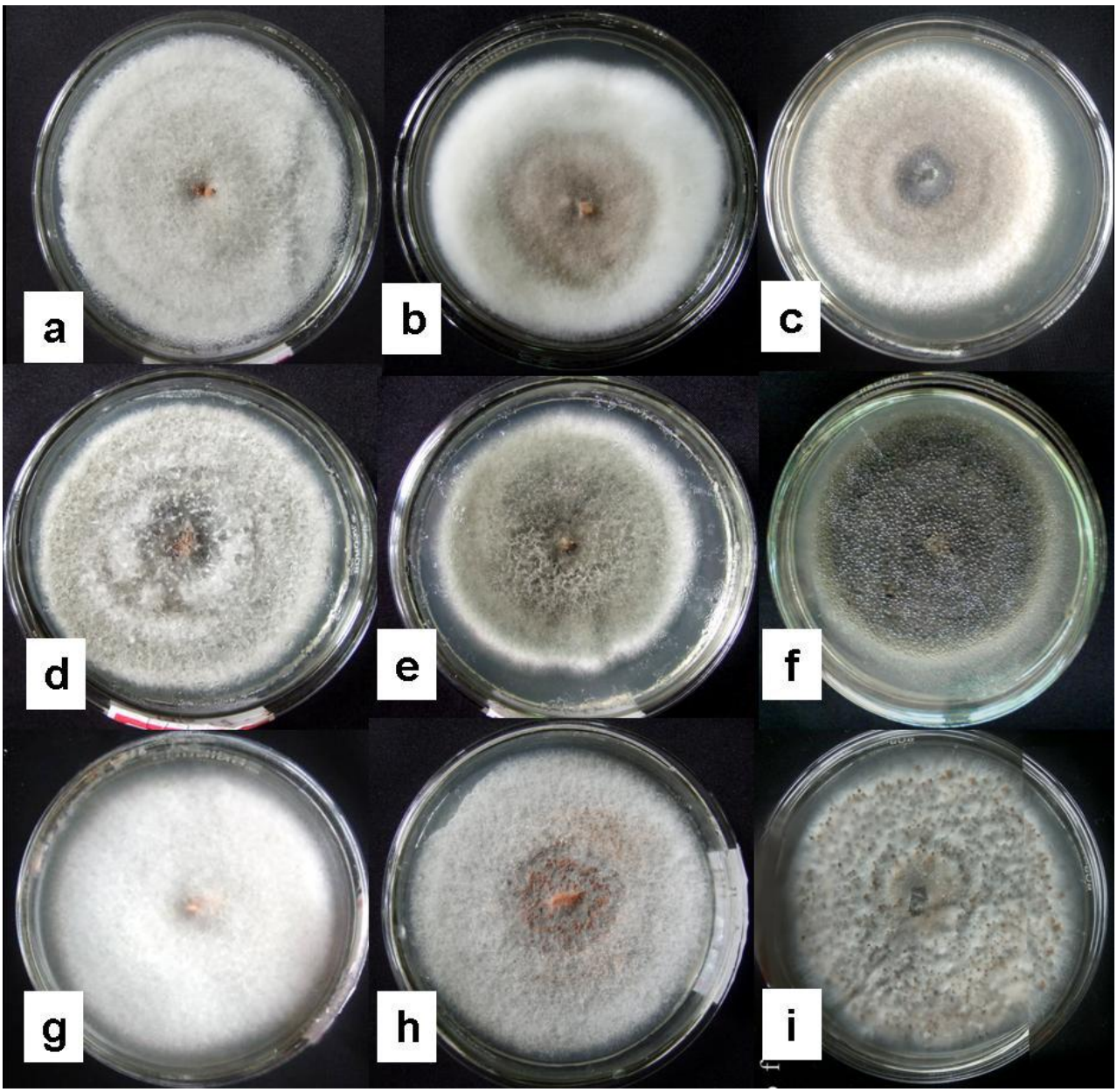

Plate – 4: a –Turmeric (Appangala), b – Cashew (Sampaje), c – Brinjal (Appangala), d – Chilli (Appangala), e – Cinnamon (Appangala), f – Cocoa (Sampaje), g – Cucumber (Appangala), h – Sapota (Appangala), i – Mango (Appangala)

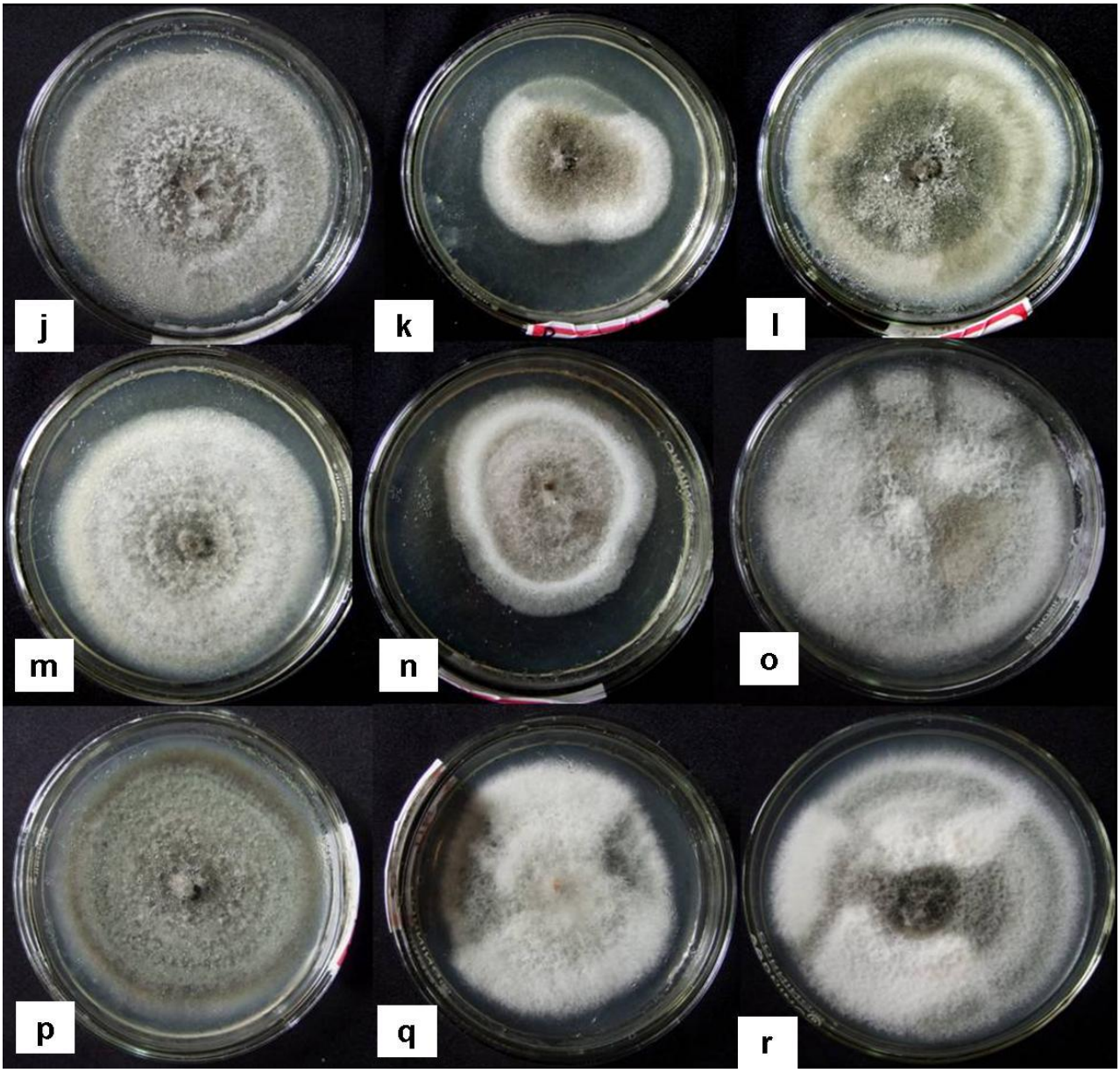

Plate – 4: j –Papaya (Appangala), k – Pomegranate(Appangala), l - Strawberry (Appangala), m – Tomato (Appangala), n – Basella (Appangala), o – Bell pepper (Appangala), p – Betelvine (Appangala), q – Arecanut (Appangala), r – Anthurium (Appangala)

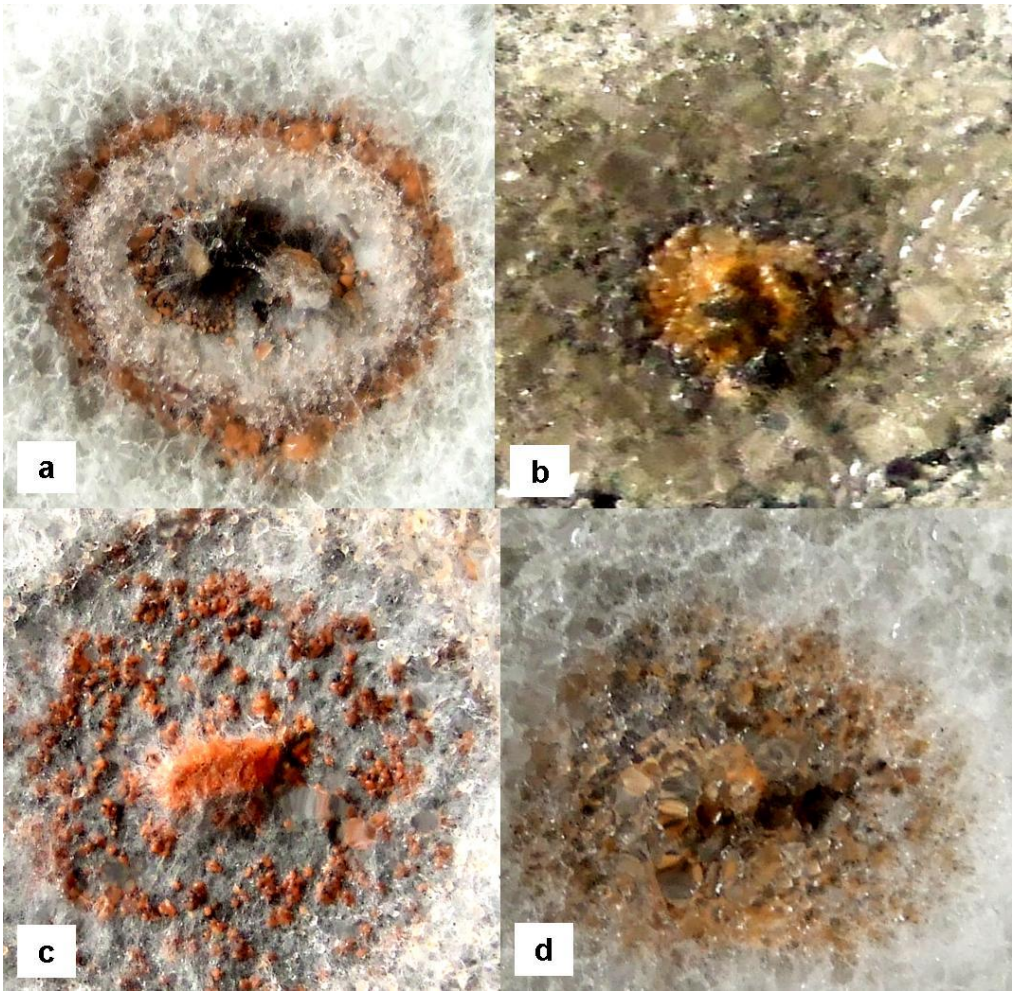

Plate – 5: a – Black pepper (Avemaria), b – Black pepper (Nelliahudikeri), c- Sapota (Appangala), d – Cardamom(Hakathur)

Table: 6 Conidial characteristics of black pepper isolates of *C. gloeosporioides*			
Place of collection	**Length of the conidia (μm)**	**Width of the conidia (μm)**	**Shape**
Nelliahudikeri	12.18	4.12	Cylindrical with obtuse ends
Magalu	17.81	4.12	Cylindrical with slightly tapered base and obtuse apex
Avemaria, Heggadde	14.75	3.60	Cylindrical
Appangala	17.60	3.75	Cylindrical with obtuse ends
Hakathur	14.60	4.50	Cylindrical with slightly tapered base and obtuse apex
Cooverkolly	10.31	3.75	Cylindrical with slightly tapered base and obtuse apex
Kodlipet	10.68	3.00	Cylindrical with obtuse ends
Halery	14.12	3.75	Cylindrical with a slightly tapered base and obtuse apex
Byakaravally	17.81	3.93	Cylindrical with Obtuse ends
Sakleshpur	17.43	3.75	Cylindrical with obtuse ends
Thithimathi	15.75	4.13	Cylindrical with obtuse ends
Pollibetta	15.37	4.00	Cylindrical with obtuse ends
Chettalli	15.00	3.75	Cylindrical with slightly tapered base and obtuse apex

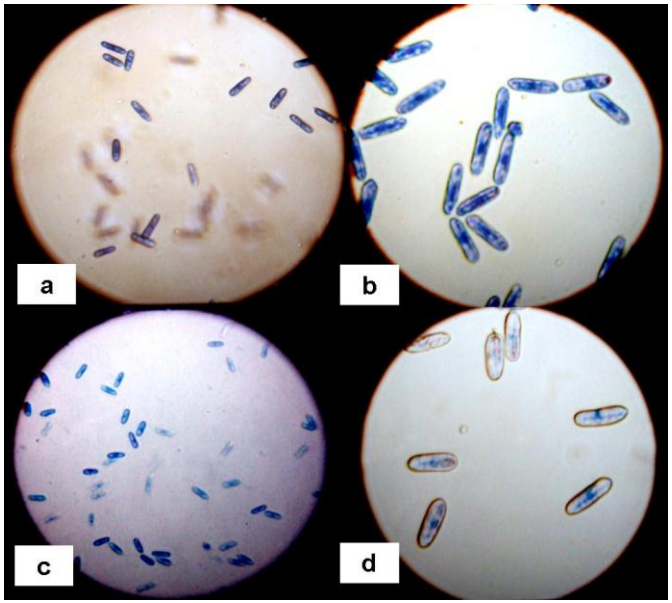

Plate – 6: a –Avemaria, b – Hakathur, c - Kodlipet, d – Nelliahudikeri

Table: 7 Conidial characteristics of *Colletotrichum* isolates from cardamom and turmeric				
Host	**Place of collection**	**Length of conidia (µm)**	**Width of conidia (µm)**	**Shape**
Cardamom	Appangala	16.12	4.00	Cylindrical with obtuse ends
Cardamom	Sakleshpur	15.75	3.75	Cylindrical with the obtuse ends with narrowing the center (Pea nut pod shape)
Cardamom	Pollibetta	15.18	4.12	Cylindrical with obtuse ends
Cardamom	Siddapur	12.75	4.38	Ovoid
Cardamom	Chettalli	15.75	4.28	Cylindrical with obtuse ends
Cardamom	Nelliahudikeri	12.56	4.50	Cylindrical with a slightly tapered base and obtuse apex
Cardamom	Hakathur	16.13	3.75	Cylindrical
Cardamom	Byakaravally	17.25	3.75	Ovoid
Cardamom	Avemaria	15.75	4.06	Cylindrical with obtuse ends
Cardamom	Thithimathi	15.00	3.30	Cylindrical with a slightly tapered base and obtuse apex
Turmeric	Appangala	19.50	3.37	Falcate shaped

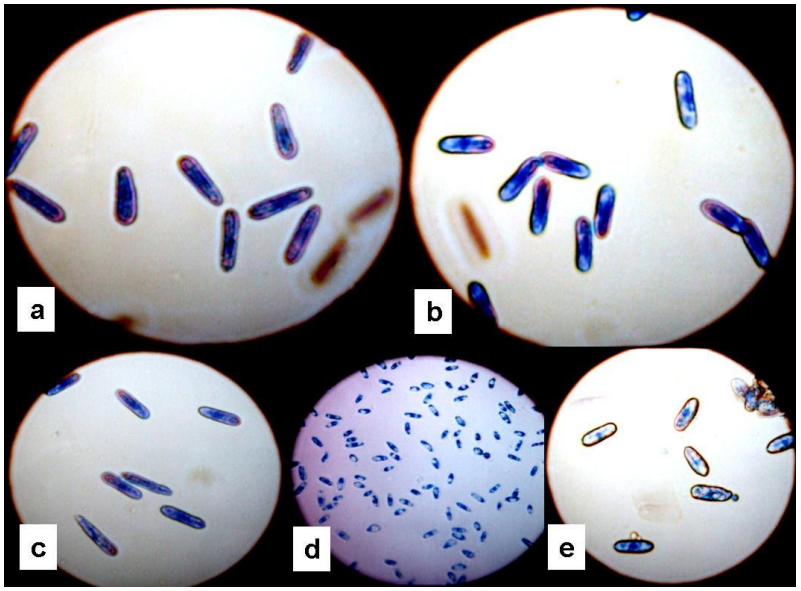

Plate – 7: a –Nelliahudikeri, b –Sakleshpur, c - Pollibetta, d –Byakaravally, e - Siddapur

Table: 8 Conidial characteristics of *C. gloeosporioides* and *C. capsici* isolates from other hosts of cardamom ecosystem

Hosts	Place of collection	Length of conidia (µm)	Width of conidia (µm)	Shape
Pomegranate	Appangala	15.00	4.29	Ovoid
Pomegranate	Kandanakolly	14.00	4.01	Cylindrical with the obtuse ends with narrowing the center (Pea nut pod shape)
Bell pepper	Appangala	12.00	3.70	Cylindrical with obtuse ends
Basella	Sakleshpur	15.00	4.00	Cylindrical with obtuse ends
Basella	Appangala	13.00	4.20	Cylindrical with obtuse ends
Brinjal	Appangala	14.00	3.75	Cylindrical with obtuse ends
Papaya	Sakleshpur	15.38	3.75	Cylindrical with the obtuse ends with narrowing the center (Peanut pod shape)
Papaya	Appangala	14.81	4.37	Ovoid
Bird's eye chilli	Appangala	12.38	3.75	Ovoid
Cashew	Sampaje	15.18	4.22	Cylindrical with obtuse ends
Betel vine	Appangala	16.12	4.50	Ovoid
Areca nut	Appangala	13.3	3.40	Cylindrical with obtuse ends
Sapota	Appangala	14.00	4.13	Cylindrical with obtuse ends
Cinnamon	Appangala	16.12	3.75	Cylindrical with a slightly tapered base and obtuse apex
Cocoa	Sampaje	14.81	4.13	Cylindrical with obtuse ends
Cocoa	Appangala	15.38	3.87	Cylindrical with obtuse ends
Tomato	Appangala	16.87	4.31	Ovoid
Caladium	Appangala	15.00	4.13	Cylindrical with obtuse ends
Cucumber	Appangala	12.56	3.94	Cylindrical with obtuse ends
Chilli	Appangala	21.56	3.75	Falcate shaped
Chilli	Sampaje	19.86	3.75	Falcate Shaped
Mango	Appangala	10.68	4.13	Cylindrical with a slightly tapered base and obtuse apex
Mango	Sampaje	14.00	3.50	Ovoid
Strawberry	Appangala	15.00	3.75	Cylindrical with obtuse ends

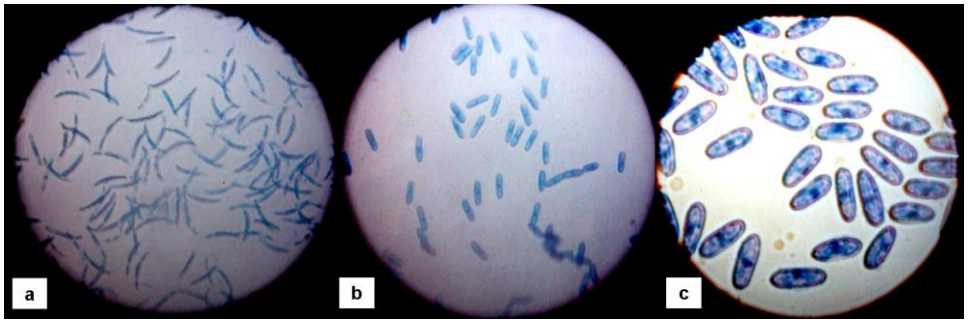

Plate – 8: a – Chilli (Appanagala), b – Cocoa (Appangala) , c – Pomegranate (Appangala)

Table: 9 Appressorial characteristics of black pepper isolates of *C. gloeosporioides*		
Host	**Place of collection**	**Appressorium characteristics**
Black pepper	Nelliahudikeri	Multi lobed (2-3 lobes)
Black pepper	Magalu	Unlobed
Black pepper	Avemaria	Multi lobed (3-4 lobes)
Black pepper	Appangala	Multi lobed (2-3 lobes)
Black pepper	Hakathur	Multi lobed (3-4 lobes)
Black pepper	Cooverkolly	Multi lobed (3-4 lobes)
Black pepper	Kodlipet	Multi lobed (3-4 lobes)
Black pepper	Halery	Multi lobed (2-3 lobes)
Black pepper	Byakaravally	Multi lobed (3-4 lobes)
Black pepper	Sakleshpur	Slightly lobed
Black pepper	Thithimathi	Multi lobed (2-3 lobes)
Black pepper	Pollibetta	Slightly lobed
Black pepper	Chettalli	Slightly lobed

Table: 10 Appressorial characteristics of *Colletotrichum* isolates from cardamom (*C. gloeosporioides*) and turmeric (*C. capsici*)		
Hosts	**Place of collection**	**Appressorial Characteristics**
Cardamom	Appangala	Multi lobed (3-4 lobes)
Cardamom	Sakleshpur	Unlobed
Cardamom	Pollibetta	Multilobed (2- 3 lobes)
Cardamom	Siddapur	Multi lobed (3-4 lobes)
Cardamom	Chettalli	Multilobed (2-3 lobes)
Cardamom	Nelliahudikeri	Multi lobed (3-4 lobes)
Cardamom	Hakathur	Multi lobed (3-4 lobes)
Cardamom	Byakaravally	Unlobed
Cardamom	Avemaria	Multi lobed (3-4 lobes)
Cardamom	Thithimathi	Unlobed
Turmeric	Appangala	Unlobed

Table: 11 Appressorial characteristics of *C. gloeosporioides* and *C. capsici* isolates from other hosts of cardamom ecosystem		
Hosts	**Place of collection**	**Appressorial characteristics**
Pomegranate	Appangala	Multi lobed (2-3 lobes)
Pomegranate	Kandanakolly	Multi lobed (3-4 lobes)
Bell pepper	Appangala	Unlobed
Basella	Sakleshpur	Unlobed
Basella	Appangala	Multi lobed (3-4 lobes)
Brinjal	Appangala	Multi lobed (2-3 lobes)
Papaya	Sakleshpur	Unlobed
Papaya	Appangala	Unlobed
Bird eye chilli	Appangala	Multi lobed (3-5lobes)
Cashew	Sampaje	Unlobed
Betel vine	Appangala	Multi lobed (4-8 lobes)
Areca nut	Appangala	Unlobed
Sapota	Appangala	Slightly lobbed
Cinnamon	Appangala	Multi lobed (2-3 lobes)
Cocoa	Sampaje	Multi lobed (2-3 lobes)
Cocoa	Appangala	Unlobed
Tomato	Appangala	Slightly lobed
Anthurium	Appangala	Unlobed
Cucumber	Appangala	Slightly lobbed
Chilli	Appangala	Multi lobed (2-3 lobes), Unlobed
Chilli	Sampaje	Multi lobed (2-3 lobes)
Mango	Appangala	Slightly lobbed
Mango	Sampaje	Unlobed
Strawberry	Appangala	Multi lobed (3-4 lobes)

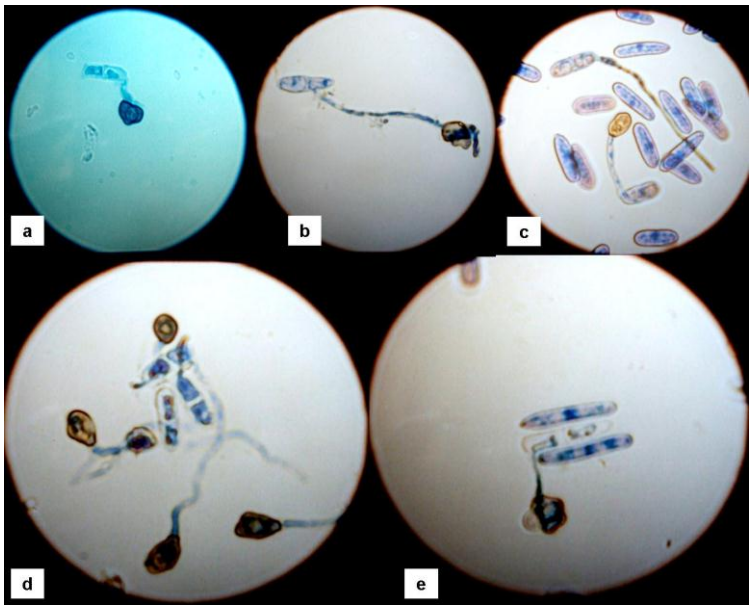

Plate – 9: a – Appangala, b – Thithimathi, c – Magalu, d – Sakleshpur, e - Avemaria

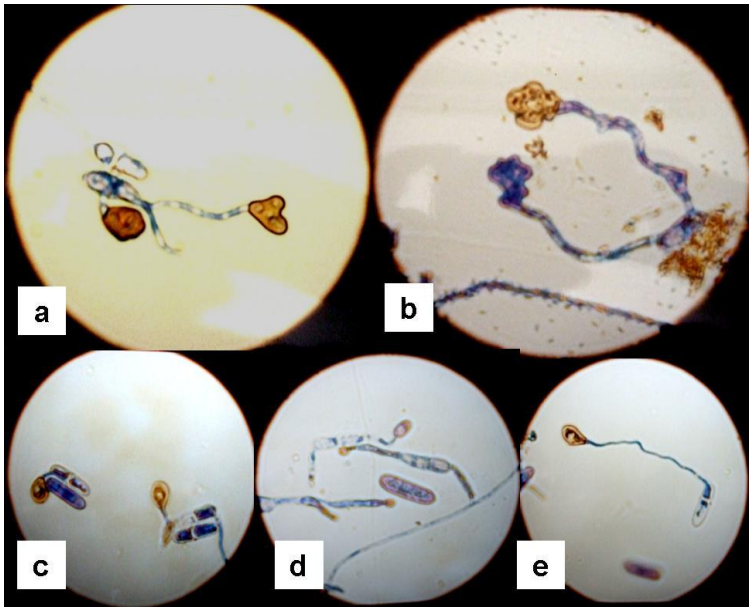

Plate – 10: a – Pollibetta, b –Siddapur, c – Byakaravally, d – Sakleshpur, e - Thithimathi

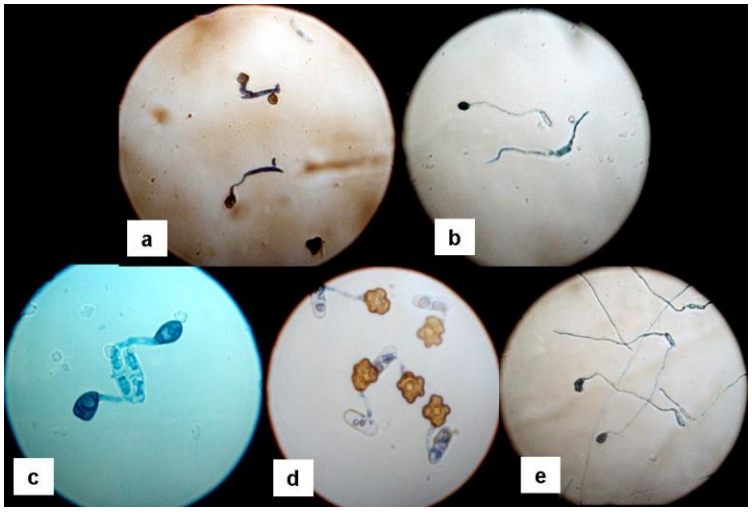

Plate – 11: a – Chilli (Appangala), b – Cucumber (Appangala), c – Basella (Appangala), d – Betelvine (Appangala) e – Sapota (Appangala)

(II) Pathogenicity and identification of resistant sources

The samples exhibiting characteristic anthracnose/ leaf blight symptoms were collected from different geographical locations representing different altitude and rainfall regions of Karnataka, Tamil Nadu and Kerala. The samples such as infected leaves and spikes were used for the isolation of the pathogen. Five isolates each from black pepper (Byakaravally, Cooverkolly, Appangala, Anamalai and Idukki) and cardamom (Byakaravally, Pollibetta, Appangala, Anamalai and Idukki) and one isolate from turmeric (Appangala) were collected during the year 2008 – 09. These isolates were used for pathogenicity studies.

Pathogenicity test

Three black pepper (Panniyur 1, Chomala and Panniyur 5) and cardamom (Njallani Green Gold, IISR Kodagu Suvasini and IISR Vijetha) cultivars/ varieties and a local cultivar of turmeric (Bhavanisagar Local) were used to study the pathogenicity of the isolates. The cultivars were selected as they were widely adopted for large scale cultivation and in most of the cultivated locations they were either grown as principal or component crop in black pepper – cardamom cropping system. For pathogenicity test, conidial suspension from these isolates was prepared in 2% sucrose solution. The conidial suspension was then swabbed using cotton on each of the cultivars/ varieties. Care was taken to swab the entire leaf surface with the conidial suspension. Cotton pieces dipped in conidial suspension were also placed on younger and older leaves and the plants were covered with polyethylene bags to maintain adequate relative humidity to facilitate conidial germination and subsequent infection process. The polyethylene bags were removed after 48 hours of inoculation and the plants were routinely observed for the development of symptoms. In order to prove Koch's postulates, the pathogen was re-isolated from the infected portion and compared with the original isolate to confirm the identity.

The results indicated that, the *Colletotrichum* isolates infecting black pepper, cardamom and turmeric have the potential to infect the varieties/ cultivars of crops other than their natural host (Table 12 and Plate 12).

Compatibility among *Colletotrichum* isolates

Crosses were made in all the possible combinations among the black pepper (5) and cardamom (5) and turmeric (1) isolates. The plates were incubated for one month at 20^0C in the

dark. The plates were periodically observed for merging of both the colonies, formation of barrage zones and perithecia at the point of contact between two isolates. (Camargo *et al*., 2007). The isolates were paired in all possible combinations on PDA medium. Mycelial reactions were recorded as incompatible when an apparent line of demarcation, a barrage zone or a Hyphal free zone was observed between the confronting paired isolates. Pairings were scored as compatible when the two isolates merged to form one colony, with no distinct interaction zone. Each pairings were replicated thrice and observed for 30 days. In order to identify the compatible groups among the isolates, selfing and crossing of predominant *Colletotrichum* isolates infecting black pepper (Appangala, Idukki, Anamalai, Byakaravally and Cooverkolly), cardamom (Appangala, Idukki, Anamalai, Byakaravally and Pollibetta) and turmeric (Appangala) in all possible combination was made. The crosses either resulted in the formation of a barrage at the point of contact between two colonies (barrage reaction) or merging of both the colonies (merging reaction) as presented in Table 13 and Plate 13. Hyphae from the overlapping zones (Plate 14) were collected using a cork borer and recombinants were generated (Plate 15).

Table: 12 Pathogenicity and cross inoculation of cardamom, black pepper and turmeric isolates of *Colletotrichum*												
Isolates →		**Black Pepper**					**Cardamom**					**Turmeric**
Cultivars/ Var. ↓		**Bya**	**Coov**	**Ana**	**APG**	**Idk**	**Bya**	**Polli**	**Ana**	**APG**	**Idk**	**APG**
Black Pepper	Panniyur-5	+	+	+	+	+	+	+	+	+	+	+
	Chomala	+	+	+	+	+	+	+	+	+	+	+
	Panniyur-1	+	+	+	+	+	-	-	+	+	+	-
Cardamom	Njallani Green Gold	-	-	-	-	+	+	+	+	+	+	+
	IISR Vijetha	+	-	+	+	-	+	+	+	+	+	+
	IISR Kodagu Suvasini	+	+	-	-	+	+	+	+	+	+	-
Turmeric	Bhavanisagar Local	-	+	-	+	-	-	-	-	-	-	+
Bya = Byakaravally, Coov = Cooverkolly, Ana = Anamalai, APG = Appangala, Idk = Idukki, Polli = Pollibetta												

Table: 13 Selfing and crossing between cardamom, black pepper and turmeric isolates of *Colletotrichum*												
Isolates		**Black Pepper**					**Cardamom**					**Turmeric**
		Bya	**Coov**	**Ana**	**APG**	**Idk**	**Bya**	**Polli**	**Ana**	**APG**	**Idk**	**APG**
Black Pepper	**Bya**	- (B)	- (M)	- (B)	- (B)	- (M)	- (B)	- (B)	- (B)	- (B)	- (B)	- (B)
	Coov	- (M)	- (M)	- (M)	- (M)	- (M)	- (B)	- (M)	- (B)	- (B)	- (M)	- (B)
	Ana	- (B)	- (M)	- (M)	- (B)	- (B)	- (B)	- (M)	- (M)	- (M)	- (M)	- (M)
	APG	- (B)	- (M)	- (B)	- (B)	- (M)	- (M)	- (M)	- (M)	- (B)	- (M)	- (B)
	Idk	- (M)	- (M)	- (B)	- (M)	- (M)	- (M)	- (M)	- (M)	- (B)	- (M)	- (B)
Cardamom	**Bya**	- (B)	- (B)	- (B)	- (M)	- (M)	- (B)	- (M)	- (B)	- (M)	- (B)	- (B)
	Polli	- (B)	- (M)	- (M)	- (M)	- (M)	- (M)	- (M)	- (M)	- (M)	- (M)	- (M)
	Ana	- (B)	- (B)	- (M)	- (M)	- (M)	- (B)	- (M)	- (B)	- (M)	- (M)	- (M)
	APG	- (B)	- (B)	- (M)	- (B)	- (B)	- (M)	- (M)	- (M)	- (M)	- (M)	- (B)
	Idk	- (B)	- (M)	- (M)	- (M)	- (M)	- (B)	- (M)	- (M)	- (M)	- (M)	- (B)
Turmeric	**APG**	- (B)	- (B)	- (M)	- (B)	- (B)	- (B)	- (M)	- (M)	- (B)	- (B)	- (M)
+ = perithecia present, - = perithecia absent, B = barrage reaction, M = merging reaction												

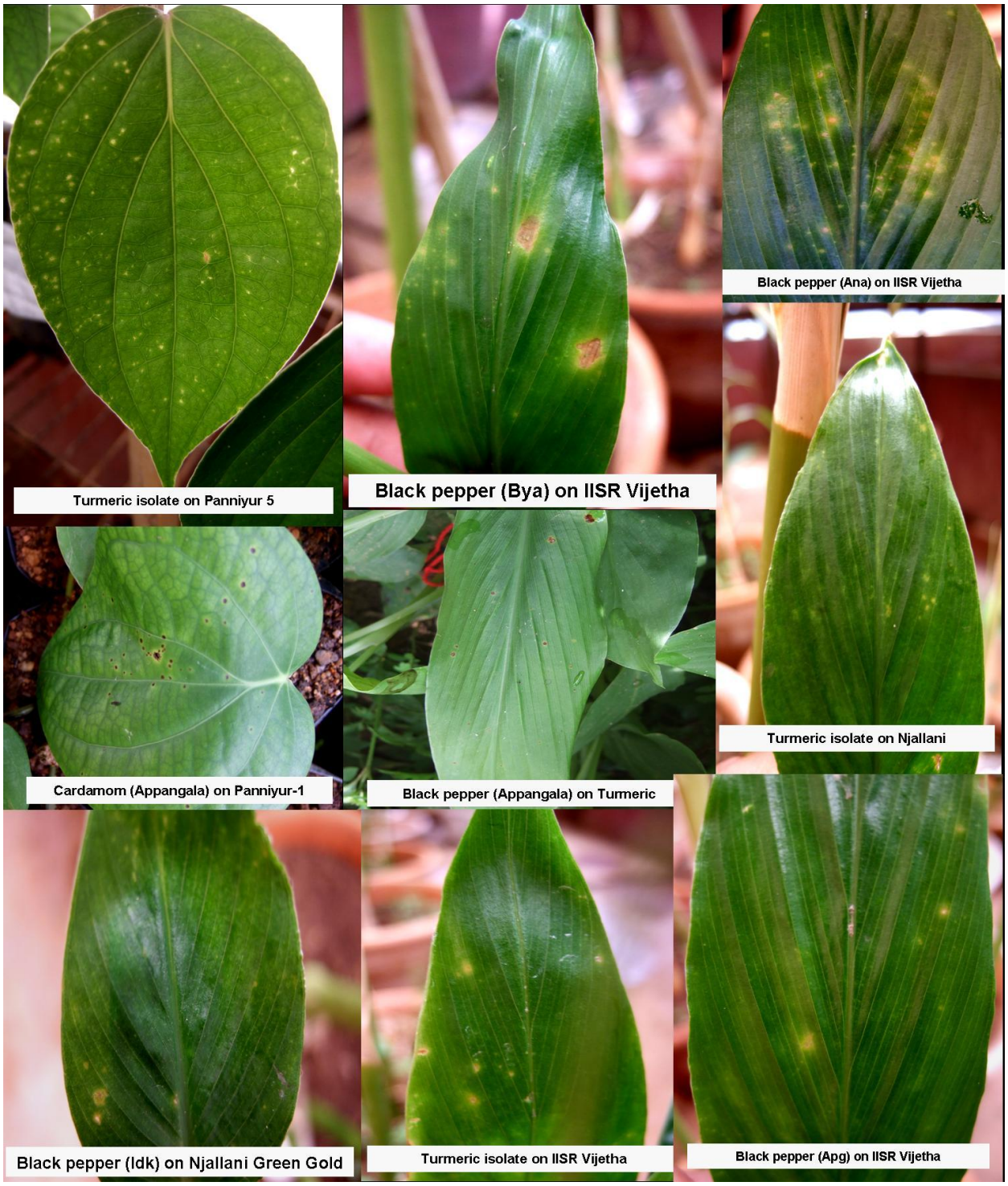

Plate – 12: Pathogenicity and cross infectivity of *Colletotrichum* isolates on black pepper, cardamom and turmeric

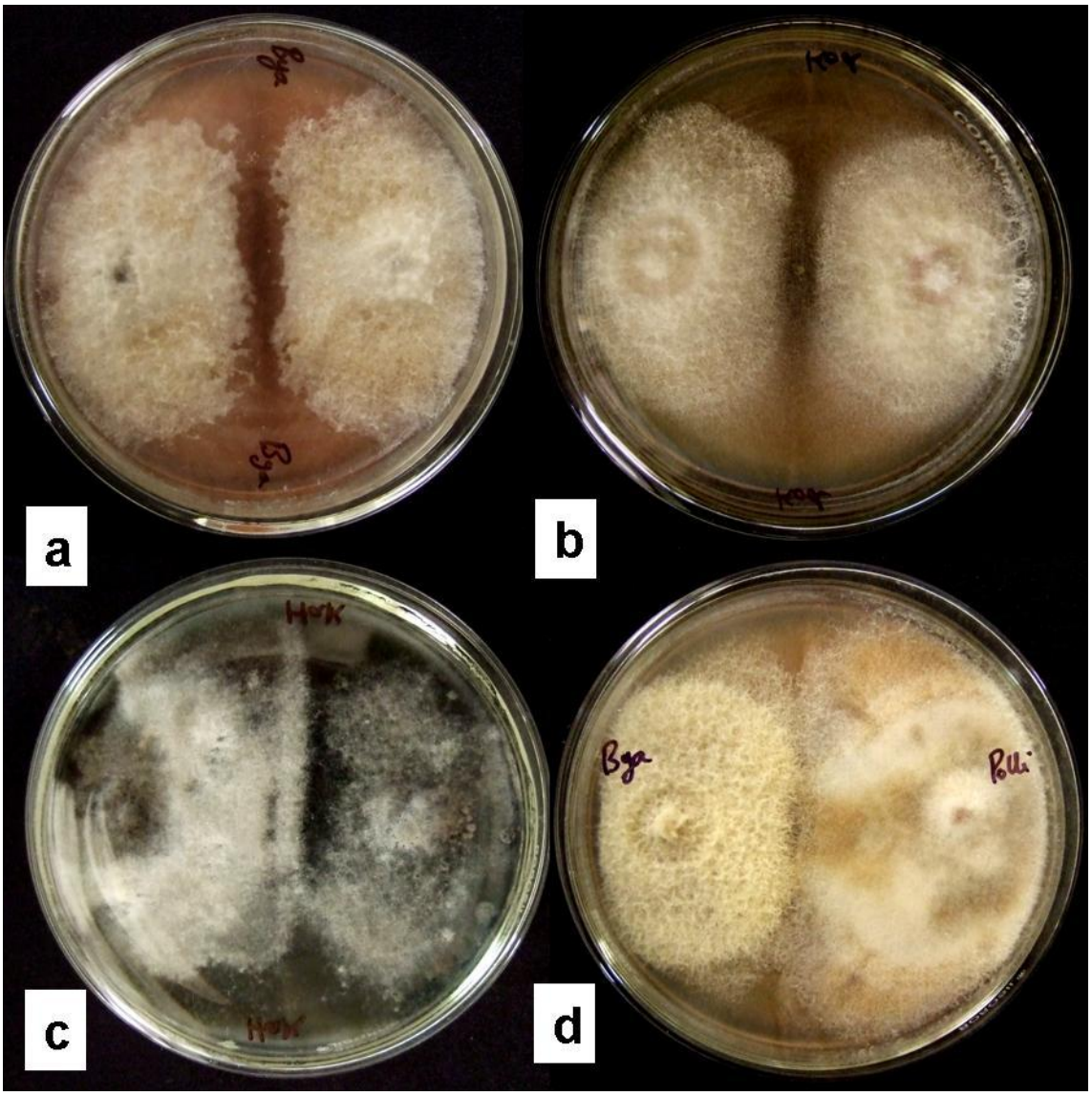

Plate – 13: Barrage reaction - a: Black pepper b: cardamom
Merging reaction - c: Black pepper d: cardamom

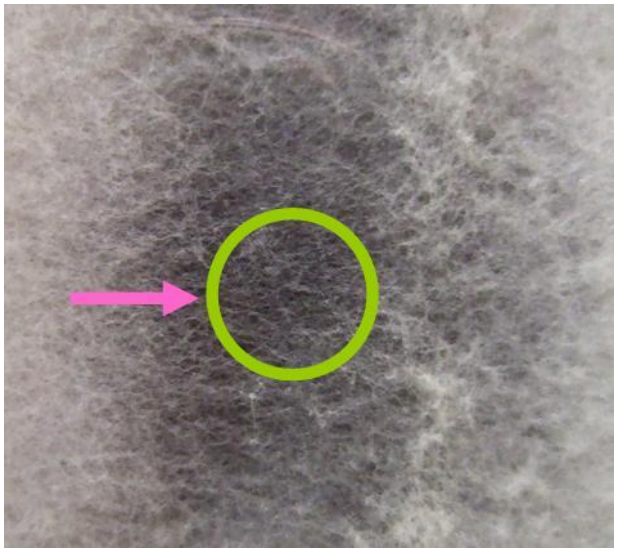

Plate – 14: Overlapping zone

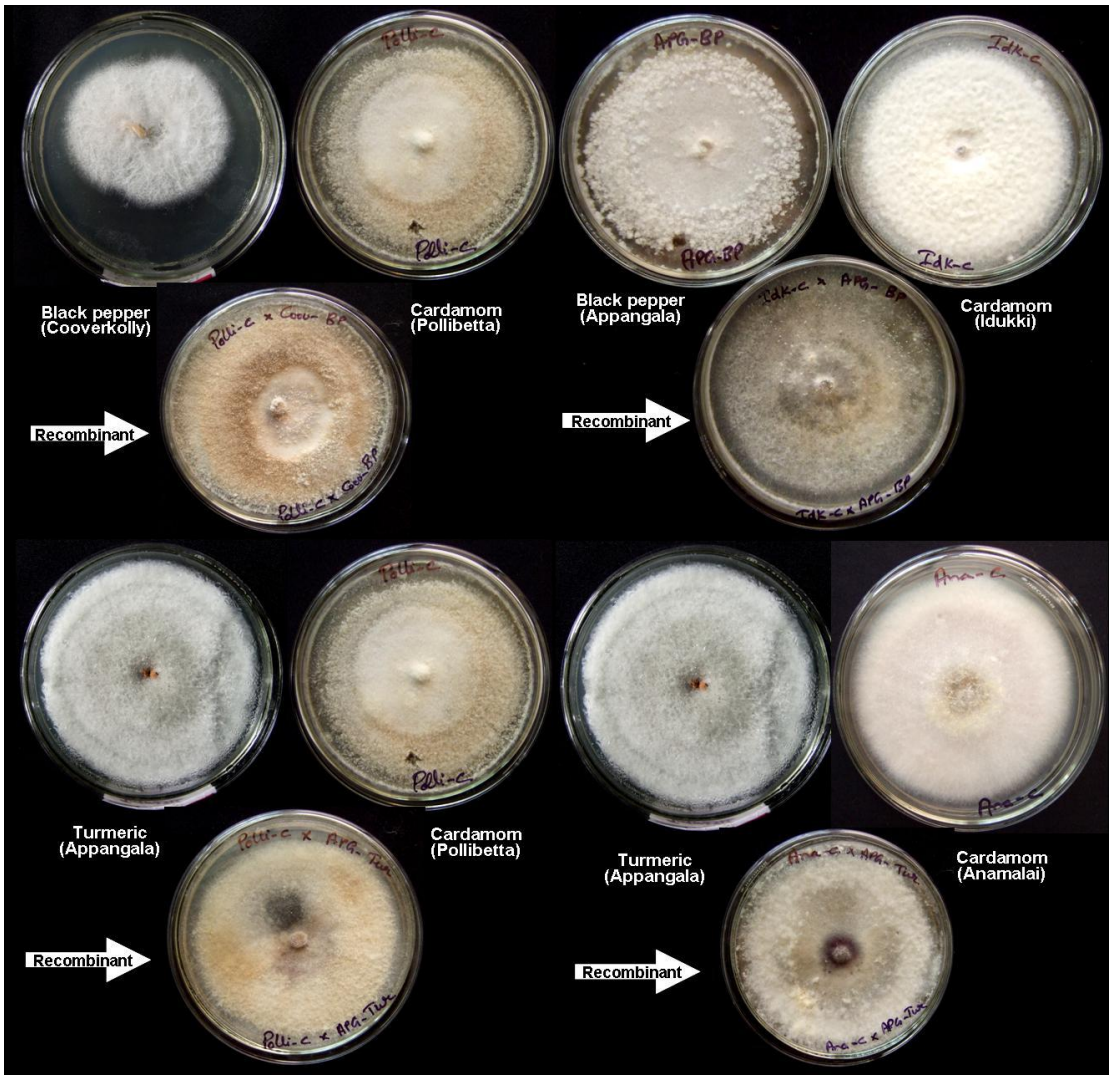

Plate – 15: Recombinants generated from black pepper, cardamom and turmeric isolates of *Colletotrichum*

(III) Survival of the pathogen and disease spread

The method followed by Anoop Sankar and Santha Kumari (2002) was adopted in the present study. Leaves of cardamom, black pepper and turmeric exhibiting the characteristic anthracnose (in case of black pepper) and leaf blight (in case of cardamom and turmeric) were washed in running water and then cut into bits of size 8- 10 cm. The bits were then packed in small bags made of nylon net for easy recovery of the samples from the soil. Earthern pots were filled with unsterilized soil collected from the rhizosphere of cardamom, black pepper and turmeric. The nylon bags containing the infected samples were either placed on the soil surface or buried at a depth of 30 cm from the soil surface. Three replications were maintained for each treatment (day of recovery).

The infected materials were recovered from each pot from 15 days of burial at an interval of 15 days for a period of 120 days. The recovered leaf materials after making into fragments and surface sterilization, were plated on PDA medium supplemented with streptomycin sulphate (10 mg per liter) to avoid bacterial contamination. The plates were incubated at 28± 50C for 8-10 days at room temperature. Survival of the pathogen was ascertained by the appearance and further development of viable fungal colonies.

The survival of *Colletotrichum gloeosporioides* infecting black pepper and cardamom was studied by conducting pot experiments. Leaves exhibiting typical leaf blight/ anthracnose symptoms, were used for the study. The leaves were placed on the soil surface (0 cm) and buried at a depth of 30 cm. The results indicated that, *C. gloeosporioides* infecting black pepper survived for 90 (24.15% recovery) and 105 (20.51% recovery) days at 30 and 0 cm respectively. *C. gloeosporioides* infecting cardamom survived for 90 (20.76% recovery) and 105 (8.15% recovery) days at 30 and 0 cm, respectively. In comparison with *Colletotrichum* infecting black pepper and cardamom, survivability of *C. capsici* infecting turmeric was found to be low both at 0 cm (60 days) and 30 cm (45 days) with a recovery percentage of 12.77 and 7.22 %, respectively (Table 14).

Table: 14 Survival of *Colletotrichum* spp. infecting black pepper, cardamom and turmeric in soil

Crop	Position in relation to soil surface (cm)	Percentage recovery after different time intervals (days)							
		15	**30**	**45**	**60**	**75**	**90**	**105**	**120**
Black pepper	0	92.83	83.76	72.92	66.42	55.54	50.40	20.51	0.00
	30	91.93	80.33	64.98	54.21	40.75	24.15	0.00	
Cardamom	0	88.93	80.83	52.77	44.29	41.19	31.69	8.15	0.00
	30	85.27	77.14	53.81	41.64	36.78	20.76	0.00	
Turmeric	0	84.44	62.23	37.22	12.77	0.00			
	30	75.55	31.18	7.22	0.00				

(IV) Sensitivity of *Colletotrichum* spp. to different biocontrol agents

Two species of *Trichoderma* viz., *T. harzianum* and *T. hamatum* maintained at Indian Institute of Spices Research, Cardamom Research Centre, Appangala, Karnataka and two bacterial isolates viz., IISR 6 and IISR 853 obtained from Indian Institute of Spices Research, Calicut were used for the *in vitro* bioassay experiments. The study was carried out by following the procedures described by Barakat *et al*., (2007), Dubey and Patel, (2007) and Bautista *et al*. (2007) were followed.

Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to *T. harzianum*

T. harzianum gave a higher percentage of inhibition for Nelliahudikeri black pepper (73.08%) and Byakaravally black pepper (73.81%) and the statistical analysis classified these in the group 'a' which had the best treatment (Table 15). Statistical analysis made nine groups in descending order of performance from group 'a' to group 'i'. *C. capsici* from turmeric showed less sensitivity towards *T. harzianum* (52.72%). *C. gloeosporioides* from cardamom Byakaravally is less sensitive (Plates 16 and 17).

Sensitivity of *Colletotrichum* isolates from other hosts of cardamom ecosystem to *T. harzianum*

The percentage inhibition by *T. harzianum* was high on the *C. gloeosporioides* from Appangala (75.90%). There was only sparse growth of *T. harzianum* against *C. gloeosporioides* from Brinjal until 5th day (Table 16). *T. harzianum* could not inhibit the growth of Brinjal isolate (Plate 18). Both test and antagonist grew independently on the media. But after fifteen days the growth of antagonist on the test organism was observed. Statistical analysis gave eight groups. *T. harzianum* showed poor treatment against C. *gloeosporioides* from bell pepper, Sapota, Strawberry isolates from Appangala.

Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to *T. hamatum*

The sensitivity to *T. hamatum* was high in *C. gloeosporioides* from black pepper Nelliahudikeri (85.84%). *C. gloeosporioides* from Cardamom Byakaravally (64.37%) and cardamom Avemaria (65.45%) had the poor treatment results. Statistical analysis gave nine groups of treatment results (Table 17). The poorest treatment was seen in *C. capsici* from turmeric (Plate 19 and 20).

Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to IISR6

Zone of inhibition produced by IISR6 was high in *C. gloeosporioides* from Nelliahudikeri isolate of black pepper (2.2 cm) (Table 18). There was no inhibition to *C. gloeosporioides* from Hakathur in two replicate and in other one replicate the zone of inhibition was only 0.1 cm. Against *C. gloeosporioides* from cardamom (Byakaravally) there was no inhibition in one replicate and the zone of inhibition in other two replicate was only 0.1 cm. As per the statistical analysis results the poorest treatment results obtained for *C. gloeosporioides* from cardamom Hakathur and Byakaravally and also for the *C. capsici* obtained from turmeric (Plate 21).

Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to IISR 853

IISR 853 produced highest zone of inhibition in *C. gloeosporioides* against black pepper Nelliahudikeri (Plate 22). It could not produce zone of inhibition in two replications of *C. gloeosporioides* from cardamom Byakaravally. The inhibition zones obtained for *C. gloeosporioides* from cardamom Halery (0.56 cm) and Hakathur (0.46) were also less .*C. capsici* from turmeric also showed less sensitivity to IISR 853. Statistical analysis revealed that the poorest performance was on *C. gloeosporioides* from Byakaravally (Table 19).

Table: 15 Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to *T. harzianum*

Hosts	Place of collection	Percentage inhibition
Black pepper	Nelliahudikeri	* 73.02 [a]
Black pepper	Magalu	70.02 [b]
Black pepper	Avemaria	66.55 [e]
Black pepper	Appangala	56.12 [d]
Black pepper	Hakathur	63.10 [c]
Black pepper	Cooverkolly	50.99 [b]
Black pepper	Kodlipet	53.00 [c]
Black pepper	Halery	62.72 [b]
Black pepper	Byakaravally	73.81 [a]
Cardamom	Halery	48.24 [e]
Cardamom	Hakathur	61.54 [f]
Cardamom	Byakaravally	42.36 [f]
Cardamom	Avemaria	65.82 [e]
Turmeric	Appangala	52.72 [f]

SEd =1.3202
LSD at 1% = 3.65
CV=2.69%
*** Average of three replications**
****Values with at least one letter in common are not statistically significant**

Table: 16 Sensitivity of *Colletotrichum* isolates from other hosts of cardamom ecosystem to *T. harzianum*

Hosts	Place of collection	Percentage inhibition
Anthurium	Appangala	* 75.90 [a]
Sapota	Appangala	48.80 [g]
Strawberry	Appangala	48.75 [g]
Papaya	Appangala	58.33 [e]
Arecanut	Appangala	64.28 [d]
Pomegranate	Kandanakolly	70.58 [c]
Cocoa	Sampaje	73.30 [b]
Bell pepper	Appangala	48.20 [g]
Mango	Appangala	66.22 [d]
Betel vine	Appangala	56.25 [f]
Brinjal	Appangala	0.05 [h]

SEd = 0.985
LSD at 1% = 2.80
CV = 2.18
*** Average of three replications**
****Values with at least one letter in common are not statistically significant**

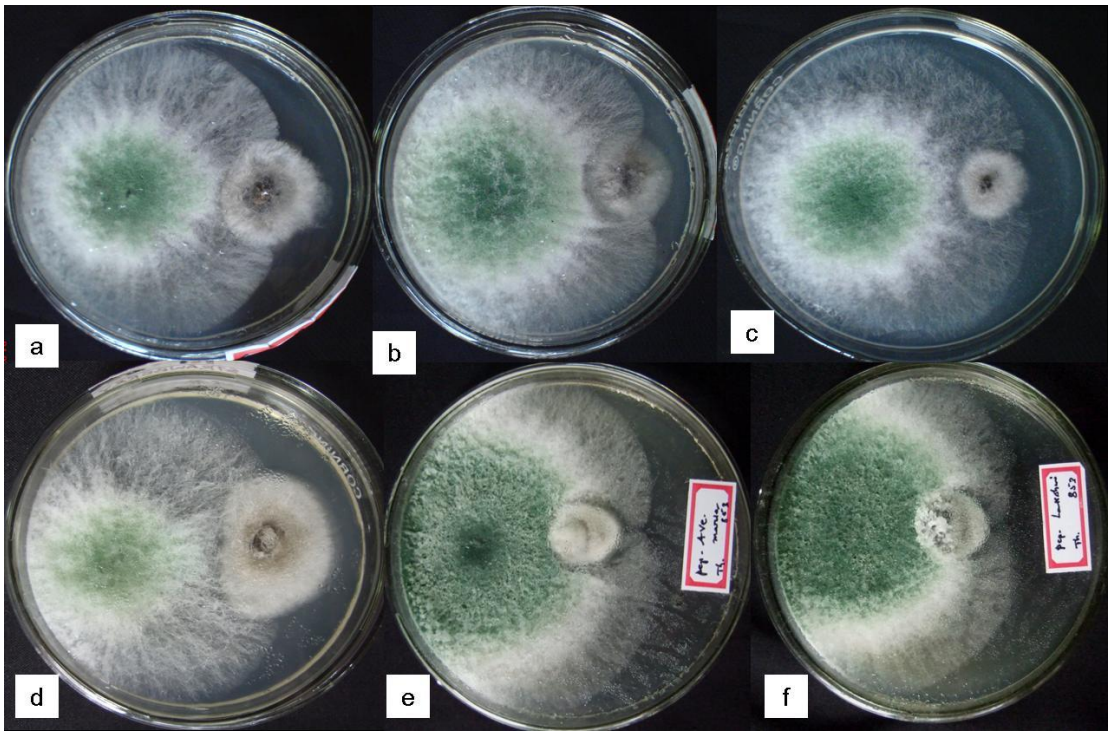

Plate – 16: Evaluation of *T. harzianum* against black pepper isolates of *Colletotrichum* (a) Cooverkolly (b) Hakathur (c) Nelliahudikeri (d) Appangala (e) Avemaria (f) Halery

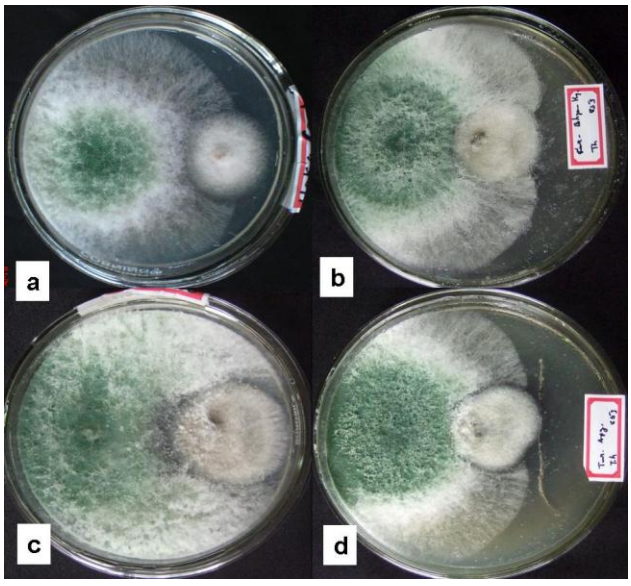

Plate – 17: Evaluation of *T. harzianum* against cardamom and turmeric isolates of *Colletotrichum* (a) Byakaravally (b) Hakathur (c) Halery (d) Turmeric - Appangala

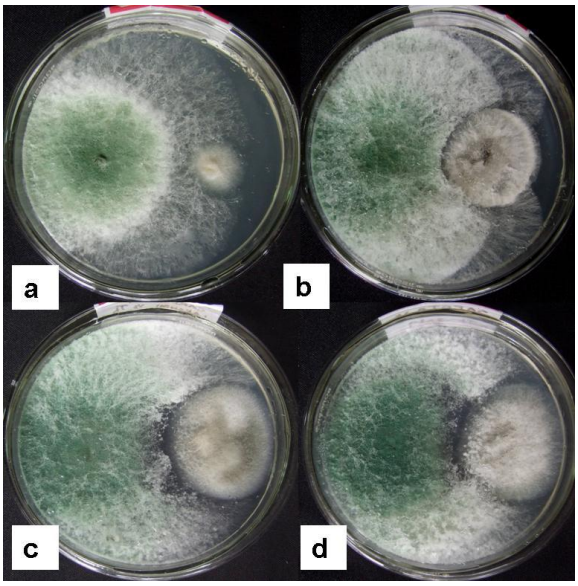

Plate – 18: Evaluation of *T. harzianum* against isolates of *Colletotrichum* from other crops (a) Anthurium (b) Papaya (c) Sapota (d) Bell pepper

Table : 17 Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric *T. hamatum*

Hosts	Place of collection	Percentage inhibition
Black pepper	Nelliahudikeri	* 85.84 [a]
Black pepper	Magalu	71.00 [e f]
Black pepper	Avemaria	77.66 [b]
Black pepper	Appangala	69.57 [f]
Black pepper	Hakathur	73.09 [c d]
Black pepper	Cooverkolly	67.18 [g h]
Black pepper	Kodlipet	74.17 [c]
Black pepper	Halery	71.60 [d e]
Black pepper	Byakaravally	70.74 [e f]
Cardamom	Halery	73.09 [c d]
Cardamom	Hakathur	69.05 [f g]
Cardamom	Byakaravally	64.37 [i]
Cardamom	Avemaria	65.45 [h i]
Turmeric	Appangala	55.09 [j]

SEd =0.9738
LSD at 1% = 2.69
CV=1.69%
*** Average of three replications**
****Values with at least one letter in common are not statistically significant**

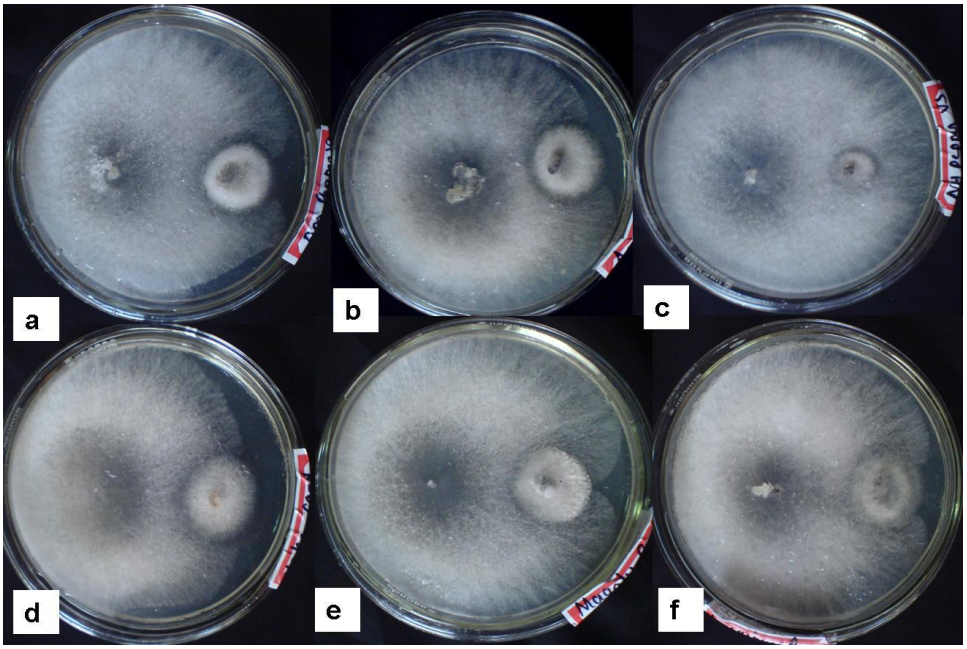

Plate – 19: Evaluation of *T. hamatum* against black pepper isolates of *Colletotrichum* (a) Appangala (b) Avemaria (c) Cooverkolly (d) Hakathur (e) Magalu (f) Nelliahudikeri

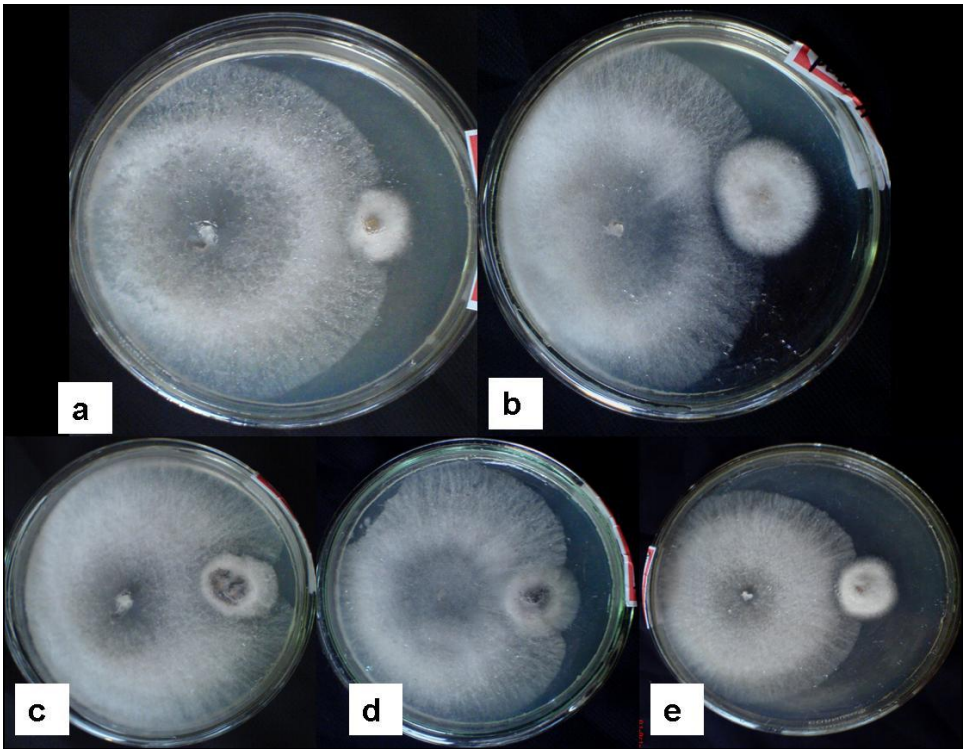

Plate – 20: Evaluation of *T. hamatum* against cardamom and turmeric isolates of *Colletotrichum* (a) Avemaria (b) Byakaravally (c) Lakshmi (d) Hakathur (e) Turmeric - Appangala

Table: 18 Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to IISR 6

Isolates	Place of collection	Zone of inhibition (cm)
Black pepper	Nelliahudikeri	* 2.20 [a]
Black pepper	Magalu	1.90 [b]
Black pepper	Avemaria	0.53 [e]
Black pepper	Appangala	1.20 [d]
Black pepper	Hakathur	1.56 [c]
Black pepper	Cooverkolly	1.76 [b]
Black pepper	Kodlipet	1.40 [c]
Black pepper	Halery	1.80 [b]
Black pepper	Byakaravally	2.10 [a]
Cardamom	Halery	0.40 [e]
Cardamom	Hakathur	0.03 [f]
Cardamom	Byakaravally	0.06 [f]
Cardamom	Avemaria	0.43 [e]
Turmeric	Appangala	0.10 [f]

SEd =0.0882
LSD at 1% = 0.24
CV=9.71%
*** Average of three replications**
****Values with atleast one letter in common are not statistically significant**

Table: 19 Sensitivity of *Colletotrichum* isolates from black pepper, cardamom and turmeric to IISR 853

Isolates	Place of collection	Zone of inhibition (cm)
Black pepper	Nelliahudikeri	* 2.25 [a]
Black pepper	Magalu	1.3 [d]
Black pepper	Avemaria	0.8 [f]
Black pepper	Appangala	1.26 [d]
Black pepper	Hakathur	1.1 [e]
Black pepper	Cooverkolly	1.8 [b]
Black pepper	Kodlipet	1.3 [d]
Black pepper	Halery	1.3 [d]
Black pepper	Byakaravally	1.93 [b]
Cardamom	Halery	0.56 [g]
Cardamom	Hakathur	0.46 [g]
Cardamom	Byakaravally	0.03 [h]
Cardamom	Avemaria	1.7 [c]
Turmeric	Appangala	0.43 [g]

SEd =0.0713
LSD at 1% = 0.19
CV=7.38
*** Average of three replications**
****Values with at least one letter in common are not statistically significant**

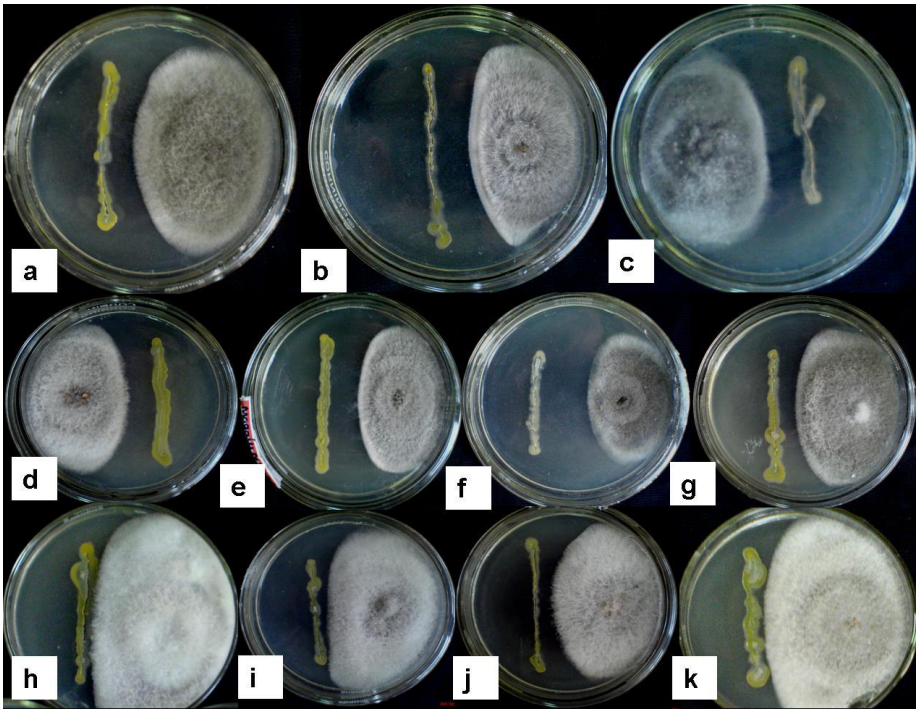

Plate – 21: Evaluation of IISR 6 against black pepper, cardamom and turmeric isolates of *Colletotrichum* **Black pepper** (a) Cooverkolly (b) Appangala (c) Hakathur (d) Kodlipet (e) Magalu (f) Nelliahudikeri **Cardamom** (g) Avemaria (h) Byakaravally (i) Hakathur (j) Halery **Turmeric** (k) Appangala

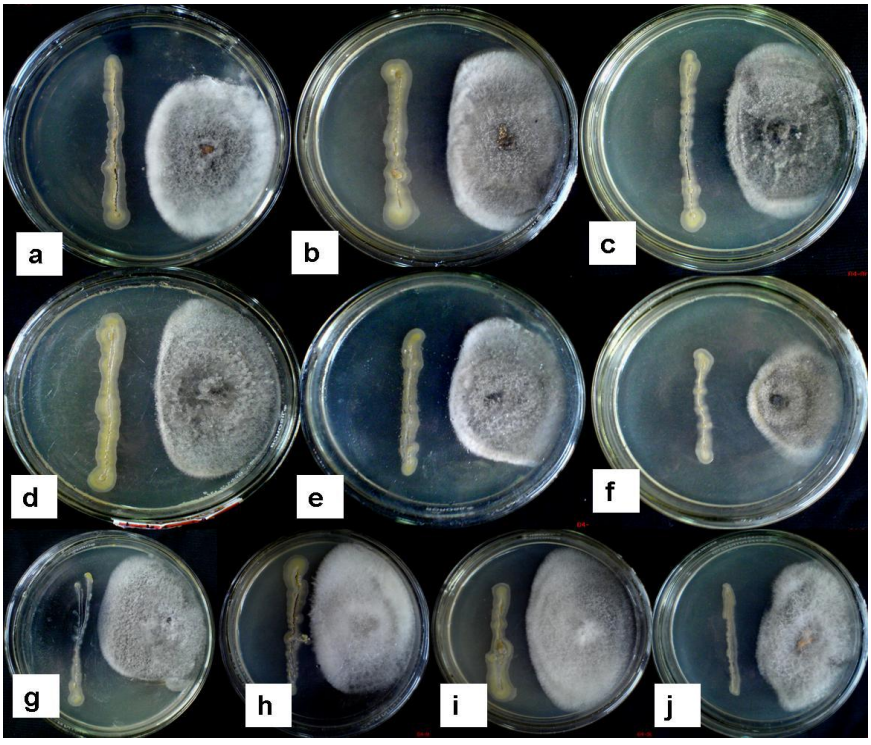

Plate – 22: Evaluation of IISR 853 against black pepper and cardamom isolates of *Colletotrichum* **Black pepper** (a) Avemaria (b) Cooverkolly (c) Hakathur (d) Halery (e) Magalu (f) Nelliahudikeri **Cardamom** (g) Avemaria (h) Byakaravally (i) Hakathur (j) Halery

(V) Identification of resistant sources

(a) Black pepper:

Natural incidence of anthracnose disease was recorded in 26 accessions including 4 hybrids, 10 selections and 18 cultivars. Panniyur – 5, IISR Girimunda and HP 780 were found to be highly resistant (Table 20).

Table 20: Reaction of black pepper accessions to anthracnose disease

Disease index (%)	Category	Field tolerant accessions	Resistant accessions
0 – 5.0	Highly resistant	Panniyur – 5, IISR – Girimunda, HP 780	Nil
5.1 – 10.0	Resistant	IISR Panchami, Aimpiriyan, IISR Subhakara, Karimunda (Idukki), Kottanadan, Jeerakamunda (Gudalur), Arakalamunda, Chomala	Panniyur – 5, IISR – Girimunda, HP 780, IISR Panchami, Aimpiriyan, IISR Subhakara, Karimunda (Idukki), Kottanadan, Jeerakamunda (Gudalur), Arakalamunda, Chomala
10.0 – 20.0	Moderately resistant	IISR Sreekara, Chetalli, IISR Malabar Excel, Vadakan, IISR Thevam, Kalluvally – 1, Panniyur – 6, Panniyur – 7, Narayakodi	IISR Malabar Excel, Vadakan, IISR Thevam, Kalluvally – 1, Panniyur – 6, Panniyur – 7, Thevanmundi

(VI) Disease management trial in sick plot

The disease management trial was conducted in a sick plot with over 20 years of disease history on Panniyur -1 under coffee based mixed crop conditions. The treatments were undertaken in Asoka Plantations, Boikeri with 12 treatments and 3 replications (Table 21). In this disease management trial, combination of fungicides (1% Bordeaux mixture, Hexaconazole, Carbendazim, Potassium Phosphonate, Mancozeb) and biocontrol agents (*Trichoderma harzianum* and *Pseudomonas fluorescens*) were imposed during pre-monsoon and mid-monsoon periods. The results indicated that the treatment with basal application of *T. harzianum* and aerial spray with 1% Bordeaux mixture was superior over other treatments.

Table: 21 Schedule of treatments	
First spray (June first week)	**Second spray (August second week)**
Hexaconazole (0.2 %)	1% Bordeaux mixture
1% Bordeaux mixture	1% Bordeaux mixture
Carbendazim (0.2 %)	1% Bordeaux mixture
Carbendazim (0.2%)	Mancozeb (0.25 %)
Mancozeb (0.25 %)	Mancozeb (0.25 %)
Hexaconazole (0.2 %)	Mancozeb (0.25 %)
Trichoderma harzianum (soil application) + 1% Bordeaux mixture (foliar spray)	*Trichoderma harzianum* (soil application) + 1% Bordeaux mixture (foliar spray)
Trichoderma harzianum (soil application) + *Pseudomonas fluorescens* (foliar spray)	*Trichoderma harzianum* (soil application) + *Pseudomonas fluorescens* (foliar spray)
Pseudomonas fluorescens (foliar spray and drench)	*Pseudomonas fluorescens* (foliar spray and drench)
Potassium phosphonate (drench) + *Pseudomonas fluorescens* (foliar spray)	Potassium phosphonate (drench) + *Pseudomonas fluorescens* (foliar spray)
Jeevamrutha (drench and spray)	Jeevamrutha (drench and spray)
Untreated control	

8222 Questions answered:

1. *Colletotrichum gloeosporioides* is consistently isolated from anthracnose infected black pepper and leaf blight of cardamom from different regions of Karnataka and Tamil Nadu. High degree of variability is observed in the isolates of *C. gloeosporioides* obtained from different regions of anthracnose infected black pepper and leaf blight infected cardamom and different hosts of same region.
2. The isolates varied in their pathogenicity towards different known/ induced hosts.
3. The pathogen survives in soil and spreads rapidly during early monsoon period. The peak spike infection is noticed during July 15^{th} to August 15^{th}. The carry over of pathogen occurs through dormant infected host parts and debris.
4. Disease management trial indicates that, by adjusting the timing of application to the crop stages, the combination of 1% Bordeaux mixture and basal application of *Trichoderma harzianum* both anthracnose and foot rot of pepper can be managed effectively.

8223 Process/ Products/ Technology developed

Aerial spray with 1 % Bordeaux mixture and basal application of *Trichoderma harzianum* during flushing and spike elongation stages manages the disease.

8224 Practical Utility (not more than 150 words)

In hilly zones both anthracnose and foot rot of pepper can be managed effectively by adjusting the timing of application of 1% Bordeaux mixture and basal application of *Trichoderma harzianum* to the crop stages (flushing and spike elongation).

Constraints, if any: Nil

823 Publications and Materials Developed

Dissertation: M. Phil Dissertation - Diversity of *Colletotrichum* species infecting black pepper and cardamom submitted by Mrs. Thaquiya. M. P. to PG Department of Applied Microbiology, Muthyammal College of Arts and Science, Periyar University, Rasipuram, Namakal.

8231 Research Papers: Nil

8232 Popular articles

M. N. Venugopal, S. J. Ankegowda, C. N. Biju and R. Senthil Kumar. (2008) Status and prospects of cardamom cultivation in Karnataka. In: *Proceedings National Workshop on Zingiberaceous Spices*, 19 - 20th March 2008, Indian Institute of Spices Research, Calicut. pp 97 - 109.

M N Venugopal, S J Ankegowda, R Senthil Kumar and C. N. Biju (2008) Technologies transferred for augmenting black pepper yield – A success story. In: Krishnamurthy, K S. Prasath D, Kandiannan K, Suseela Bhai R, Saji K V and Parthasarathy V A (Eds) *National seminar on Piperaceae – Harnessing agro technologies for accelerated production of economically important Piper species*. Indian Institute of Spices Research, Calicut, November 2008. pp189 -198.

8233 Reports: Annual reports, IISR, Calicut.

8234 Seminars, conferences and workshops (relevant to the project) in which the scientists have participated (List of abstracts forwarded)

Scientists	Seminars	Date	Location
Dr. M.N. Venugopal	!9th AICRP on Spices held at OUAT, Bhuvaneswar	23rd to 25th, November, 2007	OUAT, Bhuvaneswar
Dr. M.N. Venugopal	National Seminar on Organic Cultivation of Spices	11th to 12th, December, 2007	Agriculture College, Navilae, Shimoga, Karnataka
Dr. M.N. Venugopal Dr. Biju. C.N.	National Workshop on Zingiberaceous Spices	19th to 20th March, 2008	Indian Institute of Spices Research, Calicut
Dr. M.N. Venugopal Dr. Biju. C.N.	Regional Seminar on Pepper	25th March, 2008	IISR, cardamom Research Centre, Appangala
Dr. M.N. Venugopal Dr. Biju. C.N.	National Seminar on Piperaceae	21st to 22nd November, 2008	Indian Institute of Spices Research, Calicut
Dr. M.N. Venugopal Dr. Biju. C.N.	Regional Seminar on Pepper and Cardamom	23rd March, 2009	IISR, Cardamom Research Centre, Appangala

824 Infrastructural facilities developed: Nil

(Details of field, laboratory, note books and final material and their location)

The documents related to the project are maintained at CRC, Appangala.

825 Comments/ Suggestions of Project Leader regarding possible future line of work that may be taken up arising out of this Project

Present study revealed the extent of variability existing in the field populations of *Colletotrichum* infecting cardamom, black pepper and other component crops. Pathogenicity trials revealed that *Colletotrichum* spp. are capable of infecting other host/ varieties other than their natural hosts. The isolates from different geographical locations origination from different crops were also found to be compatible in some cases. Parasexual recombination facilitated by compatible reactions among the isolates would result in the evolution of new strains which may be either highly pathogenic than their parent isolates or may be resistant to commonly used fungicides or may possess both these characters. Diseases incited by these strains may be difficult to manage as they possess the ability to overcome the resistance offered by the existing field tolerant varieties/ cultivars and commonly used fungicides (at their recommended doses). Hence, extensive surveys need to be undertaken to study the occurrence as well as distribution of recombinants in cardamom and black pepper growing regions where fungicidal sprays are taken up on a regular basis. Characterization of these isolates by employing molecular tools would throw light in the area of origin and evolution of new strains and would facilitate the formulation of a comprehensive disease management strategy with a combination of fungicides, plant products/ extracts and biocontrol agents.

Part – IV – Project Expenditure
(Summary)
2006 – 2010

830	**Total Recurring Expenditure**		
8301	**Salaries**	**Estimated**	**Actual (Rs.)**
	(i) Scientific	**8,85,000**	**10,90,000**
	(ii) Technical	**75,000**	**25,000**
	(iii) Supporting	**90,000**	**78,000**
	(iv) Wages (Contractual)	**75,000**	**55,000**
	Sub Total	**11,25,000**	**12,48,000**
8302	**Consumables**		
	(i) Chemicals	**75,000**	**45,000**
	(ii) Glasswares	**35,000**	**12,000**
	(iii) Others	**-**	**14,000**
	Sub Total	**1,10,000**	**71,000**
8303	**Travel**	**40,000**	**35,000**
8304	**Miscellaneous (other costs)**	**25,000**	**10,000**
8305	**Sub Total (Recurring)**	**13,00,000**	**13, 64, 000**
831	**Total Non-Recurring Expenditure (Equipments and works)**	**25,000**	**-**
Total (830 and 831)		**13,25,000**	**13,64,000**

Part – V: Declaration

This is to certify that the final report of the project has been submitted in full consultation with the Project workers as per the approved objectives and technical programme and the relevant records, note books, material are available for the same.

Signature of the Project Investigator: Biju. C. N.

Signature of Co – Principal Investigator: D. Prasath

Signature and comments of the Head of the Centre:

Signature and Comments of the Head of the Division/ Section:

Signature and Comments of the Director: