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A Review of Papaya Black Spot - A Fungal Disease (*Asperisporium caricae*)

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Abstract

Papaya (*Carica papaya* L.) is one of the important table fruit amongst the tropical and subtropical fruits of the world, because of its taste, nutritional importance and medicinal value. Papaya is affected by several major diseases *viz.,* foot rot, anthracnose, powdery mildew, black spot, papaya ring spot, mosaic and leaf curl disease. Among these, black spot disease caused by *Asperisporium caricae* Mable is an emerging disease and it is one of the severe limiting factor for papaya production and the disease is distributed to all the papaya growing countries of the world. The disease also causes severe post-harvest loss, leads to impairing export and Import. Papaya fruits are being used as one of the everyday diet in a new generation era. Morphologically *Asperisporium caricae* produces sporodochia on which densely fasciculate conidiophore and two celled conidia were produced on the spot. Black spot occurs with greatest intensity under conditions of temperatures between 23 to 27 ºC and high rainfall or overhead irrigation. Optimum soil depth, good soil health and ideal soil moisture are the key factors to preserve the resistance character of papaya varieties for longer period. Soil test based fertilizer and micronutrient application, seedling dip treatment and foliar spray of *Trichoderma viride* (5g/l), Fungicides *viz.,* Prior spray of Mancozeb (0.2 %), followed by Difenoconazole (0.1 %) followed by Chlorothalonil (0.2 %) or Propiconazole (0.1 %) and Hexaconazole (0.1 %) at fifteen day intervals during *kharif* months are very effective in managing papaya black spot disease.

Keywords: *Carica papaya,* Black spot, Etiology, Epidemiology, Integrated approach

Papaya (*Carica papaya* L.) is treated as an important fruit amongst the folks of the tropical and subtropical countries because of its taste, nutritional importance and medicinal usage. It belongs to the small family *Caricaceae*. It is a dicotyledonous, polygamous, diploid species consisting of a small genome size with 372 Mbp/1C and it comprises of eighteen chromosomes (Bennett and Leitch, 2005). The origin of papaya is Mexico and Central America (Storey *et al.,* 1986).

The share of papaya cultivation to the global economy is evident by its wide distribution. It was once had a status of home garden crop but then emerged to that of commercial orchards in many tropical countries. This crop is one amongst the highest producer of fruits per hectare (Singh, 1990). It has short-lived perennial growth habit, large palmate leaves, rapid growth, hollow stems, petioles and fruits, and high phenotypic plasticity. Plant produces climacteric fruits throughout the adult plant life. In cultivation papaya trees grow quickly and gives mature fruits within 9-12 months period after planting (Gonsalves, 1998).

Globally, papaya is the third utmost cultivated tropical crop. India and Brazil are principal producers of papaya and is the fourth most traded tropical fruit. It has more importance due to its high palatability, early fruiting, maximum productivity per unit area, multifarious uses such as food, medicine and as an industrial input (Evans and Ballen, 2012).

Amongst common fruits, papaya is in top position regarding the nutritional scales for the percentage of vitamin C, vitamin A, potassium, niacin, folate, thiamine, iron, calcium, fiber and riboflavin (Huerta-Ocampo *et al.,* 2012).

It is consumed as dessert fruit and it is also well-known for good medicinal property in plant parts such as fruits, pulp, seeds, bark, peel, and roots. It is used for medicinal purpose as a source of chemical compounds such as papain, chymopapain and carpaine (Saran and

Choudhary, 2013). Commercially papain production is bound for digestion of protein, primarily in tenderizing the red meat, brewing of beer and treatment of skin (Ming *et al.,* 2012). Roots of papaya plants are utilized to cure piles, and yams, barks and stems can be managed to make ropes. It is used to extract oils with good amino acid and protein sources and also used as a vermifuge (Watson, 1997).

Papaya crop is grown in about 60 countries, with the substance production contributed from developing economies. Major global producers of papaya are India, Brazil, Nigeria, Indonesia, Mexico, Dominican Republic, Democratic Republic of Congo, Philippines, Venezuela and Thailand. Global annual production of papaya accounts for 13.01 million tonnes. India is leading country in papaya cultivation with area of 1.38 lakh hectares and annual outcome of 5.9 million tonnes (Anonymous, 2018). The largest papaya producing states include Andhra Pradesh, Gujarat, Karnataka, West Bengal, Madhya Pradesh and Maharashtra. Major papaya growing districts of Karnataka are Kolar, Chikkaballapura, Bengaluru, Mysuru, Tumkur, Mandya, Hassan, Chitradurga, Koppal, Ballary and Kalburgi. In Karnataka, papaya cultivation covers 8.75 thousand hectares with yearly production of 5.7 lakh tonnes (Anonymous, 2018).

Occurrence of different diseases are major constraints in papaya cultivation. Papaya plant suffers from several diseases such as foot rot, anthracnose, powdery mildew, papaya ring spot, leaf curl and mosaic, brown spot and black spot (Rajukumar *et al.,* 2018).

Papaya fruit is very much prone to diseases caused by many microorganisms especially fungi, for the reason that fruit has a very thin skin, high in moisture and nutrients (Kumar and Rawal, 2009). It is susceptible to more than a dozen fungal pathogens, Phytophthora (*Phytophthora palmivora*) root and fruit rot, anthracnose (*Collectricum gloerosporioides*), powdery mildew (*Oidium caricae*) and black spot (*Asperisporium caricae*) are the most important fungal pathogens (Zhu *et al.,* 2004).

Among the emerging diseases of papaya, black spot disease caused by *A. caricae* is the most lethal. Both leaves and fruits of papaya can be affected by the black spot disease. In addition, it causes the reduction of photosynthetic area and hence the pathogen can affect commercial value of the fruits (Ventura *et al.,* 2008).

Importance

Black spot diseases of papaya, caused by *A. caricae,* is a wide spread fungus disease found in many countries such as the USA, Brazil, South Africa, China, Philippines, Sri Lanka and Taiwan (Desmond and Ronald, 2001).

In India, the disease was observed as early as 1977 on the papaya variety Coorg Honey Dew at Chettali, Karnataka, and in Palani hills on Variety Co 1 (Ullasa and Rao, 1977).

If the disease is not controlled at early stage, leaf function will be damaged and defoliation can occur, thereby reduces fruit sugar content and quality. Black spot is one of the fungal diseases that have expressive consequences in terms of photosynthetic area and recurring damages to production and papaya fruit quality (Cooke *et al.,* 2009).

The pathogen affects the leaf and fruit parts which get attention by producers and consumers in reducing the economic value. The tissue beneath the lesions remains firm, but the value of harvested fruit with these symptoms is reduced (Peterson and Grice, 1999).

Fruits covered with black spot are unmarketable for the more demanding internal and external markets. When it is commercialized for the less demanding consumer, it gets its value depreciated. Thus, markets that look for products with lower rates of pesticide residues request more sustainable cultivation systems (Dianese *et al.,* 2008 ; Martileto *et al.,* 2009; Poltronieri *et al.,* 2017).

Approximately 30 per cent losses in papaya fruit commercialization was reported due to black-spot disease (Santos and Barreto, 2003). Despite of substantial amount of losses caused by the disease in

many parts of the world only few works are available regarding the management of this disease.

Symptomatology

Black pustules on the abaxial surface of the leaf were distinguishing symptom of this disease. The first symptoms were scattered small spots, visible on both surfaces of the leaf. On the upper surface, the lesions were rounded or somewhat angular, 1 to 4 mm in diameter, pale yellow, with dark margins. Later the lesions became necrotic and whitish. On the lower surface, the lesions were covered with masses of fungal spores which appear as dark dots. The pustules covered the whole lesion (Maublanc, 1913).

Peterson *et al*. (1993) described that the initial symptoms of black spot caused by *A. caricae* were small, water-soaked spots which develop on the upper surface of young leaves and later become greyish-white in color. Black conidial masses form on these lesions on the underside of leaves. Affected leaves curl, become necrotic, brittle and subsequently die under severe disease pressure, which results in extensive defoliation. Lesions on fruit begin as small black spots that can enlarge to 2 to 6 mm in diameter. The tissue beneath these lesions remains firm, but the value of harvested fruit with these symptoms is reduced.

The presence of papaya black spot (*A. caricae*) was recorded in Sri Lanka for the first time during early 1992, the mature leaves and fruits of several pawpaw cultivars showed uncommon disease. The disease was diagnosed as black spot caused by *A. caricae* and was confirmed using Koch's postulates. The disease is now widespread in several localities in the Kandy District and affects almost every pawpaw cultivar (Adikaran and Wijepala, 1995).

Ventura (2008) reported that the disease occurs on the leaves and on the fruits. On upper surface of leaves, characteristic symptoms consist of round, light-brown (tan) necrotic spots, encircled by a yellow halo. On the lower surface of the leaves, in the areas corresponding to the spots, the powdery growth of the fungus with gray to black color was observed. In some cases, over these, a pale mycelium produced by a fungal hyper parasite of the pathogen may be observed. When it occurs, coalescence of the lesions was a common cause of leaf senescence and defoliation of the plants. Abundant spotting cause defoliation and over 50 per cent leaf fall occurred. Young leaves generally did not showed symptoms. Initially, the presence of circular areas of watery aspect were observed on fruits, later disease became brown in color, prominent, with pal points, and that may attain 5 mm of diameter. These lesions generally were epidermal and did not reach the pulp of the fruit, causing only a hardening of the skin of the affected part.

Symptoms of the papaya disease were detected, when the plants were still in early phase of growth. The disease occurs both on the leaves and fruits. Symptoms initiate from older leaves progressively to the middle and upper leaves. On upper surface of older leaves symptoms consists of round, light brown necrotic spots, encircled by yellow halo. On the lower surface of leaves, in the areas corresponding to the spots, black colored fungus growth was observed. On fruits, initially symptoms consists of water soaked lesions and later it becomes brown in color. Initially these lesions were epidermal and did not affect the pulp region of the fruit (Shantamma, 2012).

Distribution

Black spot symptoms on the leaf and the fruits of *Carica papaya* due to infection of *Asperisporium caricae* (Speg.) Maubl. has been reported in Florida (Stevens, 1939) and South America (Saldana *et al.,* 1985). The fungus was originally restricted to Central and South America, West Indies and the USA (Ellis and Holliday, 1972). Reports indicated that the disease was wide spread in South Africa (Chambers and Rijkenfurg., 1987) and in Tanzania (Teri and Keswani, 1981).

In 1992, unusual black spotting observed in mature leaves of several papaya cultivars grown in certain areas around Kandy and the examination of diseased leaves revealed that the main causal agent was *Asperisporium caricae.* There were two other fungi

found associated with the disease at different times of the year. These two were identified as *Sclerospora* sp. and *Verticillium* sp. The papaya cultivars were not known by name but all of them were common and popular local cultivars. Later in 1993 the disease rapidly spread to several areas within the Province and is now common in many other cultivars including Solo Hawaii (Adikaran and Wijepala, 1995).

Black spot diseases of papaya, caused by *A. caricae,* is a wide spread fungus disease found in many countries such as the USA, Brazil, South Africa, China, Philippines, Sri Lanka and Taiwan (Desmond and Ronald, 2001). Among the reported diseases of papaya, black spot has been emerging as economically important disease to major papaya producing areas, majorly in the Central rift valley of Ethiopia (Anonymous, 2001). It is also one of the most serious fungal diseases of papaya in Brazil, where papaya is continuously grown throughout the year in a climate conducive to outbreaks of severe epidemics (Ventura *et al.,* 2003).

In Philippines a survey of papaya diseases was conducted in four provinces namely, Batangas, Laguna, Cavite and Quezon. The typical symptoms of black leaf spot of papaya were collected, on variety papaya 'red lady'. Symptoms of this disease and the causal organism were similar to that previously reported by Cumagun and Padilla (2007). The fungus on the infected papaya leaves was identified as *A. caricae* by comparison with the description and illustrations in Ellis and Holliday (1972) and Liberato and Shivas (2006) .

In India, papaya black spot disease was observed as early during 1977 in the papaya variety Coorg Honey dew at Chettali, Karnataka and in Palani hills in Variety Co 1 during cooler months (January to March) (Ullasa and Rao, 1977) and in Chittor of Andhra Pradesh (Reddikumar *et al.,* 2015), the disease did not emerge in a devastating manner thereafter.

A random survey was conducted for occurrence of black spot disease in papaya growing regions of South Karnataka caused by *Asperisporium caricae* during late winter season of 2011 (Shantamma *et al.,* 2014). A maximum severity of 69.5 per cent and 37.33 per cent on leaves and fruits respectively was recorded at Chikkanahalli in Mysore district.

Recently, in Tamil Nadu during October 2014 to March 2015, black leaf spot symptoms caused by *Asperisporium caricae* were observed on matured leaves in papaya varieties *viz.,* Co2, Co8, Red Lady and Sinta at various districts *viz.,* Coimbatore, Erode, Tirupur, Theni and Krishnagiri of Tamil Nadu state. The disease incidence ranged with PDI range of 10.0 to 23.8. Plants of all ages were susceptible and symptoms initiated during cooler weather accompanied with rains and the disease spread continued even after rains (Thiribhuvanamala *et al.,* 2016).

Identification in Relation to Morphological, Numerical and Molecular Characterization

Sporulation of *Asperisporium caricae* was hypophyllous ranging from dark blackish brown to black. Stroma was well developed, erumpent. Conidiophores were olivaceous brown, geniculate, smooth in dense fascicles with several prominent conidial scars at the tip up to 52 µm long × 6 to 9 µm wide. Conidiogenous cells were polyblastic with thickened and darkened scars. Conidia were solitary, ellipsoidal, pyriform or clavate, 1-septate (mature), hyaline to mid pale brown, verrucose, 16 to 32 × 5 to 11 µm in size (Lavoura, 1913).

Sporodochia of *Asperisporium caricae* was hypophyllous, dark blackish brown to black, stroma well developed, erumpent. Conidiophores closely packed together and covering the surface of the stroma, usually unbranched, hyaline to olivaceous brown, with several prominent conidial scars at the apex, up to 45 x 69 µm. Conidia solitary, ellipsoidal, pyriform or clavate, 1-septate, hyaline to mid pale brown, verrucose, 14-26 x 7-10 µm (Maublanc, 1913; Ellis and Holliday, 1972).

Morphological description of *Asperisporium caricae* was found that sporodochia and conidia were produced on the spot. The sporodochia were subcuticular or intra epidermal, olive-brown to dark brown 40 to 120 µm in diameter. Conidiophores were densely fasciculate,

simple, straight or curved, greenish-brown to olive-brown, 1 to 2 septate. Conidia were terminal, elliptic to ovoid, rounded at the top, truncate at the basal end, hyaline and one-celled at first, then turned to greenish-brown and become two celled, 12 to 28 x 7 to 14 µm with many rough warts (Kobayashi *et al.,* 1998).

Minnis *et al.* (2011) reported *A. caricae* comes under the class-Dothideomycetes, order: Capnodiales, family-Mycosphaerellaceae, synonyms *viz., Cercospora caricae, Epiclinium cumminsii, Fusicladium caricae, Pucciniopsis caricae* and *Scolicotrichum caricae* (Ellis and Everh, 1923).

Morphological findings of *Asperisporium minutulum viz.*, mycelium internal, subcuticular to intra epidermal, branched, 2.5 to 5 µm wide, septate, conidiophores numerous, in dense fascicles, arising from stroma, emerging through stroma or erumpent through the cuticle, forming sporodochial conidiomata, erect, straight to slightly flexuous, short cylindrical or conical, unbranched, conidia formed solitary, straight, broadly ellipsoid to subspherical, 10 to 23 x 8 to 13 µm, 0 to 2 septate (Konstanze and Braun, 2005).

Minnis *et al.* (2011) generated DNA sequence data from the ITS region and nLSU of type species of *Asperisporium* and *Pantospora*, analysed phylogenetically, placed into an evolutionary context within *Mycosphaerellaceae* and compared to existing phylogenies. They observed that *Asperisporium caricae,* the type of *Asperisporium* and cause of a leaf and fruit spot disease of papaya, was closely related to several species of *Passalora* including *P. brachycarpa*.

Shantamma *et al.* (2014) observed that *Asperisporium caricae* conidiophores are compact, covered with stroma, hyaline to brown in color. Conidia are elliptic to oviod, rounded at the top, one or two septate, hyaline to brown in color, size of the conidia varied from 27 to 30 µm.

Shreedevasena *et al.* (2019) subjected *Asperisporium caricae* isolate to polymerase chain reaction (PCR) for confirmation of pathogen at genus level using universal primers such as ITS 1 and ITS 4. Molecular confirmation of *Asperisporium caricae* through 18S rRNA gene sequencing gave an amplicon size of 560bp.

The colonies of *Asperisporium caricae* on potato dextrose agar were near dark green to black in color. Mycelium formed a raised mound covered with whitish, short erect hyphae or whitish aerial hyphae. Surface slightly velutinous with scattered black spherical structures. Hyphae are branched with walls smooth, hyaline to brownish, septate, 3 to 6.5 µm diameter. The conidial production on potato dextrose agar was sparsely distributed. Sporulation usually occurred after a month at 24 °C with a 12 h light / dark regimen (Shreedevasena *et al.,* 2019).

PCR amplification of ten isolates of *A. caricae* with ITS 4 and ITS 5 yielded single fragment amplicon of 590 bp. Dendrogram clustering of ten isolates of *A. caricae* grouped them into two clades, where AcG isolate belonged to clade I and AcH (Hassan), AcKa (Kaduru), AcKu (Kushalnagara), AcMa (Madduru), AcMu (Mudbidire), AcMy (Mysuru), AcNa (Nagamangala), AcR (Ramanagara) and AcV (V. C. Farm) belonged to clade II. According to this AcG (GKVK, Bengaluru) isolate was less similar (62 %) to other isolates. AcH and AcKu isolates had highest similarity (85 %) with each other followed by AcMa and AcMu (78.5 %). The similarity between AcH and AcKu evident in some of the cultural characters also (Shetty, 2020).

Epidemiological Factors on Black Spot Fungi

Black spot occurs with greatest intensity under conditions of temperatures between 23 to 27 ºC, with strong winds and high rainfall or overhead irrigation. The incidence is seasonal, and most infection occurs in late winter and spring. These conditions favor development of the lesions and dispersion of spores from older leaves, considered the principal sources of inoculum and where the disease occurs initially, being disseminated subsequently to the younger leaves. The penetration of the fungus is stomatal and macroscopic symptoms are visible between 8-10 days after inoculation (Holliday, 1980). Fruits can be infected when still green and the lesions resulting from the

eruption of the stroma will emerge completely at the beginning of maturation, liberating new spores when the fruit is totally mature.

Black spot disease of papaya can infect papaya plants at any growth stage. Periods of wet weather and severe soil moisture perhaps elevates the progress of the disease (Shantamma, 2012).

Edaphic Factors of Black Spot Fungi

Shetty *et. al.* (2020) studied the correlation between soil edaphic factors and papaya black spot disease severity on leaves and fruits of papaya plant. The results revealed positive correlation coefficients (increase in disease severity) for soil pH (0.13), available nitrogen (0.30), available phosphorus (0.18), exchangeable calcium (0.08), exchangeable magnesium (0.39) and hot water extractable boron with leaf disease severities, whereas, electrical conductivity (-0.03), organic carbon (-0.35), available potassium (-0.06), available sulfur (-0.05), DTPA extractable zinc (-0.33), DTPA extractable manganese (-0.35), DTPA extractable iron (-0.32) and DTPA extractable copper (-0.17) were negatively correlated (disease severity decreased) with disease severities on leaves. Further disease severities on fruits were positively correlated with soil pH (0.06), available N (0.06), available P (0.09), exchangeable Ca (0.16), exchangeable Mg (0.24), DTPA extractable Cu (0.12) and negatively correlated with EC (-0.06), OC (-0.18), available K (-0.02), available S (-0.21), DTPA extractable Zn (-0.17), DTPA extractable Mn (-0.08), DTPA extractable Fe (-0.06), and hot water extractable B (-0.13).

Management of Black Spot Fungi

Host Resistance

Genetic resistance has emerged as a promising and sustainable control alternative for black spot disease of papaya (Vivas *et al.,* 2015). It is essential to be aware of the genetic variability of papaya genotypes to set plans for improvement strategies (Vivas *et al.,* 2016). Evaluated 41 papaya genotypes against black spot and the genotypes that showed better resistance were lines 1, 4, 9, and 19. Lines 4 and 9 and the parent 'SEKATI' generated the best results in all the variables assessed (Stevans, 1939).

Cultural Methods

Infected old leaves hanging from trees should be removed carefully to reduce the number of spores that spread the disease. Wind protection around plantings is important to minimize fruit abrasions which can create an entry for pathogens (Constantinides and McHugh, 2005). Heavily infected leaf blades should be removed by cutting the petiole half way between the leaf blade and the trunk to protect insects and pathogens to enter the wound (Vivas, *et al.,* 2015). Scouting the orchard periodically is very important to decrease infestation level by weeds, reduce the suffocation of the orchard, and fertilize the plantation. Removal of leaves and fruits with symptoms of black spot disease from the orchard reduces the initial inoculum (Suzuki *et al.,* 2017).

Chemical and Biological Management

In Brazil, fungicides are used to control this disease for all papaya plantations produced commercially (Ferreira and Avidos, 1999). It is also reported that high black spot pressure influence the efficacy of mancozeb and tebuconazole fungicides (Peterson and Grice, 1999).

Effect of foliar applications of phosphates with K, Ca, Mg and Cu evaluated indifferent doses on papaya black spot. In both field and greenhouse trials the Phosphite with other nutrients were found to reduce the incidence and severity of black spot disease (Dianese *et al.,* 2008).

Laboratory studies have showed that *A. caricae* was more sensitive to Difenoconazole (EC50 of 2 ppm) then Tebuconazole (EC50 of 14 ppm) (Vawdrey *et al.,* 2008).

Fourth generation fungicides including strobilurins (Pyraclostrobin and Azoxystrobin), Third generation fungicides *viz.*, triazoles (difenoconazole and tebuconazole), Second generation fundicides *viz.,* dithiocarbamates (Propineb, metiram, ziram and mancozeb) and pthalimide (chlorothalonil) were

evaluated in three field experiments at North Queensland and Australia for the control of papaya black spot (Vawdrey *et al.,* 2008). Among these chemicals difenoconazole, pyraclostrobin and chlorothalonil were better than mancozeb and tebuconazole. Efficacy of combi-product fungicides *viz.,* tebuconazole + trifloxystrobin, pyraclostrobin, azoxystrobin and difenoconazole against Asperisporium caricae was observed good control of the fungus (Livia *et al.,* 2011).

Among the different bio agents tested against *A. caricae* under in vitro condition the maximum reduction in colony growth was observed in *Trichoderma viride* (53.33 mm) which was significantly superior over all the bio agents tested. Next best was *Trichoderma virens* (53.00 mm) and *Trichoderma koningi* (52.00 mm) (Taj and Kumar, 2013).

Taj and Kumar (2013) evaluated different plant extracts against black spot of papaya under *in vitro* condition. Among the different botanicals, neem leaf extract at both the concentration of 5 per cent (43.00 %) and 7.5 per cent (47.66 %) was significantly superior over all other plant extracts.

Fungicides *viz.,* Trifloxystrobin, Tebuconazole, Benomyl, Trifloxystrobin + Tebuconazole, Hexaconazole and Chlorothalonil were found effective among seven fungicides evaluated in inhibiting the mycelial growth of *A. caricae* at 0.2 per cent. Least inhibition was observed at 0.05 per cent by Trifloxystrobin (Taj and Kumar, 2013).

Eight fungicides were evaluated under field condition, for their efficacy in controlling the black spot disease. Out of eight fungicides evaluated difenconazole was most effective against pathogen on leaves followed by chlorothalonil. Whereas, bitertanol was least effective. On fruits also difenoconazole was most effective against the pathogen followed by chlorothalonil. (Shantamma *et al.,* 2014).

The effect of different fungicides on spore inhibition of *Asperisporium caricae* was studied (Shantamma, *et al.,* 2014). Among those difenoconazole inhibited 100 per cent spore germination at 150 ppm followed by chlorothalonil and propiconazole.

Reddikumar *et al.* (2015) conducted *in vitro* studies to test efficacy of new fungicides comprised combination of systemic and contact fungicides *viz.,* Tricyclazole +Mancozeb, Carbendazim + Mancozeb, Hexaconazole + Zineb and two systemic fungicides *viz.*, Azoxystrobin, Difenconazole. Among these fungicides tested, combiproduct Hexaconazole + Zineb had shown most effective result *i.e.,* 100 per cent inhibition at 100 ppm under *in vitro* conditions.

It is advisable to look for signs of disease on the new growth since the fungicides protect the new leaves and fruits, but old damage cannot be undone (Constantinides and McHugh, 2005; Thiribhuvanamala *et al.,* 2016).

Application of protective or systemic fungicides when the first symptoms appear is the best option to early manage black spot disease of papaya (Suzuki *et al.,* 2017).

Fungicides *viz.,* Difenoconazole, Chlorothalonil, Propiconazole and Hexaconazole were very effective in managing this pathogen (Shantamma *et al.,* 2018). In-vitro studies by Patel (2019)[28] reported Carbendazim 50 per cent WP. inhibited 100 per cent mycelial growth of *A. caricae.*

Patel (2019) reported that *Allium sativum* was highly effective in maintaining lesser infection percentage (9.87 %) of papaya black spot disease on infected fruits over of *Prosopis juliflora* (11.21 %), *Vitex negunda* (12.06%), *Lawsonia inermis* (13.65%), *Ocimum sanctum* (15.62%) and *Lantana camara* (17.63%). Further *Azadirachta indica* (20.15 %) was reported to be least effective in decreasing the infection percentage when black spot infected fruits of papaya were dipped into aqueous extract of this plant.

Among the seven bio agents evaluated in the experiment by following dual culture technique *T. viride* (72.59 %) exhibited highest mycelial inhibition, followed by *T. asperellum* (70.37%), *T. harzianum* (64.81 %), *Ampelomyces quisqualis* (63.33 %),

antagonistic bacteria *Bacillus subtilis* (9.63 %), *P. fluorescens* (6.67%) whereas, least inhibition was observed by *Bacillus pumilis* (4.44 %). Poison food technique was followed with seven plant extracts to test their efficacy against papaya black spot (*A. caricae*). Excellent mycelial growth inhibition was observed by Allium sativum (27.93 %) which was significantly higher than all other treatments, which was followed by *Zingiber officinale* (24.15 %). Next best inhibition was imparted by *Vinca rosea* (1.77 %) but which was much less effective as compared to *Allium sativum* and *Zingiber officinalis*. Little inhibition was imposed by *Tinospora cordifolia* (1.47 %), *Azardiracta indica* (1.12 %), *Tagetes erecta* (1.07 %) and Seaweed extract (0.67 %) which were on par with each other (Shetty, 2020).

Five contact fungicides, four systemic fungicides and four combiproduct fungicides were evaluated for their effectiveness against *A. caricae* under *in vitro* condition by following poisoned food technique. Among contact fungicide tested Mancozeb 75 % WP (44.35 %) showed maximum and Copper hydroxide 50 % WP (24.03) showed least inhibition of radial mycelial growth. Carbendazim 50 % WP and Propiconazole 25 % EC gave cent percent mycelial inhibition among the four systemic fungicide evaluated under *in vitro* condition whereas, least inhibition was reported on Hexaconazole 5% EC (38.33 %). Among the combiproduct fungicide used in the treatment to evaluate their efficacy against *A. caricae* 100 % inhibition was obtained by (Carbendazim 12 % + Mancozeb 63 %) 75 % WP and Picoxystrobin 7 % + Propiconazole 12 % SC and Metiram 5 % + Pyrachlostrobin 55 % WG (21.60%) imparted minimum mycelial growth inhibition (Shetty, 2020).

Black spot disease of papaya is very lethal and thus both leaves and fruits of papaya can be affected. Severe black spot infections can cause the leaves to curl and die prematurely which affects photosynthesis. The pathogen can cause direct damage by causing spots on the fruit and post-harvest rotting. Knowledge on distribution of the black spot disease in the world, symptomatology, etiology of the parasite and epidemiological factors influencing disease development are the major concern. Further Probing for integrated approaches *viz.,* adopting host plant resistance, enriching soil health, soil moisture management, maintaining plant to plant distancing and following East-West direction planting, subsequent cultural practices, prior spray of extract of plant products and need based spray of fungicides to manage the black spot disease are an important operations for the increased production of Papaya in the country.

Black spot occurs with greatest intensity under conditions of temperatures between 23 to 27 ºC and high rainfall or overhead irrigation. Integrated approaches in managing the black spot disease are one of the vibrant actions to reduce the residual toxicity and adverse effect on consumers. Optimum soil depth, good soil health and ideal soil moisture are the key factors to preserve resistance character of papaya varieties for longer period. Soil test based fertilizer and micronutrient application, seedling dip treatment and foliar spray of *Trichoderma viride* (5g/l), Fungicides *viz.,* Prior spray of Mancozeb (0.2 %), followed by Difenoconazole (0.1 %) followed by Chlorothalonil (0.2 %) or Propiconazole (0.1 %) and Hexaconazole (0.1 %) at fifteen day intervals during of *kharif* months are very effective in managing papaya Black spot disease.

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