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U. Narain, Alka Kushwaha, Piyush Mishra,  
Sunil Kumar Singh, Harshita and Gyan  
Prakash Gupta

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# Disease Diagnosis and Parasitism of *Alternaria* species on Brassicaceous Vegetables, Oleiferous Crops, and Ornamental Plants

U. Narain<sup>1</sup>, Alka Kushwaha<sup>\*2</sup>, Piyush Mishra<sup>3</sup>, Sunil Kumar Singh<sup>4</sup>, Harshita<sup>5</sup> and Gyan Prakash Gupta<sup>\*6</sup>

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## ABSTRACT

The family Brassicaceae (Crucifers) including a number of vegetables grouped as Cole crops, root crops, herbaceous vegetables, oleiferous (oilseed) crops, and also ornamental plants, were observed to be infected by six species of *Alternaria*, causing leaf spots and blight, lesions on stems, petioles, silique; blossom blight, seedling blight, and damping off. *Alternaria brassicae*, the representative species of Brassicaceae was found to infect plants of all the groups of Crucifers followed by *A. raphani* restricted to eight hosts, *A. brassicicola* to five, *A. japonica* to four and *A. alternata* to only broccoli and radish. *A. cheiranthi* appeared to be a single species of *Alternaria* confined only to wallflower (*Cheiranthus cheiri*) to cause the leaf spot disease. Symptoms of all the groups of Brassicaceous hosts due to *Alternaria* species, the most distinguishing morphological features of the causative fungus have been described. The differences in symptomatology and etiology of diseases have been critically analyzed. A very simple and feasible key has also been framed for the correct and easy identification of all the six species of *Alternaria* associated with brassicaceous vegetables, oleiferous and ornamental plants.

**Key words:** *Alternaria* spp, Brassicaceae, Cole crops, Vegetables, Oilseeds, Ornamentals, Leaf spots, Blight diseases

*Alternaria* is a worldwide fungal genus that comprises saprobic, endophytic, and pathogenic species [1]. It is allied with a variety of substrates like seeds, plants, agronomic products, animals, soil, etc. Species of *Alternaria* are known as stern plant pathogens, causing major losses in a wide range of crops [2]. *Alternaria* makes large monetary losses due to its host range and its worldwide distribution. Approximately, 300 species of the genus *Alternaria* have been notified globally, which includes *Alternaria alternata*, *Alternaria brassicicola*, *Alternaria solani*, *Alternaria arborescence*, *Alternaria infectoria*, and *Alternaria tenuissima* [3]. These *Alternaria* species have been reported to cause diseases in more than 400 plant species, in which *A. alternata* alone infects nearly 100

plant species. It is also responsible for post-harvest diseases in several crops [4]. This paper deals with disease analysis and parasitism of *Alternaria* species on brassicaceous vegetables, oleiferous crops, and ornamental plants. Oilseed crops and vegetables of the Brassicaceae family play a significant role in the national economy owing to their oil content and nutritive value, and they form virtually the essential constituents of the human diet. Oil-yielding (oleiferous) crops like rapeseed, mustard, rai, and raya are the main sources of oil for cooking purposes. Brassicas are the backbone of the vegetable garden. They include major cole crops like cauliflower, cabbage, knol khol, and broccoli, as well as herbage vegetables that are commonly grown in India and European countries. Besides these, there are several root vegetables included in the family Brassicaceae, like radish, turnip, and ornamental plants also. Fifteen hosts, including oilseeds, vegetable crops, and ornamental plants, are included in the family, commonly called "Crucifers" (Table 1). Brassicaceae is a rich family from an economic point of view, but like other crops, they are also affected by several diseases of different origins, among which *Alternaria* diseases are one of them. Because of their occurrence from seedling to maturity stage and storage, they reduce the quantity and quality of their produce. It suffers greatly due to attacks by six species of *Alternaria*, viz., *A. brassicae*, *A. raphani*, *A. brassicicola*, *A. japonica*, *A. cheiranthi*, and *A. alternata* (Table 1) [5-6].

\* **Alka Kushwaha**

✉ alkakushwaha17march@gmail.com

\* **Gyan Prakash Gupta**

✉ gyanprakashgupta\_kn03@csjmu.ac.in

<sup>1,5</sup> Department of Plant Pathology, C.S. Azad University of Agricultural and Technology, Kanpur - 208 002, Uttar Pradesh, India

<sup>2-4,6</sup> Department of Botany, Dayanand Anglo-Vedic (DAV) College, Kanpur - 208 001, Uttar Pradesh, India



*Alternaria* species associated with various Brassicaceous hosts

The disease in Brassicaceous hosts is identified by many names as *Alternaria* blight, *Alternaria* leaf spot, *Alternaria* pod spot, *Alternaria* dark leaf spot, black spot, and an early stage as "damping off" [7]. The seed production of Brassicas has been reported to be significantly reduced by the attack of *Alternaria* diseases which invade the curds, heads, and siliquae and the causative pathogens penetrate the seeds besides damaging the assimilatory tissues of the leaves and stems [8-11]. *Alternarioses* often occur on older leaves, since they are close to the soil and are more rapidly infected as a consequence of

rain splashes or wind-blown rain [12-14]. Among the six species of *Alternaria* infecting vegetables, oil yielding oleiferous crops, and ornamental plants (Table 1). *A. brassicae* is a more destructive one and occurs more frequently [15] and is the representative species infecting Brassicaceous hosts [16-17]. *A. raphani*, *A. japonica*, and *A. brassicicola* have been reported from every continent on Crucifers [18-19]. *A. cheiranthi* is only a pathogen of a wallflower and *A. alternata*, a ubiquitous fungus infecting broccoli (cole crop) and radish (root crop). A great deal of variation occurs in all the species with regards to their morphological characters [20-21].

Table 1 *Alternaria* species associated with Brassicaceous hosts

Hosts	<i>Alternaria</i> spp.
<b>A. Vegetables :</b>	
<b>I. Cole crops</b>	
a. Cabbage ( <i>Brassica oleracea</i> var. <i>capitata</i> )	<i>Alternaria japonica</i> <i>Alternaria brassicae</i> <i>Alternaria brassicicola</i>
b. Cauliflower ( <i>Brassica oleracea</i> var. <i>botrytis</i> )	<i>Alternaria brassicae</i> <i>Alternaria brassicicola</i> <i>Alternaria raphani</i> <i>Alternaria japonica</i>
c. Knol khol ( <i>Brassica oleracea</i> var. <i>caulorapa</i> )	<i>Alternaria brassicae</i> <i>Alternaria brassicicola</i>
d. Broccoli ( <i>Brassica oleracea</i> var. <i>italica</i> )	<i>Alternaria brassicae</i> <i>Alternaria brassicicola</i> <i>Alternaria raphani</i> <i>Alternaria alternata</i>
<b>II. Herbage Vegetables</b>	
a. Kale ( <i>Brassica oleracea</i> var. <i>acephala</i> )	<i>Alternaria brassicae</i>
b. Brussel sprout ( <i>Brassica oleracea</i> var. <i>gemmifera</i> )	<i>Alternaria brassicae</i>
c. Rocket ( <i>Eruca vesicaria</i> )	<i>Alternaria japonica</i>
<b>III. Root crops</b>	
a. Radish ( <i>Raphanus sativus</i> )	<i>Alternaria brassicae</i> <i>Alternaria japonica</i> <i>Alternaria raphani</i> <i>Alternaria alternata</i> <i>Alternaria brassicae</i> <i>Alternaria raphani</i> <i>Alternaria japonica</i>
b. Turnip ( <i>Brassica rapa</i> sub sp. <i>rapa</i> )	
<b>B. Oilseed crops :</b>	
a. Rapeseed/mustard ( <i>Brassica juncea</i> / <i>B. campestris</i> )	<i>Alternaria brassicae</i> <i>Alternaria brassicicola</i> <i>Alternaria raphani</i> <i>Alternaria brassicae</i>
b. Raya ( <i>Eruca sativa</i> )	
<b>C. Ornamental plants:</b>	
a. Candytuft ( <i>Iberis amara</i> )	<i>Alternaria brassicae</i> <i>Alternaria raphanin</i>
b. Wallflower ( <i>Cheiranthus cheiri</i> )	<i>Alternaria cheiranthi</i>
c. Stock ( <i>Matthiola incana</i> )	<i>Alternaria brassicae</i> <i>Alternaria japonica</i> <i>Alternaria raphanin</i>
d. Lepidium ( <i>Lepidium sativum</i> )	<i>Alternaria raphanin</i>

*Alternaria* species associated with Brassicaceous vegetables  
Cole crops

These are the vegetable crops of temperate regions of the family Brassicaceae (Crucifers), which include cabbage, Chinese cabbage, cauliflower, knol khol, and broccoli. In India also, these are the crops of the winter season. Among these vegetables, knol khol is the underground root vegetable of which roots and tender parts are utilized. *Alternaria* blight is one of the most widely occurring diseases of cole crops and is caused by four species of *Alternaria*, viz., *A. brassicae*, *A. brassicicola*, *A. raphani*, and *A. japonica*, of which the first two

are worldwide pathogens. One more, *A. alternata* also causes the leaf spot disease, confined only to a single cole crop broccoli [22-24].

## Symptomatology

The symptoms caused by five species of *Alternaria* on cole crops as follows:

(i) *Alternaria brassicae*: Symptoms caused by *A. brassicae* in all the vegetables included under cole crops, initially start from the margin of leaves or at the tip and spread inward. The dark brown irregular spots are accompanied by a



characteristic "yellow halo" appearance and have distinct or indistinct zonations, which increase in size in a concentric manner (Fig 1a). Two or more spots may coalesce to form bigger spots. In the well-advanced stage, some of the spots are covered with a dark olive-green mass of the fungal spores [25-26].

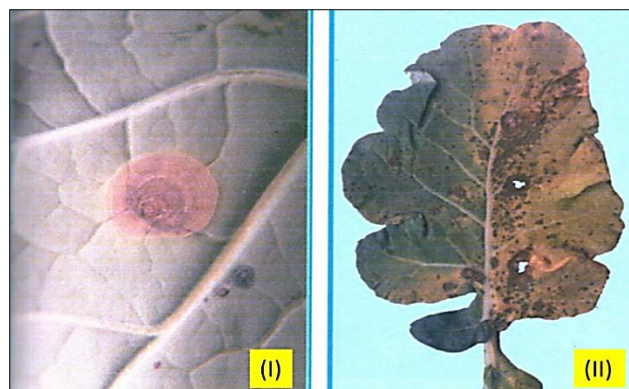


Fig 1a Symptom (i) concentric ring (ii) shot-hole appearance of *Alternaria brassicae* on cole crop

(ii) *Alternaria brassicicola*: The leaf spot disease of cauliflower, cabbage, and broccoli caused by *Alternaria brassicicola* are circular to elliptical and olivaceous in color which vary from 4-10 mm in size. In case of severe infection, several lesions coalesce to cover a larger area (Fig 1b). Severely infected leaves show a burning effect, which ultimately dries up and may fall prematurely [13]. The pathogen has been reported to be seed-borne in nature.

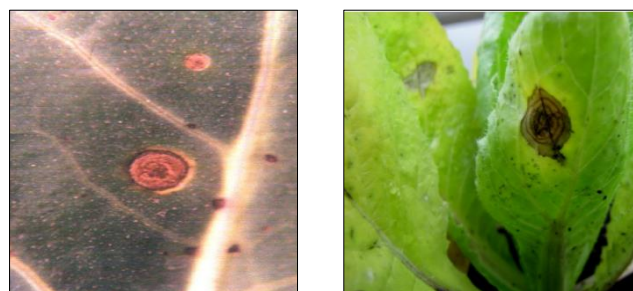


Fig 1b Symptom of *Alternaria brassicicola* on cole crop (cabbage) showing concentric lesions on the abaxial leaf side

(iii) *Alternaria raphani*: The symptoms of *Alternaria* leaf spot of cauliflower and broccoli, caused by *A. raphani* are brown to dark brown patches starting from the margin of leaves, which develop inward in an irregular fashion (Fig 1c). The affected areas soon turn blighted and wither [27-28].

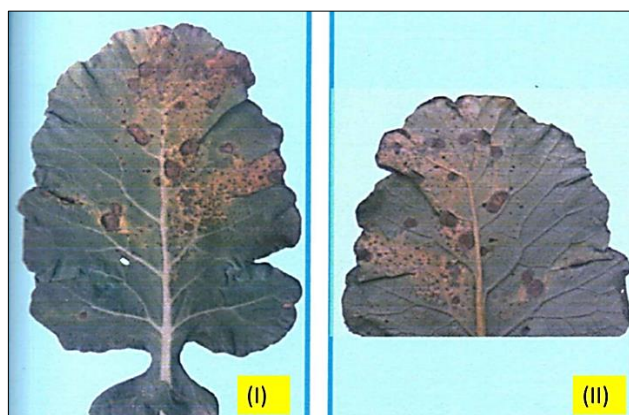


Fig 1c Symptom of *Alternaria raphani* on upper (i) and (ii) lower surfaces of cole crop (Broccoli)

(iv) *Alternaria alternata*: Broccoli is the only cole crop that is also infected by *A. alternata*. The symptoms of *Alternaria* leaf spot of broccoli caused by *A. alternata*, primarily appear as minute dark brown lesions which start from the margin and center of leaves, and at a later stage of disease development, a number of spots coalesce to form the irregular dark brown patches (Fig 1d) [29].



Fig 1d Symptom of *Alternaria alternata* on cole crop (enlarged view)

(v) *Alternaria japonica*: Cole crops like cabbage and cauliflower are infected by *A. japonica*. The disease caused by this fungus is reported on all continents, found often in North America, Europe, and the Middle East [30]. It is known to affect most parts of infected plants depending on the growth of the stage. Like, hypocotyls, cotyledons of seedlings and on the leaves, petioles, stem, inflorescences, fruits (silique), and seeds of matured plants. Leaf lesions are normally small black to grey, dry with raised margins [31], and sometimes surrounded by raised margins [32]. It is a seed-borne pathogen of plants in Brassicaceae, and its disease may occur wherever the hosts of this family are grown [33].

#### Herbage vegetables

These are the vegetables that yield nutrients in shoots developed above ground. They include "pot-herbs" and "salads". The most nutritive part is the tender and more or less thickened stem. Sometimes as in kale, brussels sprouts and rocket leaves are most important all belonging to the family Brassicaceae. Kale and Brussel's sprout get infected by *A. brassicae* while *A. japonica* causes the leaf spots and lesions in the rocket (*Eruca vasicaria*), which are light black in appearance. Black lesions also appear on tender shoots which lead the shriveling and falling in immature conditions [34]. Symptoms of disease on these three herbaceous vegetables resemble those as described in Cole crops. As these two species of *Alternaria* occur on the foliage, sometimes due to severe infestation, the quality and quantity of produce are greatly reduced by making it unfit for consumption [5].

#### Root crops

**Radish:** It is considered a poor man's vegetable. This root crop is attacked by 4 spp. of *Alternaria* viz., *A. raphani*, *A. alternata*, *A. japonica*, and *A. brassicae* (Table 1). The leaf spot due to *A. raphani* appears first and is the most common of worldwide occurrence (Walker, 1952). The symptoms appear as brown to dark brown patches starting from the margin of leaves, which develop inward in an irregular fashion. The affected areas soon turn blighted and wither [5], [7]. On seed



crop of radish, the causative fungus produces circular black spots, up to 4 mm in diameter as "black pod blotch" [18] and "black patches" on Chinese radish during post-harvest storage [35]. Secondary infection may also occur due to the transmission of spores by rain splash and wind-borne conidia [12]. Symptoms produced by *Alternaria* pathogens are more common, but some variation may also be noticed. As in the case of *A. japonica*, the spots are initially black in the center due to sporulation, but the center eventually dries out and falls out [35]. The symptoms of *Alternaria* leaf of radish caused by *A. alternata* initially appear as minute dark brown lesions which start from the periphery or center of leaves. At the later stage of disease development, a number of lesions (spots) coalesce to involve more areas in an irregular fashion [29]. In *A. brassicae*, the spots are dark brown, circular, scattered on leaf surfaces with zonation somewhat different from the symptoms produced by *A. raphani* and *A. alternata* [36].

**Turnip:** It is an annual vegetable crop cultivated for the consumption of its succulent root. *A. japonica* Yoshii is a pathogen of turnip to cause the disease symptoms which are observed both on leaves and roots. *A. japonica* causes mainly black spots of Crucifers (Brassicaceae). It is considered more dangerous during the seedling stage. The fungus affects its host in all stages of growth right from roots to inflorescences. Infection generally causes black or grey sunken lesions with a concentric yellow border. On leaves, the infection may cause dark water-soaked spots. Infection may be found anywhere on plants. Lesions on seedlings and stems cause the "damping off" stage [37]. Black sunken lesions also appear in the swollen storage root [38]. Infected seeds become black or grey. Transmission of *A. japonica* occurs from infected seeds and plant debris or conidia produced in wet conditions [39]. Other hosts of *A. japonica* are cauliflower, cabbage, wild and cultivated rocket [34]. A more or less similar type of symptoms is produced by all species of *Alternaria* infecting this underground root crop [40].

In *A. raphani*, the lesions are nearly circular often zonate and show various shades of brown or black coloration. The fungus also causes leaf spots on the plants kept for seeds [41]. It has been observed that when foliage is infected, the roots also get affected which results in the reduction of the number and size of roots [42]. A rot of turnip in storage has been described by Chupp and Sherf [13]. Narain and Saxena [27] reported *A. raphani* to be associated with turnip whereas, Agarwal [43] recorded *A. brassicae* on this host causing the more or less similar type of symptoms as on other cole crops caused by this pathogen.

**Knol khol:** This root vegetable included in the cole crop also is used raw or uncooked and in cooked form also and tender leaves are utilized as greens. In this vegetable crop, two species of *Alternaria* may be attributed to causing leaf spot and blight. They are *A. brassicicola* and *A. brassicae*. The symptoms produced by these two pathogens overlap to some extent and the pathogens may attack simultaneously but even there are some distinctions in symptoms. Like in other cole crops, the leaf spots due to *A. brassicicola* are dark brown to black, circular, varying from 4-10 mm in size, and are surrounded by dark concentric zonations. More severe occurrence of disease may be noticed in seed crops of knol khol. Severely infected leaves lastly dry up and may fall prematurely. The spots incited by *A. brassicae* have much in common with that of *A. brassicicola*. They are mostly smaller and also lighter in color having distinct concentric zonations and 'yellow halo' appearance [44]. Both the pathogens are seed-borne and may cause low germination [23].

*Alternaria* spp. associated with Brassicaceous oilseed (oleiferous) crops

**Rapeseed and mustard:** Four species viz., *A. brassicae* [45], *A. brassicicola* [46], *A. raphani* [47] and *A. alternata* [48] parasitize the oleiferous crops like rapeseed, mustard, and raya causing the characteristic leaf spots and blight, lesions on stems, branches and petioles, inflorescence and siliquae. A comparative study of disease symptomatology and etiology has been made with the ultimate aim to develop a most suitable and feasible key and correct identification of *Alternaria* spp. allied with oil-yielding crops of Brassicaceae.

#### Symptomatology

The symptoms caused by four species of *Alternaria* on Oleiferous crops are as follows:

(i). *Alternaria brassicae*: Symptoms start from the margin of leaves or at the tip and spread inward and downward accordingly. The dark brown, irregular spots are accompanied by a characteristic "yellow halo" appearance and have distinct zonation, which gradually increases in size in a concentric manner. The spots may coalesce to form larger areas [49]. The well-developed spots are covered with a dark olive-green mass of the fungal spores with a shot-hole appearance (Fig 2a).



Fig 2a Symptom of (i) dark brown (ii) yellow halo of *Alternaria brassicae* on the oleiferous crop (enlarged view)

(ii) *Alternaria brassicicola*: The leaf spots due to this pathogen are circular to elliptical and olivaceous in color which vary from 4-12 mm in size with clear distinct zonations. In severe infection, several lesions coalesce to cover a large area and cause drying and death of leaves. The young and actively developing leaves are almost free from the disease or may have small necrotic areas. The severely infected leaves show a burning effect, which ultimately dries up and may fall prematurely (Fig 2b).

(iv). *Alternaria alternata* in this case symptoms initially appear to produce minuscule, dark brown patches which start from the margin or center of the leaf, and at a later stage of disease development, a number of spots coalesce to form the irregular dark brown spots (Fig 2d).

(iii). *Alternaria raphani*: The spots are brown to dark brown in patches starting from margin of leaves, developing inwards, in irregular fashion. The spots are circular to irregular in appearance, dark brown with indistinct zonations on both surfaces of leaves. The affected areas soon turn blighted and wither. Necrotic lesions also appear on petioles, branches, stems and siliquae (Fig 2c).





Fig 2b Symptom of *Alternaria brassicicola* on the oleiferous crop (enlarged view)

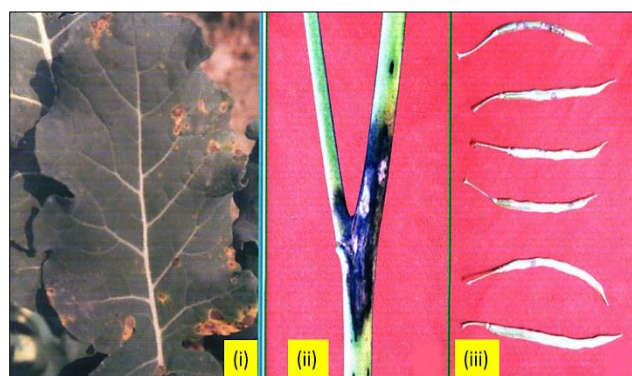


Fig 2c Symptom of *Alternaria raphani* on (i) leaf and (ii) stem (iii) siliquae of the oleiferous crop (enlarged view)



Fig 2d Symptom of *Alternaria alternata* on the oleiferous crop (enlarged view)

It has been observed that the lesions coalesce rapidly and cause premature ripening and splitting of siliquae and may result in a high level of seed infection. Infected seeds are shrunken, discolored, or covered with fungal growth and have low quality. Cankers may form just below the inflorescence which may result in the premature death of plants. Under such a situation, there is a great loss not only in yield but also in the quantity and quality of oil contents [50].

#### *Alternaria* spp. associated with Brassicaceous ornamental plants

A comprehensive study on leaf spot diseases of ornamental plants was made by Bilgrami in [51]. Later, Sohi [52] carried out some investigations on important diseases of ornamental plants. Chakrabarti *et al.* [53], Singh *et al.* [54] made an exhaustive study on diseases of ornamental plants caused by different entities including the species of *Alternaria*. A number of ornamental plants are also utilized for medicinal purposes [55] and have been found to be infected by some species of *Alternaria* [16].

#### Symptomatology

(i). *A. brassicae*: On stock (*Matthiola incana*) due to infection of *A. brassicae*, the leaves become pale greyish green with concentric zonations and the center becomes dark brown to black with sporulations [56].

(ii). *A. raphani* causes symptoms almost similar to those as described on radish and turnip. On candytuft (*Iberis amara*) there is the involvement of two species of *Alternaria* in the causation of the leaf spot disease. The symptoms due to *A. brassicae* are circular in shape, small in size, and dark brown with distinct concentric zonations.

(iii). *A. cheiranthi*: The leaf spots produced by *A. cheiranthi* only on wallflower (*Cheiranthus cheiri*) appear in the beginning as small dots, scattered on leaf surfaces. The mature spots are variable in size, 2-8 mm in diameter, dark brown with yellow margins and distinct zonations, and abundant sporulation [57]. The fungus is known to survive in seed and soil [58].

(iv). *A. raphani*: *Lepidium* (*Lepidium sativum*), an annual ornamental plant was observed to be affected only by *A. raphani* in which the spots are scattered, brown to dark brown in appearance with the formation of indistinct zonations [59] whereas in case of, the spots are irregular in appearance, light brown with indistinct zonation and profuse sporulation [28].

In general, all the pathogens produce leaf spots mostly circular or irregular in shape and turn light to dark brown in color with slight distinct zonations with or without "halo" [8]. The symptoms caused by different species of *Alternaria* on different Brassicaceous hosts have close resemblance with that described by Changsri and Weber [22], Walker [12], Ellis [45-46], Narain and Saksena [27], Atkinson [41], Narain [44], Gupta and Basuchaudhary [26], Meena *et al.* [60].

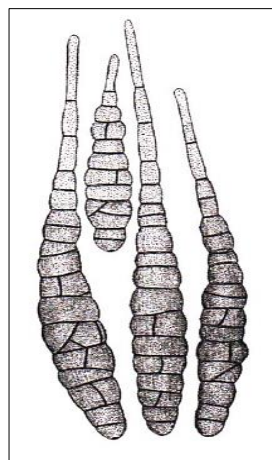
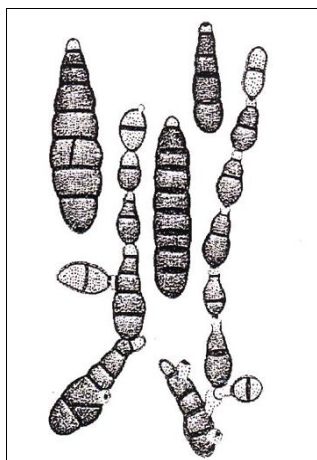
#### Comparative symptomatology of *Alternaria* diseases on Brassicaceous hosts

The comparative pathogenicity and symptom of *Alternaria* spp. occurring on Brassicaceous hosts plant part has been presented in (Table 2). The symptoms caused by different species of *Alternaria* on different Brassicaceous hosts have close resemblance as described by Walker [12], Changsri and Weber [22], Narain and Saksena [27], Narain *et al.* [5], Narain [28], Gupta and Basuchaudhary [26], Chand *et al.* [24].

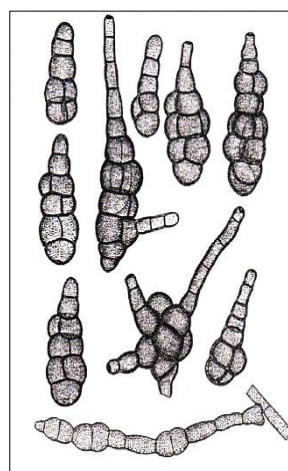
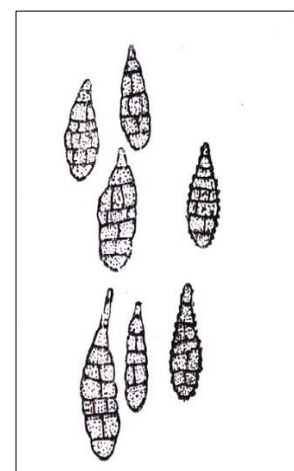


Table 2 Comparative symptomatology of *Alternaria* diseases occurring on Brassicaceous hosts plant part

Symptoms	<i>Alternaria brassicae</i>	<i>Alternaria brassicicola</i>	<i>Alternaria raphani</i>	<i>Alternaria alternata</i>	<i>Alternaria cheiranthi</i>	<i>Alternaria japonica</i>
Leaves	Spots dark brown to black with halo chlorotic tissues, 0.5 to 12mm in diameter and in a concentric circle.	Numerous, dark brown to black spots, 4-10 mm in diameter, zonate, lesions with sooty black appearance.	Spots dark brown or black, 3-8 mm in size, raised with distinct or indistinct zonations.	Spots minute to large, dark brown, often coalescing to form irregular dark brown patches.	Spots are minute to large, almost circular, scattered on the leaf surfaces, with distinct zonations and abundant sporulation.	On leaves dark, water-soaked spots later on black or grey sunken leaf spots with yellow border
Stems	The dot like linear or elongated lesions.	Spots/lesions numerous, dark brown to black.	Lesions dark brown to black, in a linear manner.	Lesions are dark brown and elongated.	Lesions variable in size, dark brown in color.	Black, linear sunken lesions which cause "damping off"
Siliquae	Linear, elongated or dot-like lesions, without concentric rings.	The appearance of minute dark brown to black spots.	Irregular brown to black lesions.	Lesions coalescing and splitting type.	-	Irregular brown to black lesions
Heads/ Inflorescence	Dark brown spots in the beginning increase in size with sporulation.	Spots brown to black in color with a sooty appearance.	Spots are dark brown to black in color.	Cankers may form just below on nearly mature heads.	Spots are dark brown to black in color.	Spots/lesions scattered, brown to black in color
Roots	-	-	Black patches	-	-	Black sunken lesions on swollen storage roots

Fig 3a Conidiophores of *Alternaria brassicae* (x650) (Ellis 1971)Fig 3c Conidiophores of *Alternaria brassicicola* (x650) (Ellis 1971)

slightly curved, obclavate, rostrate with 5-10 transverse and 0-8 longitudinal or oblique septa, olive or greyish olive, 40-150 x 15-30 µm in size; *Beak* usually pale brown, short, cylindrical, 10-130 µm in length and 3-8 µm in width (Fig 3a).

Fig 3d Conidiophores of *Alternaria raphani* (x650) (Ellis 1971)Fig 3e Conidia of *Alternaria alternata* (x650) (Ellis 1971)

#### Characteristic of *Alternaria* spp. associated with Brassicaceous hosts

The formation of massive, multicellular, melanized conidia with longitudinal and transverse septa (phaeodictyospores) is a fundamental taxonomic trait of the genus *Alternaria*. The broadest part of these conidia is towards the base, and they progressively taper to an extended beak, giving them a club-like look. On short, erect conidiophores, conidia are generated in single or branched chains. The most distinguishing characters of various species of *Alternaria* associated with Brassicaceous hosts are-

##### (i). *Alternaria brassicae* (Berk.) Sacc.

*Conidiophores* in groups (2-10), usually simple, erect, geniculate, septate, greyish to olive, 15-150 x 5-10 µm in size; *Conidia* solitary or occasionally in chains of 3-4, straight or

##### (ii). *Alternaria brassicicola* (Schw.) Wiltshire

*Conidiophores* singly or in groups (2-12), occasionally geniculate, cylindrical, septate, pale to mild olivaceous brown, 20-75 x 4-8 µm; *Conidia* mostly in chains of up to 20 or more, usually tapering slightly towards apex, obclavate, basal cell round, apical rectangular or as truncate cone with 2-10 cross and 0-6 longitudinal septa, pale to dark olivaceous brown, 20-120 7-25 µm in size; *Beak* usually non-existent (Fig 3b).

##### (iii). *Alternaria raphani* Groves and Skolko



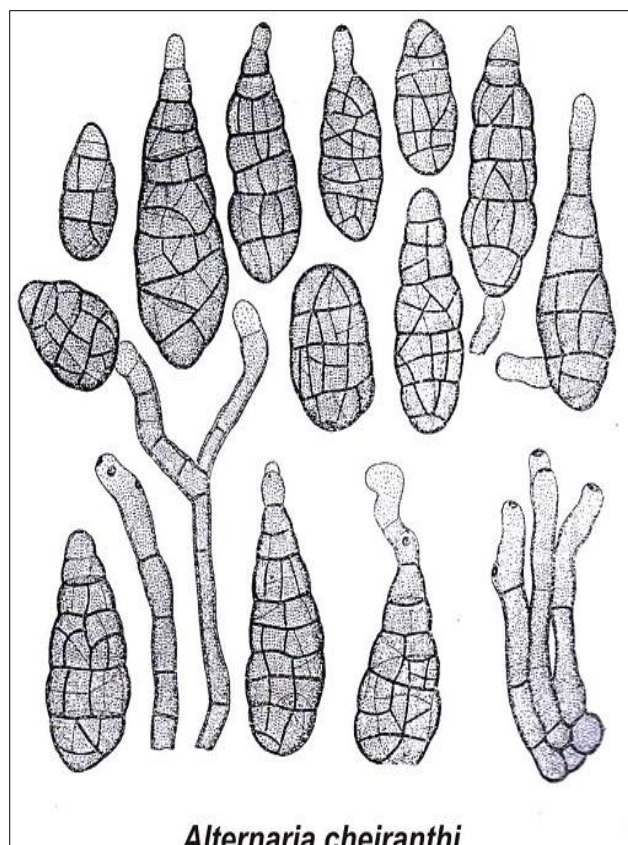


Fig 3g Conidia of *Alternaria cheiranthi* (x650) (Ellis 1971)

*Conidiophores* are simple or occasionally branched, septate, olivaceous brown, 2.5-8.0x25-150  $\mu\text{m}$  in size; *Conidia* in chains (3-4), obclavate or ellipsoidal, dark golden brown to

olivaceous brown, with 3-7 transverse and often a number of longitudinal or oblique septa, and 20-60  $\mu\text{m}$  long and 10-30  $\mu\text{m}$  thick; *Beaks* of conidium smaller than that of *A. brassicae*; formation of *chlamydospores* in chains or in groups (Fig 3d).

(iv). *Alternaria alternata* (Fr.) Keissler

*Conidiophores* singly or in groups, simple, septate, straight, geniculate, pale to mid olivaceous brown, 24.5-68.5 x 3.50-7.25  $\mu\text{m}$  in size; *Conidia* formed in long and often branched chains, varying in shape and sizes, dark brown, smooth to verruculose, 8.50-53.50 x 5.0-21.50  $\mu\text{m}$  in size; *Beaks* usually short, conical or cylindrical but never equal in length of conidium, often one third or half of the spore body, usually lighter in color, 10-45.5  $\mu\text{m}$  in length and 1.5-6.5  $\mu\text{m}$  in width (Fig 3e).

(v). *Alternaria cheiranthi* (Libert) Wiltshire

*Conidiophores* dark olive-buff to buffy brown, septate, singly or in groups, mostly simple but branched also, 25-153 x 3.5-8.0  $\mu\text{m}$  in size; *Conidia* singly or in the chain (3-4), light olive to a golden brown, oval to ellipsoidal or elongated, ovoid to pyriform often with rounded base, with 4-12 cross and 2-10 longitudinal septa, 15-95x10.5-25.0  $\mu\text{m}$  in size; *Beaks* often of the same color of spore body, 4.5-45  $\mu\text{m}$  in length and 3.0-7.5  $\mu\text{m}$  in width with 0-3 cross septa and prominent scars (Fig 3f).

(vi). *Alternaria japonica* Yoshii

*Conidiophores* are simple or occasionally branched, septate, 55-60 x 5x6  $\mu\text{m}$  in size; *Conidia* long, ellipsoid or long ovoid with a rounded apical cell without a distinct apical beak, 80-100 (55-70) x 20-30 (18-22)  $\mu\text{m}$  in size with 3-7 transverse and 1-3 longitudinal septa; *Beak* rudimentary; *Chlamydospores* usually formed in culture (Fig 3h).

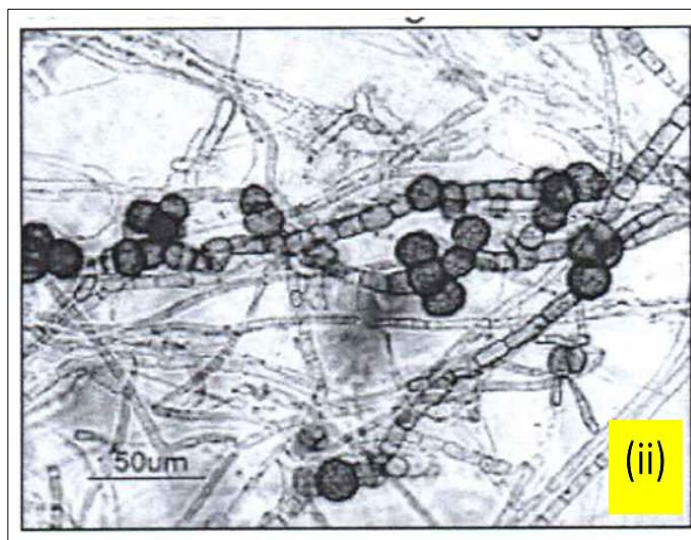
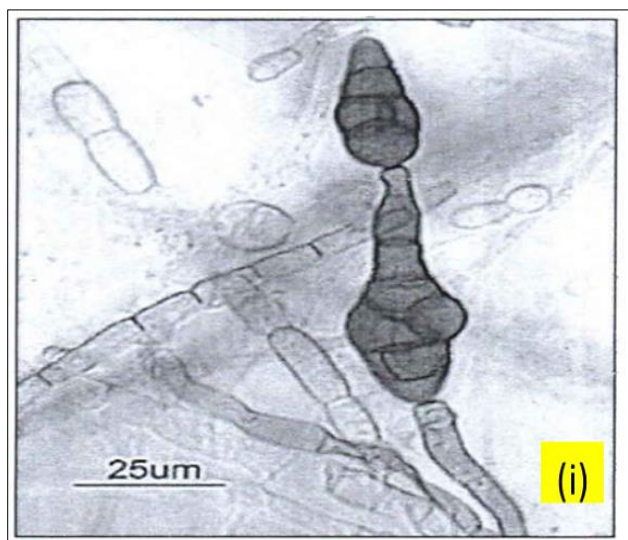


Fig (3h) *Conidia* of *Alternaria japonica* (i) Chain of conidia (ii) Chlamydospores (enlarged view)

*Comparative variation in Conidial morphology of Alternaria spp. infecting Brassicaceous hosts*

On the basis of conidial morphological observations of all the six species of *Alternaria* in culture (PDA) as well as in nature (host) and their comparative variation [16] [20], [61] are mentioned in (Table 3). In nature, *A. brassicae* conidia are much longer and have long genuine beaks, and they are generated individually on the conidiophores. *A. brassicicola* produces conidia in longer chains without beaks [62]. *A. raphani* and *A. japonica* are known to frequently produce chlamydospores in culture. In *A. raphani* conidia are with short

beaks whereas in *A. japonica* the conidia are with bluntly rounded apical cells rather beakless [63-64].

*A. alternata* and *A. cheiranthi* are quite different in morphological characters from the species associated with crucifers [5]. Conidia of *A. alternata* are produced in long chains with short conical or cylindric beaks, polymorphic and universal in nature while in *A. cheiranthi*, conidia are produced in short-chain (2-3) with a short beak and have a greater number of both cross and longitudinal septa and being confined only to wallflower (*Cheiranthus cheiri*). This fungus has been reported from India by [44].



Table 3 Conidial variation of *Alternaria* species infecting Brassicaceous hosts

Morphological characters	<i>Alternaria brassicae</i>	<i>Alternaria brassicicola</i>	<i>Alternaria raphani</i>	<i>Alternaria alternata</i>	<i>Alternaria cheiranthi</i>	<i>Alternaria japonica</i>
Conidiophores	Mid-pale greyish to olive, simple, erect, swelling at base, geniculate, septate.	Pale mid olivaceous brown, simple, septate, erect or curved.	Olivaceous brown, simple or occasionally branched, septate.	Olive brown, erect, simple, and septate.	Pale olive with scars produced singly or in groups.	Olivaceous brown, simple or occasionally branched. Septate
Length	15-150 µm	20-75 µm	25-150 µm	24.5-68.5 µm	25-153 µm	55-60 µm
Width	5-10 µm	4-8 µm	2.5-8 µm	3.50-7.25 µm	3.5-8 µm	5 - 6 µm
Conidia						
Conidia in chain	Solitary or occasionally up to 4	Up to 20 or more	Up to 3-4	Up to 20 or more	Solitary or 2-3 in chains	In short chains of 2 to 3
Shape	Obclavate rostrate	Obclavate	Obclavate or ellipsoidal	Polymorphic	Oval to ellipsoidal	Ovoid to ellipsoid
Color	Olive or greyish olive	Pale to dark olivaceous brown	Golden brown to olivaceous	Dark brown	Dark brown	Light brown or mid-brown
Cross-septa	5-10	2-10	3-7	3-10	4-12	3 – 8
Longitudinal septa	0-8	0-6	0-5	0-8	2-10	1 – 3
Length	40-150 µm	20-120 µm	20-60 µm	8.5-53.5 µm	15-95 µm	80 - 100 µm
Width	15-30 µm	7-25 µm	10-30 µm	5.0-21.50 µm	10.5-25 µm	20 - 30 µm
Beak						
Length	10-130 µm	Non-existent	5-75 µm	10-45.5 µm	4.5-45 µm	Without a distinct apical beak
Width	3-8 µm	-	2.5-6.0 µm	1.5-6.5 µm	3.0-7.5 µm	-
Cross-septa	0-5	-	0-3	0-3	0-3	-
Chlamydospores	-	-	Thick-walled, in chain or groups	-	-	Dark thick-walled, multicellular

**Key to identify *Alternaria* spp. parasitic on Brassicaceous hosts**

Based on the cultural and morphological characters of all the six species of *Alternaria*, a very simple and feasible key has been framed for ready identification of *Alternaria* spp. associated with Brassicaceous oilseeds, vegetables, cole crops, herbage, and ornamental plants [65]. Joly [66] has also emphasized the need and importance of framing of a key of most common species of *Alternaria*.

- I. Conidia solitary or occasionally 3-4 in chains, obclavate, rostrate, tapering gradually into thick cylindric beaks..... *A. brassicae*
- II. Conidia in long chains, consisting of twenty or even more:
  - (a) Conidia usually cylindrical, basal cells rounded and apical cell more or less rectangular and beaks usually almost non-existent..... *A. brassicicola*
  - (b) Conidia usually variable in shape (polymorphic), often with short conical or cylindrical short beaks ..... *A. alternata*
- III. Conidia 3-4 in chains, straight or curved, obclavate or ellipsoidal, generally with short beaks:
  - (a) Conidia with a limited number of cross and longitudinal-septa, chlamydospores formed abundantly in culture ..... *A. raphani*

- (b) Conidia with numerous cross and longitudinal septa, without chlamydospore formation in culture ..... *A. cheiranthi*
- IV. Conidia small, with a rounded apical cell and without a distinct beak, chlamydospores formed in culture ..... *A. japonica*

**CONCLUSION**

*Alternaria* is a fungus genus including saprobic, endophytic, and pathogenic species found all over the world. They are notorious plant diseases, wreaking havoc on a wide range of crops. The symptoms and characteristics of *Alternaria* species on brassicaceous vegetables, oleiferous crops, and ornamental plants have been discussed in this article. It has been severely harmed by the attack of six well-known *Alternaria* species viz: *A. brassicae*, *A. brassicicola*, *A. raphani*, *A. japonica*, *A. alternata*, and *A. cheiranthi*. *A. brassicae* is the most harmful and appears most frequently among them, and it is the representative species infecting Brassicaceous hosts. On Crucifers, *A. raphani*, *A. japonica*, and *A. brassicicola* have been found on every continent. *A. cheiranthi* is a wallflower pathogen, while *A. alternata* is a common fungus that infects broccoli (cole crop) and radish (root crop). *Alternaria* blight is



one of the most common diseases of cole crops, and it is caused by four *Alternaria* species: *A. brassicae*, *A. brassicicola*, *A. raphani*, and *A. japonica*, the first two of which are global pathogens. *Alternaria* symptoms on oleiferous crops include lesions that consolidate quickly, causing premature ripening and splitting of siliquae, as well as a high level of seed infection. Seeds that have been infected are withered, discolored, or coated in fungal growth, and are of poor quality. Cankers can occur right below the inflorescence, causing plants to die prematurely. There is a significant decrease in yield, as well as the amount and quality of oil content, in such a condition. All infections cause leaf spots on ornamental plants that are typically circular or irregular in shape, light to dark brown in color, and have slight distinct zonations with or without "halo." All six *Alternaria* species may be easily taxonomically classified based on conidial morphological observations because they generate massive, multicellular, dark-colored conidia with longitudinal and transverse septa. Conidia are generated in single or branched chains on short, erect

conidiophores and conidia are broadest towards the base and progressively taper to an elongated beak, giving them a club-like look that is unique to *Alternaria* species.

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#### Conflicts of interest

The authors declare no conflict of interest.

#### Declaration

This is to certify that we, the following authors of this Review have contributed and have gone through the manuscript. We also declare that this article has not been submitted for publication in any Research Journal.

### LITERATURE CITED

- Dang HX, Pryor B, Peever T, Lawrence CB. 2015. The *Alternaria* genomes database: A comprehensive resource for a fungal genus comprised of saprophytes, plant pathogens, and allergic species. *BMC Genomics* 16: 239.
- Saharan SG, Naresh M, Meena PD. 2016. *Alternaria* Diseases of Crucifers: Biology, Ecology and Disease Management. doi:10.1007/978-981-10-0021-8.
- Blagojević JD, Vukojević JB, Ivanović ŽS. 2020. Occurrence and characterization of *Alternaria* species associated with leaf spot disease in rapeseed in Serbia. *Plant Pathology* 69(5): 883-900.
- Meena M, Gupta SK, Swapnil P, Zehra A, Dubey MK, Upadhyay RS. 2017. *Alternaria* toxins: potential virulence factors and genes related to pathogenesis. *Frontiers in Microbiology* 8: 1451.
- Neergaard P. 1945. *Danish species of Alternaria and Stemphylium*: Taxonomy, parasitism and economic significance. Oxford University Press, London. pp 560.
- Rao BR. 1977. Species of *Alternaria* on some Cruciferae. *Geobios* 4: 163-166.
- Sangwan MS, Mehta N. 2007. Eco-friendly management of diseases of rapeseed and mustard. In: *Eco-friendly management of plant diseases*. (Eds) Ahmad, Shahid and Narain, U., Daya Publishing House, Delhi. pp 416-427.
- Chahal AS, Kang MS, Chauhan JS. 1977. *Alternaria* blight: A serious disease of rapeseed and mustard. *Progressive Farming* 12: 21-22.
- Chahal AS. 1981. Seed-borne infection of *Alternaria brassicae* in Indian mustard and its elimination during storage. *Current Science* 50: 621-623.
- Kadian AK, Saharan GS. 1983. Symptomatology, host range, and assessment of field loss due to *Alternaria brassicae* infection in rapeseed and mustard. *Indian Jr. Mycol. Pl. Pathology* 13(3): 319-323.
- Kadian AK, Saharan GS. 1984. Studies on spore germination infection of *Alternaria brassicae* of rapeseed and mustard. *Jr. Oilseeds Research* 1: 183-188.
- Walker JC. 1952. *Diseases of Crucifers*. In: *Diseases of vegetable crops*. McGraw Hill Book Co. New York. pp 150-152.
- Chupp C, Sherf AF. 1960. *Crucifer Diseases*. In: *Vegetable diseases and their control*. Ronald Press Company New York. 8: 237-288.
- Singh RS. 1999. *Diseases of Vegetable Crops*. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.
- Ansari NA, Khan MW, Muheet A. 1990. Host-range of *Alternaria brassicae*. *Acta Botanica Indica* 18: 104-105.
- Narain U, Kant S. 2008. Diversity of species and parasitism in the genus *Alternaria*. *Applied Botany Abstracts* 28: 272-281.
- Narain U, Kant S, Chand G. 2016. Characterization of species and parasitism in the genus *Alternaria*. In: *Crop diseases and their management: Integrated approaches*. Apple Academic Press, Canada. pp 385-404.
- Ellis MB. 1971. *Dematiaceous hyphomycetes*. Commonwealth Mycological Institute, Kew, England. pp 464-497.
- Verma PR, Saharan GS. 1994. Monograph on *Alternaria* diseases of crucifers. *Research Branch Technical Bulletin* 1994, Saskatoon Research Centre, Canada.
- Wiltshire SP. 1947. *Alternaria* on Brassicae. Imp. Mycol. Inst. Mycol. Paper. pp 20.
- Joly P. 1959. Morphological variation and idea of species in the genus *Alternaria*. *Bull. Soc. Mycology* 75: 149-158.
- Changsri W, Weber GD. 1963. Three *Alternaria* species pathogenic on certain cultivated crucifers. *Phytopathology* 53: 643-648.
- Groves JW, Skolko AJ. 1944. Notes on seed-borne fungi-II. *Alternaria*. *Can. Jr. Res. Sect. C.*, 12: 217-234.
- Chand G, Narain U, Kumar M, Verma S. 2007. Symptomatology, etiology, and eco-friendly management of *Alternaria* leaf spots and blight of broccoli. In: *Eco-friendly management of plant diseases*. (Eds) Ahmad, Shahid, and Narain, U. Daya Publishing House, Delhi. pp 461-472.
- Thomas P. 1984. *Alternaria* black spot (grey leaf spot). In: *Canola Growers Manual*. Canola Council of Canada, Winnipeg, Manitoba, Canada. pp 1056-1058.
- Gupta DK, Basuchaudhary KC. 1992. Occurrence and prevalence of *Alternaria* species in crucifers grown in Sikkim. *Indian Jr. Hill Farming* 5: 129-131.
- Narain U, Saxena HK. 1975. A new leaf spot of turnip. *Indian Phytopathology* 28: 98-100.



28. Narain U, Singh J, Koul AK. 1982. Leaf spot of candytuft caused by *Alternaria raphani*. *Nat. Acad. Sci. Letters* 5: 13.
29. Suhag LS, Singh R, Malik YS. 1985. Epidemiology of pod and leaf blight of radish caused by *Alternaria alternata*. *Indian Phytopathology* 38: 148-149.
30. CABI. 2002. *Alternaria japonica*. Distribution Maps Plant Diseases, No. 862. Wallingford, U.K. International.
31. Yoshii H. 1941. On the black spot of Asiatic crucifers and the black mold of cabbage. *Jr. Plant Protection* 28: 14-18.
32. Tohyama A, Tsuda M. 1990. *Alternaria* on cruciferous plants. Identity of *Alternaria japonica* and *A. raphani*. *Trans. Mycol. Soc. Japan* 31: 501-509.
33. Valkonen JPT, Kaponen H. 1990. The seed-borne fungi of Chinese cabbage (*Brassica pekinensis*), their pathogenicity and control. *Plant Pathology* 39: 510-516.
34. Siciliano I, Gilardi G, Ortu G, Gisi U, Gullino ML, Garibaldi A. 2017. Identification and characterization of *Alternaria* species causing leaf spot on cabbage, cauliflower, wild and cultivated rocket by using molecular and morphological features and mycotoxin production. *European Jr. Plant Pathology* 149(2): 401-413.
35. Su XJ, Yu H, Zhou T, Lix-Z, Gong J, Chu CL. 2005. First report of *Alternaria raphani* causing black patches on Chinese radish during post-harvest storage in Canada. *Plant Disease* 89: 1015.
36. Narain U, Kushwaha A, Prasad R, Ved R. 2020. Symptomatology and etiology of Alternariose in root, fruits and leafy vegetables. In: *Diseases of fruits and vegetable crops*. (Eds.) Chand, G., Akhtar, M.N. and Kumar, S. Apple Academic Press, USA. pp 461-487.
37. Ren XX, Zhang GZ, Dai WA. 2012. First report of damping-off caused by *Alternaria japonica* on Chinese cabbage seedlings in China. *Plant Disease* 96 (9): 1378.
38. Bassimba DD, Mira JL, Vincent A. 2013. First report of *Alternaria japonica* causing a black spot of turnip in Spain. *Plant Disease* 97(11): 1505.
39. Gilardi G, Demarchi S, Ortu G, Gullino ML, Garibaldi A. 2015. Occurrence of *Alternaria japonica* on seeds of wild and cultivated rocket. *Jr. Phytopathology* 163(5): 419-422.
40. Bessadat N, Hamon B, Bataille-Simoneau N, Marboub K, Simoneau P. 2020. *Alternaria telliensis* sp. nov., A new species isolated from *Solanaceae* in Algeria. *Phytotaxa* 440(2): 89-100.
41. Atkinson RG. 1950. Studies on parasitism and variation of *Alternaria raphani*. *Can. Jr. Res. Sect. C* 18: 288-317.
42. Cotty PJ, Alcorn SM. 1984. *Alternaria raphani* on turnip. *Plant Disease* 68: 732.
43. Agarwal DK. 1985. New host records of *Alternaria* from India. *Indian Phytopathology* 38: 392-393.
44. Narain U. 1986. Studies on *Alternaria* spp. associated with leaf spots of Crucifers in India. *Adv. Biol. Res.* 4(1/2): 187-191.
45. Ellis MB. 1968. *Alternaria brassicae*. Description of pathogenic fungi and bacteria. No. 162, Commonwealth Mycological Institute, Kew, England.
46. Ellis MB. 1968b. *Alternaria brassicicola*. Description of pathogenic fungi and bacteria. No. 163, Commonwealth Mycological Institute, Kew, England.
47. Gorves JW, Skolko AJ. 1944. Notes on seed-borne fungi: II. *Alternaria*. *Canadian Journal of Research* 22C(5): <https://doi.org/10.1139/cjr44c-018>
48. Prasad R, Narain U. 2007. Integrated management of Alternaria blight of rapeseed and mustard: An overview. In: *Eco-friendly Management of Plant Diseases*. (Eds) Ahmad, Shahid and Narain, U., Daya Publishing House, Delhi. pp 201-214.
49. Gupta K, Saharan GS, Mehta N, Sangwan MS. 2004. Identification of pathotypes of *Alternaria brassicae* from Indian mustard [*Brassica juncea* (L.) Czern. and Coss]. *Jr. Mycol. Plant Pathology* 34: 15-19.
50. Degenhardt KJ, Skoropod WP, Kondra ZP. 1974. Effects of Alternaria black spot on yield, oil content and protein content of rapeseed. *Canadian Jr. Pl. Sciences* 54: 795-799.
51. Bilgrami KS. 1963. Leaf spot disease of some ornamental plants. *Proc. Nat. Acad. Sci., India* 33B: 429-452.
52. Sohi HS. 1992. *Diseases of Ornamental Plants in India*. Publications and Information Division, Indian Council of Agricultural Research, New Delhi.
53. Chakrabarti DK, Kumar S, Chand G. 2010. *A Guide Book for Diseases of Horticultural Crops*. Narendra Publishing House, Delhi. pp 30-47.
54. Singh VK, Singh Y, Kumar P. 2012. Diseases of ornamental plants and their management. In: *Eco-friendly Innovative Approaches in Plant Disease Management*. International Book Distributors, Dehradun. pp 543-572.
55. Chadha KL. 1995. *Advances in Horticulture, Medicinal and Aromatic plants*. Vol. 11, Malhotra Publishing House, New Delhi.
56. Davis LH, Sciaroni RH, Pritchard F. 1949. Alternaria leaf spot of garden stock in California. *Plant Dis. Reporter* 33: 432-433.
57. Narain U, Singh J. 1981. Alternaria leaf spot of Cheiranthus from India. *Nat. Acad. Sci. Letters* 4: 3-4.
58. Nasr IA. 1973. Survival of *Alternaria cheiranthi* in soil. *Plant and Soil* 38: 203-208.
59. Singh RS, Upadhyay. 1971. Alternaria leaf disease of *Lepidium sativum*. *Indian Phytopathology* 24: 621-622.
60. Meena PD, Awasthi RP, Chattopadhyay C, Kolte SJ, Kumar A. 2010. Alternaria blight: a chronic disease in rape-seed mustard. *Jr. Oilseed Brassica* 1(1): 1-6.
61. Mehta N, Sangwan MS, Srivastava MP. 2003. Morphological and pathological variations in rapeseed and mustard isolates of *Alternaria brassicae*. *Indian Phytopathology* 56: 188-190.
62. Tewari JP, Buchwaldt L. 2007. Alternaria diseases. In: (Eds.) Rimmer, S.R., Shattuck, V.I. and Buchwaldt, L. *Compendium of Brassica Diseases*, St. Paul Minn. USA: American Phytopathological Society. pp 15-18.
63. Joly P. 1964. *Le Genre Alternaria*. Editions Paul Lechevalier Paris. pp 150.
64. Chalkley D. 2020. Invasive Fungi: Alternaria leaf spot of cole crops- *Alternaria japonica*. [Systematic Mycology and Microbiology Laboratory. ARS USDA from/sbmlweb/fungi/index.cfm.
65. Narain U, Kant S, Chand G. 2016. Characterization of species and parasitism in the genus. *Alternaria*. Crop Diseases and Their Management: Integrated Approaches. (Eds) Chand, G., Kumar, S. pp 385-391.
66. Joly P. 1967. Key for determination of most common species of *Alternaria* (Nees) Wilts. Emend Joly. *Plant Disease Reporter* 51: 296-298.