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**REVIEW PAPER**

# Alternaria Leaf Spot Disease as a Key Constraint to Kale Production: A Review on Prospects for its Sustainable Management

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**ABSTRACT**

Kale is a green leafy vegetable that is rapidly gaining popularity in the entire world due to its nutritional richness. Its higher concentration of antioxidants and other health-benefiting compounds coupled with its industrial use, which has significantly increased in recent decades, compared to other vegetables, are some potential factors that have made many people interested in consuming it. Global kale production is reported to be globally hampered by Alternaria Leaf Spot diseases as one of the major biotic factors. This disease is not new but it has become more severe and worse in kale in recent years. This paper gives insights into the importance of kale, kale production requirements, biotic and abiotic constraints to kale production, Alternaria leaf disease, practices that contribute to increased disease severity, current ALS management and prospects for sustainable disease management approaches such as the utilization of biological, botanical and cultural and integrated management approaches.

**HIGHLIGHTS**

- Kale consumption provides the body with good quantities of vitamins C and K, fibre, antioxidants, iron, and many other important minerals besides improving the economy at country and individual farmer's level.
- Alternaria Leaf Spot (ALS) disease in kale significantly reduces the yield quality and quantity.
- ALS management by use of synthetic fungicides compromises both human and environmental health.
- The use of sustainable ALS management approaches can minimize the qualitative and quantitative yield losses caused by the disease.

**Keywords**: Efficacy, plant extracts, biocontrol, fungicides, pesticides, integrated disease management

Kale (*Brassica oleraceae var. acephala* D.C.) ($2n = 18$), sometimes referred to as "cabbage cousin" because of its ancestral relationship with cabbage, is a cool-season crop in the Brassicaceae family (Šamec *et al.* 2019). It is a hardy biennial crop with glacial green or blue-green, frequently finely split leaves, and an open growth style. The plant neither forms a head nor makes edible blooms; instead, the leaves grow upward from the rootstock. The term "kale" is

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Scottish and comes from the Latin and Greek words "coles" and "caulis. Kale cultivars come in a wide range of sizes and heights, as well as in the shape and colour of their leaves (Onyango and Onyango, 2002). Because of its many applications, kale has become more and more popular worldwide (Hahn *et al.* 2016; Ayaz *et al.* 2006). China is the world's highest kale producer and exporter with a 30% share worth $462.27 million, whereas the US comes at second position at 16% equivalent to $246.47 million (Xue and Revell, 2009).

Kale originated in the eastern Mediterranean and Anatolia, where it was first cultivated for food around 2000 B.C. (Maggioni *et al.* 2018). In contrast, around the fourth century B.C, flat-leaved and curly-leaved kinds of cabbage were grown in Greece. As a result, the Romans called these cultivars Sabellian kale, and they are also credited with giving rise to modern kale (Perry, 2018). In the 1600s, kale went from Canada to America (Dixon, 2007). By then, kale was a common crop in Croatia because of its low cultivation costs, convenience of use, and capacity to draw salt out of the soil. For most of the twentieth century, kale was mostly used as a decoration in the US; but, due to its high nutritional value, it gained popularity as a vegetable in the 1990s (Luczaj, 2012).

In Kenya, kale was first introduced by Europeans as a fodder crop when they arrived in the Kenyan Highlands, and it has since become a significant vegetable with high demand in the country where it has become a staple food. Kale leaves are used to make stews of all kinds and are consumed as green vegetables together with other dishes, particularly grains. Kale and collard leaves have significant nutritional content compared with other vegetables in the brassica family. The leaf yields produced in Kenya are still incredibly low, averaging 15 tons per hectare (Onyango and Onyango, 2002). Currently, kale is being grown in European countries like Scotland, Ireland, Germany, Netherlands, and Sweden for food and other uses such as decoration, especially in France where it is grown along the roadsides for beauty (Dixon, 2007).

Kale is regarded as a leaf vegetable that is high in nutrients since it is high in minerals like potassium, calcium, and magnesium as well as prebiotic-related carbs and vitamins A, C, and K. Together, these 17 vital elements found in kale provide around 10% of the daily intake (Pathirana *et al.* 2017; Thavarajah *et al.* 2016). According to Ngugi *et al.* (2022), kale is a lower-calorie vegetable that is rich in vitamins, minerals, and phytochemicals. Due to their higher antioxidant content than other vegetables, kales have attracted more public attention in recent decades. Many phytochemicals from plants that are present in kale tissue can minimize the risk of chronic problems in the body like cancer, diabetes, arthritis, and heart related issues (Zhang *et al.* 2012, 2015; Makhaik *et al.* 2021; Houston and Harper, 2008).

In the worldwide superfood markets, organic kale leaves are economically necessary for making the powder that is used to prepare nutritional supplements for many applications, including the food, beverage, pharmaceutical, and nutraceutical industries. To boost the nutritional value of processed food and beverages, such as smoothies and juices, kale powder is added. Furthermore, because of its excellent functional qualities, it is projected that the superfood industry will continue to see an enormous need for organic kale powder. World-leading food and medicine manufacturers tend to incorporate organic kale powder into their products due to its numerous health benefits. Organic kale also contains trace amounts of several elements (Khalid *et al.* 2021, 2022; Chweya 1985). These elements include $Ca^{2+}$, $K^{+}$, $Mg^{2+}$, $Fe^{2+}$, $Na^{2+}$, and $Zn^{2+}$. In addition, the ability to fight against bacteria and cancer in the body has been reported in kale and its products. According to Khalid *et al.* (2023), Das *et al.* (2022), and Szutowska *et al.* (2020), kale contains numerous bioactive phytochemicals for instance plant lipids have been extensively used as an important ingredient in the formulation of many functional foods. These include medium-chain triglycerides, oleic acid, carotenoids, phytosterols, fatty alcohols, and polyunsaturated fatty acids.

The global production of kale is reported to be hampered by biotic and abiotic factors. Kale is a crop grown in the cool season that grows ideal at temperatures between 18 and 24 °C during the day and between 4 and 7 °C at night (Banadyga, 1977). Non-elevated levels of carbon dioxide are another factor that contributes to the abiotic constraints, while insect pests like cabbage looper, aphids, and diamondback moths are among the biotic factors (Reddy and Hodges, 2000; Allen and Boote, 2000). Additionally, kale plants are susceptible to parasite and bacterial infections (Lema Márquez *et al.* 2008). Among the fungal diseases are powdery mildew, which is caused by *Erysiphe* spp., and damping off, which primarily affects kale seeds in nursery soils and affects kale seeds and seedlings. *Fusarium* spp, *Pythium spp*, *Rhizoctonia spp* and Alternaria leaf spot (black spot) inflicted by different *Alternaria species.*

Alternaria Leaf Spot is a destructive disease that infects kale, it has been reported to be the most devastating disease since it turns the leaves unmarketable and can lead farmers to lose up to 50% of their crop (Shahid *et al.* 2017). Alternaria leaf spot is a fungal infection that causes dark, grey patches to form on kale leaves. Kapoor (1999), states that the fungal infection is more common in damp weather. *Alternaria brassicicola* and or other species of Alternaria such as *A. alternata, A. brassicae,* and *A. arborescens* are responsible for causing ALS. Several ALS control techniques, that primarily use conventional pesticides, have been employed; however, documentation of the sustainable management approaches is lacking.

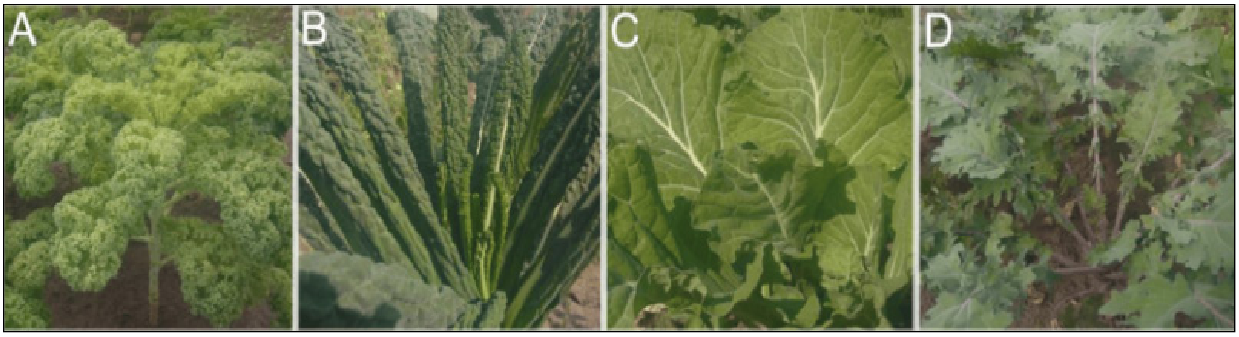
Therefore, this paper aims to provide highlights on the status and current management practices for ALS. Given the current world demand for sustainable plant disease management, the paper provides insights into sustainable ALS management for farmers and other stakeholders such as extension, pesticide manufacturers, police markers, and researchers.

## METHODOLOGY

For this literature review, information was gathered from a variety of databases. The majority of the databases used in this literature study originated from Google Scholar. Using keywords like "kale," "Alternaria leaf spot," and "management," the literature was searched. Legitimacy as peer-reviewed literature and suitability and pertinence to the goal of this investigation were taken into account while choosing to use the material. The snowball sampling strategy was used to gather more articles that were pertinent to this literature study. Finally, the titles, abstracts, and keywords were used to filter the articles. After removing duplicate articles, the eligibility of the remaining articles was evaluated.

### Kale Varieties

Studies on kale have reported that three kale cultivars can be distinguished, these include curly kales, Italian kales, Russian kales and collards (Figure 1). The most popular known cultivar in Europe especially in Northern Europe is the curly cultivar (*Brassica oleracea* convar. *acephala* var. *sabellica)* also known as the Scotch type. The second variety is Italian kale (*Brassica oleracea* convar. *acephala* var. *palmifolia*) also known as the Lacinato type. This variety is majorly cultivated in Tuscany but traditionally was cultivated in Italian cuisine. Collards (*Brassica oleracea* convar. *acephala* var. *viridis*) is mainly are cultivated in the United States. Collards resemble the wild and feral cabbages also known as "herbs of big leaves". The leaves of the collards are larger but also flat-roundish in shape. Another variety is Russian kale (Siberian type, *B. napus* var. *pabularia*), which is believed to have originated from the domestication of different species that are closely related (Hahn *et al.* 2016; Pelc *et al.* 2015; Farnham and Garrett, 1996; Farnham 1996; Branca *et al.* 2012; Christensen *et al.* 2011).




***Source:*** Hahn *et al.* (2022).

**Fig. 1:** Different cultivars/varieties of kale. Curly variety/Scotch type **(a)**, Italian/Lacinato kale type **(b)**, Collards **(c)** and Russian / Siberian kale **(d)**

## Ecological Requirements for Kale Production

Low temperatures of 5 to 21°C are ideal for kale's production (Munthali and Tshegofatso 2014). It is probably the most prominent cool-season crop (Dunsin, 2016). Though it can withstand frost and slightly alkaline soil, it grows best in fertile soil with good drainage, an optimal, pH range of 6.0 to 7.5 and adequate organic matter, and it can survive in a variety of ecological settings. Kale has to spend at least six hours a day in direct sunlight. It thrives in high, continuously wet soils, while some types of kale may withstand drought.

In terms of rainfall requirements, kale needs enough moisture at all times of the year. Therefore, an average rainfall of roughly 300-500 mm per year is adequate for the optimal crop yield. Therefore, a rainfall of roughly 300-500 mm per year is adequate for the optimal agricultural yield. But after the rainfall reduces, crop growth will require irrigation (Owino, 2019; Pathirana *et al.* 2017).

However, Gotame *et al.* (2018), and Gibson (2000) found that 40–50°F (4–21°C) is the optimal temperature range for kale growth. This crop, should be grown in both the spring and the fall. It was mentioned that because kale can withstand frost, it is referred regarded as a hardy plant. It is best to have the soil at between 12 and 24°C (55 and 75°F) for germination to take place. Kale seedlings should be placed outside or in a cold frame for future transplanting once the risk of a hard frost has gone. To guarantee that the plant matures in cold circumstances in time for the fall crop to be harvested, the sowing process must be carefully planned (Chowdhury *et al.* 2021).

Although it is commonly done in July, seeding in October may be achievable in warmer Southern locations. To get a ready-made plant, use nitrogen from composted manure or animal bone meal. Sow seeds 0.5 inches (12 mm) deep, allowing 3.5 cm (1 in) between each plant in the row, up to an ultimate row distance of 45–60 cm by remove any excess seedlings (18–24 in). Maintain moisture in the soil throughout the germination phase to avoid water deficit (Singh and Devi, 2015).

## Agronomic Requirements of the Kales

The techniques that apply to other Brassica crops also apply to kale. It is recommended that transplanting should be done on the same soil every three to four years and that kale should be alternated with other crops besides Brassicaceae. Although kale can be cultivated in a variety of soil types, the greatest results are obtained in deep, loamy, optimum pH soils, with good porosity (Filippo D'Antuono and Neri, 1997). Brassica plants assimilate a substantial amount of nitrogen. Consequently, applying a large amount of organic manure and deep plugs are the main techniques for preparing the soil (Gitari *et al.* 2016; Mwadalu *et al.* 2022). Applying nitrogen fertilizer to kale crops enhances their vegetation production and postpones their premature commencement (Gaskell and Grande, 2005; Hoyt *et al.* 2000; Onyango and Onyango, 2002; Yegon, 2019).

Kale plants are usually reproduced from seed. Strong taproots are first formed by the seedlings, and many lateral roots follow (Navazio, 2012). In warmer climates, planting seedlings at the end of summer or the start of autumn is customary. This enables the harvesting of edible leaves all winter long due to low temperature that promotes vernalization and thus early bolting. For a summer or fall crop, particular varieties can also be sown in the spring (Farnham and Garrett 1996). Furthermore, Hanna (2015) demonstrated that fresh kale is consistently offered for sale. Kale is an extremely common vegetable that is consumed widely in Europe, Asia, and the US. Its popularity has been rising recently. This might be the result of its low cost, ease of cultivation, and resistance to adverse conditions.

## Kale Production Constraints

Many factors, such as weed impediments and infertile soil, fall into the biotic and abiotic categories and limit Kenya's ability to produce kale for commercial use (Onyango and Onyango, 2002).

### 1. Abiotic constraints

Kale is a crop grown in the cooler months that thrives in temperatures between 18 and 24 °C in the daytime and 4 to 7 °C during the night. Kale is quite susceptible to elevated temperatures. Planning will therefore lessen the effects of stress and assist shield young plants from extremely high or low temperatures. Combinations of environmental stressors can sometimes make managing plants more difficult and have greater detrimental consequences on growth, productivity, and output (Banadyga 1977). Crop yields and growth of plants have been shown to be significantly impacted by higher levels of $CO_2$ in crops, which can counteract the potential effects of a warming climate. There have been few direct effects observed on kale plants, despite C3 plants having observed that an increase in $CO_2$ content results in a considerable rise in yield. Rather, insufficient research has been done to accurately anticipate future crop yield, much less the interplay of increasing $CO_2$, temperature, and UV-B (Reddy and Hodges, 2000; Allen and Boote, 2000).

## 2. Biotic constraints

Two caterpillars that are particularly drawn to the plant are the cabbageworm and the cabbage looper. Both like nibbling on the plant's leaves and will swiftly cause a plant to go barren if they are left unchecked. Aphids are an additional prevalent kale pest (Khalif, 2007). Aphids are other pests that targets kale plants; they can be any size or colour. In addition to turnips, cabbage, and other aphids, there are regular, everyday green aphids. All of the aforementioned several aphid species are fond of kale. By sucking the leaves for their juice, the pests cause deformity, stunting, and yellowing of the kale plants. In addition, the plant is susceptible to fungal and bacterial infections, both of which can be fatal (Gandhi and Mehta, 2011).

Alternaria Leaf spot is an infection that develops dark, grey areas on kale leaves are known as Alternaria leaf spot. According to Kapoor (1999), the prevalence of fungal infections is higher in wet weather. Camporota and Perrin (1998) state that another disease that mostly affects kale seeds and seedlings in nursery soils is damping off. Rhizoctonia species, Pythium species, and Fusarium species are the causes of this illness. An infected seedling will eventually rot and die, even though it prevents damaged seeds from germinating.

According to a study by Tariq-Khan *et al.* (2017), the kales are also infected by root-knot nematodes, which are microscopic parasitic organisms that reside in the soil and form enlargements or galls on plant roots. Plant vigour is reduced as a result, leading to crop retardation and ultimately crop death.

### 2.1 Alternaria Leaf Spot Disease

According to Scheufele (2013), Alternaria leaf spot (ALS) is a fungal disease that is characterized by the formation of tiny black spots on leaves, stems, and heads that enlarge into large lesions with distinctive concentric rings. Another study by Poursafar (2020), defined Alternaria leaf spots as elongated lesions that form on the seethe and petioles in dark brown colour which eventually change into grey as they mature. The lesions can form concentric rings and resemble borders of break and resemble borders of black and purple.

The leaf spots that form is always spherical, grey to black, a little larger than a quarter, and usually have a target pattern. The spots may seem velvety when the virus releases a large number of its black spores (Fox, 2015). The spores are dispersed by the wind, however, they often fail to spread very far because of their smaller size in comparison to the spores produced by the pathogens that cause powdery and downy mildew. Therefore, spread is unusual among farms that are close together but not next to each other. As they age, leaf spots usually become papery, dry, and brittle (Saharan *et al.* 2016). Fig. 2 shows the typical symptom of ALS on the kale leaf.

***Source:*** Rop *et al.* 2009.

**Fig. 2:** Kale leaf infected by Alternaria leaf spot disease

Furthermore, since this disease may survive in agricultural waste, Sharma (2004), indicated that it is imperative to disable crops as soon as possible after harvest. By pulverizing and incorporating waste from crops into the ground, its decomposition will be expedited. A three-year rotation is ideal. Leaf spot infections significantly reduce production both in terms of quality and quantity.

Dharmendra *et al.* (2014) revealed that shriveled seed, early pod shatter, rapid senescence and decreased photosynthetic capability as some of the losses caused by the disease. Alternaria leaf spot disease has significant negative effects on the global economy and may occasionally result in output declines of 20–50% in crops like kale. Black spot is another disease that Alternaria species produce. It manifests as rotting sores on plants. Usually black and sooty, the lesions are surrounded by chlorotic yellow haloes (Jagadeesh *et al.* 2022). A survey study by Rop *et al.* (2009), found that 46 out of 89 kale fields were found to be affected by ALS incidence of the disease ranging between 0 to 100% where two species on the stems, leaves, siliquae, and seedlings, there are black necrotic spots with surrounding chlorotic regions. Rop *et al.* (2009), added that ALS is a common infection that affects brassicas at any crop growth stage. Furthermore, Meena *et al.* (2021) indicated that one of the main reasons for Kenya's low yields of brassicas, especially kale, was ALS, which is caused by Alternaria spp. Furthermore, Spence *et al.* (2005) indicated that the ALS has significantly reduced the production of brassicas, particularly kale, in Kenya. The disease is more severe in sections of the country that are higher in elevation (JP, 1991).

*Alternaria brassicicola* and *A. Japonica* were isolated from the black spots of the collected leaf sample the incidence for *A. brassicicola* was 52.6% greater than *A. japonica* (29.1%) for the combined kale and cabbage fields. The kale cultivars that were susceptible to black spots caused one of two species of Alternaria were thousand-headed, local variety, and collards. The two species were discovered to be more common at higher elevations, in the higher agroecological zones, and under conditions of medium to high rainfall. When compared with dry seasons and locations with comparatively little rainfall, there was a reported higher incidence of ALS disease in regions that receive high rainfall but in wet seasons of the year (Smith *et al.* 1998).

## The Occurrence, Incidences and Severity of Alternaria Leaf Spots in Kale

Studies conducted in different areas where kale is cultivated have reported variable degrees of ALS occurrence and incidences. For example, a study performed in Kenya by Rop *et al.* (2009) revealed that 18 out of 37 (41.8%) surveyed farms were infected by Alternaria leaf spots while the average disease incidence was 8.7%. On the occurrence of the disease, the study revealed that the symptoms of dark centres surrounded by chlorotic haloes were evident on the petioles, stem and true leaves where it was found that 46 out of 89 (51.7%) kale farms showed these symptoms of the disease. But also, young plants were less affected when compared to the older kale plants and thus the disease accelerated to senescence. On the other hand, two species of Alternaria were found to be responsible for causing the disease which were *A. brassisicola* (66.7%) and *A. japonica* (11.1%). It was also reported the two pathogens were able to occur either singly or in mixtures, whereas the varieties that occurred in combination were Thousand-headed, local kale and collards as shown in Table 1.

High incidences of ALS have been reported in the upper agroecological zones or areas with higher elevations but also in regions characterized by high rainfall (Balai *et al.* 2022; Rop *et al.* 2012). This finding was in line with Rop *et al.* (2009) who reported that the two species *A. japonica* and *A. brassicicola* that were responsible for causing Alternaria black spots were more prevalent in the upper ecological zones of the area.

Alternaria significantly compromise the kale yield and quality. For instance, the study by Rop *et al.* (2009) conducted in Kenya reported that the disease infects almost the entire plant and causes serious damage and losses. The disease was reported to infect the kale plant from seedling to the harvesting stage. The loss of between 20-50% was reported by Jantasorn *et al.* (2017) but also the symptoms noted in the fields infected by ALS were black necrotic lesions encircled by a yellow chlorotic lesion. But also, the higher severity and losses were reported during the rainy or wet seasons (Jantasorn *et al.* 2017).

According to Verma and Saharan (1994), the three factors associated with ALS disease namely; reduced photosynthetic potential, unseasonable pod shatter, and wrinkling of the seeds are responsible for important yield losses in kale. Alternaria leaf spot was able to affect the entire plant despite the plant

**Table 1:** The mean ALS disease incidences at different altitudes, temperatures, and rainfall, agro-ecological zone for the disease survey conducted in Kenya

| Province | Division | Altitude (m) a.s.l | Agroecological zone (AEZ) | Rainfall (mm) | Temperature ($^0$C) | Kale cultivar | Alternaria species | Disease incidence |
|---|---|---|---|---|---|---|---|---|
| Central | Lari | 2387 | UH1 | 1200-1600 | 13.5-15.2 | LPS | *A. japonica* | 30.3 |
| Central | Lari | 2396 | UH1 | 1200-1600 | 13.5- 15.2 | LPS | *A. brassicicola* | 23.0 |
| Central | Njabini | 2676 | UH1 | 1150-1600 | 10.0-14.6 | LPS | *A. japonica* | 9.3 |
| Central | Njabini | 2682 | UH1 | 1150-1600 | 10.0-14.6 | LPS | *A. brassicicola* | 25.0 |
| Central | Njabini | 2704 | UH1 | 1150-1600 | 10.0 -14.6 | LPS | japonica | 11.5 |
| Central | Kinangop | 2666 | UH1 | 1150-1600 | 15.2-18.0 | LPS | *A. japonica* | 19.5 |
| Eastern | Kibirichia | 2277 | LH1 | 1300-1500 | 21.4-22.3 | THK | *A. japonica* | 18.8 |
| Nyanza | Central | 1805 | UM1 | 1400-2100 | 21.4-22.3 | LPU | *A. japonica* | 20.0 |
| Nyanza | Kanemo | 1282 | LM2 | 1450-1600 | 21.4-22.3 | LPU | *A. japonica* | 16.3 |
| Nyanza | Ugunja | 1238 | LM2 | 1450-1600 | 21.4-22.3 | LPU | *A. japonica* | 19.6 |
| Nyanza | Ugunja | 1241 | LM2 | 1450-1600 | 21.4-22.3 | LPU | *A. japonica* | 18.3 |
| Nyanza | Ugunja | 1244 | LM2 | 1450-1600 | 21.4-22.3 | LPU | *A. japonica* | 19.3 |
| Nyanza | Ukwala | 1207 | LM2 | 1450-1600 | 21.4-22.3 | LPU | *A. japonica* | 14.8 |
| Nyanza | Wagu | 1374 | LM1 | 1500-1900 | 21.4- 22.3 | LPU | *A. japonica* | 22.3 |
| Nyanza | Ugunja | 1313 | LM2 | 1450-1600 | 21.4-22.3 | LPU | *A. japonica* | 19.5 |
| Nyanza | Wagai | 1312 | LM2 | 1450-1600 | 21.4- 22.3 | LPU | *A. japonica* | 12.0 |
| Western | Soy | 2143 | LH3 | 900-1100 | 15.1-17.9 | CLRD | *A. brassicicola* | 10.0 |
| Rift Valley | Kapsakwoky | 1961 | LH2 | 1300-1700 | 16.4-18.8 | LPU | *A. brassicicola* | 22.0 |
| Mean | | | | | | | | 17.9 |

*Key: Agroecological zones: UH1= Sheep dairy zone, LH1 = Tea dairy zone, UM1 = Coffee-tea zone, LM1 = Maize-sugarcane zone, LM2 = Marginal sugarcane zone, LH2 = Wheat-maize-pyrethrum LH3 = Wheat-barley zone Kale varieties: LPU- Local kale propagated from suckers, LPS-Local kale propagated from seeds THK-Thousand headed kale, CLRD-Collards Source: Modified from Rop et al. (2009).*

leaves being more affected (Verma and Saharan, 1994). Another study by Intana *et al.* (2008), found that the disease incidence for ALS ranged between 20 to 50% in the infected plants. The disease was associated with the velvety appearance of black sooty spots that were surrounded by chlorotic halos. The disease-causing pathogen (*A. brassicicola*) was found to contain basiciccolin A which is a toxin responsible for pathogenesis. Table 2 shows an example of ALS disease severity in Chinese kale where a significant difference was recorded between treatments and the control.

## Management of Alternaria Leaf Spot Disease in Kales

According to Srivastava *et al.* (2020), fungicides are typically used to treat Alternaria leaf spot diseases in kales. Such fungicides include chlorothalonil, fludioxonil, imazalil, iprodione, maneb, mancozeb, and thiram, and they are applied directly on affected plants. However, for the farmers who grow vegetables organically, they can only use copper or captan fungicide sprays, which makes maintenance considerably more difficult (Choudhury *et al.* 2018). Enhancement of sanitation and agricultural rotation is also part of integrated ALS management; these strategies are employed to halt new outbreaks (Ogle, 1997; Van Bruggen and Finckh, 2016; Badenes-ez and Shelton, 2006).

Additionally, fungicides are applied to seeds before sowing; Nowicki *et al.* (2012) observed that numerous individuals do this to protect their crops. Therefore, Iprodione and strobilurins are the most common active ingredients that are used against ALS. Various studies have revealed that the enzyme contains two histidine residues that directly attack and probably affect the region of iprodione. Therefore, the extensive use of fungicides against the pathogens, makes them more resilient (Macioszek *et al.* 2018; Huang and Levy, 1995).

A study by Karonji *et al.* (2024) discovered that farmers employ synthetic fungicides based on sulfur and copper. However, the same study also found

**Table 2:** Main studies on sustainable Alternaria Leaf spot management

| Study title | Main findings | Reference |
|---|---|---|
| Effects of plant extracts and chitosan against Alternaria leaf spot of Chinese kale | In Chinese kale cultivation, piper betle and *Coscinium fenestratum* Show promise as environmentally acceptable alternatives to manage Alternaria leaf spot disease. | Ounchokdee and Dethoup, (2020) |
| Fungicidal activity of Thai medicinal plant extracts against *Alternaria brassicicola* causing black spot in Chinese kale | Thai medicinal plants can be used to alleviate black spots on Chinese kale produced by *A. brassicicola* instead of synthetic fungicides. | Dethoup *et al.* (2018) |
| Use of antifungal metabolite from *Trichoderma virens* for controlling Chinese kale leaf spots caused by *Alternaria brassicicola* | Two strains of *Trichoderma virens* suppressed the mycelial growth of *A. brassicicola*. Additionally, the metabolite they extracted from two strains worked well in the laboratory and the greenhouses. | Intana *et al.* (2005) |
| Effective of Neosartorya and Talaromyces to control *Alternaria brassicicola* causing leaf spot of kale | *Neosartorya spinosa* was the antagonist that was most successful in controlling the *Alternaria brassicicola* | Punyanobpharat (2018) |
| Efficacy of some Bacillus antagonists for controlling *Alternaria brassicicola*, the causal agent of Chinese kale leaf spot. | In a dry time, five isolates of *Bacillus spp*. cell suspension might lower the ALS disease better than water spraying treatment. | Udomsak *et al.* (2013) |
| In vivo, testing of antagonistic fungi against *Alternaria brassicicola* causing Chinese kale black spot disease | It was discovered that *Talaromyces flavus* Bodhi001 offered Chinese kale significant protection, making it a promising biological control agent against *A. brassicicola.* | Komhorm *et al.* (2021) |
| Control of *Alternaria brassicicola* with thermotherapy and propolis and its effect on the physiological quality of kale seeds | The best method for controlling A. *brassicicola* in kale seeds is thermotherapy at 55°C for 15 minutes, as it does not affect the physiological quality of the seed. | Cardoso *et al.* (2020) |
| Biological Efficacy of marine-derived *Trichoderma* in controlling chilli anthracnose and black spot disease in Chinese Kale | Alternaria black spot disease in kale and chilli disease can be controlled by the marine-driven Trichoderma. | Nujthet *et al.* (2023) |
| Alternaria Leaf Spot of Brassica Crops: Disease Incidence and Sustainable Management | The potential of cultural activities to lessen the severity of ALS disease in organic cropping systems is highlighted by mulching a field contaminated with ALS crop residues. Mulching promotes plant development while lowering the incidence of ALS. | Scheufele (2013) |
| Exploring the potential of *Catharanthus roseus*, *Ricinus communis*, *Carrica papaya* and *Annona squammosa* used as biopesticides | It was discovered that the leaves of *Annona squammosa*, *Ricinus communis*, *Carrica papaya*, and *Catharanthus roseus* were efficient against the population of field pathogenic fungi. | Kumawat *et al.* (2016) |
| In vivo antifungal activity of five plant extracts against Chinese kale leaf spot caused by *Alternaria brassicicola* | The four plant extracts: namely: *Hydnocarpus anthelminthicus*, P.L. *Crateva magna* (Lour.) DC., *Xanthophyllum lanceatum* J. J. Sm., and *Carallia brachiata* (Lour.)<br>At the concentrations of 10,000 and 50,000ppm, were able to effectively suppress the growth of *A. brassicicola* under field conditions | Jantasorn *et al.* (2017) |
| Antimicrobial activities of chilli and black pepper extracts on pathogens of Chinese kale. | All tested concentrations of black pepper extracts (0.75%, 1.5%, and 3.0) were able to suppress the radial growth of *Alternaria brassicicola* by 100% while for chilli pepper extracts, only 3.0% concentration achieved 100% radial growth inhibition after three days of incubation all tested 100% inhibition of the radial growth of the mycelia was achieved. | Kunasakdakul *et al.* (2012) |
| Use of pently pyrone extracted from ultraviolet-induced mutant strain of *Trichoderma harzianum* for control of leaf spots in Chinese-kale | Under room temperature, the extracted pently pyrone at a concentration of 100mg/L achieved 100% mycelial growth inhibition in five days while the severity of the 100mg/L treatment was 6.5% and 19.0% in the laboratory and greenhouse respectively. | Intana *et al.* (2008) |

that using these fungicides over an extended period had negative impacts on the environment (Reda *et al.* 2021). *Curcuma longa* extracts showed the biggest percentage in mycelial growth at 57.7% while *Zingiber officinale* achieved a reduction of 53.8%. These findings have shown that *Curcuma longa* and its concentrates can be used to suppress Alternaria species which are linked to kale leaf spot. Instead of using synthetic fungicides, the extracts can be used in integrated disease management to lessen or completely eradicate dissemination of Alternaria (Kipkogei *et al.* 2019).

Mulch tends to minimize the spread of Alternaria spores that already exist in the soil when applied soon after planting (Gupta and Devi, 2014). Research conducted at the Agricultural Experiment Station in New York State, for example, demonstrated that mulches made of black plastic or biodegradable plastic were much less effective than mulches made of straw in controlling Alternaria leaf spot. Kale crops mulched with straw also reported fewer and less severe ALS than the control plants, and their plants grew significantly taller when compared to other plants in the trial (Scheufele, 2013).

Conversely, gardens that rotate their crops every four years can prevent Alternaria from building up in the soil, according to Scheufele (2013), removing plants that have died and fallen leaves as soon as possible will also minimize the count of spores in the soil. In healthy, well-spaced plants, Alternaria usually causes less damage than in plants with similar characteristics that are under too much stress.

### Sustainable ALS Management Approaches

Numerous studies have investigated the methods of managing ALS are alternative to synthetic fungicides. These include botanical, biological and cultural control methods as shown in Table 2.

## CONCLUSION

Amongst other biotic stresses, this review has disclosed how ALS challenge kale farmers in Kenya. The majority of these farmers rely on regular pruning of the infected leaves and the use of synthetic fungicides as strategies to manage the disease. Whereby regular pruning of the leaves significantly reduces the farm yield quantities while the use of synthetic fungicides is not regarded as a sustainable approach since such fungicides would eventually end up in compromising human, and environmental health. The review has shed light on the potential ALS management approaches towards achieving a sustainable disease management system but also engineering of kale varieties resistant or tolerant to ALS is another potential method that has not been exploited widely, despite the genetic resistance technique being long-lasting, and environmentally safe. The information extracted from this study is to be utilized by farmers, breeders, extension agents, policymakers, and other kale farming stakeholders. This will significantly reduce the negative effects caused from use of synthetic chemicals on humans, biodiversity, and the environment in general while optimizing the quality and quantity of produce to satisfy home consumption and local and export markets.

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