

Full Length Research Paper

Major diseases of cashew: A perspective on etiology, epidemiology and management for sustainable crop production in Tanzania

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Received 18 January, 2025; Accepted 4 March, 2025

Anacardium occidentale L., is an economically important cash crop seriously threatened by multiple biotic factors, including diseases. Updated information on the current situation of diseases in the cashew cropping system is limited, particularly in Tanzania. This narrative review provides, for the first time, an elucidation of the etiology, epidemiology, and management status of important cashew diseases in Tanzania. The review offers a comprehensive overview of major cashew diseases, including powdery mildew caused by *Oidium anacardii*, cashew leaf and nut blight (*Cryptosporiopsis* species), anthracnose (*Colletotrichum gloeosporioides*), and Fusarium wilt disease (*Fusarium oxysporum*), which can cause 100% yield and crop losses. A literature review has been conducted to explore available methods for managing these diseases, including the use of resistance/tolerance varieties, biocontrol, botanicals, and chemical fungicides. However, these management methods have proven ineffective against Fusarium wilt disease, partly due to a lack of familiarity among end-users. This narrative review suggests that the accumulated information can be disseminated to widen stakeholders' knowledge and improve the cashew industry. Further comprehensive research on diagnostic, modern breeding, and integrated management approaches to combat cashew diseases is of utmost importance.

Key words: Cashew diseases, *Oidium anacardii*, *Cryptosporiopsis* species, *Colletotrichum gloeosporioides*, *Fusarium oxysporum*.

INTRODUCTION

Cashew (*Anacardium occidentale* L.) is an evergreen perennial tree crop belonging to the Anacardiaceae family, which also includes mango (*Mangifera indica* L.), pistachio nut (*Pistacia vera* L.), and various species of Spondias (*Spondias* species) (Kapinga et al., 2011;

Monteiro et al., 2022). The crop thrives in the hot, dry tropics at sea level, characterized by an extensive root system and deep taproot that enables it to grow well even in sandy soils with low fertility (Dondeyne et al., 2003; Ngatunga et al., 2001). The tree can grow up to 15 to 20

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m high, with a canopy of spreading habit (Adeigbe et al., 2015). The crop produces a pseudo-fruit consisting of a nut and an apple, with the apple being approximately nine times the size and weight of the nut (Kapinga et al., 2011). Cashew is ecologically well-adapted to tropical and subtropical countries, including Tanzania, Côte d'Ivoire, Guinea-Bissau, Ghana, Nigeria, Benin, Brazil, Vietnam, India, Cambodia, and others (Akyereko et al., 2022). Native to tropical Brazil, cashew is recognized as the center of origin (Hammed et al., 2008). In Tanzania, cashew was introduced by Portuguese travelers in the 16th century and initially distributed to areas in Lindi, Mtwara, Coast, Tanga, and Tunduru districts in the Ruvuma region (NBS, 2012). Over time, it has spread to non-traditional regions, including Morogoro, Dodoma, Singida, Mbeya, Katavi, and others (Masawe and Kapinga, 2017; NBS, 2012). The widespread distribution of cashew has been driven by its increasing economic importance, benefiting smallholder farmers in particular.

The crop is the most important cash crop contributing to the income of over 500,000 households and national foreign earning (Masawe and Kapinga, 2017). The vast increase of country's income from 174,240,000 million Tanzanian shillings in 2011/2012 season to 1.3 trillion Tanzanian shillings (565,168,240 USD) in 2017/2018 season has been reported by the Bank of Tanzania (BOT, 2019). Apart from economic contribution, cashew is a source of raw materials for production of syrups, juice, wine, alcohol, and jam in food industries (Msoka et al., 2017; Nwosu et al., 2016).

Nonetheless, the processed cashew kernels products are a source of vitamins (A, D and E), proteins (17.8%) and fats (46.5%) (Akyereko et al., 2023; Duguma et al., 2021). Beside, nut contribute to dietary amount of minerals like phosphorus (4600 mg/kg), potassium (5600 mg/kg), iron 90.8 mg/kg), calcium (504.0 mg/kg), zinc (31.3 mg/kg), copper (16.4 mg/kg), and magnesium (2400 mg/kg) (Msoka et al., 2017). The cashew apple products contain vitamin C, iron (Fe), and zinc (Zn), which are essential for human health and 88.34% of dry matter, 96.50% of organic matter; 19.02% of crude protein, 44.61% of nitrogen free extract, and 3.50% of total ash for soil and plant health (Sreekutty et al., 2019). In spite of the importance, various factors have been threatening its production and productivity leading to year wise fluctuation. Diseases including cashew powdery mildew disease (*Oidium anacardii*), cashew leaf and nut blight (*Cryptosporiopsis* species), cashew anthracnose (*Colletotrichum gloeosporioides*) and Fusarium wilt disease (*Fusarium oxysporum*) are the major contributor of the decline of cashew production (Nene et al., 2017). These diseases causes yield losses of 70 to 100% if not controlled (Nene and Sijaona, 2017; Sijaona et al., 2006). Despite awareness of the diseases, there is a knowledge gap regarding the status of major diseases among stakeholders, sparking concern during cashew production seasons. Furthermore, outbreaks of previously minor

economic diseases cause confusion in differentiating their characteristics and limited management options. Therefore, an in-depth understanding of these diseases, including their historic timeline, etiology, epidemiology, and management practices, is crucial for cashew stakeholders. This knowledge can alert researchers (crop protectionists, plant breeders, and agronomists), policymakers, and decision-makers on how to collectively address the knowledge gap and develop strategies to combat cashew diseases. This narrative review aims to provide an overview of the current knowledge on the etiology, epidemiology, and management options of major cashew diseases, promoting sustainable production in Tanzania.

Overview of cashew production trends in Tanzania

To understand the etiology, epidemiology, and management practices necessary for sustainable cashew production, it is essential to first grasp the current production trends. According to the Bank of Tanzania (2021), Tanzania ranks as the fifth-largest cashew nut producer globally and the second-largest in Africa, after Ivory Coast, with production levels of 970,000 MT, followed by India (752,000 MT), Vietnam (341,680 MT), and the Philippines (217,580 MT). However, reports from the Cashewnut Board of Tanzania (2023) and the Bank of Tanzania (2024) indicate fluctuating production trends in Tanzania over the years, as depicted in Figure 1. Notably, cashew production peaked at 313,800 MT in 2017/2018, earning approximately Tsh. 1.3 trillion (BOT, 2019), but declined to 189,100 MT in 2022/2023 (BOT, 2023).

The fluctuations in production can be attributed to various factors, including diseases and insect pests of economic importance.

The major diseases of cashew

Various diseases are threatening the production and productivity of cashew in the world. Different studies have indicated the diseases such as powdery mildew (*O. anacardii*), blight disease (*Cryptosporiopsis* spp.), and anthracnose (*C. gloeosporioides*), causes up to 100% yield losses (Dooh et al., 2020; Sijaona et al., 2006). According to Adeigbe et al. (2015), Seema et al. (2020) and Monteiro et al. (2022) the minor disease such as dieback (*Phomopsis anacardii*), pestalotia leaf spot (*Pestalotia* species), gummosis (*Lasiodiplodia* species), and damping off which is caused by fungi complexes including *Fusarium* species, *Pythium* species, and *Phytophthora palmivora* Butler have been causing the cashew yield loss of less than 70%. According to Sijaona (2013), cashew diseases including powdery mildew, cashew leaf and nut blight and anthracnose have been

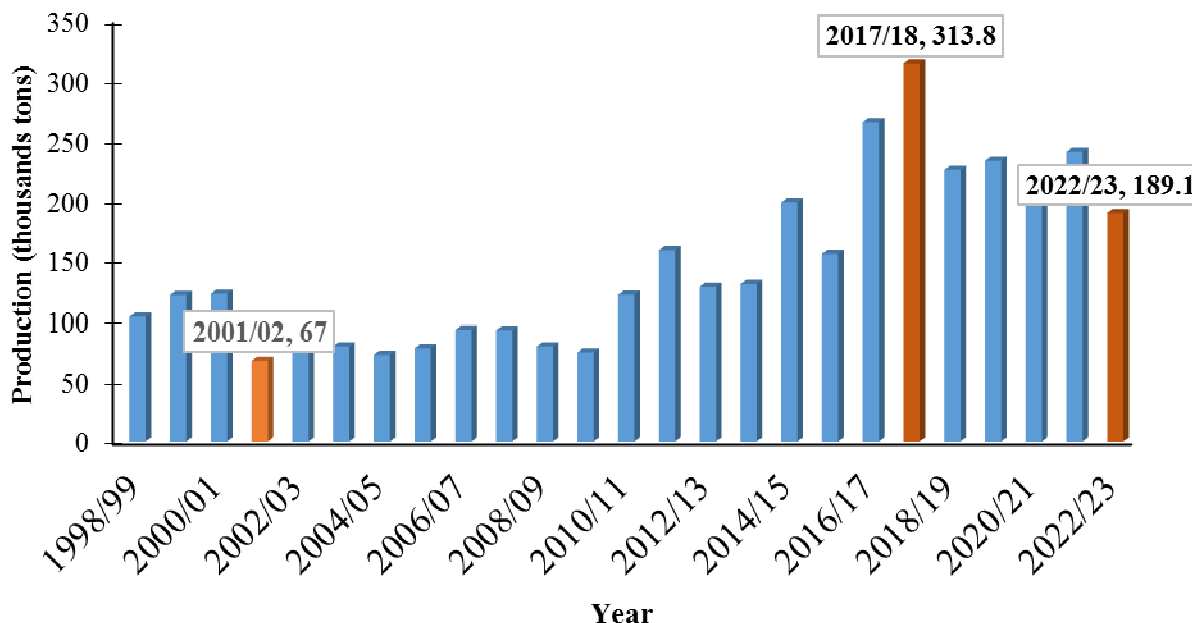


Figure 1. Trend of production of cashew for the past 25 years in Tanzania.

major diseases of cashew for about more than 30 years in Tanzania. According to a report by Tibuhwa and Shomari (2016), *Fusarium* wilt, caused by *F. oxysporum*, is currently the most economically important disease contributing to the fluctuation in cashew production and productivity in Tanzania. Although the presence of this disease is well-known, a detailed understanding of its etiology, epidemiology, and management practices is essential for effective diagnosis and management.

Cashew powdery mildew disease (PMD): Etiology and epidemiology

Studies by Shomari and Kennedy (1999) and Waller et al. (1992) indicated that powdery mildew of cashew is incited by *O. anacardii* Noak; the airborne pathogenic fungus with water hating (hydrophobic) characteristics. In mid-1970s, according to Monteiro et al. (2022) and Waller et al. (1992), the powdery mildew disease was reported and vast spread to various countries including Mozambique, Tanzania and lately in Zambia, Ivory coast and Brazil. In Tanzania, the disease has been reported in various cashew growing areas including Lindi, Mtwara, Ruvuma, Tanga and Coast region since 1975 (Sijaona and Shomari, 1987). The outbreak and spread of powdery mildew was greatly influenced with the poor management of cashew including poor plant spacing, pruning and thinning practices, and currently climate changes (Martin et al., 1998).

Epidemiological studies performed by Shomari and Kennedy, (1999) and Ohler (1979) indicated that the presence of temperature ranges between 25 to 28°C with

optimum at 26°C and relative humidity ranging between 80 to 100% with optimum at 95% are the major contributing factor to the vast prevalence of the powdery mildew disease in various areas within and outside Tanzania. Studies have shown that environmental conditions play a crucial role in the development and spread of powdery mildew disease (PMD) in cashew. According to Shomari (1996), the overlapping of cashew branches and twigs under the crown, which prevents sunlight penetration and lacks rainfall, favors the harboring of the powdery mildew fungus. Furthermore, Sijaona (2013) revealed that cold nights followed by warm days, leading to mist and fog conditions in the early mornings, frequently contribute to PMD outbreaks. The epidemic of powdery mildew can persist from one season to another through fallen infested leaves, water shoots, and off-season flowers (Sijaona et al., 2006, 2013). Additionally, Monteiro et al. (2022) found that wind and human activities, such as the movement of infested seeds and seedlings, are the primary dispersal agents of *O. anacardii* spores, consistent with the report by Waller et al. (1992).

Altering these favorable environmental conditions can aid in the cultural management of the disease. For instance, rainfall can deter the growth and dispersion of *O. anacardii*, as articulated by Shomari (1996) and Sijaona (1997).

Symptoms of powdery mildew

Powdery mildew disease develop symptoms on the tender tissues including leaves, flower inflorescence and



Figure 2. Symptoms of Powdery Mildew Disease on tender tissue of cashew. (A) Whitish mildew on tender leaves of cashew. (B) Whitish mildew and weathered flower. (C) Wrinkled nut and cracked apple after PMD infestation.

young nuts on cashew as shown in Figure 2, with most economical on flowers (Lima et al., 2019). The attack occurs during dry season in months of June to October (Sijaona, 2013). During that period, symptomatic presence of white powdery on the infested leaves, turning to wrinkled with blackened spot (Figure 2A), inflorescence which appears brownish with dried tea leaf colouration (Figure 2B) have been described as the common symptoms (Sijaona and Mansfield, 1999; Sijaona, 2013). These symptoms have been also reported by the research of Lima et al. (2019) in Brazil. Further investigation has noted that the lesions of the infected leaf and inflorescence gradually shrink after 2 to 3 weeks, become dry and shed, leading to drying out and drop (Cardoso et al., 2017; Sijaona, 2013). Infected apples turn dull and their skin becomes much coarser (Figure 1C). The apples when heavily infected show deep cracks on the surface and gradually shrivel and dry up (Sijaona, 2013). The tender nuts and apple when infected are deformed on the shell and turn grey (Monteiro et al., 2022). Infected nuts deteriorate in quality during storage, decays easily and produce poor quality kernels when processed (Shomari, 1996; Waller et al., 1997; Sijaona, 1997). The use of these symptoms has been helpful in early diagnostic and timely management of powdery mildew disease not only in Tanzania but also in other cashew growing countries. Additionally, current spread of cashew to non-traditional areas in Tanzania triggers for characterization of *O. anacardii* for possible occurrence of diversity.

Management of powdery mildew

Research on the management practices of cashew has been conducted at various stages, not only in Tanzania (Nathaniels et al., 2003) but also in other affected countries (Monteiro et al., 2022; Oliveira et al., 2020). Initially, studies focused on the use of cultural practices to

manage powdery mildew disease, including sanitation measures such as removing water shoots underneath tree canopies and pruning branches to allow aeration, which can reduce and delay the occurrence of the disease for several weeks (Lima et al., 2019). Additionally, Sijaona (2013) noted that clearing dropped branches, leaves, and nuts helps remove the source of inoculum. However, the failure of cultural practices to effectively manage the disease and continued yield losses at the farm level led to further research on the application of chemical fungicides (Nene and Sijaona, 2017). The use of sulphur dust to manage powdery mildew disease in cashew was first studied in Tanzania by Smith and Cooper (1997), and later, Freire et al. (2002) reported similar efficacy in Brazil. Sulphur dust is a contact and preventive fungicide, with limited efficacy on previously infected cashew plants (Sijaona, 2013). Furthermore, studies by Majule (2003) and Ngatunga et al. (2001) showed a slight change in acidity after applying sulphur dust fungicides. Subsequent studies investigated the use of water-based fungicides; including triadimenol, tebuconazole, and hexaconazole, which have both curative and preventive effects against powdery mildew disease (PMD) in Tanzania (Dominic and Marthamakobe, 2016; Nathaniels et al., 2003).

More recently, research by TPRI (2021) has shown that other active ingredients, such as carbendazim, azoxystrobin, and difenaconazole, are also effective in managing PMD in Tanzania. Foliar spraying using a motorized blower has been a common practice for applying water-based fungicides to cashew plants. The availability of various chemical fungicides has expanded farmers' options, reduced market prices, and maintained high levels of cashew production and productivity compared to the late 1990s. However, the use of chemical fungicides has raised concerns worldwide about potential side effects on users (Ahmad et al., 2024; Edward, 2021), although no such reports have been made from a Tanzania perspective. In response to

these concerns, research has focused on developing resistance/tolerance cashew varieties against powdery mildew disease in Tanzania (Nathaniels et al., 2003). According to Masawe (2006), several half-sib cashew clones exhibited tolerance to powdery mildew disease in Tanzania. These clones were subsequently made available to farmers through Cashew Development Centers (CDCs) located in the main cashew-growing areas (Kidunda et al., 2013). However, the tolerance exhibited by these cashew varieties has not adequately addressed the issue of high disease severity and the resulting fluctuations in cashew production and productivity, not only in Tanzania but also in other cashew-growing countries. Given the understanding of various introduced management practices, there is a pressing need to establish a holistic approach that integrates these management practices to effectively combat powdery mildew disease in cashew in Tanzania.

Cashew leaf and nut blight disease (CLNBD): Etiology and epidemiology

Infestation of cashew leaf and nut blight disease are current the second most devastating in cashew production as inferred by Masawe and Kapinga (2017). According to Sijaona et al. (2006), *Cryptosporiopsis* spp., is the main causative agent of the disease. Meanwhile, the findings of Menge and Shomari (2016) and Nene et al. (2022), revealed that *Cryptosporiopsis* spp. is a hydrophilic pathogen (water-loving) flourish on wet weather especially during raining days and high humidity accompanied with mist. Studies of Nene et al. (2022) outlined that the continuous exposure of *Cryptosporiopsis* spp., to about 8 h triggers attacks and symptoms occurrence of blight disease on cashew leaves similar to previous findings of Dominic et al. (2014). Beside of moisture generated from rains or high humidity, a temperature range of 25 to 30°C and pH level of 6.0 to 7.0 are among the environmental conditions favoring the growth of *Cryptosporiopsis* pathogen (Menge et al., 2013; Nene et al., 2022). However, to date the etiological characterization of *Cryptosporiopsis* spp., is limited to genus level in cashew crop, thus a molecular delineation is of paramount importance.

Epidemiologically, *Cryptosporiopsis* spp. was first reported in 2000 at Itoculo, Monapo District, Nampula in Mozambique according to Sijaona et al. 2006. The outbreak was confusingly related to cashew anthracnose disease as reported by Menge and Shomari (2016a). Further reports articulate that, in Tanzania the disease was noted in 2002 in a cashew field of the Newala District, Mtwara (Menge and Shomari, 2016a; Sijaona et al., 2006). Current reports indicates that the disease has vast spread in different cashew growing regions encompasses traditional and non-traditional regions of Tanzania (Nene et al., 2022). Nonetheless, limited information is available on the attacks of *Cryptosporiopsis*

spp. on cashew on the other cashew growing countries. Reports by Agyare et al. (2022) and Dooh et al. (2020) have exhibited resembling symptoms in neighboring countries to be caused by a distant pathogens such as *Pestalotia*, *Lasioidiplodia*. and *Colletotrichum* spp. In addition, *Cryptosporiopsis* spp., have prevailed to alternative hosts including eucalypt and citrus as the most destructive pathogen (Davison et al., 2009; Zhu et al., 2012). Thus, understanding the epidemic of *Cryptosporiopsis* spp., alert the stakeholders to plan and prepare for appropriate management practices of the disease. Moreover, reported host range of the pathogen, alarm for revisiting the agronomic practice of intercropping with reported crops to avoid for a possible increase of disease epidemic.

Symptoms of cashew leaf and nut blight disease

Symptomatology of cashew leaf and nut blight disease reveal the attack on young tissues on leaves, nuts and apple with most importantly on young nuts (Menge and Shomari, 2016b). The attacks occur during cashew season (June to October) and off-season (January to May) with presence of mentioned favorable conditions. Studies by Menge et al. (2014) and Sijaona et al. (2006) indicated that attacked cashew leaves (Figure 3A), develop angular lesions, dark tan with a dark reddish brown margin often vein-localized that enlarge and coalesce causing blighting and defoliation. These symptoms were further reported on fruit with either immature nut and apple is attached (Figure 3B and C). According to Menge et al. (2014) and Nene et al. (2022) the infected immature nuts become rapid blackened and abscised, subsequent causes significant yield losses. Moreover, Menge et al. (2014) found that infested mature nuts are characterized with dark, slightly sunken, 'tar spot'-like lesion that frequently extends onto the apples. The development of *Cryptosporiopsis* spp., symptoms were further noted to form white spore masses (conidiamata) within the lesions (Menge and Shomari, 2016). Confirmation of presence of host range according to Davison et al. (2009) and Zhu et al. (2012) revealed presence of congruent symptoms of blight disease on citrus and eucalyptus respectively as presented in Figure 3. Additionally, the morphological features of the *Cryptosporiopsis* spp., on cashew (Figure 3C) and other host crops (Figure 3F) look-like with conidia possessing smooth-walled, ellipsoid to elongate-ellipsoid, aseptate, and arose from single fields. The presence of host range of *Cryptosporiopsis* spp., alert on the concern of the intercropping of these plants.

Management of CLNBD

Management of CLNBD has been through cultural practices, which include the removal of infested leaves,

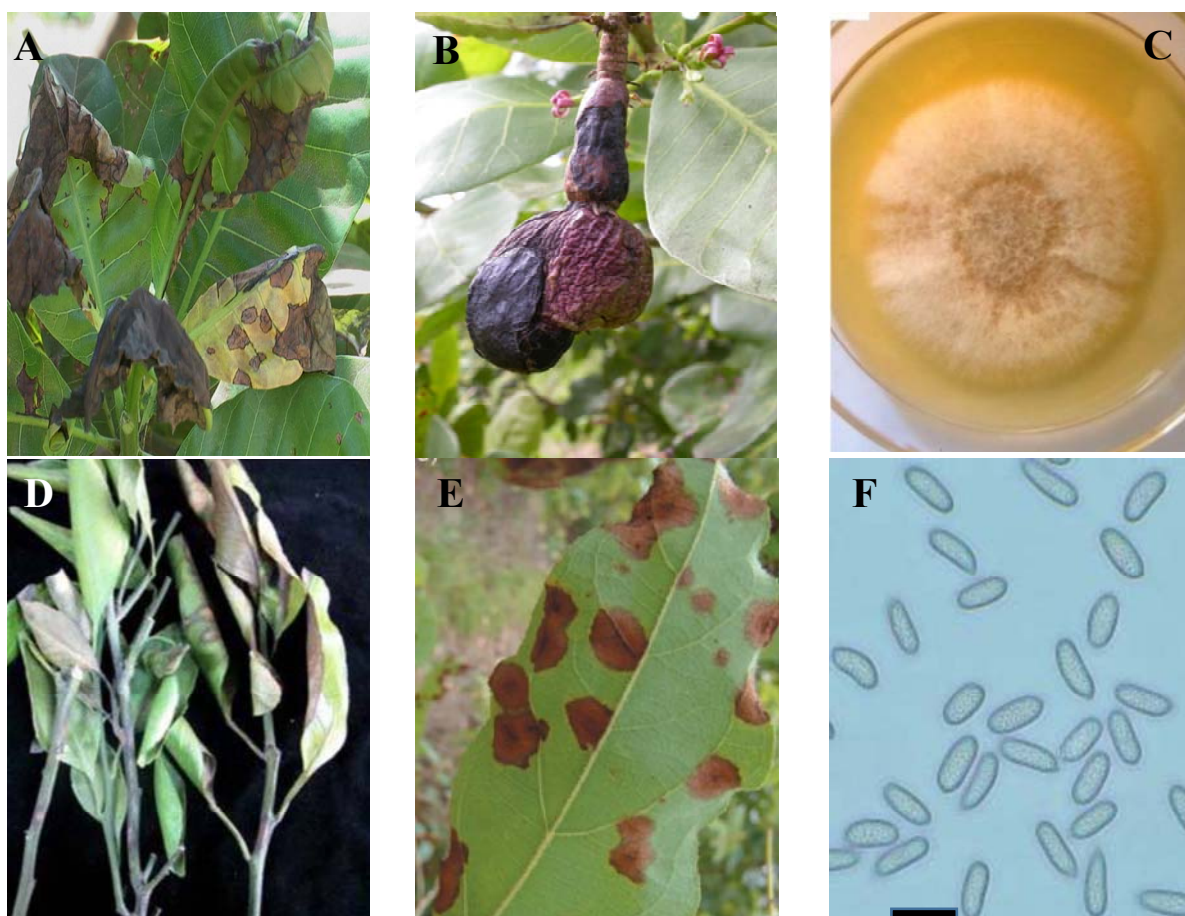


Figure 3. Infections of *Cryptosporiopsis* spp.: A) Dark reddish-brown coalesced spots on leaves of cashew, B) Blackened and aborted young nut with 'tar spot' extended to the apple, and C) Mycelial growth of *Cryptosporiopsis* on PDA, D) Coalesced reddish brown spots on Citrus, E). Reddish brown spots on Eucalypt leaf, and F) Conidia of Eucalypt, bar = 20 µm.

nuts, and apple then burn (Zhongrun and Masawe, 2014). Nonetheless, the method best intended for prevention of disease spreading and delay the onset of the epidemic by reducing the level of inoculum (Sijaona et al., 2006). Later on after various researches by Menge (2016); Nene and Sijaona (2017), spraying chemical liquid or granule formulated fungicides using motorized blower noted to manage cashew leaf and nut blight diseases. The formulations contained different active ingredients such as Trifloxystrobin, Difenaconazole, Picoxystrobin and mixture of Trifloxystrobin and Tebuconazole (Sijaona, 2013; Nene and Sijaona, 2017). Further, a new active ingredient to widen farmers' option and lowering market price has been recommended; those are Chlorothalonil, Propamocarb hydrochloride and Azoxystrobin (Nene et al., 2017; TPRI, 2021). Recommendation provided by Sijaona et al. (2006), reveals that the application of fungicides against blight disease commences when first symptoms occur particularly during fruiting season. However, current prevalence studies have revealed the presence of severe

attacks during off-fruiting season, thus necessitating reassessment of spraying regime is of paramount importance.

In recent times, the focus has been research to develop resistance/tolerance cashew varieties against leaf and nut blight disease. Tanzania Agricultural Research Institute (TARI) through its Naliendele Centre has developed different cashew varieties namely AZA2, AZA17, TARIKO 1, TARIKO 2, TARIKO 3, TARIKO 4, TARIKO 5, TARIKO 6, TARIKO 7 and TARIKO 8, which are resistance to leaf and nut blight disease in Tanzania (TOSCI, 2024). Unfortunately, cashew is the perennial tree crop, which is cultivated in polyclonal mode, thus widening the resistant/tolerance varieties is an endless research.

Cashew anthracnose disease: Etiology and epidemiology

Different scientific investigation has identified the

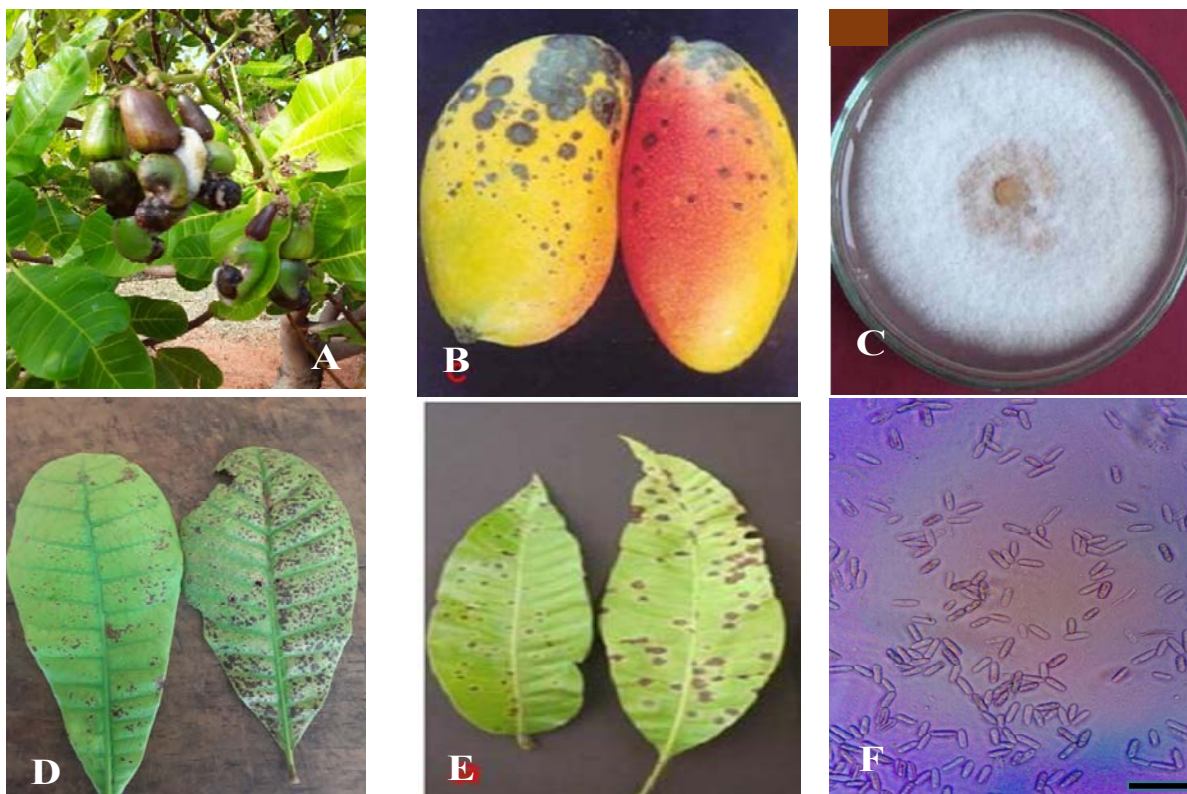


Figure 4. Host range of *C. gloeosporioides*: A). Whitish exudates on cashew nut and apple, -B). Black lesions on mango fruits, D-E). Angular to sub-circular black lesions on cashew and mango leaves, C and F). Mycelia and conidia of *C. Gloeosporioides*, bar = 20 µm.

presence of anthracnose disease incited by *C. gloeosporioides* Penz to cause disease in cashew crop (Amin et al., 2014; Uaciquete, 2013; Sijaona, 2013). The inciting pathogen after thoroughly investigation by Monteiro et al. 2022; and Muntala et al. 2020 has been classified to possess conidia which spread over relatively short distance by rain splash, irrigated water, wind and infect other health plant tissues. The attach on cashew has been suggested to occur when the conidia dwell on the host plant, and penetrate on weakened or injured host tissues through specialized developed structures known as appressoria (Patrice et al., 2020; Nakpalo et al., 2017; Kamle et al., 2013).

Studies on epidemic of *C. gloeosporioides* have identified the spread of the disease in various countries including Brazil, India, Ghana and Mozambique with a yield loss of up to 100% (Khatoun et al., 2017; Freire et al., 2002).

However, further epidemic has been reported in different West African countries including Burkina Faso and Nigeria as a minor disease with less than 20% yield loss (Wonni et al., 2017; Hammed et al., 2008). Anthracnose disease has been reported in Tanzania since 1978 (Casulli, 1981) and was initially considered a minor disease of cashew (Sijaona, 2013). However,

studies by Freire et al. (2002) and Sijaona (2013) have shown that the disease also affects other host crops in Tanzania, including citrus, mango, banana, avocado, and papaya. Ecological factors that favor the disease include high humidity (95 to 100%) and temperatures between 22 and 28°C, accompanied by at least 10 h of saturation during the cashew season. The disease severity peaks during the "cashew rain" period, which coincides with the flowering and fruiting stages (Freire et al., 2002). A thorough understanding of the etiology and epidemiology of anthracnose disease is essential for devising effective and timely management practices for not only cashew but also other host crops.

Symptoms of anthracnose disease

Studies from various regions have reported similar symptoms of anthracnose on the leaves, inflorescence, and fruit of cashew, as shown in Figure 4 (Ji et al., 2021; Nakpalo et al., 2017). These symptoms typically occur during the cashew season, which includes the dry season months of June to October. However, dos Santos et al. (2019) and Muntala et al. (2020) have emphasized that the primary focus of disease attacks is on nuts and

pseudo-fruits/apples. Similarly, Sijaona (2013) reported that in Tanzania, economically important attacks occur on pseudo-fruits (nuts and apples), characterized by whitish resin exudation and reddish-brown, shiny, water-soaked lesions (Figure 4A), consistent with lesions found on mango fruit (Kamle et al., 2013). Infected nuts wither and remain as "hanging nuts," which can serve as a source of disease infection during the next season (Uaciquete, 2013). In Mozambique, Ghana, Vietnam, and Brazil, leaf infestations of anthracnose are economically significant, displaying coalesced, water-soaked lesions that eventually turn orange-brown to light reddish with age, similar to attacks on other host crops, including mango (Figure 4D and E) (Uaciquete, 2013; Sijaona, 2013; Freire et al., 2002). Familiarization with these symptoms enables new cashew growers, particularly those from non-traditional areas, to accurately identify the disease and prepare for the implementation of effective management practices.

Management of cashew anthracnose

According to various research studies, the management of cashew anthracnose has involved different practices, including cultural methods (removing and burning infected pseudo-fruits and leaves), resistant varieties, and chemical fungicides (Majune et al., 2018; Nene et al., 2017). In several countries, including Tanzania, cashew varieties resistant or tolerant to anthracnose have been developed, commercialized, and made available to farmers as grafted seedlings (Saroj, 2015; Freire et al., 2002). Additionally, reports by Sijaona (2013) have shown that effective control measures include the use of fungicides containing copper-based ingredients, which are sprayed on the foliar parts using a motorized blower. Furthermore, studies by Uaciquete (2013) and Wonne et al. (2017) in Mozambique and Brazil have demonstrated that fungicides such as captan, benomyl, dithianon, and triadimenol can effectively manage anthracnose disease. These studies also emphasize that the optimal time for spraying fungicides is during the new flush, flowering, and fruiting stages, when young tissues are highly susceptible (Kumar et al., 2020; Uaciquete et al., 2013). The availability of these management practices enables farmers to effectively contain the disease, leading to improved production and productivity of cashew.

Cashew Fusarium wilt disease (CFWD): Etiology and epidemiology

Fusarium wilt is a disease of economic importance that affects various host crops, including cashew. The disease is caused by the soilborne pathogenic fungus *F. oxysporum* (Tibuhwa and Shomari, 2016). According to Groenewald (2005), *F. oxysporum* is a member of the genus *Fusarium*, which occurs in both pathogenic and

non-pathogenic forms. The pathogenic strains of *F. oxysporum* exhibit parasitic and saprophytic phases in their life cycle, characterized by various phenotypic features, as illustrated in Figure 5 (Lecomte, 2019; Groenewald, 2005; Gordon and Martyn, 1997).

These features include whitish mycelia that grow into chlamydospores, a saprophytic resting stage with dormant and immobile characteristics, allowing the fungus to survive for extended periods in the absence of hosts. Furthermore, studies by Ploetz (2015), Belgrove and Africa (2011), and Pegg et al. (2019) have shown that macro and microconidia are the active spores responsible for initiating the parasitic phase of *F. oxysporum*. The pathogenic strains of *F. oxysporum* exhibit wide genetic diversity, leading to differences in pathogenicity among host crops. As a result, these strains have been reclassified into an informal taxonomic hierarchy of "Formae speciales" (Groenewald, 2005; Gordon and Martyn, 1997). This classification has led to the identification of various strains, such as *F. oxysporum* f. sp. *cubense*, which causes banana wilt disease (Thangavelu and Mustaff, 2012), and *F. oxysporum* f. sp. *vasinfectum*, which causes wilt disease in cotton (Armstrong and Armstrong, 1960). Recently, Jun et al. (2022) identified a new *forma specialis*, *F. oxysporum* f. sp. *ginseng*, which attacks horticultural ginseng plants in China. Additionally, researchers (Jangir et al., 2021; Kappelman, 1983) have identified the presence of a sub-specific unit called "race," as exemplified by the report of Olivares et al. (2021) on the presence of eight races of *F. oxysporum* f. sp. *cubense*.

The presence of different hosts of *F. oxysporum* raise the concern to cashew cropping system, since the cultivation of cashew goes with intercropping with other crops including sesame, pigeon pea, mango and others. Despite the various reported information on etiological agent of wilt disease in cashew, limited information is available on the pathogenesis and genetic diversity relationship of *F. oxysporum* with other host crop in cashew cropping system.

Since the first reported outbreak of *F. oxysporum* in Mkuranga district, Coast region, Tanzania in 2012 (Tibuhwa and Shomari, 2016), the epidemic of Fusarium wilt disease in cashew crops has spread to various cashew-producing regions and countries. Recent studies by Lilai et al. (2021) and Mbaso et al. (2021) have reported the further prevalence of the disease in the regions of Lindi, Mtwara, Tanga, and Ruvuma. Globally, the wilt disease of cashew has been reported in India, with studies by Manjusha et al. (2023) and Packesh et al. (2023) revealing that young cashew plants (less than 5 years old) are infested by *Fusarium decemcellulare* and *Fusarium falciforme*. The widespread epidemic of *F. oxysporum* is attributed to its adaptation to different ecologies, including cultivated and non-cultivated fields, as first reported by Lilai et al. (2021). These studies further revealed that various complex conditions influence

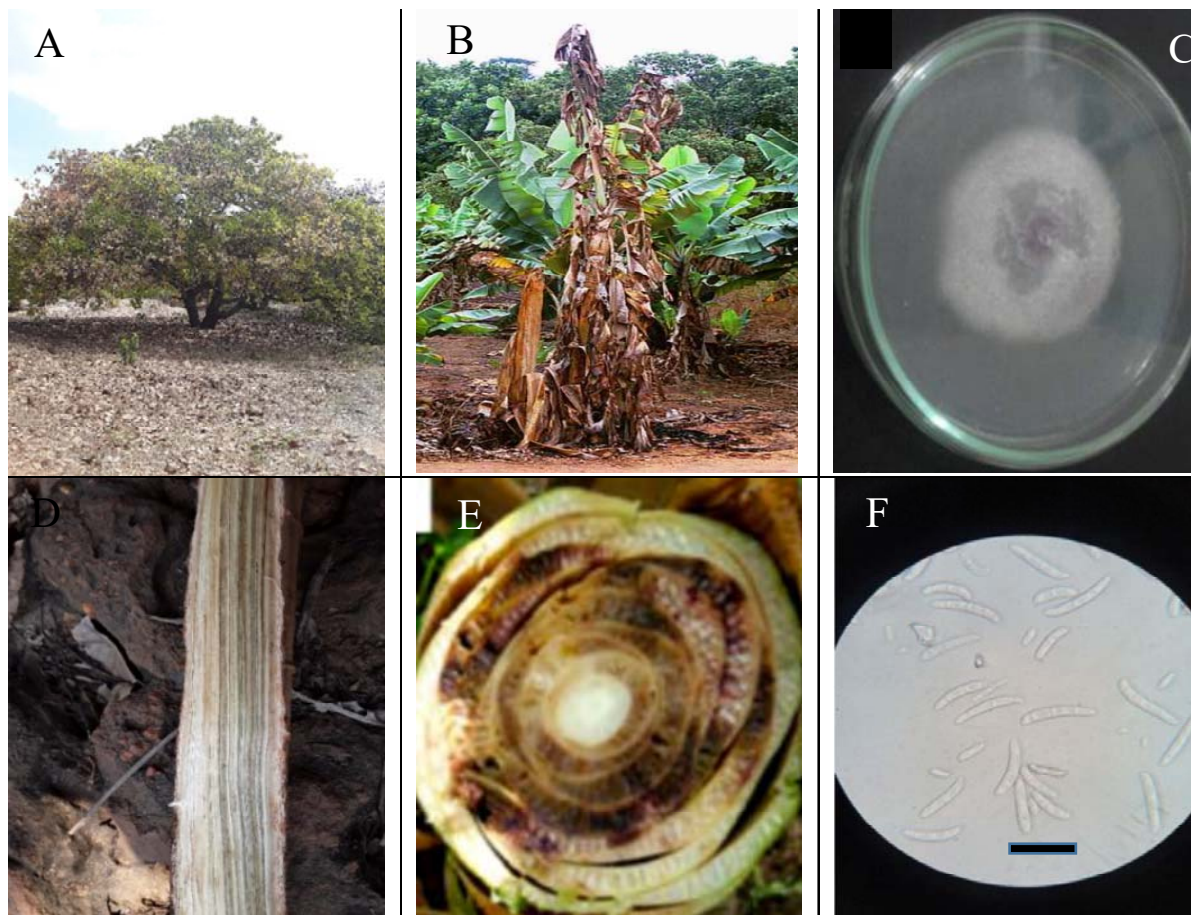


Figure 5. Characteristics diversity of *Fusarium* wilt disease: Yellowing and browning of cashew (A) and banana (B); Internal brownish to blackish stem strips on cashew (D) and Banana (E); macroscopic mycelia growth (C) and microscopic conidia (F), bar = 20 µm.

the growth and development of *F. oxysporum* in cashew, similar to other previously infested host crops (Ploetz, 2015). The reported conditions include relative humidity of 65 to 75%, optimal soil pH ranging from 4.8 to 6.5, and soil and air temperature ranges of 28 to 35.6°C (Manjusha et al., 2023; Lilai et al., 2021; Khatoon et al., 2017). Moreover, the spread of the disease has been influenced by anthropogenic factors, rainfall-runoff water, and wind-borne pathogen spores (Lilai et al., 2021; Tibuhwa and Shomari, 2016). Despite this information, further research on the epidemic agent of *Fusarium* wilt disease in cashew is crucial.

Symptoms of *Fusarium* wilt disease

Symptomatology studies of *Fusarium* wilt disease in cashew, consistent with other host crops, are presented in Figure 5. Manjusha et al. (2023) and Tibuhwa and Shomari (2016) described that the disease symptoms appear on infected cashew plants when pathogenic *F. oxysporum* is stimulated by root exudates and enters the

plant's vascular system.

During field diagnosis of *Fusarium* wilt disease in cashew, it was observed that colonized cashew plants and other hosts display yellowing and browning of leaves at the initial stages (Mbasa et al., 2021; Dita et al., 2018). Mbasa et al. (2021) noted that the symptoms typically occur in a localized pattern, progressing from one branch to another, before advancing to leaf withering and wilting of the entire cashew plant. Similar symptomatic characterization was reported on young cashew seedlings in India, despite the presence of different pathogen types (Manjusha et al., 2023; Khatoon et al., 2017). Additionally, a distinctive symptom of direct color change from green to pale brown on cashew leaves, accompanied by stem gummosis, attributed by severe water stress and heavy inoculum load was "characterized by Mbasa et al. (2021) and Ploetz (2015). Ploetz (2015) indicated that the production of the phytotoxin fusaric acid contributes to leaf chlorosis and ultimate browning.

Internally, the vascular tissues of infected cashew plants display consistent symptoms of brown and yellow streaks (Manjusha et al., 2023; Mbasa et al., 2021;

Molinero-Ruiz et al., 2011). A study on the movement pattern of *F. oxysporum* spores within host plants by Warman et al. (2018) revealed that the blockage of vascular tissues is caused by the growth of pathogen mycelium and/or the deposition of secondary plant metabolites. The vascular symptoms appear in both root and stem vessels, triggered by the translocation of conidia of the pathogen, as noted by Tibuhwa and Shomari (2016) in cashew, Rekah et al. (2000) in tomato, and Warman et al. (2018) in banana crops. The characterization of disease symptoms facilitates early diagnosis and the timely implementation of management practices to combat the disease.

Management of Fusarium wilt disease in cashew

Management practices on Fusarium wilt disease have been studied by various researchers including Sampaio et al. (2020), Bawa (2016) and Perez-Vicente (2014) respective to different host crops. In every new report of the disease outbreak, the use of cultural practices including cutting and burning of infested plants and quarantine of seed and seedling/plantlets have been the primary recommended for prevention of the disease in various crops including cashew (Joshi, 2018; Perez-Vicente, 2014).

In different host crop, the preferred and considered effective method to manage Fusarium wilt disease has been, and continues to be the use of chemical fungicide (Mbasa et al., 2020; Bawa, 2016; Rutherford and Kangire, 1998).

Systemic chemical fungicides such as carbendazim, thiophanate, benomyl (Benzimidazole family), prochloraz (Imidazole) and propiconazole, tebuconazole and difenaconazole (Triazole family or class) have been studied and reported to be effective in managing *F. oxysporum* in crops such as tomato, banana, oil palm, cotton, and the like (Perez-Vicente, 2014, Ajilogba and Babalola, 2013). These chemical fungicides are broad spectrum attributed with their mode of action, for instance benzimidazole act by inhibiting mitosis and xylem mobile/translocation, while triazole and imidazole both inhibit sterol biosynthesis (Zhou et al., 2016). The broad spectrum influences the management of wide range of microbes, lead to effect to non-target organism, which hinder beneficial microbial activities in the soil (Rodríguez et al., 2010). In cashew, a groundbreaking studies by Mbasa et al. (2021) have indicated that a soil spraying of systemic fungicide including carbendazim, thiophanate methyl and azoxystrobin (Methoxy-acrylate) have promising efficacy on wilt disease. Unfortunately, the chemicals were tested in single location and season with failed efficacy to severed infested cashew over 70% (Mbasa et al., 2021), thence, deemed inadequate for recommendation at farm level.

Considering all the facts, the chemical method

for managing Fusarium wilt disease in various host crops including cashew is not yet a satisfactory approach with infancy status at farmer's level. These documentations emphasize extensive research of chemical method to manage the devastating fusarium wilt disease in Tanzania.

Biofungicide using fungi/bacteria and botanical fungicide from plants have been proclaimed advantageous in control of Fusarium wilt disease in different host crops (Priya et al., 2019). In cashew, report by Lilai et al. (2022) revealed that *Trichoderma* spp., and *Bacillus* species, preliminary managed *Fusarium* wilt disease of cashew under farmers condition. On the other hand, Mbasa et al. (2020) reported that botanical fungicides managed to inhibit the growth of *F. oxysporum* under *in vitro* condition. Nonetheless, the findings on bio and botanical fungicides are to date grounded to *in vitro* and *in vivo* but not under farmers use. Thence, with various encouraging findings, extensive researches are required for the biological method to become a practical and economical option for the management of Fusarium wilt disease.

The use of resistance varieties is widely regarded as the most important approach to future plant disease control, offering the most effective, economic, and practical long-term option for small-scale farmers worldwide (Faustine et al., 2016). Given the destructive nature of Fusarium wilt disease across various host crops, the development of resistance varieties is of paramount significance, particularly for crops with limited rejuvenation capabilities (Ulloa et al., 2006; Rutherford and Kangire, 1998). Research has led to the development of resistance varieties against Fusarium wilt disease in several host crops, exemplified by the creation of hybrids (FHIA-01 and FHIA-03) resistant to *F. oxysporum* f. sp. *cubense* races 1 and 4 (Pérez-Vicente, 2004; Tushemereirwe et al., 2000). In Tanzania, preliminary research has been conducted on developing resistance varieties against Fusarium wilt disease in cashew crops. However, this approach is hindered by the lack of true-to-type cashew plants for hybridization to confer resistance against the soilborne pathogen (Khatoon et al., 2017). Therefore, the adoption of modern breeding approaches, particularly molecular and tissue culture techniques is crucial for developing true-to-type cashew plants.

Conclusion

This narrative review highlights the status of the most significant cashew diseases and their management options in Tanzania. The information provided is vital for stakeholders, including farmers, extension officers, researchers, policymakers, and decision-makers, to understand the current progress in cashew research and make informed improvements in sustainable cashew production in Tanzania and globally. The review has identified various research gaps that hinder sustainable

production and productivity, emphasizing the need to address them.

RECOMMENDATION

Therefore, this narrative review recommends further research on the following areas:

- i) Promote the recommended strategies for reducing the impact of diseases to users for implementation and management.
- ii) Strengthening an inclusive diagnostic approach using both smart molecular and conventional approaches to easy disease management.
- iii) Establishing extensive breeding programs through bringing together new technologies including tissue culture, high throughput genotyping and genetic engineering.
- iv) Developing an integrated management approach encompassing cultural (organic amendments and cover crops), biological (biological agent and botanicals) and improved chemical fungicide application using drones for combating major cashew disease particularly the Fusarium wilt disease of cashew for sustainable production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thank the University of Dar es Salaam for providing an environment that fostered the development of this perspective review document. They thank the Tanzania Agricultural Research Institute (TARI) Naliendele for conceiving the ideas and providing financial support for research on cashew diseases, particularly cashew Fusarium wilt disease. Gratitude is expressed to the Principal Investigators of the Fusarium Wilt Disease Research Project

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