Journal of Plant Pathology (2022) 104:929–938
https://doi.org/10.1007/s42161-022-01127-w

ORIGINAL ARTICLE

Cashew leaf and nut blight disease outbreaks under unimodal rainfall pattern in Tanzania

Wilson Nene[1] · Fortunus Kapinga[2] · Shamte Shomari[1] · Bobnoel Assenga[1]

Received: 17 July 2020 / Accepted: 5 May 2022 / Published online: 30 May 2022

Abstract

Cashew (*Anacardium occidentale* L.) which is an important cash crop in Tanzania, is susceptible to various abiotic and biotic stresses. Cashew leaf and nut blight disease caused by *Cryptosporiopsis* spp. is a devastating disease of cashew crop resulting in a significant reduction of nut production. We conducted a study to assess the association between weather variables, particularly rainfall and temperature, on cashew leaf and nut blight disease (CLNBD) outbreaks and establish a minimum wetness duration period for initiation and development of the disease. Poisson regression analysis indicated a significant association between rainfall and temperature with CLNBD incidence (df = 3, Chi Pr < 0.001). Rainfall was positively associated with CLNBD and a unit increase of 1 mm in rainfall caused a 2 percent increase in the percentage of disease incidence (e = +0.01995, $p < 0.011$). However, temperature was negatively associated with disease incidence and a unit increase of 1 °C in temperature caused a 21.56% decline in disease incidence (e = –0.2428, $p < 0.001$). Blight incidence was significantly higher ($p < 0.001$) during the rainy season (range: 11.7 to 36.6%) compared to the dry season (1.4 to 11.5%). Cashew trees in Mtwara District recorded higher blight disease incidence as compared to the rest of the studied areas. This study also established that symptoms for blight disease on cashew leaves appear 8 h post exposure to continuous wet periods. Thus, it appears that for the blight pathogen to initiate and complete its infection processes, a continuous wet period of at least 8 h is required. Findings from this study, particularly the association of rainfall and temperature on disease epidemics, can be used as tools for forewarning incidences of CLNBD. This would help timely initiation of appropriate management strategies.

Keywords Cashew · Blight disease · Disease incidence · Weather variables

Introduction

Plant diseases continue to be one of the major constraints to agricultural production (Palmgren et al. 2015). These diseases can be caused by biotic factors such as fungi, bacteria, viruses, and mycoplasmas or abiotic factors including light, heat, cold, drought, excessive precipitation, pH, nutrition, chemical, and mechanical injury (Manners 1993). Direct yearly agricultural production losses associated with biotic stress have been estimated to be between 20 and 40% (James 1998; Oerke 2006; Oerke et al. 2012; Savary et al. 2012). Plant disease epidemics are associated with weather patterns and climatic parameters, and each disease can be affected differently by weather parameters (Burt 2002).

In Tanzania, cashew is the topmost cash crop, contributing significantly to the foreign exchange earnings (BOT 2016) and is a source of income for more than 500,000 households (NARI 2018). However, like other crops, many different diseases can affect cashew at different stages of its growth (Freire et al. 2002; Sijaona 2013; Wonni et al. 2017). Diseases such as powdery mildew, blight, anthracnose, dieback (Nene and Sijaona 2017; Sijaona 2013), black mould, angular leaf spot and gummosis (Freire et al. 2002) have been considered as the major challenges in cashew nut production. Similarly, recent cashew attacks by *Fusarium oxysporum* represent yet another alarming challenge for cashew producers (Tibuhwa and Shomari 2016).

Cashew Leaf and Nut Blight Disease (CLNBD) continues to be a serious destructive disease of cashews often causing

✉ Wilson Nene
wilsoninene@gmail.com

[1] Department of Cashew Crop Protection, Tanzania Agricultural Research Institute - Naliendele, P. O. Box 509, 10 Newala Road, Mtwara, Tanzania

[2] Department of Cashew Breeding, Agricultural Research Institute (TARI) - Naliendele, 10 Newala Road, P. O. Box 509, Mtwara, Tanzania

substantial yield losses. Investigations of the disease, including pathogen identification in collaboration between the Naliendele Agricultural Research Institute (NARI) and Commonwealth Agricultural Bureaux International (CABI), identified the pathogen at the genus level as a *Cryptosporiopsis* sp. (Sijaona et al. 2006). The disease was originally called “cashew leaf and nut blight disease” because of the pathogen’s ability to infect and show symptoms both on cashew leaves and nuts. However, further observation and monitoring have indicated that the disease can also attack flowers and cashew apples. The disease was first observed in 2000 in a cashew field at Itoculo, Monapo District, Nampula in Mozambique, where it was confused with anthracnose. In 2002, similar symptoms were observed in a cashew field of the Newala District, Mtwara, Tanzania (Sijaona et al. 2006), and only five years later, the disease was recorded in all cashew growing regions in the country (Nene and Sijaona 2017). The disease infests young tissues of newly flushed leaves and developing nuts. Tender leaves show dark tan lesions bordered by dark reddish-brown margins on the leaf laminar, while older leaf lesions appear papery, silver or grey colour and the centre often falls out resulting in a so-called "shot-hole" appearance. The developing nuts and young apples become blackened, and most of them drop down prematurely whereas infected older nuts and apples become darkish and slightly sunken (Sijaona et al. 2006). The disease has been reported to be fast-spreading and can cause yield losses between 40 and 100%, if not controlled (Nene and Sijaona 2017; Sijaona 2013).

Studies have indicated that CLNBD has an incubation period of seven days under field observation (Sijaona 2013) and three days under laboratory conditions (Menge et al. 2014). Laboratory investigations on the biology of *Cryptosporiopsis* sp. identified those environmental factors that favor the growth and development of the pathogen, and have determined that water-based media is an ideal substrate for its growth (Menge et al. 2014).

A study by Menge et al. (2013) investigated for the environmental conditions favouring the growth of *Cryptosporiopsis* pathogen which include a temperature range of 25 to 30 °C and pH level of 6.0 and 7.0

Experiences of researchers from the Tanzania Agricultural Research Institute (TARI) at the Naliendele Centre and general observations have shown that growth and development of *Cryptosporiopsis* sp. is affected both by rainfall and temperature and that period of plant wetness is necessary for infection. However, to date, there have been no attempts of investigating the association between rainfall and temperature or wetness duration, which might be necessary for infection and subsequent development of the pathogen. Understanding the conditions favourable to disease development and disease incidence or severity can serve as the basis for not only estimating the negative impact of the pathogen on cashew yields but also in designing timely initiation of appropriate control strategies against the disease. Thus, this study aimed to assess the association between rainfall and temperature on CLNBD epidemics and the minimum wetness duration required for the initiating of the infection by the blight pathogen and further development of the disease.

Materials and methods

Description of the study area

We conducted a study from June 2016 through May 2017 to assess the association between weather variables particularly rainfall and temperature on cashew leaf and nut blight disease outbreaks. This study was carried out in four locations in the south-eastern part of Tanzania that produces more than 80% of all cashew nut produced in the country. The study involved field work under natural conditions in cashew fields, in the locations of Mtwara 10.3112°S, 40.1760°E, Tandahimba 10.7620°S, 39.6260°E, Masasi 10.7324°S, 38.8101°E, and Nachingwea 10.3318°S, 38.7159°E and screen house under artificial inoculation conditions at the Tanzania Agricultural Research Institute (TARI) Naliendele Centre. The four locations present areas which are suitable for cashew production (Rejani et al. 2013). The studied area covers the Coastal with altitude from below 20 m above sea level, the hinterlands and the plateaux to above 700 m.a.s.l.

The studied areas receive a unimodal type of rainfall that usually starts in November / December through April/May (Nene et al. 2016), though in recent years there have been several changes of off-season rains which fall in between July and September (Nene et al. unpublished data). The mean annual rainfall ranges from 820 to 1245 mm. The mean temperature is 26 °C in the coastal areas and 24 °C in the inland areas (Dondeyne et al. 2003).

Assessment of CLNBD incidences

Six surveys were conducted (three surveys during the dry season and three during the rainy season) for each of the four locations described above. During each blight-monitoring survey, four unsprayed cashew fields were selected randomly in each location, and ten cashew trees per field were assessed. This means forty trees were assessed in every survey for each location. Assessed cashew fields were those with improved cashew seeds distributed by TARI Naliendele (Masawe and Kapinga, 2017). The cultivars are produced from polyclonal seed gardens, however all these cultivars are found in each of the assessed cashew fields, and have similar disease susceptibility. The sampling unit was a one-metre square quadrat whereby shoots on four sides north, south, east and west and those showing the presence of blight for each tree were recorded. This means forty trees were assessed in every survey for each location. We counted all the shoots enclosed within the quadrat and the shoots that were showing symptoms of the disease. The percentage of blight disease incidence was determined by the number of shoots showing symptoms of the disease divided by the total number of shoots enclosed within the quadrat × 100. Data for rainfall and temperature were collected from the nearby weather station whereby each assessed cashew field was estimated at ten (10) kilometres from the weather station. Masasi and Nachingwea are both found in the hinterland areas with similar weather conditions, therefore, weather information from Nachingwea weather stations represents both areas. Summary of the sampling procedures is shown in Table 1 below.

Determination of leaf wetness duration (LWD)

In this experiment, leaf wetness duration (LWD) was considered as, the period when free water caused by either dew or rain remains deposited on the plant tissues. Therefore, we conducted a study to ascertain the minimum wetness duration required for the initiating of the infection by the blight pathogen and further development of the disease.

A total of thirty holes were prepared on a seedbed at TARI Naliendele centre nursery. Two cashew seeds were sown per hole spaced at 1 m apart. After three months, the stands were thinned to one plant and left for inoculation work (Fig. 1).

About 100 tender cashew leaves infected with blight fungus were collected from Naliendele cashew fields and brought to the laboratory. The leaves were thoroughly washed with distilled water, placed into Petri dishes containing filter paper, and wetted with moisture vapour. The Petri dishes were finally covered and incubated at 30 °C to enhance sporulation. After six days, the leaves were removed from the Petri dishes and the conidial suspension was made by adding 600 ml of distilled water.

The plants were later inoculated by spraying with the prepared conidial suspension. Inoculum concentrations were not determined in order to mimic field situations where disease incidence varies. The plants remained enclosed in wet plastic transparent cage or chamber for 24 h to increase humidity (Fig. 2). Six different wetness duration periods (0 h, 4 h, 8 h, 12 h, 16 h, and 20 h) were used and replicated four times. Preliminary observations indicated no any symptom of blight disease on cashew leaves in four (4) hours post application of inocula. Therefore an interval of four (4) hours duration was chosen and found to be appropriate in this experiment. Appearing of dark brown spots of blight disease were assessed on 10 upper most cashew leaves in five (5) seedlings in each wet duration periods.

Fig. 1 Cashew plants without a transparent plastic cage

Fig. 2 Cashew plants enclosed in a transparent plastic cage to increase humidity

Table 1 Summary of sampling procedures

Number of surveys per location	6
Number of cashew fields assessed per location	4
Number of cashew trees per field	10
Total cashew trees per survey per location	40
Total cashew trees per one season	120
Sampling unit	1 m^2 square quadrat

Table 2 Association between rainfall and temperature on cashew leaf and nut blight disease epidemics

Parameter	Estimate	s.e	t(*)	t pr	Exp [β]
Rainfall	0.01995	0.00782	2.55	0.011	1.020
Temperature	-0.2428	0.0329	-7.37	0.001	0.7844
Rainfall*Temperature	-0.000576	0.000294	-1.95	0.051	0.9994

estimate estimate or coefficient of parameters, *s.e* standard error of estimates, *t(*)* estimate/standard error, *tpr.* probability, *Exp [β]* exponent of estimate

At the end of each respective wetness period, the plants were gently dried using a table fan. The prevailing temperatures during the experiment fluctuated between 27 to 31 °C and 20 to 24 °C for days and nights, respectively. After 24 h, the plastic bags were removed, and the plants were observed daily for blight symptoms expression for ten (10) days. The percentage of blight disease incidence was determined by counting the number of leaves showing symptoms of the disease divided by the total number of leaves per plant × 100.

Data analysis

We performed Poisson regression analysis for data on blight disease incidence in the fields to determine the association between rainfall and temperature on blight epidemics. Data for blight incidence between locations, season (dry and rainy) within locations and between locations and wetness durations were not normally distributed even after transformation. Therefore, a non-parametric one-way ANOVA (Kruskal–Wallis) test was performed to find out variations between locations. Mann–Whitney U test was used to compare the differences in blight disease incidence between dry and rainy season. Data were analysed using GenStat software 15th edition.

Results

Association between rainfall and temperature on blight disease epidemics

The Poisson regression results (Table 2) showed significant associations between rainfall and temperature with CLNBD incidence (df = 3, Chi Pr < 0.001). Rainfall was positively associated with CLNBD (Table 2). A unit increase in rainfall caused a 2 percent increase in the percentage of disease incidences (e = +0.01995, $p < 0.011$, Exp [β] = 1.02). The temperature was associated with a low disease incidence. A unit increase in temperature caused a 21.56 percent decline in the disease incidences (e = –0.2428, $p < 0$ 0.001, Exp [β] = 0.7844).

Comparison of blight disease incidence in different locations and season

Figure 3 presents the CLNBD incidences per cashew fields. Generally results indicated insignificances of CLNBD incidences within fields. Results in Fig. 4 indicate that, CLNBD differs significantly (df = 3, Chi Pr < 0.001) with locations when percentage disease incidences for both rainfall and dry seasons are pooled together. The highest disease incidence was 24%

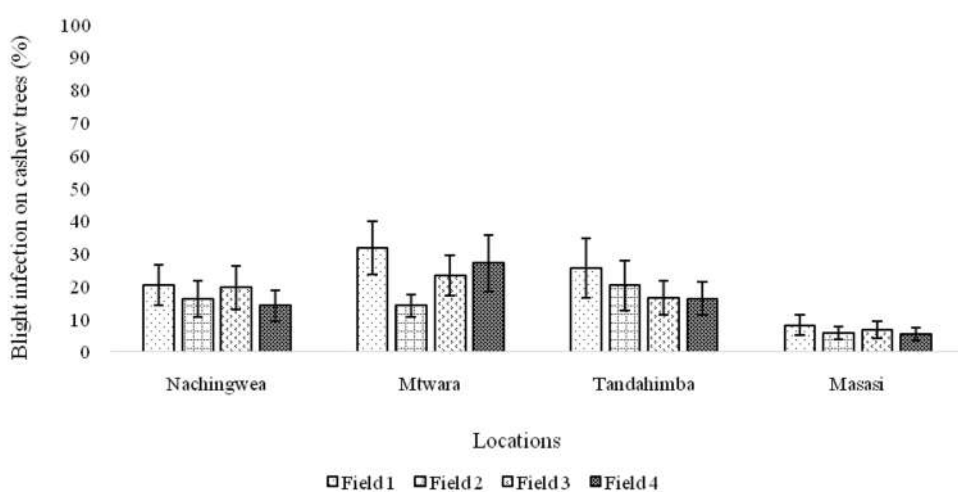


Fig. 3 Cashew leaf and nut blight infection in each of the assessed cashew field (Nachingwea: df = 3, n = 12, H = 0.7653 Chi Pr = 0.857, Mtwara: df = 3, n = 12, H = 1.940, Chi Pr = 0.585, Tandahimba: df = 3, n = 12., H = 0.4143 Chi Pr = 0.937 and Masasi: df = 3, n = 12, H = 0.1677, Chi Pr = 0.982)

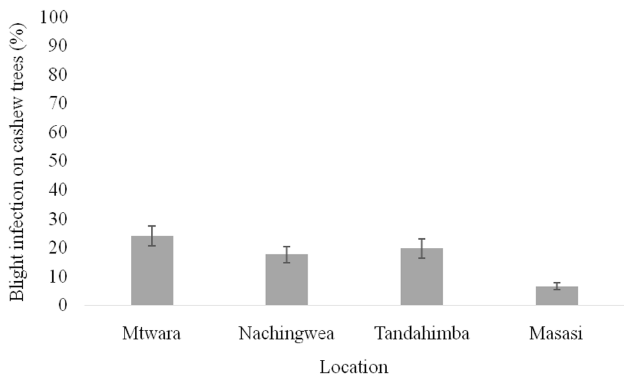


Fig. 4 Cashew leaf and nut blight infection in different locations (df = 3, n = 48, H = 17.06, Chi Pr < 0.001)

in Mtwara whereas cashew fields in Masasi recorded the least blight disease infection (6.6%). Nachingwea and Tandahimba recorded blight disease incidence of 17.6 and 19.7 respectively.

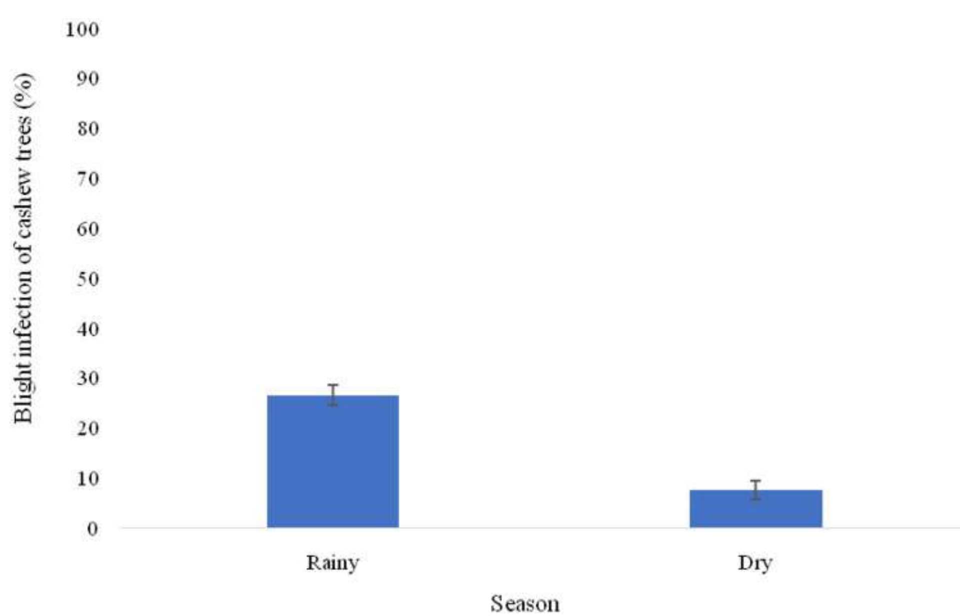
Figure 5 shows the CLNBD incidence level between rainy and dry season (without considering locations). Significantly (Mann–Whitney U test = 1167, n = 96, p < 0.001) more incidence of CLNBD was recorded during the rainy season (December to May = 26.5%) as compared to the dry season (June to November = 7.5%). Considering locations (Fig. 6), blight infection was higher in each cashew field of Mtwara, Tandahimba, Masasi, and Nachingwea during rainy season as compared to the dry season. Masasi site recorded lower blight incidence during both rainy and dry seasons of 11.7 and 1.4 respectively compared to other locations. Higher mean percentage of blight disease was recorded in Mtwara District during rainy (36.6%) and 11. 5% during the dry season compared to other locations.

Results in Table 3 indicate maximum and minimum CLNBD incidences during the rainy and dry season in studied locations. During rainy season, minimum blight incidence was 0% in Masasi while maximum recorded disease incidence was 97.5% in Tandahimba. We recorded blight incidence of between 0.0 and 85.4% during the dry season.

Rainfall during this study ranged from 15.5 mm recorded in December at Nachingwea site (Fig. 7) to 298.6 mm recorded in February at Mtwara site (Fig. 8). Results indicated that the mean temperature ranged from 24.7 °C to 27 °C during the dry period and from 24. 5 to 28.3 °C during the rainy season, whereby the lowest temperature (24.5 °C) was recorded in May in Nachingwea and highest of 28.3 °C was recorded in December in Mtwara. Results in Fig. 9 indicated that, amount of rainfall in March was higher in Tandahimba (274.7 mm) compared to other locations. Temperature in Tandahimba ranged from 24.7 (recorded in May) to 27.0 °C which was recorded in February.

Results obtained six days after the inoculation showed that blight symptoms were vividly clear on cashew leaves, which were wet for more than 8 h. Furthermore, disease incidence on those leaves increased with an increase of wetness period as shown in Fig. 10. The observation indicates that young and tender leaves were more affected than did mature ones.

Fig. 5 Cashew leaf and nut blight infection during rainy (December to May) and dry season (June to November) (Mann–Whitney U test = 1167, n = 96, $p < 0.001$)



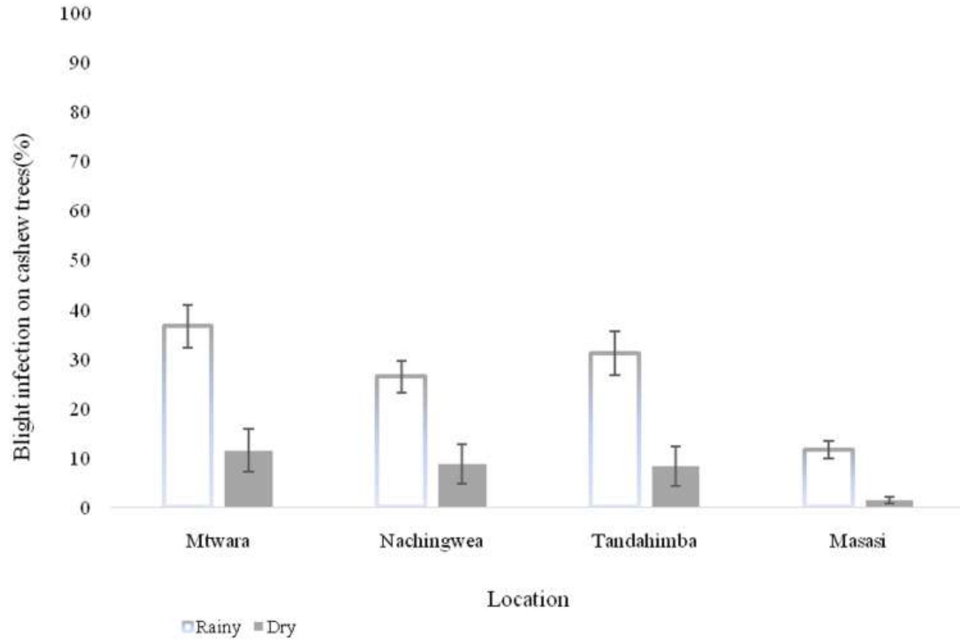


Fig. 6 Cashew leaf and nut blight infection in different locations in the rainy and dry season (df = 3, Chi Pr < 0.001)

Discussion

This study revealed the association between weather parameters, particularly rainfall or wetness duration and temperature on CLNBD incidence. The study also compared the disease incidence in terms of weather period (rainy and dry) and locations. The study recorded CLNBD incidence under both natural (through field surveys) and artificial (inoculated) conditions. Results indicate that CLNBD severity was significantly associated with rainfall, temperature, and wetness duration. To the best of our knowledge, this is the first report of analyzing the association of rainfall or wetness duration and temperature on CLNBD epidemics. A higher infestation of CLNBD was positively associated with rainfall, and accordingly a higher disease incidence was recorded during the rainy season compared to the dry season. However, an increase in temperature and the interaction between temperature and rainfall caused a decrease in disease incidence. A similar result was observed by Shafaullah et al. (2011) who reported an increase of blast disease of rice as rainfall increases and a decrease of the disease as temperature increases. The studied areas receive a uni-modal type of rainfall, which is from December through May. Periods of June through November is considered a dry period with almost no rains. However, in recent years because of climate, change there has been repeated several events of rains during this dry period; and these are termed as 'rains of the off-rainy season'. Cashew farmers consider this rain as 'bad rain' as it favours blight disease development. Virulent pathogens require conducive environments to infect susceptible hosts (Pannu 2013; Velásquez et al. 2018). Environmental parameters on pathogen and plants can have favourable, neutral or negative effects on disease development (Velásquez et al. 2018). Conditions such as temperature and humidity influence virulence factors of the pathogen such as virulence proteins, toxins production, reproduction and survival of the pathogen (Velásquez et al. 2018). A work by Sandhu et al.

Table 3 Comparison of blight incidence between rainy and dry season in cashew fields within the locations. Mann–Whitney (U) test and probabilities are as shown

	Minimum	Mean	Maximum	Sample size	Mann–Whitney test (U)	Probability
Mtwara (Rainy)	5.3	36.6	90.0	12	78	< 0.001
Mtwara (Dry)	0.0	11.5	79.8	12		
Nachingwea (Rainy)	4.1	26.4	75.1	12	81	< 0.001
Nachingwea (Dry)	0.0	8.7	57.0	12		
Tandahimba (Rainy)	4.5	31.2	97.5	12	66	< 0.001
Tandahimba (Dry)	0.0	8.2	85.4	12		
Masasi (Rainy)	0.9	11.7	27.2	12	40	< 0.001
Masasi (Dry)	0.0	1.4	11.7	12		

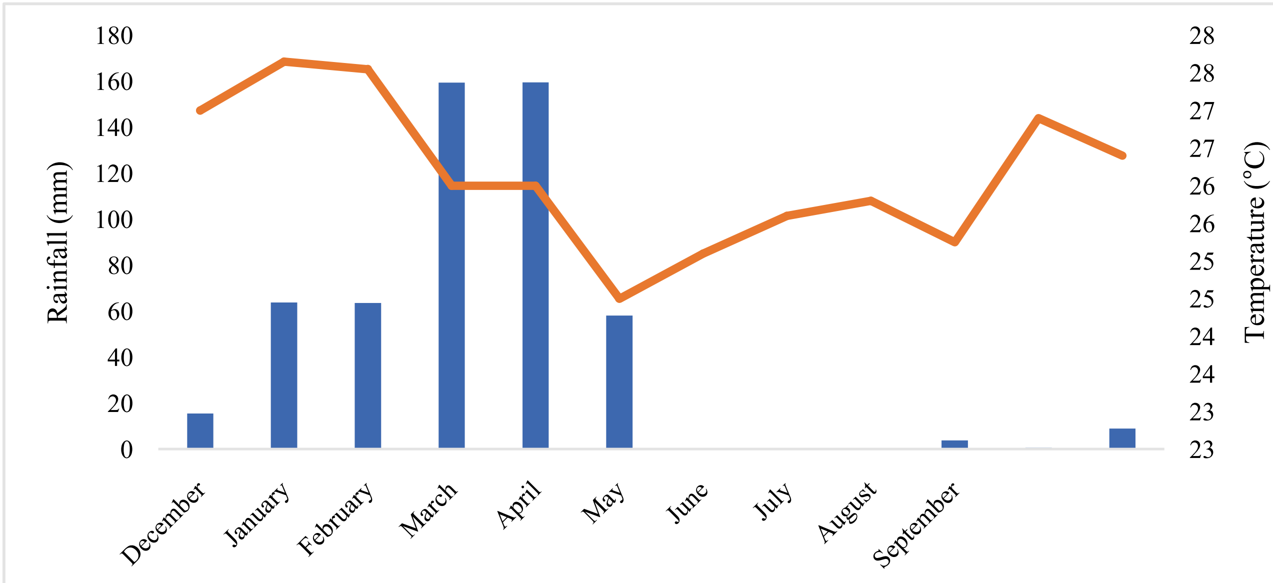


Fig. 7 Monthly rainfall and temperature from June 2016 to May 2017 at Nachingwea, Tanzania

(2017) indicated that temperature and relative humidity are highly correlated with stripe rust incidence caused by *Puccinia striiformis* f. sp. *tritici.* The month with the highest rainfall, temperature, and relative humidity recorded higher disease incidence of leaf spot of Jack fruit compared to other months (Shiblu et al. 2015). Like other fungi such as yeasts (Park et al. 2008), the infection mechanism of the *Cryptosporiopsis* pathogen is favoured by water. Therefore, the pathogen can be considered as hydrophilic fungi with a strong affinity to water (Babič et al. 2017; Park et al. 2008).

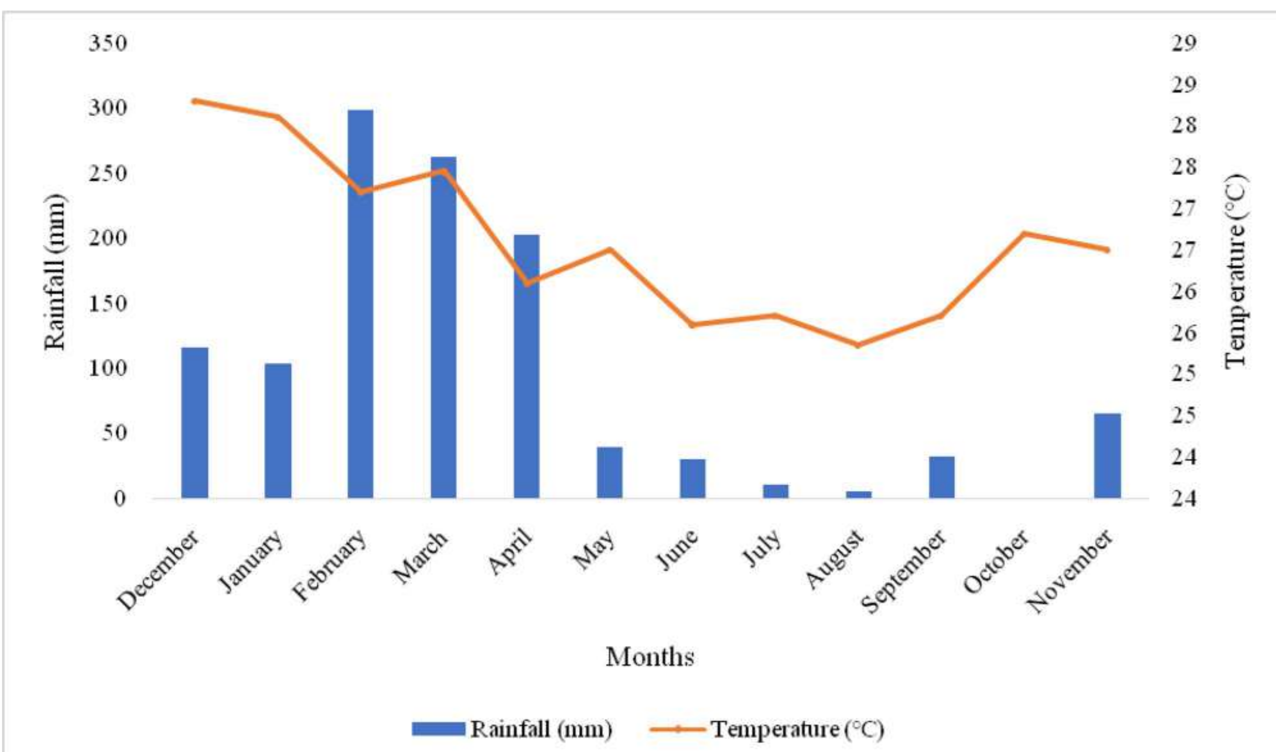


Fig. 8 Monthly rainfall and temperature from June 2016 to May 2017 at Mtwara, Tanzania

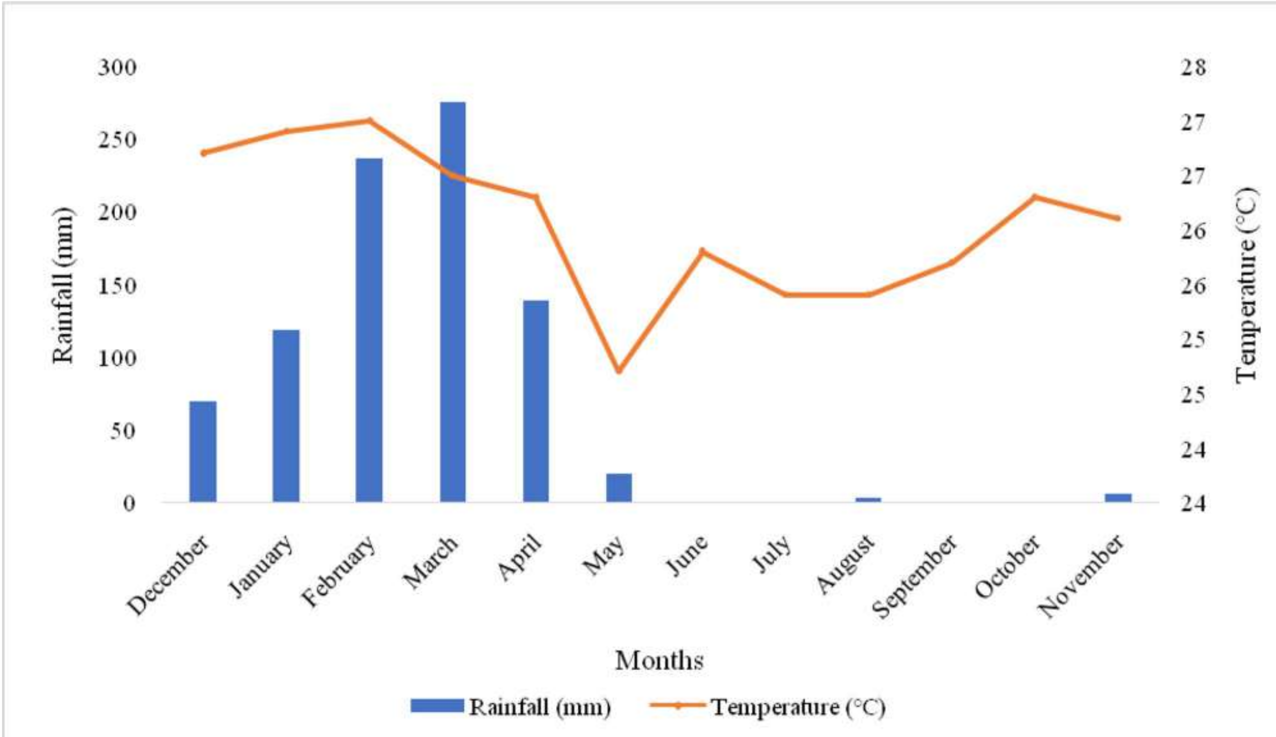


Fig. 9 Monthly rainfall and temperature from June 2016 to May 2017 at Tandahimba, Tanzania

The symptoms during observations in the fields showed that the disease infests young tissues of new flush leaves and developing nuts. The attacked leaves show angular lesions, which enlarge and coalesce, causing blighting and defoliation. Leaves showed lesions, which are dark tan and bordered by dark reddish-brown margins on the leaf laminar.

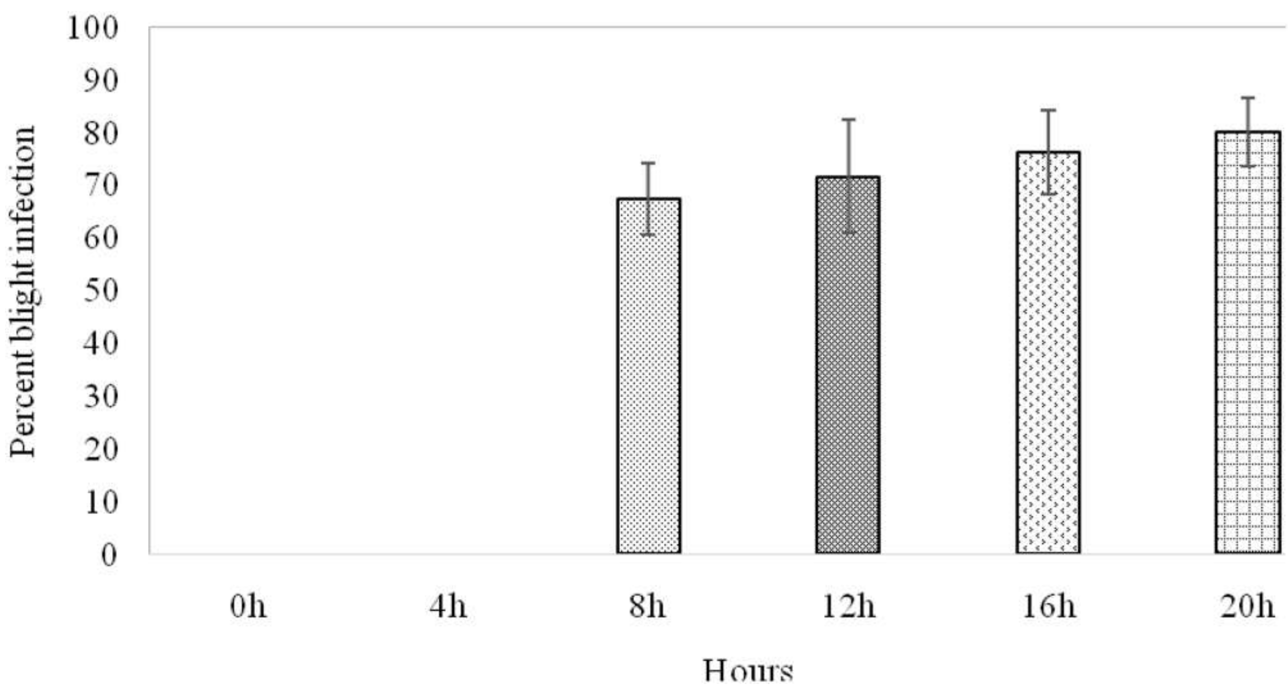


Fig. 10 Percentage of blight disease incidence observed on cashew leaves after being subjected to different wetness durations (df = 5, H = 61.40, n = 50, Chi Pr < 0.001)

This situation was noticed under severe infection particularly at the early stages of disease development. Older leaf lesions appear papery, silver or grey colour and the centre often fall out giving a shot-hole appearance.

Infection by the *Cryptosporiopsis* pathogen tends to spreads to the developing nuts and young apples particularly during the reproductive phase of the cashew (Nene et al. 2016). Subsequently, infected young nuts blacken and most of them drop down prematurely, resulting in significant yield losses. Infected older nuts and apples become darkish and slightly sunken (Sijaona et al. 2006).

The present study revealed that cashew leaf and nut blight disease incidence levels varied across locations. Factors such as different agricultural practices, the build-up of inoculum, weather conditions, and climate change cause variation in the disease epidemics. Lower blight disease incidence was recorded in Masasi cashew fields. Field observations indicated that cashew canopies in Masasi cashew fields had fewer new flush leaves and tender parts as compared to other areas.

Screen house results experiment show that cashew blight disease grows rapidly when exposed to continuous wet periods of more than 12 h. However, when subjected to less than 12 h of wetness, blight spots were also visible, but of reduced sizes. Disease incidence increased with increased duration of wet periods. Thus, it appears that for the blight pathogen to initiate and complete its infection processes, including penetration of host tissues and colonization, a film of water lasting more than 12 h is required. The findings show that increased wetness duration accelerates infection and trigger the occurrence of blight epidemics. Some pathogens release their spores in the films of water from rain or dew on the surface of the leaf (Hardwick 2002), sot it is also possible that longer wetness periods may increase sporulation of the CLBND pathogen.

Conclusions and recommendations

We recorded CLNBD in all of the studied areas but in varying incidence levels. This study revealed that the *Cryptosporiopsis* pathogen is favoured by wet conditions, and the presence of wetness condition on tender new flush leaves is associated with rapid growth and development of CLNBD. The TARI at Naliendele Centre has recommended different management strategies, which include the use of fungicides against cashew leaf and nut, blight disease. The majority of the recommended chemical brands contain active ingredients such as tebuconazole, trifloxystrobin or chlorothalonil (NARI 2018). The application of chemicals is done only during the reproductive phase, which is between June and November to protect flushing leaves, flowers, and developing nuts. The findings of this study can be used as disease predictor for forewarning incidence of CLNBD. Based on incubation period for the disease to show symptoms; three days under laboratory study (Menge et al. 2014) or seven days in the field (Sijaona 2013), it is therefore recommended that appropriate time for initiating application of chemicals can be within three days after the fall of rains.

Acknowledgements Authors are thankful to Mr. Betram Barnabas, Erick Mrope, and Issaya Mwakabaga for their support during data collection. The Government of Tanzania through the Cashew Research Programme financially supported the study.

Declarations

Research involving human participants and/or animals The research did not involve either human participants or animals.

Conflict of interest There is no conflict of interest (financial or non – financial).

References

Babič MN, Gunde-Cimerman N, Vargha M, Tischner Z, Magyar D, Veríssimo C, Brandão J (2017) Fungal contaminants in drinking water regulation?. A tale of ecology, exposure, purification and clinical relevance. Int J Environ Res Public Health 14(6):636

BOT (2016) Bank of Tanzania monthly economic review March 2017 (http://www.bot.go.tz), Accessed on 10 May 2020

Burt P (2002) Weather and pests. Weather 57(5):180–184

Dondeyne S, Ngatunga EL, Cools N, Mugogo S, Deckers J (2003) Landscapes and soils of South Eastern Tanzania: their suitability for cashew. In book: Knowledge transfer for sustainable tree crop development. A case history of the Tanzanian Integrated Cashew Management Programme, BioHybrids Agrisystems Ltd, Chapter: 12.

Freire F, Cardoso J, Dos Santos A, Viana F (2002) Diseases of cashew nut plants (*Anacardium occidentale* L.) in Brazil. Crop Prot 21(6):489–494

Hardwick N (2002) Weather and plant diseases. Weather 57(5):184–190

James C (1998) Global food security. Abstr Int Congr Plant Patho, 7th Edinburgh, UK, Aug (4.1)

Manners J (1993) Principles of plant pathology: Cambridge

Masawe PLA, Kapinga FA (2017) The First Dwarf Cashew Varieties in Tanzania. Naliendele Agricultural Research Institute, Mtwara Tanzania pp 1–125

Menge D, Makobe M, Agboton B, Shomari S, Tiedemann A (2014) Biology and infection mechanisms of cryptosporiopsis spp fungus causing blight disease on cashew (*Anacardium Occidentale* L.). J Plant Sci 2(6):266–275

Menge D, Makobe M, Shomari S, Tiedemann AV (2013) Effect of environmental conditions on the growth of Cryptosporiopsis spp. causing leaf and nut blight on cashew (*Anacardium occidentale* Linn.) J Yeast Fungal Res 4(2):12–20

NARI (2018) Annual Cashew Research Report for 2018/2019. Retrieved from Ministry of Agriculture, Tanzania Agricultural Research Institute - Naliendele, Mtwara, Tanzania

Nene W, Rwegasira G, Mwatawala M (2016) Temporal abundance of African weaver ant, *Oecophylla longinoda* (Hymenoptera: Formicidae) under unimodal rainfall pattern in Tanzania. Biocontrol Sci Technol 26(4):539–547

Nene W, Sijaona M (2017) Assessment of Incidences and Severity of Cashew Leaf and Nut Blight Disease (CLNBD) in the Southern Areas of Tanzania

Oerke E-C (2006) Crop losses to pests. J Agric Sci 144(1):31–43

Oerke E-C, Dehne H-W, Schönbeck F, Weber A (2012) Crop production and crop protection: estimated losses in major food and cash crops: Elsevier

Palmgren MG, Edenbrandt AK, Vedel SE, Andersen MM, Landes X, Østerberg JT, Sandøe P (2015) Are we ready for back-to-nature crop breeding?. Trends Plant Sci 20(3):155–164

Pannu P (2013) Influence of weather factors on occurrence and development of stripe rust (*Puccinia striiformis* f. sp. *tritici*) of wheat and its management. PAU Ludhiana, India

Park J-H, Cox-Ganser JM, Kreiss K, White SK, Rao CY (2008) Hydrophilic fungi and ergosterol associated with respiratory illness in a water-damaged building. Environ Health Perspect 116(1):45–50

Rejani R, Rupa TR, Nayak MG (2013) Suitability of cashew growing areas in India – an appraisal using GIS. J Agrometeorol 15 (Special Issue-II): 123–128.

Sandhu SK, Dhaliwal L, Pannu P (2017) Effect of weather parameters on incidence and severity of stripe rust in wheat under natural and artificial conditions. J Agrometeorol 19:272–277

Savary S, Ficke A, Aubertot J-N, Hollier C (2012) Crop losses due to diseases and their implications for global food production losses and food security. Food Security. https://doi.org/10.1007/s12571-012-0200-5

Shafaullah MAK, Khan NA, Mahmood Y (2011) Effect of epidemiological factors on the incidence of paddy blast (Pyricularia oryzae) disease. Pak J Phytopathol 23(2):108–111

Shiblu MR, Chowdhury MS, Mazed HE, Pulok MA, Chowdhury MS (2015) Effect of weather components on the incidence and severity of leaf spot of jackfruit seedling (*Artocarpus heterophyllus* L.) in Bangladesh. Int J Innov Appl Res 3(1):37–41

Sijaona M (2013) Important diseases and insect pests of cashew in Tanzania. Naliendele Agricultural Research Institute, Mtwara, Tanzania

Sijaona MER, Reeder RH, Waller JM (2006) Cashew leaf and nut blight - a new disease of cashew in Tanzania caused by *Cryptosporiopsis* spp. Plant Pathol 55:576. https://doi.org/10.1111/j.1365-3059.2006.01365.x

Tibuhwa DD, Shomari S (2016) Fusarium wilt disease: an emerging threat to cashew nut crop production in Tanzania. Asian J Plant Pathol 10:36–48

Velásquez AC, Castroverde CDM, He SY (2018) Plant–pathogen warfare under changing climate conditions. Curr Biol 28(10):R619–R634

Wonni I, Sereme D, Ouedraogo I, Kassankagno A, Dao I, Ouedraogo L, Nacro S (2017) Diseases of Cashew Nut Plants (*Anacardium Occidentale* L.) in Burkina Faso. Adv Plants Agric Res 6(3):00216