Assessment of leaf spot disease on water leaf (*Talinum triangulare* (jacq.) Willd) and *in vitro* effect of three medicinal plant extracts on pathogen(s) in the Northwest Region of Cameroon

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Cultivation of waterleaf improves the life quality of families and provides additional income for farmers. However, waterleaf production in Cameroon has suffered a major blow from leaf spot disease. Ten farms with dimensions of 4 m by 3 m each in Nkwen, Bamenda, Cameroon were surveyed for leaf spot disease of *Talinum triangulare*. Disease incidence and severity were assessed by surveying the farms after every fourteen days for three months. Small pieces of infected leaf parts were inoculated on prepared plates of potato dextrose agar. After 7 days of incubation, pure cultures were made, and isolated fungi were identified according to recommended references. Aqueous extracts from *Moringa oleifera* (Leaves), *Ocimum gratissimum* (Leaves) and *Zingiber officinale* (Rhizomes) were evaluated for *in vitro* antifungal activities on *Alternaria* and *Cercospora*. Data collected for disease incidence and severity showed varying intensities at the different locations. Two fungi species were isolated from the diseased leaf samples collected from 5 farms and were identified as *Alternaria* spp. and *Cercospora* spp. All the extracts had inhibitory activities on the test fungi with the highest inhibition (79.6%) obtained from *Zingiber officinale* (Rhizomes) extract and the lowest inhibition (4%) obtained from *Ocimum gratissimum* extract.

**Key words:** Identification, incidence, severity, leaf spot, plant extracts, waterleaf.

**INTRODUCTION**

Increase in world population has led to increasing demands for more enhanced vegetable consumption and meat-based diets over the second half of the last century (Rasadhika et al., 2018; Ismail et al., 2020). This has led to a large increase in the urban population in Africa (Holdsworth and Landais, 2019). There are projections that the urban population will reach 63% by 2050, in West and Central Africa. Therefore, there is the need for effective urban and peri urban agricultural production systems to complement rural systems (Billa et al., 2017).

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Water leaf (Talinum triangulare (Jacq.) is a plant belonging to the family, Portulacaceae and it is commonly found in humid tropics. It is believed to be of South American origin but an African origin may not be doubted (Oluwol et al., 2019). Waterleaf cultivation like other leafy vegetable cultivation in home gardens improves the life quality of families and may provide additional income for female farmers (Mwadzigeni et al., 2021). Waterleaf plays a major role in eradicating malnutrition in Africa (Ikeyi et al., 2020).

Leaf spot diseases are very common in ornamental crops and are usually caused by micro-organisms such as fungi and bacteria (Dicklow, 2019) but the most common are fungal leaf spot (Douglas, 2020). The causal agents of a great deal of crops include fungi species such as Alternaria, Cercospora, Colletotrichum and Myrothecium species, as well as bacterial species such as Xanthomonas and Pseudomonas species (Dicklow, 2019). Some indicators of leaf spot diseases include the appearance of yellow, orange, red or brown spores that appear to be powdery (Grabowski, 2018). The spots occur in various sizes, ranging from pinhead to those that may occupy the whole plant leaf (Douglas, 2020). Also, there is usually the appearance of dead lesions where the edges appear black or dark, surrounding a brownish or reddish center (Douglas, 2020). Leaf spot disease can be controlled by ensuring proper sanitary measures and minimizing the moisture content around the crops (Dicklow, 2019). Another measure is to space plants during planting (Grabowski, 2018).

Various production practices and variation in climatic conditions are thought to influence disease incidence, severity and damage to the crops, under field conditions (Stenglein et al., 2003; Alleorent and Savary, 2005; Mwangombe et al., 2007). Leaf spot diseases are mostly identified based on cultural, morphological, biochemical and physiological tests for rapid differentiation of the causative pathogen (Kaur et al., 2012). Current crop protection efforts focus on developing biopesticides that are environmental friendly and effective in managing plant pests and diseases. Natural plant products have been shown to be good sources of agrochemicals since they are easily biodegradable and do not pollute the environment (Goussous et al., 2010). Various natural products of plant origin have been proven to be effective in controlling various foliar pests and pathogens in a semi basin situated at the foot of the Bamenda fault scarp, lying in an altitude of 1200 m above sea level (Chombeng, 2014). The climatic variation of this area fits in two seasons being the dry season and the rainy season. It experiences the tropical rain forest climate. The rainy season begins in March and ends in October while the dry season begins in October and ends in February. The temperature of the rainy season ranges between 23 to 30°C (Kinge et al., 2016). People in this area carry out subsistence agriculture, cultivating crops like maize, beans, sweet potatoes, banana, plantain, cocoyam just to name a few. Some engage in water leaf cultivation. Figure 1 shows the map of the study farms.

Determination of disease incidence and severity

Survey was conducted to determine the percentage disease incidence and severity of leaf spot disease on waterleaf in 10 farms with dimensions of 4 m by 3 m for each of the farm in 10 different quarters of Nkwen for 3 months. February to April 2021. Leaf spot disease on Talinum triangulare was recorded from all the ten farms during the three months but with varying intensities. The symptoms observed in the different farms were light brown to dark brown, roundish-oval to irregular spots of 1 to 2 mm in diameter at the initial stage, which later expanded, often coalesced and produced ‘Shot hole” during severe infection. The plants were examined every fourteen days and quantitative assessment (number of plants / leaves infected) was made. Assessment of the number of infected plants and leaves was done in two randomly selected quadrates (1 m by 1 m) per farm and scored for leaf spot severity on a scale of 0-6 as shown in Table 1 according to the method of Annih et al. (2020).

The following formulae were used to determine the percentage of disease incidence and severity,

\[
\text{Percentage of disease incidence (PDI)} = \frac{\text{Total Number of Infected Plants}}{\text{Total Number of Plants Assessed}} \times 100
\]

\[
\text{Percentage of disease severity (PDS)} = \frac{\text{Number of Individual ratings} \times \text{Maximum scale}}{\text{Number of plants Assessed}}
\]

Isolation and identification of the causative pathogen

The farms were visited, and pictures of the diseased plants (Figure 2) were taken. 23 samples of the diseased leaves were collected from 5 different farms in 5 quarters [Below Foncha (farm 1), Ntasen (farm 2), Muye (farm 3), Ndumukong (farm 4) and Banja (farm 5) of Nkwen village]. 5 samples were collected from farms 1, 2 and 3 each and four samples from farms 4 and 5 each. The samples were separately put in zip lock plastic bags and transported by public transport to the University of Buea Life Science Laboratory for isolation and identification of the causative pathogen(s) of leaf spot disease of Talinum triangulare.
Potato dextrose agar (PDA) was used for the isolation of fungi, and was prepared following the manufacturer’s instructions (Beever and Bollard, 1970), in which 42 g of potato dextrose agar (PDA) was weighed and distilled water added to make 1000 ml. The

Figure 1. Location map of study area.
Source: Author
Table 1. Disease severity scale.

| Index | Percent affected (%) | Description                                                                 |
|-------|----------------------|------------------------------------------------------------------------------|
| 0     | 0                    | No disease infection                                                         |
| 1     | 5 - 15               | Few lesions of leaf spot disease infection dotted on fewer leaves             |
| 2     | 15 - 25              | Moderate lesions of leaf spot infection on fewer leaves                       |
| 3     | 25 - 50              | Leaf spot infection on at least half of the water leaf plants                 |
| 4     | 50 - 75              | Leaf spot infection on the surface of the leaves and showing holes            |
| 5     | 75 - 85              | Leaf spot infection on almost all the leaves with spots coalescing           |
| 6     | Above 85             | About 90% of the leaves showing leaf spot disease with leaves tearing off    |

Source: Author

medium was autoclaved at 121°C for 15 min, allowed to cool to about 50°C before the addition of 0.1 g/L of gentamycin and penicillin to prevent growth of bacteria. The mixture was stirred by gently swirling the flask, before pouring into sterile Petri dishes. The medium was allowed to solidify before inoculation.

Isolation of fungi

Isolation of the fungi was based on the method described by Hallman et al. (2007). Three diseased areas including some healthy part of about 3 mm were cut under aseptic conditions from each diseased leaf sample using a sterile scalpel. The small pieces of the diseased parts were washed with tap water to remove dust and debris adhering to them. They were then immersed in 10% sodium hypochlorite solution for 3 min and were removed using a sterile forceps and rinsed in distilled water. This was followed by rinsing with 70% alcohol for 1 min. They were finally rinsed in three changes of sterile distilled water and blotted dry on sterile tissue paper. Each plate was inoculated with 3 pieces of the surface sterilized diseased area of the diseased leaf samples. Inoculation was done such that there were 23 plates; 15 from samples of farms 1, 2 and 3 (5 Petri plates for each farm), 8 from samples of farms 4 and 5 (4 Petri plates for each farm). Plates were sealed with parafilm wax and incubated at room temperature (25°C), in the dark for 7 days. Fungi growing out of the inoculants were sub-cultured on fresh PDA plates at room temperature. Fresh plates of PDA were prepared. The distinct fungi colonies from the primary cultures were cut out using a sterile scalpel, and then transferred to the fresh PDA plates to obtain pure cultures. Inoculated plates were sealed with parafilm wax and incubated at room temperature (25°C), in the dark for 7 days.

Morphological and cultural characterization

For macroscopic observation, the cultural appearances (colony diameter, colony colour, texture, margin, form, elevation and aerial hyphae) were noted on PDA. Colony colours were determined using Methuen handbook of colour chart (Kornerup and Wanscher, 1978). A laboratory manual and a pictorial atlas for identification of fungi by Watanabe (2002) were equally used in the description of colony morphology.

For micro-morphological characterization, all isolates sub-cultured were observed under a microscope for the presence of hyphae, presence or absence of septa on their hyphae, clamp connections, the kind of asexual reproductive structures in order to determine their taxonomic classes. Identification of the fungi was done according to Fawole and Oso (1995). A drop of methylene blue stain was placed on a clean slide and with the aid of a mounted needle, a small portion of the mycelium from the fungal cultures was removed and placed in the drop of stain. The mycelium was spread very well on the slide with the aid of the two mounted needles and a cover slip was gently lowered on it. The slide was then examined under the microscope. The observation was done at high power objective (×40) of the microscope.
Morphological characteristics of the fungi such as type of hyphae and asexual reproductive structure were observed. Pictures of fungi isolates were taken for further characterization and comparison with a document book of fungi (Sarah et al., 2017) and other representative pictures of fungi species.

**In vitro control of fungi that cause leaf spot disease on waterleaf**

The extracts of the three plants used were leaves of *Moringa oleifera* and *Ocimum gratissimum* and the rhizomes of *Zingiber officinale*. These plants were selected because of their availability, accessibility, affordability or low cost, environmental friendliness, high versatile anti-microbial spectrum (Okoi and Afuo, 2009; Mohammed et al., 2012) and because they cause no health issues on humans when consumed. The rhizomes of *Z. officinale* were bought from Nkwen market, Bamenda, Cameroon and the leaves of *M. oleifera* and *O. gratissimum* were harvested from Ndumukong quarter Nkwen, Bamenda, Cameroon. They were sealed in zip lock plastic bags and transported to the University of Buea Life Science Laboratory for extraction.

Fungi inhibitory effect was checked by food poisoning technique using different plants extract in the laboratory. For this purpose, three plants were selected; *M. oleifera* (Leaves), *O. gratissimum* (Leaves), *Z. officinale* (Rhizomes). 10 grams of plants’ relevant part was macerated with the help of pistol and mortar by adding equal amount of distilled water (1:1 w/v). At last extracts were filtered with the help of muslin cloth and poured into sterile test tubes. An aqueous solution (100%) was obtained. Further, the extracts were diluted by adding sterilized water to get 10% concentration. Plant extracts were heated at 50°C to avoid contamination. 1 and 0.5 mL of the plant extract measured with a micro pipette was poured in 10 mL PDA Petri plates and gently swirled for mixing of plants extract in the media. When PDA and plant extracts solidified, then 8 mm disc of 10 days old fungi (*Alternaria* and *Cercospora*) were separately placed in the center of the Petri plates. Two Petri plates were prepared as control for each fungus and no plant extract was introduced into them. Only sterile distilled water was used. All Petri plates were sealed with parafilm wax and incubated at 23°C for 10 days. Growth inhibition of fungi inoculated and uninoculated was calculated according to the formula given by Vincent (2012):

\[ I (\% \text{Inhibition}) = \frac{C-T}{C} \times 100 \]

Where: I=Percent inhibition; C=Growth in control and T=Growth in treatments.

**Data analysis**

All data collected on disease incidence and severity were subjected to analysis of variance (ANOVA) at the end of the study by using GenStat Release 10.3 (2011) software application and statistical software (J.M.P.B). Data for percentage disease incidence and severity were presented in tables.

**RESULTS**

**Disease incidence**

The data collected for disease incidence (Table 2) show that the percentage of disease incidence ranged between 5.1 and 92.4% at different locations. The highest mean percentage (63.9%) was observed in the Below Foncha farm and the lowest mean percentage (25.8%) is observed in the Muyeb farm. As for the months, the highest mean percentage (69.5%) was observed in the first half of March and the lowest mean percentage (12.5%) was observed in the first half of February. The highest monthly mean percentage (56.2%) was observed in the month of March and the lowest monthly mean percentage (27.4%) was observed in the month of February. The difference in the monthly mean percentage between the months of February and April was 2.6%.

**Disease severity**

After conducting survey on the ten farms using the dimensions 4 m by 3 m on each of the farm for three months, the data collected for disease severity (Table 3) show that the percentage disease severity ranged between 2.5 and 73% at different locations. The highest mean percentage disease severity (30.5%) was observed in Below Foncha farm, and the lowest mean percentage disease severity (10.5%) was observed in Muyeb farm. As for the months, the highest mean percentage disease severity (33%) was observed in the first half of March and the lowest mean percentage (4.8%) was observed in the first half of February. The highest monthly mean percentage (27.3%) was observed in the month of March and the lowest monthly mean percentage (12%) was observed in the month of February.

**Isolation and Identification of pathogens**

After seven days of inoculation of diseased area samples on PDA, two types of fungi culture were found growing on the culture media: A white fungi culture and a black fungi culture. These two fungi cultures were sub-cultured and after seven days, pure fungi culture of the black and white fungi isolates were obtained as shown in Figures 3 to 7.

The description of some cultural and morphological characteristics of the fungi isolates such as colony diameter, colony color, texture, margin, form, elevation and aerial hyphae is shown in Table 4.

**Micro-morphological identification**

When the sub-cultured isolates were observed under the microscope, it was seen that both the black and white fungi isolates had branched septate hyphae with no clamp connections. Conidia, conidiophores and conidiospores were also seen (Figures 8 and 9).

Based on cultural, macro-morphological and micro-morphological characters, the two fungi isolates were believed to belong to Phylum Ascomycota, since they all had septate and irregularly branched hyphae which lacked clamp connections. Both isolates also had conidia,
Table 2. Data for percentage disease incidence of leaf spot disease on waterleaf collected every 14 days from ten farms for three months.

| Quarters / farms | February 1st half | Percentage | 2nd half Infected plants | Percentage | March 1st half | 2nd half Infected plants | Percentage | April 1st half | 2nd half Infected plants | Percentage |
|------------------|-------------------|------------|--------------------------|------------|----------------|--------------------------|------------|----------------|--------------------------|------------|
| Below Foncha     | 86                | 16.7       | 280                      | 54.4       | 476            | 92.4                     | 381        | 73.9          | 321                      | 62.3       |
| Ntasen           | 67                | 15.4       | 200                      | 45.9       | 321            | 73.8                     | 269        | 61.8          | 206                      | 47.4       |
| Muyeb            | 50                | 10.8       | 150                      | 32.4       | 239            | 51.7                     | 108        | 23.4          | 100                      | 21.6       |
| Foncha           | 25                | 7.8        | 70                       | 21.8       | 186            | 58.1                     | 119        | 37.2          | 112                      | 35         |
| Ndamukong        | 45                | 10.9       | 130                      | 31.7       | 362            | 88.3                     | 139        | 33.9          | 67                       | 16.4       |
| Ntabessi         | 38                | 13.1       | 125                      | 42.9       | 193            | 66.3                     | 71         | 24.4          | 30                       | 10.3       |
| Sisia ll         | 43                | 11.4       | 139                      | 36.8       | 182            | 48.3                     | 152        | 40.3          | 171                      | 45.4       |
| Banja            | 73                | 14.5       | 237                      | 47.2       | 371            | 73.9                     | 342        | 68.1          | 305                      | 60.7       |
| Mofo             | 33                | 8.5        | 176                      | 45.4       | 252            | 64.9                     | 109        | 28.1          | 53                       | 13.7       |
| Ntamoche         | 55                | 15.7       | 227                      | 64.8       | 269            | 76.8                     | 121        | 34.6          | 89                       | 25.4       |
|                  | 12.5              |            |                          |            | 69.5           |                          | 43.6       | 35            |                          | 24.9       |
|                  | 27.4              |            |                          |            | 56.2           |                          | 30         |               |                          |            |

*All data collected on disease incidence and severity were subjected to analysis of variance (ANOVA) at the end of the study by using GenStat Release 10.3 (2011) software application and statistical software (J.M.P.B). Data for percentage disease incidence and severity was presented on tables.

Source: Author

Table 3. Data for percentage disease severity of leaf spot disease on waterleaf collected every 14 days from ten farms for three months

| Quarters/ farms | February | March | April | Mean (%) |
|-----------------|----------|-------|-------|----------|
|                 | 1st half | 2nd half | 1st half | 2nd half | 1st half | 2nd half |
| Below Foncha    | 8        | 40      | 73     | 35       | 15       | 12       | 30.5     |
| Ntasen          | 6        | 18      | 38.4   | 24       | 17.8     | 25       | 21.5     |
| Muyeb           | 3        | 15.3    | 18.3   | 12.6     | 8        | 6        | 10.5     |
| Foncha          | 2.5      | 13.2    | 20     | 18       | 12.3     | 9.8      | 12.6     |
| Ndamukong       | 4        | 24.3    | 49     | 27       | 15       | 8.2      | 21.2     |
| Ntabessi        | 5        | 17      | 21     | 14       | 16.2     | 10.5     | 14       |
| Sisiall         | 3.5      | 9.6     | 19.8   | 12.8     | 13.4     | 11       | 11.7     |
| Banja           | 6        | 17      | 30     | 25       | 42       | 39.4     | 26.6     |
| Mofo            | 3        | 13.5    | 25.5   | 23       | 16.2     | 13.1     | 15.7     |
| Ntamoche        | 7.3      | 29      | 35     | 24.7     | 19.7     | 14       | 21.6     |
| Mean (%) for each half | 4.8 | 19.6 | 33 | 21.6 | 17.3 | 14.9 |
| Monthly mean (%) | 12 | 27.3 | 16.1 |

Source: Author
Figure 3. Culture of fungi isolate from farm 1, sample (d). Source: Author

Figure 4. Culture of fungi isolate from farm 2, sample (d). Source: Author

Figure 5. Culture of fungi isolate from farm 3, sample (a). Source: Author
**conidiophores and conidiospores.** The white fungus isolate was identified as *Alternaria* while the black fungus isolate was identified as *Cercospora*. The *Alternaria* culture was white to grey-brownish, suede-like to floccose in nature, and based on micro-morphological features, the *Alternaria* culture was made up of multicelled irregularly branched septate chains (hyphae) with dark brown conidiophores. Oblclavate to obpyriform conidia bearing large dark spores were seen on the conidiophores. The conidia also had short beaks and fine long septae. The *Cercospora* culture has a dark velvet surface texture, round margin and raised at the centre and based on micro-morphological features, the *Cercospora* culture had branched septate hyphae with conidiophores and conidia which were obtuse at the apex and truncated at the base, bearing obclavate (tail shaped) spores.

**In vitro activity of plant extracts**

Three plant extracts (*M. oleifera*, *O. gratissimum* and *Z. officinale*) were tested against the black and white fungi isolates. According to the result shown in Figures 10 to 13, fungal growth inhibition ranged between 4 and 64% against the black fungus and between 18.9 and 79.6% against the white fungus. The maximum growth inhibition against the black fungus (64%) was recorded by *Z. officinale*, followed by *M. oleifera* (20%) and the least growth inhibition (4%) by *O. gratissimum*. The maximum growth inhibition against the white fungus (79.6%) was recorded by *Z. officinale*, followed by *M. oleifera* (22.2%) and the least growth inhibition (18.9%) by *O. gratissimum*. Generally, it is observed that growth inhibition by plant extracts increased with increase in the concentration of extract from 0.5 to 1 mL.

The percentage inhibition of fungi growth by plant extracts as explained above is represented in Figures 14 and 15.
Table 4. Data of cultural and morphological characteristics of fungi isolates after seven days of subculture

| Sample code | Average colony diameter (cm) | Surface texture | Margin                        | Elevation | Colony tint | Reverse tint | Zonation | Growth pattern | Aerial hyphae |
|-------------|-------------------------------|-----------------|-------------------------------|-----------|-------------|--------------|----------|----------------|---------------|
| F1(c)       | 10                            | Velvet          | Round                         | Flat      | Cream white | Light brown  | None     | Radiate        | None          |
| F1(d)       | 20                            | Velvet          | Round                         | Raised at centre | Dark centre, white margin | Dark centre, white margin | Two zones | Zonate         | Present at centre |
| F2(b)       | 13                            | Velvet          | Round                         | Raised at centre | Black centre, grey margin | Black centre, white margin | Two zones | Zonate         | None          |
| F2(d)       | 23                            | Cottony centre, velvet margin | Irregular | Raised at centre | Light brown centre, white middle, Cream white margin | Light brown centre, cream white margin | Three zones | Zonate         | None          |
| F3(a)       | 9                             | Cottony        | Irregular | Raised | White | Light brown centre, white margin | None | Radiate | Present |
| F3(b)       | 21.5                          | Velvet          | Round                         | Flat      | Black       | Black       | None     | Radiate        | None          |
| F4(b)       | 21                            | Velvet          | Round                         | Flat      | Black centre, white margin | Black centre, white margin | Two zones | Zonate         | None          |
| F4(d)       | 23                            | Cottony        | Round                         | Raised | Cream white centre, Grey margin | Light brown centre and cream white margin | Two zones | Radiate | Present |
| F5(c)       | 20                            | Cottony and velvet | Round | Flat and raised | Grey centre, cream middle, brown margin | Black centre, cream middle, brown margin | Three zones | Radiate | Present |
| F5(d)       | 25                            | Cottony and velvet | Round | Flat and raised | Dark centre, grey margin | Black centre, cream white middle, brown margin | Three zones | Radiate | Present |

Source: Author

Identification of fungi isolates

The symptoms on the leaves of the plant appeared as small, circular to irregular spots of 2 to 4 mm in size. Further, light brown to dark brown patches with characteristic concentric zonnations inside the spots were conspicuous and in severe cases, the spots enlarged in size with complete drying and blighting of leaves. Similar results were reported by Nagrale et al. (2007) and Farhood and Hadian (2012).

The two fungi isolates identified were believed to...
to belong to the phylum Ascomycota because, based on cultural, macro-morphological and micro-morphological characters, the two fungi isolates had septate and branched hyphae which lacked clamp connections. Both isolates also had conidia, conidiophores and conidiospores. The two fungi isolates were believed to be
Alternaria (the white fungus isolate) and Cercospora (black fungus isolate) based on the pictures of the fungi isolates taken for further characterization and comparison with a documents book on fungi (Sarah et al., 2017) and other representative pictures of fungi species. The Alternaria culture was white to grey-brownish, suede-like to floccose in nature and based on micro-morphological features, the Alternaria culture was made up of multicelled irregularly branched septate chains (hyphae) with dark brown conidiophores. The characters like irregular branching of mycelium and septation are in conformity with the results of Shinde (2003) who observed similar kind of mycelium of Alternaria spp. infecting gerbera, pomegranate, water melon, soybean and chilli, respectively. Obclavate to obpyriform Conidia bearing large dark spores were seen on the conidiophores. The conidia also had short beaks and fine long septae. The present findings about shape and septation of conidia are in conformity with the reports of Shinde (2003).
The *Cercospora* culture had a dark velvet surface texture, round margin and was raised at the centre. Based on the micro-morphological features, *Cercospora* culture had branched septate hyphae with conidiophores and conidia which were obtuse at the apex, truncated at the base, had 3 to 20 septae, bearing obclavate (tail shaped) spores. These morphological characteristics were consistent with those of *C. amalayensis* (Sung-Hee et al., 2017).

**In vitro activity of plant extract**

Natural plant products have been shown to be good sources of agrochemicals since they are easily biodegradable and do not pollute the environment (Goussous et al., 2010). Various natural products of plant origin have been proven to be effective in controlling various foliar pests and pathogens in a similar way as the synthetic pesticides (Kagale et al., 2004; Goussous et al., 2010).
The antimicrobial activities of several plant products against fungal pathogens have been studied under both in vitro and in vivo conditions (Kagale et al., 2004). In this study, we investigated the antifungal activities of extract of M. oleifera (leaves), O. gratissimum (Leaves) and Z. officinale (Rhizomes) against Alternaria and Cercospora in vitro. From the result of this study, there was a great similarity in the actions of M. oleifera and O. gratissimum extracts. Similar studies have been carried out by different researchers on the antifungal activities of extracts of many plants (Anwar and Rashid 2007; Satish et al., 2007; Jamil et al., 2010).

The results clearly showed that the extract of M. oleifera leaves tested at different concentrations had some antifungal activity against the fungi isolates in vitro. The inhibition of the fungal growth was observed from the decreased growth of the fungal colony compared to that of the control. These results are consistent with those obtained by other investigators such as Adandonon et al. (2006), Al-Asker and Rashad (2010), Talreja (2010), Abdulmoneim and Zaid (2011), Seint and Masara (2011), and Moyo et al. (2012), who found an antifungal activity of Moringa plant extracts against several pathogens. The fungicidal effect of Moringa extracts on some soil-borne fungi such as Rhizoctonia, Pythium and Fusarium was recorded by many investigators. Dwivedi and Enespa (2012) indicate that Moringa oleifera extracts (leaves, bark and seeds) 75% (v/v) showed significant inhibition in the mycelial growth of Fusarium solani and Fusarium oxysporum f. sp. Lycopersici. Moringa oleifera provides a rich and rare combination of zeatin, quercetin, b-sitosterol, caffeoylquinic acid and kaempferol which have antifungal and antibacterial activities as confirmed by the findings of Anjorin et al. (2010). The results of this work showed that the antifungal activity of M. oleifera was greater than that of O. gratissimum but lower than that of Z. officinale. This is probably because the antifungal active principles of M. oleifera are more efficient in inhibiting fungal growth than those of O. gratissimum. The difference observed in fungitoxic activity of the extracts is likely to be due to the solubility of the active compound(s) in water or the presence of inhibitors to the fungitoxic principle. This also agrees with the report of Qasem and Abu-Blan (1996), Amadioha (2001), Phiri and Mbewe (2010).

The results obtained from this study also indicated that the extract of O. gratissimum leaves is able to inhibit the growth of both fungi in vitro to an extent. The findings of this study also showed that the inhibitory activity of the plant extract of O. gratissimum against both fungi was affected by the concentrations of the extract. The antifungal activity of the plant extract increased with increased concentration of the extract. This finding agrees with the earlier report of Banso et al. (1999) that indicated that antifungal compounds found in the plant extracts were fungistatic at lower concentrations, while becoming fungicidal at higher concentrations of the extracts. Amadioha (2001) was able to show that O. gratissimum leaf extract was able to control spore germination and mycelia growth of Rhizopus oryzae. The active principles present in plants are influenced by many factors which include the age of plant, extracting solvent, method of extraction and time of harvesting plant materials as indicated by Qasem and Abu-Blan (1996), Amadioha (2001), Okigbo and Ajalle (2005). The phytochemical evaluation of O. gratissimum by Sofowora (1993) shows that it is rich in alkaloid, tannins, phytates, flavonoids, steroids and oligosaccharides in the coastal area of Nigeria. The results of this study show that O. gratissimum had the least antifungal activity probably because the active principles are not very efficient in inhibiting fungal growth.

The results obtained from this study also indicated that extract of Z. officinale was very efficient in inhibiting the growth of both fungi in vitro compared to O. gratissimum and M. oleifera extracts. The findings of this study also showed that the inhibitory activity of the plant extract of Z. officinale against both fungi was greatly affected by the concentrations of the extract. The greater the concentration of the plant extract, the more efficient the anti-fungal effect. This finding agrees with the earlier report of Banso et al. (1999) who indicated that antifungal compounds found in the plant extracts were fungistatic at lower concentrations, while becoming fungicidal at higher concentrations of the extracts. In addition, growth inhibitory activity of the crude plant extracts might be due to the synergistic effect of various active compounds that are in higher or small proportion in the crude extract but not due to the action of a single active compound. This agrees with the findings of Banso et al. (1999), Díaz Bellavalle et al. (2011), Pinto et al. (2015), and Rashid et al. (2016). The chief active constituents of ginger are volatile oil (zingiberene, zingiberol, D-camphor), Shogaols, Diarylheptanoids, Gingerols, Paradol, Zerumbone, 1-Dehydro-(10) gingerdione, Terpenoids and Ginger flavonoids (Baliga et al. 2012). Ginger has wide range of biological activities that are attributed to its active constituents (Shukla and Singh, 2007). The most prevalent compound identified in the rhizome of Z. officinale is the phenolic compound gingerol (in natura), which can be potentially active and converted into compounds such as shogaol and zingerone (dehydrated). These bioactive compounds play an important role in disease prevention. This is in accordance with the findings of Banso et al. (1999), Díaz Bellavalle et al. (2011), Pinto et al. (2015), Rashid et al. (2016), but the mechanism of biological action is still not well understood. Various biological functions are altered by ginger, including antioxidant, anti-inflammatory, and antimicrobial activities (Suhad et al., 2012; Rahmani et al., 2014; Liu et al., 2017; Sharifi-Rad et al., 2017). The gingerol produced by Z. officinale may be responsible for this antimicrobial activity, as when in contact with the cell wall, it ruptures the cell wall and consequently inhibits cellular permeability leading to cell damage and death of
the microorganism. This is in line with the results of Oonmetta-Aree et al. (2006), Poeloengan (2011), Hasan et al. (2012), Suhad et al. (2012) and Rahmani et al. (2014). The antimicrobial activity of extracts (methanol and hexane) from the rhizome of Z. officinale is related to the previously mentioned bioactive compounds. They can attack cell wall and cell membrane, affecting permeability and interfering in cellular functions such as electron transportation, nutrients, synthesis of proteins and nucleic acids, and enzymatic activity. Thus, such bioactive compounds may have several invasive targets that may lead to inhibition of microbial growth. This is in conformity with the results of Oonmetta-Aree et al. (2006), Poeloengan (2011) and Hasan et al. (2012).

Conclusion

This survey revealed that the disease incidence and severity had varying intensities in the different farms. Based on micro-morphological characters and other representative pictures of fungal species, the two fungal species were identified as Alternaria and Cercospora. These two fungal species identified in this study could be regarded as the most common causes of leaf spot disease of waterleaf. In vitro antifungal control using extracts of M. oleifera, O. gratissimum and Z. officinale carried out in this study showed that Z. officinale was very efficient in inhibiting the growth of Alternaria and Cercospora. Ginger is easy to obtain, cheap and grows in all regions. Using ginger to inhibit the growth of fungi and protect crops would be economically and environmentally rewarding to many leafy vegetable producers.

CONFLICT OF INTERESTS

The authors declared no competing interests.

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REFERENCES

Abdulmonem MS, Zaid IA (2011). An In vitro antimicrobial activity of Moringa oleifera L. seed extracts against different groups of microorganisms. Australian Journal of Basic and Applied Sciences 5(5):129-134.

Adandonon TA, Aveling S, Labuschagne N, Tamo M (2006). Biocontrol agents in combination with Moringa oleifera extract for integrated control of Sclerotium-caused cowpea damping-off and stem rot. European Journal of Plant Pathology 115(4):409-418.

Alleonent D, Savary S (2005). Epidemiological characteristics of angular leaf spot of bean: A systems analysis. European Journal of Plant Pathology 113(4):329-341.

Amadioha AC (2001). Fungicidal activity of some plant extracts against Rhizoctonia solani in cowpea. Archives of Phytopathology and Plant Protection 33(6):509-517.

Anjorin TS, Ikohok P, Okolo S (2010). Mineral composition of Moringa oleifera leaves, pods and seeds from two regions in Abuja, Nigeria. International Journal of Agriculture and Biology 12(3):431-434.

Annih MG, Tatiana NCB, Kinge TR, Mariette A, Kebei AK (2020). Effect of animal manure on the incidence and severity of leaf spot disease of fluted pumpkin (Telfaria occidentalis) in Dschang, West Region of Cameroon. American Journal of Plant Sciences 11(7):1057-1076. https://doi.org/10.4236/ajps.2020.117076.

Anwar F, Rashid U (2007). Physico-chemical characteristics of Moringa Oleifera seeds and seed oil from a wild provenance of Pakistan. Pakistan Journal of Biological Sciences 39(5):1443-1453.

Banso A, Adeyemo SO, Jeremiah P (1999). Antimicrobial properties of Vernonia amygdalina extract. Journal of Applied Science and Management 3:9-11.

Beever RE, Bolland EG (1970). The nature of the stimulation of fungal growth by potato extract. Journal of General Microbiology 60:273-279.

Billa SF, Ngome AF, Tsi EA (2012). First report of Alternaria solani). Archives of Phytopathology and Plant Protection 41(6):503-509.

Chombeng RG (2014). Cameroon: A Geographical Account, Bamenda-Cameroon. Vision Educational Publications P 19.

Correa-Corralles MA, Saetther AW (1989). Angual leaf spot. In: Schwartz, H.F. and Pastor-Corralles, M.A., (Eds.). Bean production problems in the tropics (second edition.). P 726.

Díaz Dellavalle P, Cabrera A, Alem D, Larrañaga P, Ferreira F, Dalla Rizza M (2011). Antifungal activity of medicinal plant extracts against phytopathogenic fungus Alternaria spp. Chilean Journal of Agricultural Research 71(2):231-239.

Dicklow MB (2018). Leaf spot diseases of trees and shrubs. In: Jamesonii L., (Ed.). Coffee foliar diseases and coffee yield in multistrata agroforestry. International Journal of Agriculture and Biology 3:129.

Douglas SM (2020). Fungal leaf spot of trees and ornamentals. Retrieved from https://portail.ct.gov/CAES/Fact-sheets/Plant-pathology/Fungal-Leaf-Spots-of-Trees-and-ornamentals on 05/07/2020.

Durand-Bessart C, Tixier P, Quiteros A, Andreotti F, Rapidel B, Tauvel P, Quinteros A, Andreotti F, Rapidel B, Tauvel P 19.

Elenfant JA (2004). Emerging infectious diseases of plants: Pathogen pollution, climate change and agrotechnology drivers. Trends Ecology and Evolution 19(10):535-544.

Grabowsk M (2018). Leaf spot diseases of trees and shrubs. University of Minnesota Extension. Retrieved from https://extension.umn.edu/plant-diseases/leaf-spot-diseases-trees-leaf-spot-of-leaf-nuts-1156511.

Hallman J, Berg G, Schulz B (2007). Isolation procedures for entophytic fungi microorganisms. Springer Berlin Heidelberg: New York P 83.
Hasan HA, Raaf AMR, Razik BMA, Hassan AR (2012). Chemical composition and antimicrobial activity of the crude extracts isolated from *Zingiber officinale* by different solvents. *Pharmacuetica Analytica Acta*, New Heaven 3:4.

Holdsworth M, Landais E (2019). Urban food environments in Africa: Implications for policy and research. Proceedings of the Nutrition Society 78(4):513-525.

Ikeyi AP, Onah GT, Ogbonna AO, Udedibo RN, Ugwuanyi RC (2020). Review of the Potentials of some Selected Vegetables in Nigeria: Towards Eradication of Malnutrition and Food Insecurity among Vulnerable Groups. *Idosr Journal of Biochemistry, Biotechnology and Allied Fields* 5(1):72-77.

Ismail I, Hwang YH, Joo ST (2020). Meat analog as future food: a review. *Journal of Animal Science and Technology* 62(2):111-120.

Jallow MFA, Awadh DG, Baiy G, Devi VY, Thomas BM (2017). Pesticide knowledge and safety practices among farm workers in Kuwait: Results of a survey. *International Journal of Environmental Research and Public Health* 14:1-15.

Jamil M, Ansari AH, Shahid M, Khan M, Ashraf M (2010). Screening of some medicinal plants for isolation of antifungal proteins and peptides. *Pakistan Journal of Botany* 39:211-221.

Jayashree M, Jamil M, Miller SH, Mohammad A, Mohammad EHC, Mohsinul H (2012). Antifungal activity and induction of systemic resistance in rice by leaf extract of *Datura metel* against *Rhizoctonia solani* and *Xanthomonas oryzae* pv. *Oryzae,* "Physiological and Molecular Plant Pathology* 65:91-100.

Kaur A, Kaur M, Samyal ML, Ahmed Z (2012). Isolation, characterization and identification of bacterial strain producing amylase. *Journal of Microbiology and Biotechnology Research* 2(4):757-769.

Kinge GTW, Ani KJ, Ojakorutu V (2016). Political crisis, protests and implications on nation building in Cameroon. *African Renaissance* 15:121-139.

Kornerup A, Wanscher IH (1978). *Methuen Handbook of Colour.* Eyre Methuen Ltd. pp. 62-75.

Mohammed A, Mohammad SH, Mohammad EHC, Mohsinul H (2012). In vitro antimicrobial activity of methanolic extract of *Moringa oleifera* Lam. Fruits. *Journal of Pharmaceutical and Phytochemistry* 4:94-98.

Moyo B, Masika PJ, Muchenje V (2012). Antimicrobial activity of *Moringa oleifera* Lam leaf extracts. *African Journal of Biotechnology* 11:2797-2802.

Mzwadzeni L, Afari-Sefa V, Shimelis H, N'Danikou S, Figlan S, Shenwmachers P, Derera J (2021). Unpacking the value of traditional African vegetables for food and nutrition security. *Food Security* 13(6):1215-126.

Mwangome A, Wagara I, Kimenju J, Buruchara, R (2007). Occurrence and severity of angler fish spot of common bean in Kenya as influenced by geographical location, altitude and agroecological zones. *Plant Pathology Journal* 6(3):235-241.

Nagale DT, Gaikwad AP, Goswami S, Sharma L (2007). Fungicidal management of *Alternaria alternata* (Fr.) Keissler causing blight of *Gerbera* (*Gerbera jamesonii*). *H. Bolus ex J.D. Hook.* Journal of Applied and Natural Science 4(2):220-227.

Ngoran BS, Ngoran SD (2015). Urban agriculture and landscape challenges in African cities: an illustration of the Bamenda City Council, Cameroon. *Journal of Poverty, Investment and Development* 15:55-72.

Njungulula P, Wimba M, Musakamba M, Musakumbi K, Kafaire M, Ugen M (2014). Strengthening local seed systems within the bean value chain experience of agricultural innovation platforms in the democratic republic of Congo. *African Crop Science Journal* 22:1003-1012.

Okiro RN, Ajali AN (2005). Inhibition of some human pathogens with tropical plants extracts *Chromolinaea odorata* and *Citrus aurantifolia* and new antibiotics. *International Journal of Molecular Medicines and Advanced Sciences* 1(1):34-40.

Okoi AL, Afuo CO (2009). Effect of leaf extracts of three plant species on *Cercospora arachidicolica* Hori, the causal fungus of leaf spot disease of groundnut (*Arachis hypogea* L) *Nigerian Journal of Plant Protection* 22:132-139.

Oluwole SO, Ogun ML, Durowoju SY (2019). Effects of Different Organic Manures on the Growth of Water Leaf (*Talinum triangulare Jacq.*). *International Journal of Innovative Science and Research Technology* 4(5):1123-1129.

Oonmetta-Aree J, Tomoko S, Grangassak G (2006). Antimicrobial properties and action of Galangal (*Alpinia galanga* L.) on *Staphylococcus aureus.* *Food Science and Technology, Londres* pp. 1214-1220.

Phipi C, Mbewe DN (2010). Influence of *Moringa oleifera* leaf extracts on germination and seedling survival of three common legumes. *International Journal of Agriculture and Biological* 12: 315-317.

Pinto CE, Farias DF, Carvalho AF, Oliveira JT, Pereira ML, Grangeiro TB, Freire JE, Viana DA, Vasconcelos IM (2015). Food safety assessment of an antifungal protein from *Moringa oleifera* seeds in an agricultural biotechnology perspective. *Food and Chemical Toxicology* 83:1-9.

Poeloengsan M (2011). The effect red ginger (*Zingiber officinale Roscoe*) extract on the growth of mastitis causing bacterial isolates. *African Journal of Microbiology Research* 5(4):382-389.

Qasem JR, AbuBlan HA (1996). Fungicidal activity of some common weed extracts against different plant pathogenic fungi. *Journal of Phytopathology* 144:157-161.

Rahmani AH, Shabrizi FMA, Aty SM (2014). Active ingredients of ginger as potential candidates for cancer prevention and treatment of diseases via modulation of biological activities. *International Journal of Physiology, Pathophysiology and Pharmacology* 6(2):125-136.

Rasadikha S, Trung TN, Ulrike G (2018). Changing Consumption Patterns—Drivers and the Environmental Impact: a review. *Sustainability* 10:4190.

Rashid TS, Sijam K, Kadir J, Sadu HM, Awla HK, Zulperi D, Hata EM (2016). Screening for active compounds in *Rhus coriaria* L. crude extract that inhibit the growth of *Pseudomonas syringae* and *Ralstonia solanacearum*. *Indian Journal of Agricultural Research* 50:15-21.

Reis A, Ribeiro FHS, Mafia LA, Mizubuti ESG (2005). Sensitivity of Brazilian isolates of *Pityrospora infestans* to commonly used fungicides in tomato and potato crops. *Plant Diseases* 89(12):1279-1284.

Sahile S, Ahmed S, Fininsa C, Abang MB, Sakhua PK (2008). Survey of chocolate spot Botrytis fabae disease of faba bean (*Vicia faba* L) and assessment of factors influencing disease epidemics in northern Ethiopia. *Crop Protection* 27(11):1457-1463.

Sarah W, Lynne B, Nicholas M (2017). *The Fungi.* Document book of Fungi. 1:56-68.

Sathish S, Mohana DC, Raghavendra MP, Raveesha KA (2007). Antifungal activity of some plant extracts against important seed borne pathogens of *Aspergillus sp.* *Journal of Agricultural Technology* 3:109-119.

Scheuermann KK, Raimondi JV, Marschalek R, Andrade A, Wickert E (2012). *Magnaporthe oryzae* genetic diversity and its outcomes on the search for durable resistance. *Mahmut Caliskan.* *The Molecular Basis of Plant Genetic Diversity* pp. 351-356.

Seint SA, Masaru M (2011). Effect of some plant extracts on *Rhizoctonia solani* and *Sclerotium hydnophilum.* *Journal of Medicinal Plants Research* 5(16):3751-3757.

Sharifi-Rad M, Varoni EM, Salehi B, Sharifi-Rad J, Matthews KR, Ayatollahai SA, Kobafard F, Ibrahim SA, Mnayer D, Zakaria ZA, Yousaf Z, Iriti M, Basile A, Rigano D (2017). *Plants Research* 6(2):227.

Shinde MA (2003). Studies on leaf spot of Aster (*Callistephus chinensis* L.Nees.), M.Sc. (Agri.) Thesis submitted to M.P.K.V. *Maharashtra University* - Nandurbar. 11:2797-2802.
Ferraris on *Phaseolus vulgaris* L. Advances in Applied Microbiology 52:209-243.

Suhad A, Ahmed I, Jabbar A, Hamssah E (2012). Study the antibacterial activity of *Zingiber officinale* roots against some of pathogenic bacteria. Al-Mustansiriya Journal of Science 23(3):63-70.

Sung-Hee P, In-Young C, Wang-Hyu L, Kui-Jae L, Galea V, Hyeon-Dong S (2017). Identification and Characterization of *Cercospora malayensis* causing leaf spot on Kenaf. Mycobiology 45(2):114-118.

Talreja T (2010). Screening of crude extract of flavonoids of *Moringa oleifera* against bacterial and fungal pathogen. Journal Phytopathology 2(11):31-35.

Vincent JH (2012). Distortion of fungal hyphae in presence of certain inhibitor. Nature 159:15:850.

Watanabe T (2002). Pictorial atlas of soil and seed fungi: Morphologies of cultured fungi and key to species (2nd edn). CRC Press LLC.