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RESEARCH ARTICLE

# Influence of sowing dates and sunflower varieties on the development of fungal diseases in Ludewa-Njombe, Tanzania

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## ABSTRACT

The study was conducted across three locations in the Ludewa District of Tanzania, namely Nkomang'ombe, Ludewa mjini, and Madope to assess the impact of sowing dates and sunflower varieties on the occurrence of major diseases. A split-plot design within a Randomized Complete Block Design (RCBD) framework was employed, featuring three sowing dates (15th January 2024, 30th January 2024, and 15th February 2024) and three sunflower varieties: Variety one (V1) Local variety (Nyeupe), Variety two (V2) record variety, and Variety three (V3) Hysun 33. The findings revealed that sowing dates had no statistically significant effect on overall crop performance, except for plant stand. Disease incidence and severity were significantly lower ($p<0.05$) when crops were grown in Ludewa mjini and with the use of Variety one (V1) and Variety two (V2). Nkomang'ombe recorded the highest disease severity and incidence. Varieties and locations significantly influenced sunflower performance, except for plant stand across varieties. Additionally, Variety one (V1) outperformed the others in all assessed parameters, including height, plant stand, capitulum size, yield, disease severity, and disease incidence. This study highlights the importance of selecting suitable varieties to improve sunflower seed quality and optimize agricultural production.

***Keywords:*** alternaria leaf blight; sclerotonia head rot; charcoal rot; rust; sowing dates; sunflower.

## INTRODUCTION

Sunflower (*Helianthus annuus* L), is a significant herbaceous crop primarily cultivated in tropical and subtropical regions (Seiler et al., 2017). The global production value of sunflower is estimated to be $18 billion, with Russia, Ukraine, Argentina, Turkey, and Romania being among the leading producers (Charney, 2010). Within Africa, Tanzania is the largest producer of sunflower, with an annual production record of 800,000 metric tons. Other notable producers in the continent are South Africa, Kenya, and Uganda (Auma et al., 2020). In Tanzania, cultivation of the crop is concentrated in the central zone (Singida and Dodoma), followed by the southern highlands (Mbeya, Iringa, Njombe, and Ruvuma), with additional production in various other regions (Msafiri et al., 2023). However, the country imports a significant amount of cooking oil and animal or vegetable fats, amounting to $126 million. This is attributed to the escalating domestic demand for these products, particularly edible oil, which currently surpasses 500,000 tons annually and is projected to reach 700,000 tons by 2030 (Msafiri et al., 2023). Sunflower is the second most important oil crop in Tanzania, after palm oil and is emphasised by the Government for solving the country's cooking oil shortage (Msafiri et al., 2023). Incidentally, sunflower productivity in the country is as low as one tonne per hectare, compared to the global average of 2 tonnes/ha.

The low productivity is attributed to several factors, including poor agricultural practices and losses due to diseases. The major fungal diseases of sunflowers in Ludewa-Njombe include Rust, Sclerotinia head rot, Alternaria leaf blight and Charcoal rot (Mwakalebela, 2025). According to several studies, Rust (Puccinia helianthi), are common disease (Stoner, 2013). Other diseases include Head rot, Rhizopus head rot, and Alternaria leaf spot (Gulya et al., 2016). The incidence and severity of these diseases might be intensified by poor agronomic practices, including poor sowing techniques, poor timing of field establishment, field management, and susceptibility of cultivars. Timely sowing is a crucial agronomic practice influenced by weather variability thresholds (Zidan et al., 2015). Delayed seed sowing can hinder crop establishment due to insufficient soil moisture or excessive soil saturation caused by heavy rainfall (Zidan et al., 2015). In Ludewa District, Njombe Region, sunflower growers typically sow their seeds between early December and early January, aiming to align with adequate rainfall for optimal yield outcomes. Nevertheless, the frequent incidence of devastating fungal diseases and recurrent low yields continue to discourage farmers in Njombe from cultivating this crop.

In Tanzania, farmers face significant uncertainty regarding sowing dates and crop management due to rising temperatures and erratic rainfall patterns (Mngumi, 2016). Research on sowing seasonality has highlighted increasing trends and variability in intra-seasonal and annual temperatures across regions currently cultivating sunflowers. Climate projections estimate a temperature rise of 2.8°C in sunflower-growing areas of western Tanzania and 2.5°C in eastern regions by 2050, driven by climate change and variability (Beteri and Msinde, 2024). Additionally, reduced rainfall intensity and shifting distribution patterns in various regions may result in poorly timed planting seasons, ultimately decreasing agricultural productivity. Climate changes are also expected to affect crop growth duration across different environmental conditions, thereby influencing yields (Liliane and Charles, 2020).

Adaptation to these changing conditions is essential. Numerous factors contribute to disease prevalence, with the environment affecting both host plants and pathogens. Global climate change drives significant shifts, such as the adoption of new cultivation methods, the introduction of crop genotypes like hybrids or open-pollinated cultivars, and the expansion of areas suitable for specific crops. For plant pathogens, changes may lead to the emergence of more aggressive strains and new pathogen races, as well as the activation of latent pathogens. Notably, global change may result in unforeseen diseases caused by the introduction of new crops or pathogens. As temperatures fluctuate, particularly under warmer conditions, pests and pathogens are expanding or redistributing their habitats. Outbreaks of diseases caused by viruses, fungi, bacteria, and other pathogens are becoming increasingly common and are consistently recorded worldwide (Garrett et al., 2021). This study seeks to evaluate the influence of sowing dates on the incidence and severity of fungal diseases in selected varieties within the Ludewa district.

## MATERIALS AND METHODS

### *Description of the study area*

Field trials were conducted from January to June 2024 in the Ludewa district of the Njombe region, Tanzania (Figure 1). The district's population is 156,176 (Mlengule, 2019). The district encompasses an area of 839,700 hectares. The region is categorised into three distinct agroecological zones: the Lowland zone, the Midlands zone, and the Highlands zone. The trial was conducted in three villages: Nkomang'ombe, Ludewa Mjini, and Madope, each located in distinct agro-ecological zones. Nkomang'ombe (Site 1) is located in the lowland zone at a latitude of 10°31'13"S and a longitude of 34°72'98"E, with an altitude of 1036 meters above sea level. Ludewa mjini (Site 2) is situated in the Midlands zone at a latitude of 10°65'51"S and longitude of 34°66'91"E, with an altitude of 1368 m.a.s.l. In contrast, Madope (Site 3) is positioned in the highland zone at a latitude of 9°66'53"S, a longitude of 34°65'36"E, and an altitude of 2187 m.a.s.l. The Ludewa district exhibits a tropical climate, characterised by an unimodal rainfall pattern, with annual precipitation ranging from 900 to 1600 mm between November and May. The annual average rainfall in the zone varies, with the highlands receiving between 1000 and 1600 mm, the midlands averaging 1200 mm, and the lowlands at 900 mm (Mlengule, 2019). The district features woody plant assemblages, with red soils in certain areas, loamy soils in many regions, and a varied landscape characterised by numerous elevations (Andrew, 2023).

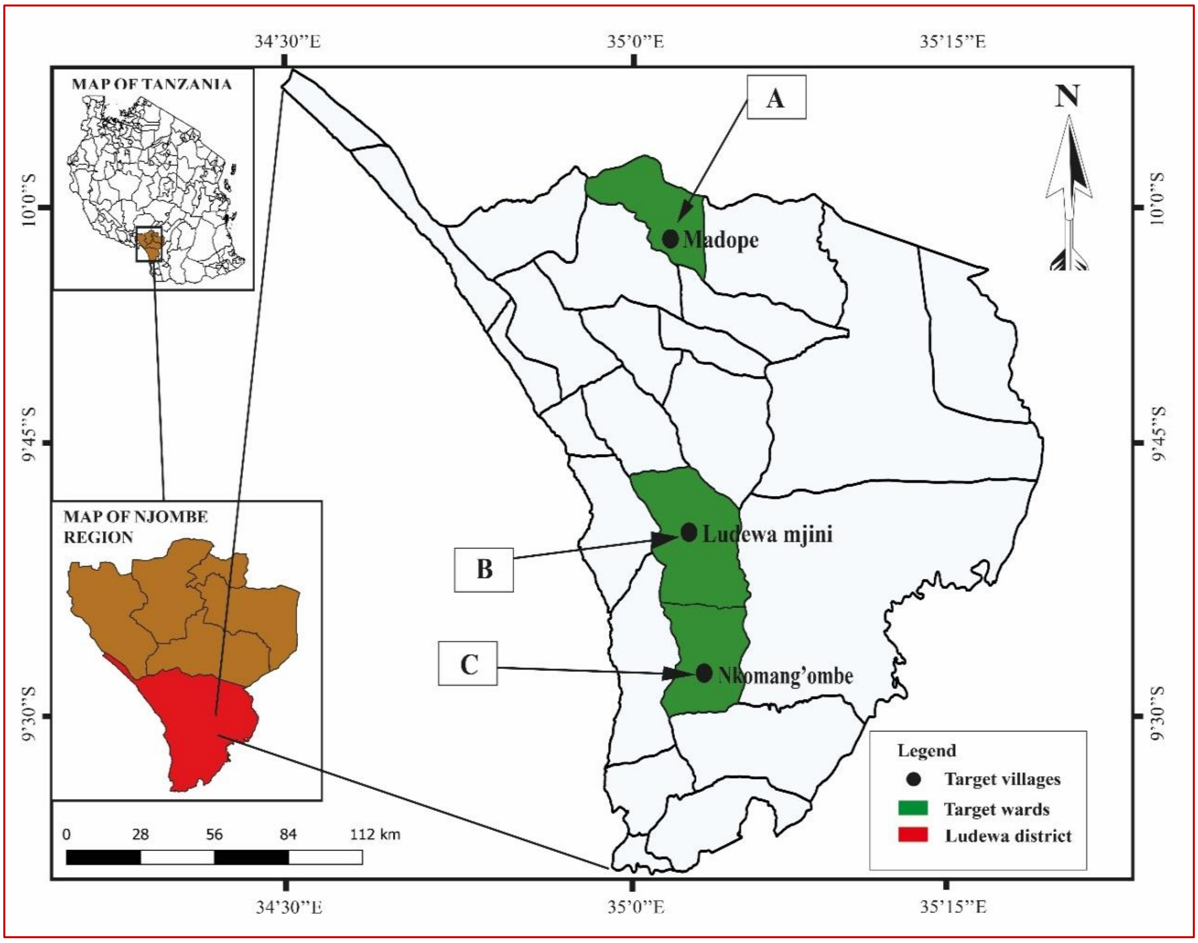


**Figure 1.** A map of Tanzania showing njombe region, ludewa district, and three villages where the trial was conducted.

### *Establishment of the trial*

The trial was conducted using a Split-plot design with three replications. The primary treatments consisted of three planting/sowing dates: (i) Date one (D1), 15 January 2024; (ii) Date two (D2), 30 January 2024; and (iii) Date three (D3), 15 February 2024. The sub-treatments consisted of three sunflower varieties: (i) Local Variety (V1), (ii) Record (V2), an open-pollinated variety (OPV), and (iii) Hysun 33 F1 (V3). The trial was conducted in three villages: Nkomang'ombe (Site 1), Ludewa Mjini (Site 2), and Madope (Site 3). The plot dimensions were 12 m by 17.5 m, totalling 210 $m^2$, arranged in 4 rows with 16 plants per row. Two seeds were planted in each hole, with an inter-row spacing of 70 cm and a distance of 20 m between holes. The inter-plot spacing within a replicate was 70 cm, while the spacing between replicate blocks was 100 cm.

Diammonium phosphate (DAP, 18% N, 46% P2O5) was applied at a rate of 5g per hole during sowing. Three weeks post-seedling development, the plants received a top-dressing of Urea (46% N) at a rate of 5g per plant and NPS (composition) at a rate of 5g per plant. Weeding of sunflowers was conducted twice: the first occurrence took place three weeks after sowing, and the second occurred two months post-sowing. The weather in variations in the study area of the experiment were presented in Figure 2.

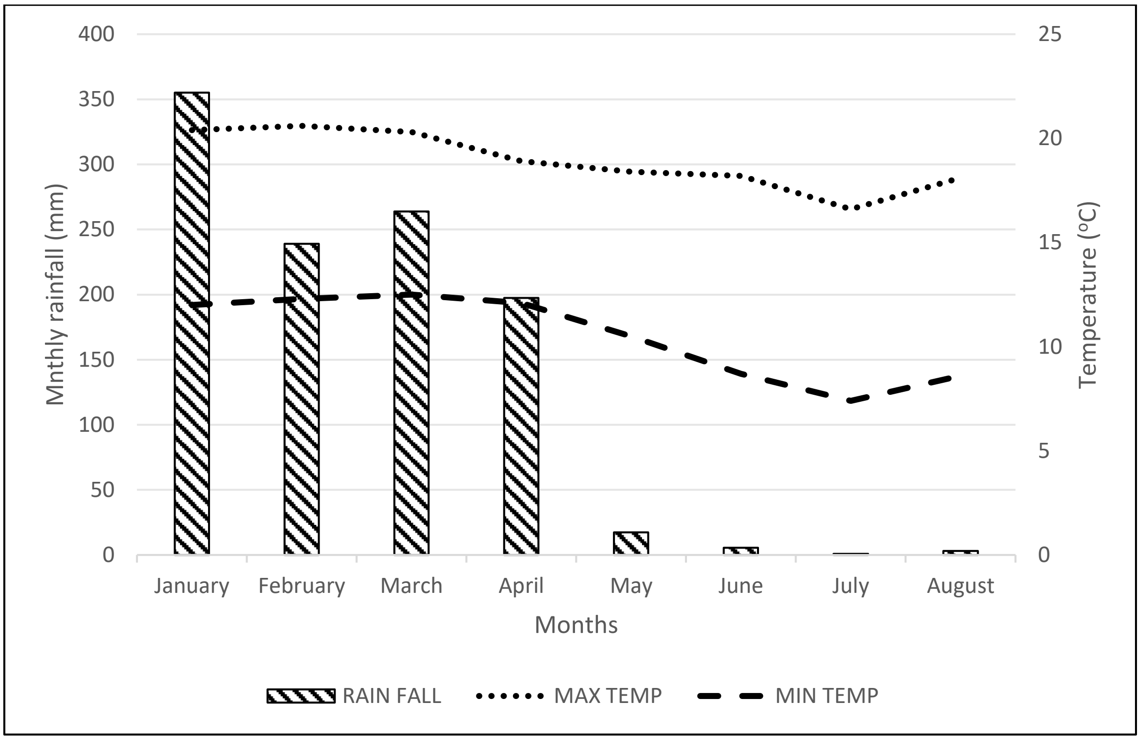


**Figure 1.** Weather variation in the study area during the experiment. (Source: Tanzania Meteorological agency Njombe, 2023).

### *Data collection*

Data coinciding with the period during when the plants were in the field is 6 months January 2024 to June 2024.6 plants were taken systematically from the experiment plot for scoring data of severity score of the major sunflower diseases so for one subplot 8 plants scored for severity of diseases, which lead to 72 plants for one experiment plot at one agro-ecological zone per week for three months, disease incidence one month after emergence of a crop the affected plant over the plant assessed for every week in three months, plant height every week for three months, plant stands every week for three months, capitulum size at harvest period at one day, yield per plant at harvest period at one day, yield per plot at harvest period for one day.

### *Disease incidence and severity*

Rust Disease Severity Scale Level Severity 0 infected 1-(0-25%) leaf area infected 2-(26%-50%) leaf area infected 3-(51%-75%) leaf area infected 4 >75% leaf area infected (Patil and Bodhe, 2011). Sclerotonia head rot, Disease severity scoring scale used to evaluate disease progression for both disease severity index and area under disease progress curve calculations. (a) 0 = no symptoms observed; (b) 1=<12.5% of the head infested (c)=12.5%–25% of the head infested(d) 3 = 26%–50%, (4) = 51%–90% of the head infested, 5 = >90% of the head infested as described by Van Becelaere and Miller (2004). Disease severity for each isolate was scored as per standard scale of 0–9 (Mayee and Datar 1986), where 0=no symptoms on leaf; 1=small, circular, scattered, brown spots on leaves covering 1% or less of the leaf area; 3 = spots enlarging, dark brown in colour, covering 1–10% of the leaf area; 5=spots enlarging, dark brown, target like appearance covering 11–25% of leaf area; 7 =spots dark brown, coalescing with a target like an appearance covering 26–50% of leaf area; 9 = spots uniformly dark brown covering 51% or more of leaf area. Charcoal rot disease severity using a score scale (0 to 5), where 0: asymptomatic, 1: less than 3 % of infected stem tissue, 2: 3 to 10 % of infected stem tissue, 3: 11 to 25 % of infected stem tissue, 4: 26 to 50 % of infected stem tissue, and 5: more than 50 % of infected stem tissue (Ambrósio et al., 2015).

### *Harvesting and processing of seeds*

Harvesting months were May and June 2024 and sunflower plants were harvested when dried and processed in a machine milled to produce sunflower oil and sunflower seed cake for animal feeds.

### *Data analysis*

Data were subjected to analysis of variance (ANOVA) using the GenStat statistical software version 16. Mean separation was done by using Tukey's range test at $P < 0.05$.

The weekly disease severity scores were used to calculate the area under the disease progressive curve (AUDPC) according to the equation of Campbell and Madden (1990).

$$AUDPC = \sum_{i=1}^{n} \left( \left( \frac{y_i + y_{i-1}}{2} \right) (t_i - t_{i-1}) \right)$$

## RESULTS

### *Plant stands and Plant height at the flowering stage*

Plant heights were generally similar across sowing dates across the three sites but in varieties, there was a significant difference across three sites where variety one V1 outperformed other variety may be due to genetic differences in variety. In plant stands there was no significant difference in sowing dates and variety performance across three sites. (Table 1).

**Table 1.** Plant height and Plant stands at the flowering stage

| Treatment | Plant Height (cm) | | | Plants stand (number) | | |
|---|---|---|---|---|---|---|
| Site | 1 | 2 | 3 | 1 | 2 | 3 |
| *Planting date* | | | | | | |
| D1 | 121.8$^{a}$ | 195.1$^{a}$ | 124.7$^{a}$ | 13.44$^{a}$ | 14.44 | 11.56$^{a}$ |
| D2 | 135.2$^{a}$ | 176.8$^{a}$ | 114.1$^{a}$ | 15.33$^{a}$ | 14.44$^{a}$ | 12.56$^{a}$ |
| D3 | 106.8$^{a}$ | 164.3$^{a}$ | 102.9$^{a}$ | 13.78$^{a}$ | 15.22$^{a}$ | 12.33$^{a}$ |
| SE (P≤ 0.05) | 7.78 | 9.05 | 11.45 | 0.971 | 0.482 | 0.902 |
| LSD | 30.56 | 12.79 | 44.94 | 3.812 | 1.893 | 3.540 |
| CV | 11.1 | 8.8 | 17.4 | 11.9 | 10.4 | 12.9 |
| Mean | 121.3 | 178.7 | 113.9 | 14.19 | 14.70 | 12.15 |
| P-value | 0.141 | 0.165 | 0.475 | 0.422 | 0.487 | 0.731 |
| *Variety* | | | | | | |
| V1 | 135.9$^{a}$ | 218.7$^{a}$ | 147.0$^{a}$ | 14.89$^{a}$ | 15.11$^{a}$ | 11.33$^{a}$ |
| V2 | 126.4$^{b}$ | 171.3$^{a}$ | 112.3$^{b}$ | | 15.56$^{a}$14.67$^{a}$ | 12.78$^{a}$ |
| V3 | 101.5$^{a}$ | 146.2$^{a}$ | 82.4$^{a}$ | 12.11$^{a}$ | 14.33$^{a}$ | 12.33$^{a}$ |
| SE (P≤ 0.05) | 6.46 | 7.61 | 6.83 | 1.076 | 0.827 | 0.996 |
| LSD | 19.35 | 22.80 | 20.48 | 3.225 | 2.481 | 2.986 |
| Mean | 121.3 | 178.7 | 113.9 | 14.19 | 14.70 | 12.15 |
| CV | 11.1 | 8.8 | 17.4 | 8.0 | 10.4 | 12.9 |
| P-Value | 0.005 | <.001 | <.001 | 0.085 | 0.803 | 0.586 |

*Note: Means followed by the same letters are statistically NOT different at 0.05 significance level in a column of a table*

Site 1-Nkomang'ombe village, Site 2-Ludewa mjini village, Site 3-Madope village, D1-Sowing date 1, D2-Sowing date 2, D3-Sowing date 3, V1-Variety 1, V2-Variety 2, V3-Variety 3, SE-Standard error, LSD-Least significance difference, P-value-calculated P value.

### *Rust disease incidence and disease severity at three sites*

Table 2 presents a summary of disease incidence and severity across three sites, as affected by sowing dates and varieties. Site 3 exhibited the highest incidence at Sowing date 1 (46.58), suggesting potential environmental influences. The incidence of Rust disease exhibited a slight decline in sowing dates 2 and 3. At Site 1, the incidence decreased from 38.19 in sowing date 1 to 37.32 in sowing date 2, and further to 37.20 in sowing date 3. Similarly, at Site 3, the incidence decreased from 46.58 in sowing date 1 to 44.12 in sowing date 2, and to 43.79 in sowing date 3. Statistical analysis indicated no significant differences in Rust disease incidence between sites and dates. Additionally, there was no significant variation in disease incidence across all sites for different varieties. In terms of Rust disease severity, sites 2 and 3 exhibited no significant differences in sowing dates; however, site 1 showed a significant difference among sowing dates 1, 2, and 3. At site 1, variety 3 exhibited a severity score of 1.640 for Rust disease, indicating a very severe condition compared to varieties 1 and 2. Similarly, at site 2, variety 3 maintained a high severity score of 1.791, again surpassing varieties 1 and 2. At site 3, the severity of rust disease was highest in variety 3 (1.999) when compared to varieties 1 and 2. The observed decrease in severity over time indicates potential advancements in management practices or enhanced resilience of the plants. Variety V1 exhibited a reduced incidence and severity relative to varieties V2 and V3, especially at Site 1. The observed differences are substantial and could guide future management strategies (Table 2).

**Table 2.** Rust disease incidence and disease severity at three sites

| Treatment | Disease Incidence | | | Disease Severity | | |
|---|---|---|---|---|---|---|
| Site | 1 | 2 | 3 | 1 | 2 | 3 |
| Planting date | | | | | | |
| D1 | 38.19[a] | 36.51[a] | 46.58[a] | 1.590[b] | 1.745[a] | 1.784[a] |
| D2 | 37.32[a] | 36.35[a] | 44.12[a] | 1.535[ab] | 1.635[a] | 1.695[a] |
| D3 | 37.20[a] | 35.86[a] | 43.79[a] | 1.426[a] | 1.830[a] | 1.686[a] |
| SE ($P \leq 0.05$) | 0.598 | 0.234 | 1.444 | 0.0240 | 0.0407 | 0.0242 |
| LSD | 2.347 | 0.917 | 5.671 | 0.0941 | 0.1598 | 0.0949 |
| P-value | 0.502 | 0.332 | 0.233 | 0.020 | 0.081 | 0.066 |
| Variety | | | | | | |
| V1 | 35.30[a] | 36.03[a] | 47.64[a] | 1.303[a] | 1.642[a] | 1.387[a] |
| V2 | 34.64[a] | 40.31[a] | 48.09[a] | 1.608[b] | 1.777[ab] | 1.779[b] |
| V3 | 42.77[a] | 32.37[a] | 38.75[a] | 1.640[b] | 1.791[b] | 1.999[c] |
| SE ($P \leq 0.05$) | 3.813 | 1.883 | 1.384 | 0.0405 | 0.0283 | 0.0311 |
| LSD | 14.970 | 7.394 | 4.266 | 0.1590 | 0.11110 | 0.1220 |
| Mean | 37.57 | 36.24 | 44.83 | 1.157 | 1.737 | 1.722 |
| P-Value | 0.051 | 0.189 | 0.067 | <.001 | <.001 | 0.028 |

*Note: Means followed by same letters are statistically NOT different at a 0.05 significance level*

Site 1-Nkomang'ombe village, Site 2-Ludewa mjini village, Site 3-Madope village, V1-Variety 1, V2-Variety 2, V3-Variety 3, D1-Sowing date1, D2-Sowing date 2, D3-Sowing date 3, LSD-Least significance difference, SE-Standard error

### *Capitulum size, yield per plant and yield per plot at the harvest stage*

No significant differences were observed among sowing dates across the three sites regarding capitulum size. However, significant differences were noted among varieties, with Variety 1, the local variety, outperforming others at all three sites. This may be attributed to the variety's adaptation to the environment. In terms of yield per plant at harvest, no significant differences were found among sowing dates. Nevertheless, at site 2, Variety 1 demonstrated superior performance, yielding an average of 128g. No significant difference was observed in yield per plot based on sowing dates; however, a significant difference was noted among varieties. Specifically, at site 2, variety one exhibited an average yield of 1894g, which is attributed to the average climatic conditions of that site (Table 3).

## Diseases severity

### *Rust disease severity across three sites*

The analysis reveals that Site 1 exhibited the highest disease severity values, indicating the most severe rust disease, followed by Site 2 with moderate severity, while Site 3 consistently recorded the lowest severity. Over the 12 weeks, disease severity showed significant fluctuations, particularly peaking between weeks 5 and 8. Initially, during weeks 1-4, all sites experienced relatively low severity levels. However, from weeks 9 to 12, a decline in severity was observed, with varying patterns across the sites. Notably, the consistently low severity at Site 3 suggests that its environmental conditions may be more conducive to disease resistance (Figure 3).

**Table 3.** Capitulum size, yield per plant and yield per plot at harvest in the three sites

| Treatments | Capitulum size (cm) | | | Yield per plant(g) | | | Yield per plot (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| *Planting date* | | | | | | | | | |
| D1 | 29.78[a] | 36.94[a] | 31.94[a] | 27.89[a] | 75.78[a] | 22.83[a] | 317.8[a] | 1092[a] | 267.2[a] |
| D2 | 32.89[a] | 36.72[a] | 26.06[a] | 30.06[a] | 64.28[a] | 18.06[a] | 443.6[a] | 995[a] | 219.7[a] |
| D3 | 29.67[a] | 37.78[a] | 26.61[a] | 30.83[a] | 60.17[a] | 17.89[a] | 441.1[a] | 951[a] | 220.2 |
| SE (P≤ 0.05) | 4.31 | 4.96 | 2.52 | 6.96 | 17.95 | 3.66 | 138.6 | 315.0 | 38.3 |
| LSD | 16.94 | 19.47 | 9.88 | 27.33 | 70.48 | 14.38 | 544.1 | 1236.6 | 150.4 |
| Mean | 30.8 | 37.1 | 28.2 | 29.6 | 66.7 | 19.6 | 401. | 1013 | 236 |
| CV | 15.6 | 6.8 | 18.8 | 16.4 | 16.1 | 28.2 | 7.5 | 20.8 | 33.3 |
| P-value | 0.842 | 0.988 | 0.297 | 0.954 | 0.824 | 0.597 | 0.777 | 0.949 | 0.636 |
| *Variety* | | | | | | | | | |
| V1 | 41.11[b] | 46.06[b] | 35.28[b] | 40.94[b] | 128.89[b] | 26.83[b] | 584.2[b] | 1894[b] | 306.9[b] |
| V2 | 29.17[a] | 35.00[a] | 29.61[b] | 27.94[a] | 35.00[a] | 19.00[ab] | 366.7[a] | 490[a] | 238.6[ab] |
| V3 | 22.06[a] | 30.39[a] | 19.72[a] | 19.89[a] | 36.33[a] | 12.94[a] | 251.6[a] | 654[a] | 161.6[a] |
| SE (P≤ 0.05) | 2.61 | 2.73 | 1.75 | 2.24 | 16.80 | 2.65 | 45.2 | 309.5 | 34.9 |
| LSD | 7.82 | 8.18 | 5.24 | 6.72 | 50.36 | 7.95 | 135.4 | 927.9 | 107.6 |
| Mean | 30.8 | 37.1 | 28.2 | 29.6 | 66.7 | 19.6 | 401 | 1013 | 236 |
| CV | 15.6 | 6.8 | 18.8 | 16.4 | 16.1 | 28.2 | 7.5 | 20.8 | 33.3 |
| P-Value | <.001 | 0.003 | <.001 | <.001 | 0.001 | 0.007 | <.001 | 0.010 | 0.038 |

*N:B Means followed by same letters are statistically NOT different at 0.05 significance level.* Site 1-Nkomang'ombe village, Site 2-Ludewa mjini village, Site 3-Madope village, D1-Sowing date 1, D2-Sowing date 2, D3-Sowing date 3, V1-Variety 1, V2-Variety 2, V3-Variety 3, SE-Standard error, LSD-Least significance different

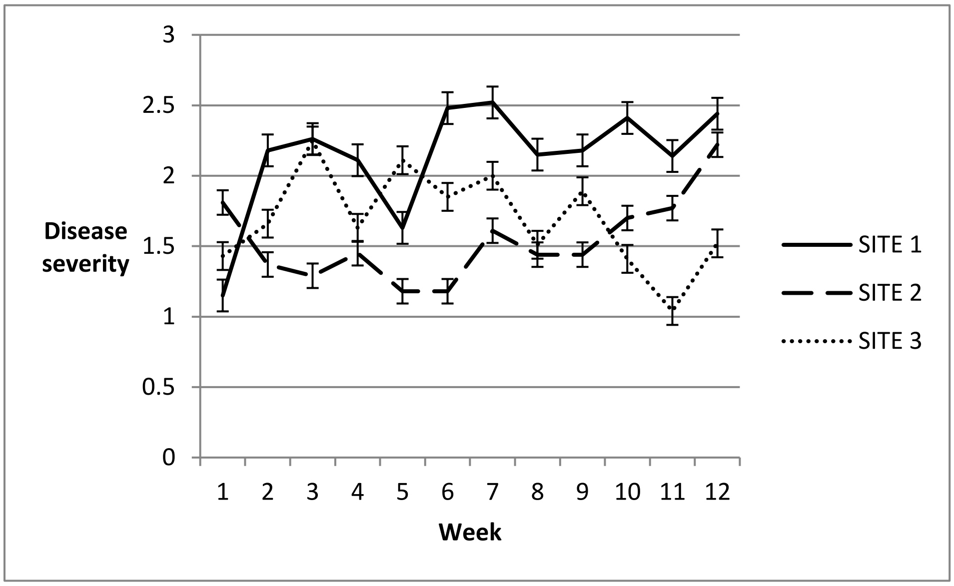


**Figure 2.** Rust disease severity across three sites

### *Alternaria leaf blight disease severity in three sites*

The analysis reveals that Site 1 exhibited the highest values for Alternaria leaf blight, followed by Site 2 with moderate severity, while Site 3 consistently recorded the lowest severity. Over the 12 weeks, disease severity fluctuated significantly, particularly peaking between weeks 5 and 8. Initially, during weeks 1-4, all sites experienced relatively low severity levels. However, from weeks 9 to 12, a decline in severity was observed, with varying patterns across the sites. Notably, the consistently low severity at Site 3 suggests that its environmental conditions may be more conducive to disease resistance (Figure 4).

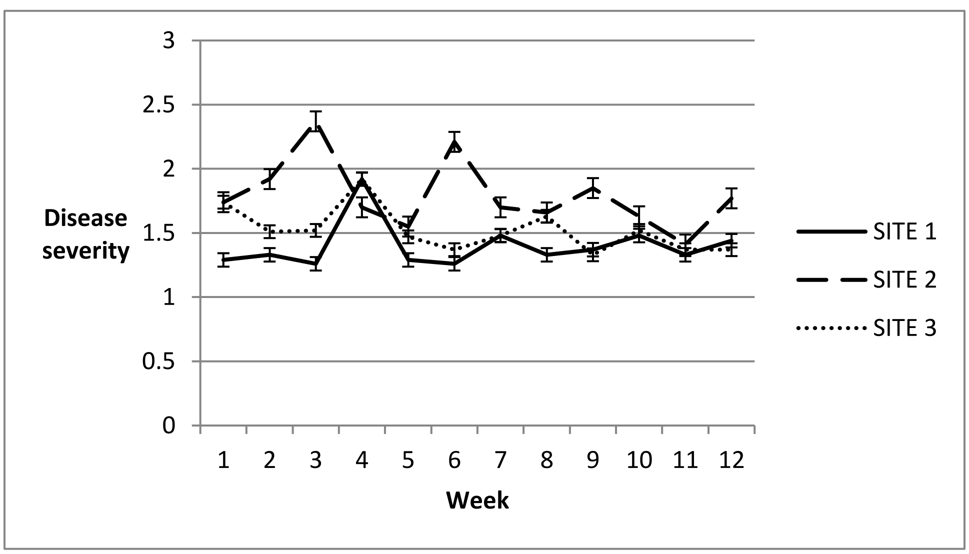


**Figure 3.** Alternaria leaf blight disease severity in three sites

### *Sclerotinia head rot Disease Severity in three Sites*

The analysis indicates that, during the 12 weeks, all sites experienced relatively low disease severity in the early weeks (1-4), followed by a significant increase maintained between weeks 4 and 8, particularly at Sites 1 and 2. Site 1 consistently exhibited the highest severity, characterized by multiple peaks and valleys, while Site

2 showed moderate fluctuations. In contrast, Site 3 maintained the lowest severity, likely due to more favourable environmental conditions (Figure 5).

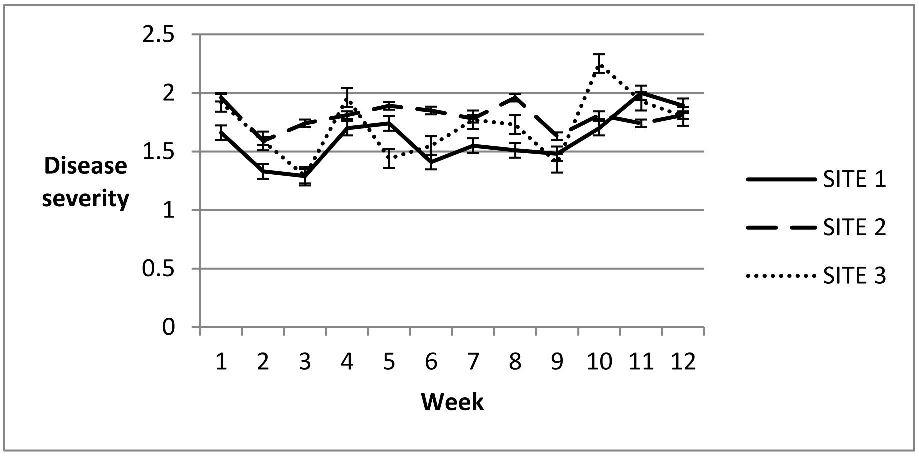


**Figure 4.** Sclerotinia head rot disease severity in three sites

### *Charcoal rot disease severity in three sites*

The analysis reveals that Site 1 exhibited the highest severity values for charcoal rot, followed by Site 2 with moderate severity, while Site 3 consistently recorded the lowest severity. In the early weeks (1-4), disease severity remained low across all sites, indicating stable conditions. However, a significant increase in severity was observed between weeks 5 and 8, particularly at Sites 1 and 2. From weeks 10 to 12, disease severity began to decline, although the patterns of decline varied among the sites. Notably, the consistently low severity at Site 3 may be attributed to more favourable environmental conditions or other mitigating factors (Figure 6).

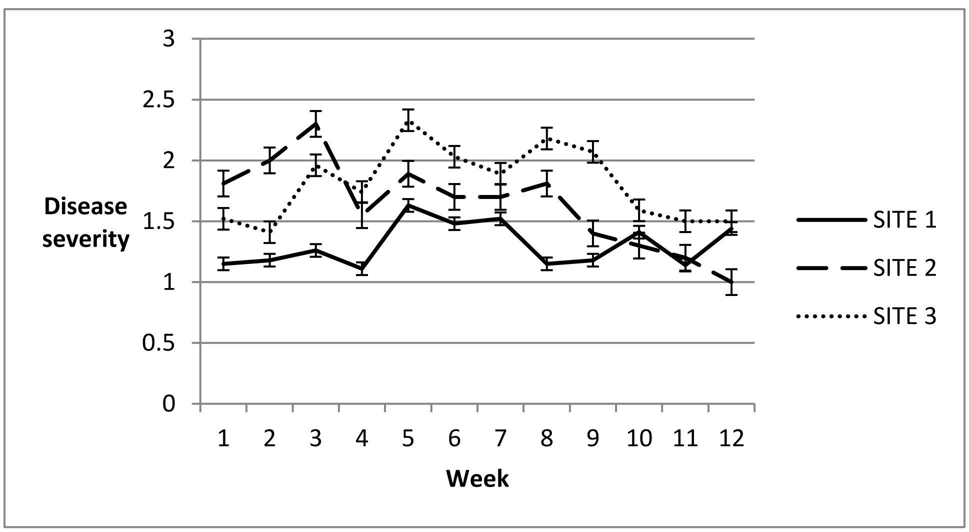


**Figure 5.** Charcoal rot disease severity in three sites

### *Rust disease severity in three varieties*

The graph illustrates the severity of rust disease across three different varieties (V1, V2, and V3) over 12 weeks. Initially, all varieties displayed low disease severity except for V1, but significant increases were observed, particularly in V1 and V2, between weeks 3 and 7. Variety V3 maintained the lowest severity throughout the season, suggesting better resistance. By weeks 9 to 12, disease severity began to decline, with varying patterns across the varieties, highlighting the need for targeted management strategies based on varietal performance (Figure 7).

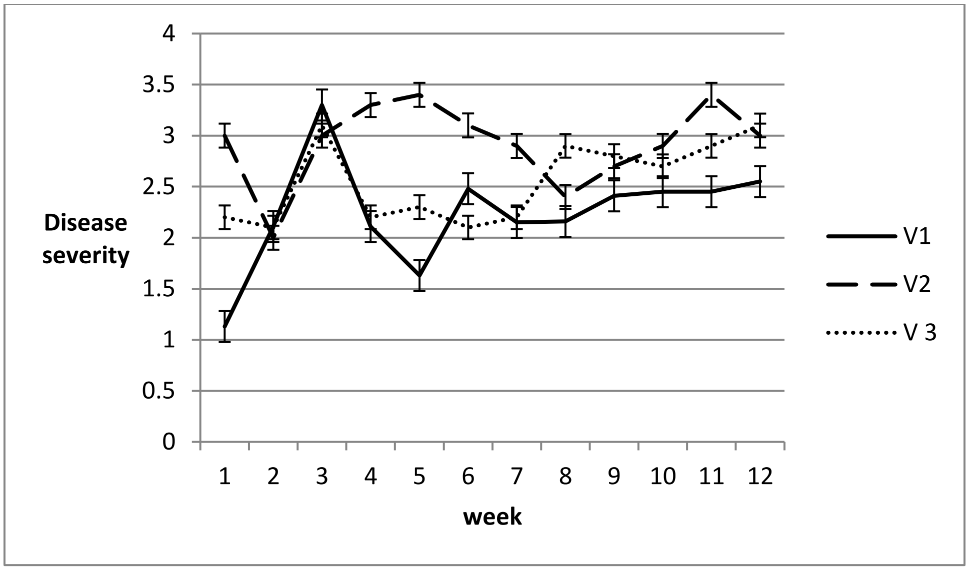


**Figure 6.** Rust disease severity in three varieties

### *Alternaria leaf blight disease severity in three varieties*

The graph depicts the severity of Alternaria leaf blight across three distinct varieties (V1, V2, and V3) over a 12-week duration. In the early weeks, all varieties showed relatively low severity levels; however, a sharp increase occurred between weeks 3 and 8, particularly in V1 and V2. Variety V3 consistently exhibited high severity, indicating lower resistance (Figure 8).

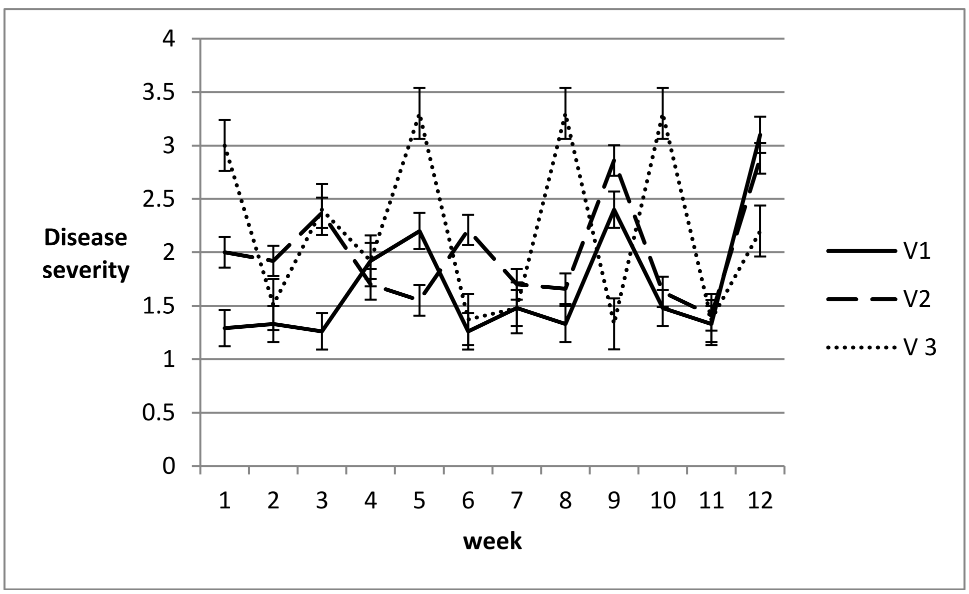


**Figure 7.** Alternaria leaf blight disease severity in three varieties

### *Sclerotinia head rot disease severity in three varieties*

The graph presents the severity of Sclerotinia head rot across three varieties (V1, V2, and V3) over 12 weeks. Initially, all varieties experienced low disease severity, but a notable increase was recorded between weeks 7 and 9, especially in V1 and V3. Variety V2 maintained the lowest severity throughout the observation period, suggesting enhanced resistance. From weeks 9 to 12, disease severity began to decline, with varying trends among the varieties, emphasizing the necessity for tailored disease management approaches based on varietal susceptibility. (Figure 9).

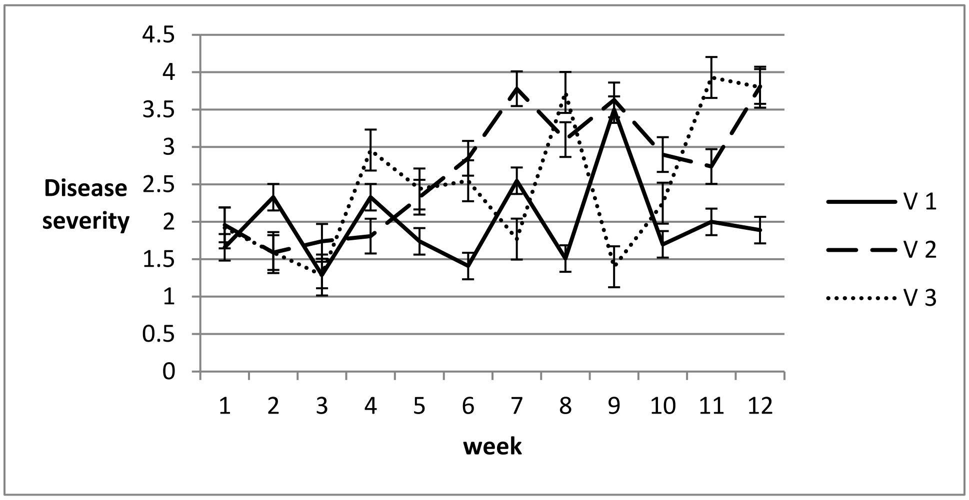


**Figure 8.** Sclerotinia head rot disease severity in three varieties

### *Charcoal rot Disease Severity in three varieties*

The graph illustrates the severity of charcoal rot across three varieties (V1, V2, and V3) over 12 weeks. In the initial weeks, all varieties maintained low disease severity, indicating stable conditions. However, a significant increase in severity was observed between weeks 4 and 8, particularly in V1 and V3, suggesting potential environmental stressors. From weeks 10 to 12, disease severity began to decline, with varying patterns among the varieties. Variety V3 consistently exhibited the lowest severity, possibly due to more favorable environmental conditions (Figure 10).

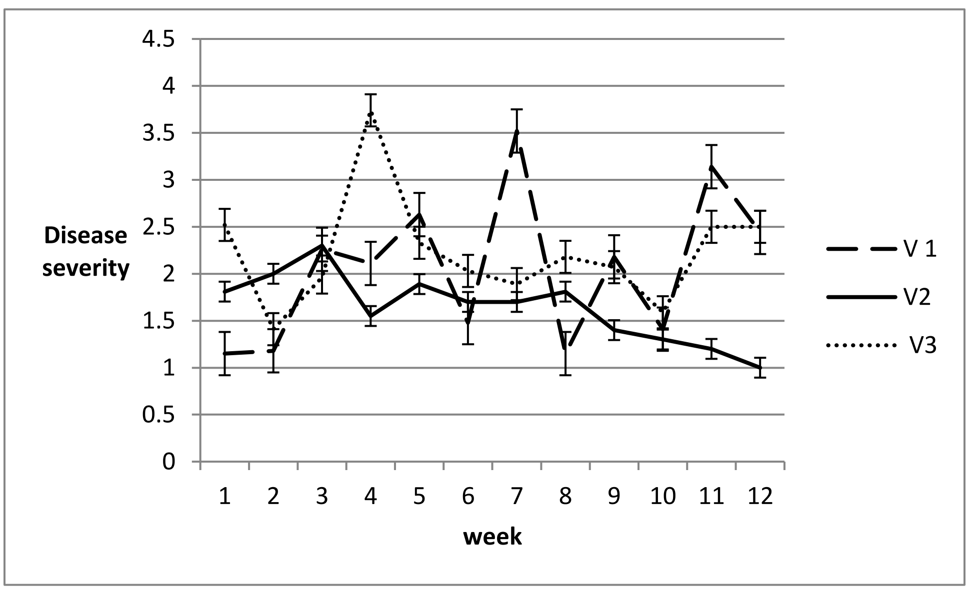


**Figure 9.** Charcoal rot disease severity in three varieties

### *Rust disease severity in three sowing dates*

The graph illustrates the severity of rust disease across three different planting dates (D1, D2, and D3) over 12 weeks. Initially, all planting dates displayed low disease severity, but significant increases were observed, particularly in D1 and D2, between weeks 7 and 9. Planting date D3 maintained the lowest severity throughout the study, suggesting better resistance. By weeks 9 to 12, disease severity was maintained except for D2, which sharply increased severity at 11 weeks, with varying patterns across the planting dates, highlighting the need for targeted management strategies based on planting date performance (Figure 11).

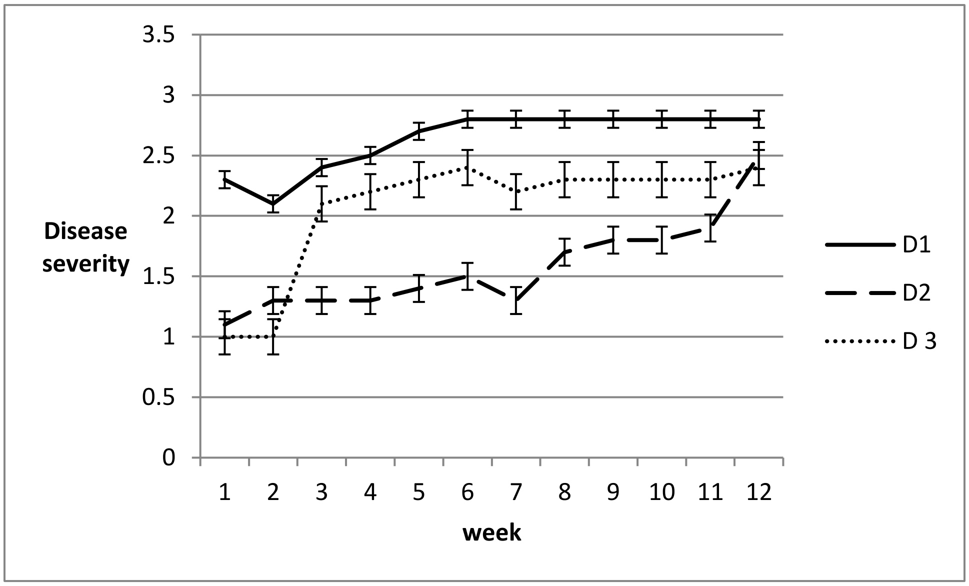


**Figure 11.** Rust disease severity in three planting dates.

### *Alternaria leaf blight disease severity in sowing dates*

The graph depicts the severity of Alternaria leaf blight across three distinct planting dates (D1, D2, and D3) over a 12-week duration. In the early weeks, all planting dates showed relatively low severity levels; however, a sharp increase occurred between weeks 5 and 9, particularly in D1 and D2. Planting date D3 consistently exhibited the lowest severity especially at 10 weeks, indicating higher resistance. As the study progressed to weeks 9 to 12, a progressive increase in severity was noted, with differing patterns among the planting dates, underscoring the importance of planting date selection for effective disease management (Figure 12).

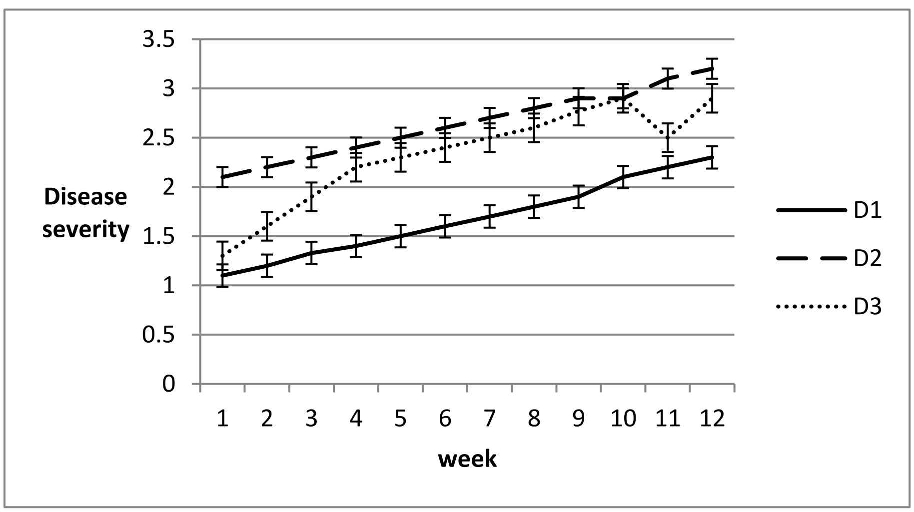


**Figure 10.** Alternaria Leaf Blight disease severity in planting dates

### *Sclerotinia head rot disease severity in sowing dates*

The graph presents the severity of Sclerotinia head rot across three planting dates (D1, D2, and D3) over 12 weeks. Initially, all planting dates experienced low disease severity, but a notable increase was recorded between weeks 5 and 8, especially in D1 and D2. Planting date D3 maintained the lowest severity throughout the observation period, suggesting enhanced resistance. From weeks 9 to 12, disease severity began to decline, with varying trends among the planting dates, emphasizing the necessity for tailored disease management approaches based on planting date susceptibility (Figure 13).

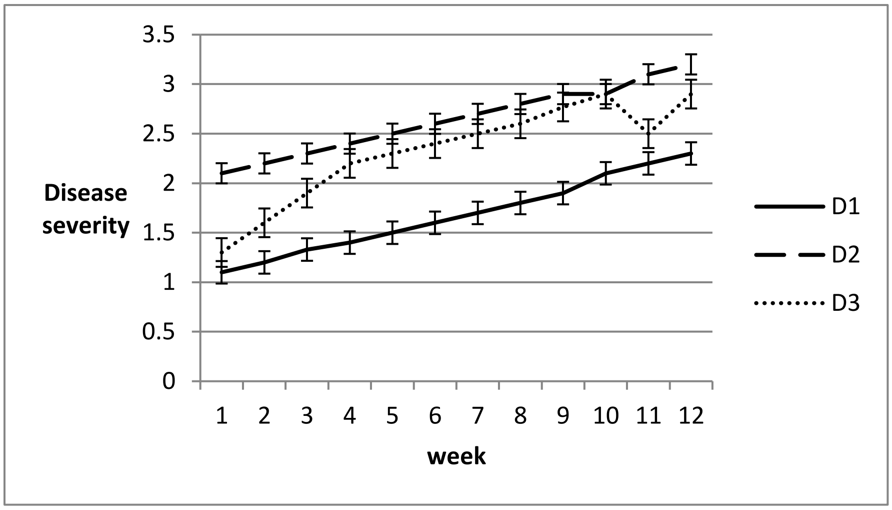


**Figure 11.** Sclerotinia head rot disease severity in planting dates

### *Charcoal rot disease severity in sowing dates*

The graph illustrates the severity of charcoal rot across three planting dates (D1, D2, and D3) over 12 weeks. In the initial weeks, all planting dates maintained low disease severity, indicating stable conditions. However, a significant increase in severity was observed between weeks 5 and 8, particularly in D1 and D2, suggesting potential environmental stressors. From weeks 9 to 12, disease severity began to decline, with varying patterns among the planting dates. Planting date D3 consistently exhibited the lowest severity, possibly due to more favourable environmental conditions, underscoring the importance of developing targeted disease management strategies (Figure 14).

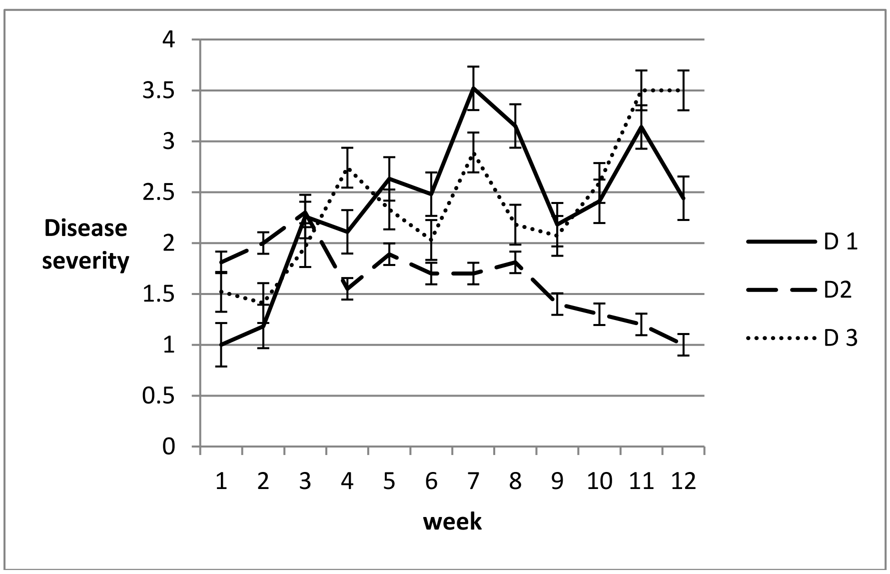


**Figure 12.** Charcoal rot disease severity in planting dates.

### The area under the disease progress curve

The differences in Area under the Disease Progress Curve (AUDPC) values were not significant, except for AUDPC for Rust disease across planting dates, except for disease at site 2 and site 3, sowing date 1 and sowing date 2. The findings in Table 3.5 present AUDPC for Rust disease and Alternaria leaf blight disease across three sites, highlighting variations due to planting dates and plant varieties. For Rust, AUDPC values are highest at the first sowing date (Date 1), particularly at Site 1 (181.8) and Site 2 (189.6). In contrast, the second planting date (Date 2) showed lower values, with Site 1 at 163.0. The trend continues with the third planting date (Date 3), which records the lowest values across all sites, especially at Site 1 (143.6). This suggests that earlier planting may be linked to increased disease severity, potentially due to environmental factors or plant susceptibility. For Alternaria leaf blight disease, similar trends were observed, with the lowest AUDPC at Site 1 for sowing date 1 (208.0) and a noticeable increase for sowing dates 2 (218.7) and 3 (228.7). While the first sowing date generally leads to higher disease severity, the second sowing dates show more decline, but the Alternaria leaf blight disease increased at the third sowing date, particularly at Site 3 (Table 4).

**Table 4.** AUDPC for Rust disease and Alternaria disease at three sites

| Treatment | AUDPC Rust disease | | | AUDPC Alternaria leaf blight disease | | |
|---|---|---|---|---|---|---|
| Site | 1 | 2 | 3 | 1 | 2 | 3 |
| *Sowing date* | | | | | | |
| D1 | 181.8[a] | 189.6[b] | 187.4[b] | 208.0[a] | 177.1[a] | 179.0[a] |
| D2 | 163.0[a] | 164.5[a] | 168.7[ab] | 218.7[a] | 165.6[a] | 169.7[a] |
| D3 | 143.6[a] | 156.5[a] | 158.4[a] | 228.7[a] | 156.1[a] | 170.1[a] |
| SE(P≤ 0.05) | 10.60 | 4.43 | 4.59 | 7.01 | 5.45 | 12.30 |
| LSD | 41.64 | 17.39 | 18.03 | 27.52 | 21.38 | 48.28 |
| CV | 4.2 | 4.2 | 6.5 | 7.8 | 8.2 | 3.8 |
| Mean | 162.8 | 162.8 | 171.5 | 218.5 | 166.3 | 172.9 |
| P-Value | 0.146 | 0.146 | 0.027 | 0.142 | 0.122 | 0.838 |
| *Variety* | | | | | | |
| V1 | 150.2[a] | 171.8[a] | 171.0[a] | 214.4[a] | 166.6[a] | 169.8[a] |
| V2 | 166.8[a] | 165.8[a] | 171.1[a] | 216.2[a] | 164.5[a] | 167.7[a] |
| V3 | 171.5[a] | 173.0[a] | 172.4[a] | 224.8[a] | 167.7[a] | 181.3[a] |
| SE(P≤ 0.05) | 11.61 | 11.44 | 10.14 | 12.67 | 11.18 | 16.40 |
| LSD | 35.78 | 35.24 | 31.24 | 39.04 | 34.45 | 50.53 |
| Mean | 162.8 | 170.2 | 171.5 | 218.5 | 166.3 | 172.9 |
| CV | 4.2 | 4.2 | 6.5 | 7.8 | 8.2 | 3.8 |
| P-Value | 0.421 | 0.421 | 0.995 | 0.754 | 0.979 | 0.822 |

*Note: Means followed by same letters are statistically NOT different at 0.05 significance level*
Site 1-Nkomang'ombe village, Site 2-Ludewa mjini village, Site 3-Madope village, V1-Variety 1, V2-Variety 2, V3-Variety 3,D1-Sowing date1,D2-Sowing date 2,D3-Sowing date 3 LSD-Least significance difference, SE-Standard error.

In contrast, the results for Sclerotinia head rot disease indicate a similar pattern, with the highest AUDPC values recorded at Site 1 for sowing date 1 (193.1), sowing date 2 (170.1), and sowing date 3 (153.1). At Site 2, the values for sowing date 1 (176.3), sowing date 2 (167.4), and sowing date 3 also showed an increase in disease severity (176.3). The differences in AUDPC values are statistically insignificant, especially regarding Sclerotinia head rot disease across the sowing dates. The values for sowing date 1 (165.4), sowing date 2 (164.2), and sowing date 3 (155.9) indicate a decrease in disease incidence over time, potentially attributable to climate variability. At site 2, the incidence of Charcoal rot disease was recorded at 206.1 for sowing date 1. This amount decreased to 171.2 at sowing date 2. However, at sowing date 3, the incidence increased to 185.8. At site 3, charcoal rot disease was recorded at sowing date 1 with a severity of 201.7, which decreased to 168.1 at sowing date 2. However, at sowing date 3, the disease severity increased significantly, potentially due to favourable climatic conditions for the pathogen. Additionally, there were no significant differences in charcoal rot disease severity across the three sites for the various sowing dates and plant varieties (Table 5).

**Table 5.** AUDPC for Sclerotonia disease and Charcoal rot diseases at three sites

| Treatment | AUDPC Sclerotinia Head rot disease | | | AUDPC Charcoal rot disease | | |
|---|---|---|---|---|---|---|
| Site | 1 | 2 | 3 | 1 | 2 | 3 |
| Sowing date | | | | | | |
| Date 1 | 193.1[a] | 176.3[a] | 173.9[a] | 165.4[a] | 206.1[a] | 201.7[a] |
| Date 2 | 170.1[a] | 167.4[a] | 176.4[a] | 164.2[a] | 171.2[a] | 168.1[a] |
| Date 3 | | 176.3[a] | 166.0[a] | 155.9[a] | 185.8[a] | 185.8[a] |
| SE (P≤ 0.05) | 13.11 | 9.02 | 8.57 | 6.11 | 10.70 | 9.21 |
| LSD | 51.46 | 35.41 | 33.65 | 24.00 | 42.01 | 36.17 |
| CV | 4.8 | 7.9 | 6.2 | 8.5 | 2.8 | 2.3 |
| Mean | 172.1 | 168.3 | 172.1 | 161.8 | 187.7 | 185.2 |
| P-Value | 0.212 | 0.549 | 0.692 | 0.538 | 0.183 | 0.141 |
| Variety | | | | | | |
| V1 | 159.6[a] | 159.4[a] | 173.9[a] | 156.2[a] | 203.6[a] | 201.5[a] |
| V2 | 175.8[a] | 165.1[a] | 170.5[a] | 161.6[a] | 188.2[a] | 184.3[a] |
| V3 | 181.0[a] | 180.5[a] | 182.9[a] | 167.7[a] | 171.3[a] | 169.8[a] |
| SE (P≤ 0.05) | 11.19 | 11.41 | 9.72 | 11.38 | 9.25 | 9.04 |
| LSD | 34.47 | 35.17 | 29.95 | 35.06 | 28.51 | 27.86 |
| CV | 4.8 | 7.9 | 6.2 | 8.5 | 2.8 | 2.3 |
| Mean | 172.1 | 168.3 | 172.1 | 161.8 | 187.7 | 185.2 |
| P-Value | 0.398 | 0.425 | 0.372 | 0.780 | 0.086 | 0.083 |

*Note: Means followed by same letters are statistically NOT different at 0.05 significance level*

Site 1-Nkomang'ombe village, Site 2-Ludewa mjini village, Site 3-Madope village, V1-Variety 1, V2-Variety 2, V3-Variety 3, Date1-Sowing date1, Date 2-Sowing date 2, Date 3-Sowing date 3, LSD-Least significance difference, SE-Standard error.

### Interaction effects on three Sowing dates, three sites, and three varieties on AUDPC

The results indicated that varieties did not significantly affect disease severity for AUDPC Rust disease (P= 0.618) and Alternaria leaf blight disease (P= 0.654), though trends emerged for Sclerotinia head rot disease (P= 0.056) and Charcoal rot disease (P= 0.087). Sowing dates significantly influenced disease severity for AUDPC Rust disease (P< 0.001) and moderately for Charcoal rot disease (P = 0.014). Sites had a significant impact on Alternaria leaf blight disease (P< 0.001) and Charcoal rot diseases (P = 0.002). Notably, interactions among varieties, planting dates, and sites showed no significant effects, suggesting that these factors operate independently (Table 6).

**Table 6.** Interaction effects on three factors, three sites, and three varieties on AUDPC

| Source of variation | d.f. | AUDPC Rust disease | AUDPC Alternaria leaf blight disease | AUDPC Sclerotinia head rot | AUDPC Charcoal rot disease |
|---|---|---|---|---|---|
| | | p-value | | | |
| Varieties | 2 | 0.618 | 0.654 | 0.056 | 0.087 |

| | | | | | |
|---|---|---|---|---|---|
| Planting Dates | 2 | <.001 | 0.934 | 0.054 | 0.014 |
| Sites | 2 | 0.516 | <.001 | 0.875 | 0.002 |
| Variety X Planting date | 4 | 0.520 | 0.533 | 0.217 | 0.518 |
| Variety X Sites | 4 | 0.754 | 0.991 | 0.984 | 0.152 |
| Planting date X Sites | 4 | 0.975 | 0.549 | 0.564 | 0.364 |
| Variety X Planting date X Sites | 8 | 0.982 | 0.791 | 1.000 | 0.699 |

AUDPC-Area under disease progress curve, Df-Degree of freedom

## DISCUSSION

The results of this investigation offer significant insights into the growth performance, disease incidence, and severity of different plant varieties across various sites and planting dates. The findings indicate a substantial influence of varietal traits and environmental conditions on agricultural output. The local variety demonstrated superior growth performance, attaining the highest height of 195.1 at site 2 during sowing date 1. This is consistent with prior research by Al-Shammary et al. (2024), which indicated that certain varieties demonstrate improved growth characteristics in optimal environmental conditions. The strong performance of V1 at Site 2 indicates a positive interaction between the variety and the local soil and climatic conditions. Variety 3 (V3) demonstrated markedly reduced heights, especially at Site 3. This observation aligns with the findings of Gao et al. (2023), who indicated that certain varieties exhibit reduced adaptability to specific environmental conditions, resulting in suboptimal growth outcomes.

The study revealed insights into plant stand performance, indicating that V2 is better suited for the conditions at Site 1, where it outperformed both V3 and V1. Numerous studies indicate a strong correlation between seed functional traits and the environmental conditions of their planting sites (Galín dez et al. 2017; Seal et al. 2017). The results concerning capitulum size and yield further support the superiority of V1, which measured 46.06 cm and yielded 128.89 g. This finding corroborates the conclusions of Ali et al. (2020), which indicated that larger capitula are associated with increased yields. This is attributed to its correlation with characteristics such as biomass per capitulum and 1000-seed weight, which enhance yield potential. The notable yield difference between V1 and V3 underscores the critical role of varietal selection in enhancing agricultural productivity, especially given the rising global food demand. Additionally, V3 matures earlier than V1. The present study finding is consistent with the results of Ahmed et al. (2015), which indicated that the yield and yield attributes of sunflowers were affected by sowing dates.

The results of this study indicate that the rust disease incidence (46.58) at site 3, sowing date 1, and severity (1.784) at the same site and date demonstrate a significant impact of environmental factors on disease dynamics. These findings align with those of Gargouri-Jbir et al. (2022), who observed that early planting dates may increase disease susceptibility due to various environmental stressors. The observed decline in disease severity over time (Table 8) indicates improved plant resilience, a phenomenon corroborated by the findings of Frankenberg et al. (2021), which demonstrate that established plants typically show enhanced resistance to diseases as they mature. The interaction effects on Area under the Disease Progress Curve (AUDPC) values for four diseases suggest that planting dates and locations do not significantly influence AUDPC disease severity. This supports findings from earlier research, including Miranda-Galvis et al. (2021), which determined that environmental conditions significantly influence disease progression. The absence of statistically significant differences among varieties regarding disease severity, specifically for AUDPC Rust disease and Alternaria leaf blight, indicates that environmental conditions may play a more crucial role than varietal resistance in these cases. This underscores the necessity for a comprehensive strategy in disease management that takes into account both varietal traits and environmental influences. A comparative analysis of the existing literature indicates both similarities and differences. This study demonstrated that V1 consistently outperformed other varieties. The variability in disease severity across different planting dates observed here aligns with the findings of Koné et al. (2017), which concluded that timely planting can mitigate disease risks. The consistently low severity at Site 3 indicates that environmental conditions in that area may inherently reduce disease incidence. This conclusion is supported by Fox et al. (2021), which found that certain microclimates are less conducive to disease development.

## CONCLUSION

This research provides important findings regarding the growth performance, disease incidence, and severity of different plant varieties across various locations and planting dates. The results indicate that Variety 1 (V1) exhibits superior traits, consistently surpassing its counterparts in height, yield, and capitulum size. This highlights the significance of choosing high-performing varieties that align with specific environmental conditions, thus improving agricultural productivity and ensuring optimal crop results. The results indicate that environmental factors significantly influence disease dynamics, with early planting dates associated with increased disease incidence. The resilience demonstrated by established plants indicates that prompt and efficient management practices can markedly diminish disease severity over time. This study highlights the complex interactions among varietal characteristics, environmental factors, and disease management, emphasising the need for additional research to create targeted strategies that enhance crop performance and support sustainable agricultural practices. This knowledge is crucial for improving food security and tackling the challenges of climate change in modern agriculture.

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## AUTHORS CONTRIBUTIONS

All the authors contributed equally to this research work.

## CONFLICT OF INTERESTS

The authors declare no conflict of interest.

## ETHICAL APPROVAL

Not applicable.

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