Occurrence of fungal foliar diseases of tomato in different agro-ecological zones of Kirinyaga County, Kenya

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Occurrence of fungal foliar diseases of tomato in different agro-ecological zones of Kirinyaga County, Kenya

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Abstract

Tomato production is characterized by inconsistent quality and yields due to biotic constraints such as fungal foliar diseases. Information on the occurrence of the diseases in different agro-ecological zones of Kenya is scanty. This study assessed the occurrence of early blight, late blight and *Septoria* spot diseases in tomato farms in five agro-ecological zones (AEZ) of Kirinyaga County in Kenya (UM2, UM3, UM4, LM3 and LM4) using cross sectional survey method. Macro plots were systematically established diagonally in tomato farms and were used to assess disease incidence and severity. Incidences and severity data were subjected to analysis of variance (ANOVA) using Kruskal Wallis is H test at $\alpha = 0.05$. Median comparison was performed using Steel Dwass Critchlow Fligner with bonferroni adjustment in Statistical Analysis Software (SAS) version 9.4. Incidences and severity of early blight, late blight and *Septoria* spot in tomato farms were significantly different ($p<0.05$) among the villages and agro-ecological zones. Incidence of early blight ranged from 35.7% to 76.65% with severity ranging from 17.15% to 50.87%. The incidence of *Septoria* spot ranged from 23.56% to 93.42% with severity ranging from 16.67% to 44.44%. The incidence of late blight ranged from 33.33% to 86.63% with severity ranging from16.67% to 33.33%. The incidence of early blight was significantly higher in AEZ UM3 (Median = 75%), the incidence of *Septoria* spot was significantly higher in AEZ LM4 (Median = 83.33%) while the incidence of late blight was significantly higher in AEZ UM3 (Median= 50%). The severity of early blight was significantly higher in AEZ UM3 (Median = 38.89%), *Septoria* spot was significantly severe in AEZ LM4 (Median = 40.28%) while late blight was significantly higher in AEZ UM4 (Median = 32.72%). It can be concluded that the incidences and severity of the three foliar fungal diseases of tomato differed in different AEZ of Kirinyaga County. These findings serve as a baseline study and can be used to enlighten farmers on tomato fungal diseases in the area. However, there is a need for studies to evaluate predisposing factors and to determine the economic impact of foliar fungal diseases of tomatoes in Kirinyaga County.

Keywords: Tomato, early blight, late blight, *Septoria* spot, Kirinyaga, Kenya

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1 Introduction

Tomato (*Solanum lycopersicum*), is a nutritive, short duration and high yield crop which is the world's second highest produced vegetable crop after potatoes with an estimate of over 170 million ton per annum (Arah et al., 2016; Njume et al., 2020). Tomato which is enriched with varied nutrients have in addition numerous health benefits. It is an important source of vitamins A, C and B2 and minerals K, Fe, and P (Gastélum-Barrios et al., 2011) and contains compounds such as carotenoids (Lutein and lycopene). Some of the compounds in tomato are anti-cancer, maintain healthy blood pressure, and reduce blood glucose in people with diabetes (Bhowmik et al., 2012). Despite its importance production of tomato in Kenya remain low due to various factors.

The potential of tomato production in Kenya is 30.7 tons per ha, but the actual yield is approximately12 tons/ha (Anastacia et al., 2011; Ochilo et al., 2019). This substantial tomato yield gap may be attributed to diseases (Birgen, 2017). The tomato diseases causes yield losses exceeding 50% (Lengai, 2016) and result to seasonal shortages and hiked prices of tomatoes (Anastacia et al., 2011; Birir, 2020; Imbayi, 2020). Globally, foliar diseases of tomato that include early blight, late blight, and *Septoria* spot are capable of causing yield losses exceeding 70% (**?**Fontem et al., 2005; Douglas, 2008; Sadana, 2013). Though crop losses may arise from single dominant pathogens, cases of co-infection by multiple pathogens occurring asynchronously or synchronously are common (Tollenaere et al., 2016; Kozanitas et al., 2017). For instance, infection by the biotrophic Albugo candida an oomycete impairs Arabidopsis' defenses, making it susceptible to infections by multiple less virulent pathogens (Cooper et al., 2008). Interactions of diseases in plantations such as in tomatoes farms may aggravate or lower incidences and severity of a given infection (Abdullah et al., 2017). Though few studies reported on co infection of diseases in tomato farms, variation in the occurrences of individual diseases has been reported in different production regions.

For instance, the incidence of tomato early blight disease was reported to range between 43.33% - 100 %, while late blight incidence ranged from 10.56% - 16.67% (Opuku, 2012; Naqvi et al., 2014; Patel et al., 2016; Testen et al., 2018). Testen et al. (2018) reported 34% incidence of *Septoria* leaf spot in tomato. In Mwea area of Kirinyaga County in Kenya, the incidence of late and early blights of tomatoes averaged at 53.8%, among other significant tomato diseases (Mwangi et al., 2015). Despite reports indicating presence of tomato diseases in Mwea, there is still insufficient information on the incidences and severity of these fungal diseases in other tomato producing AEZ of Kirinyaga County. These regions vary in tomato agronomic practices and climatic conditions that can contribute to variation in the occurrence of tomato diseases. Knowledge on the distribution of tomato diseases may form the basis for farmer's awareness programs, and form a basis for improved management strategies for high tomato yields. This study assessed the occurrence of early blight, late blight and *Septoria* spot fungal diseases in tomato farms in different villages within five AEZ (UM2, UM3, UM4, LM3 and LM4) of Kirinyaga County in Kenya.

2 Materials and Methods

2.1 Study area

The study was carried out in Kirinyaga which is located in the Southern outskirts of Mt. Kenya and about 100 km North-East of Nairobi (Serede, 2015). Kirinyaga County was suitable for this study since it is one of the leading tomato production counties in Kenya (Paul, 2018). Kirinyaga County lies between latitudes 0° 37'S and 0° 45'S and between longitudes 37° 14'E and 37° 26'E, and within altitudes of between 1,100 m and 1,200 m above the sea level (Jaetzold et al., 2007). Kirinyaga County has varied climatic conditions and receives an average annual rainfall of 940 mm (Jaetzold et al., 2007). The long and short rains occur between April to May and October to November, respectively. The temperatures range from a minimum of 12 °C to a maximum of 26 °C with an average of 20 °C (Kaggikah, 2017). The County has 6 AEZ that include LH 1 (Tea Dairy Zone), UM 1, UM 2, UM 3 (Three Coffee Zones), LM 3 and LM 4 (Marginal Cotton Zone). Specifically, the study was conducted in five tomato growing agro-ecological zones of Kirinyaga namely LM 3, LM 4, UM 3 and UM 3 (Fig. 1) in April and May in the year 2020.

2.2 Survey and sampling procedures

Prevalence and distribution of early blight, late blight and *Septoria* spot were carried out using a cross sectional survey design across the five different agro-ecological zones (AEZ) of Kirinyaga County. The AEZ (UM2, UM3, UM4, LM3 and LM4) were identified as areas where tomato is commercially grown and twenty-seven villages were purposively selected. Out of the twenty-seven villages, 7 were from AEZ LM4 comprising of Kandongu, Kiaminiki, Kiumbu, Kiamukuyu, Nguka, Mugo and Ndindiruki. In AEZ LM3, 6 villages that included Chemise, Kathiga, Siranga, Kionya, Nguvaine and Yaboi were surveyed. In AEZ UM4 four villages that included Gechenjo, Kamigwi, Kianganga and Thumaita were surveyed. In AEZ, UM3 5 villages that included Gachai, Kamathori, Kiamathambi, Kiangungu and Kidaruni were surveyed. Lastly, in AEZ UM2, 5 villages that comprised of Kerigo, Keria, Geotheri, Kemicha and Kiangunga were surveyed. A sample size of 103 farm was obtained using Cochran (1963) formula from 1000

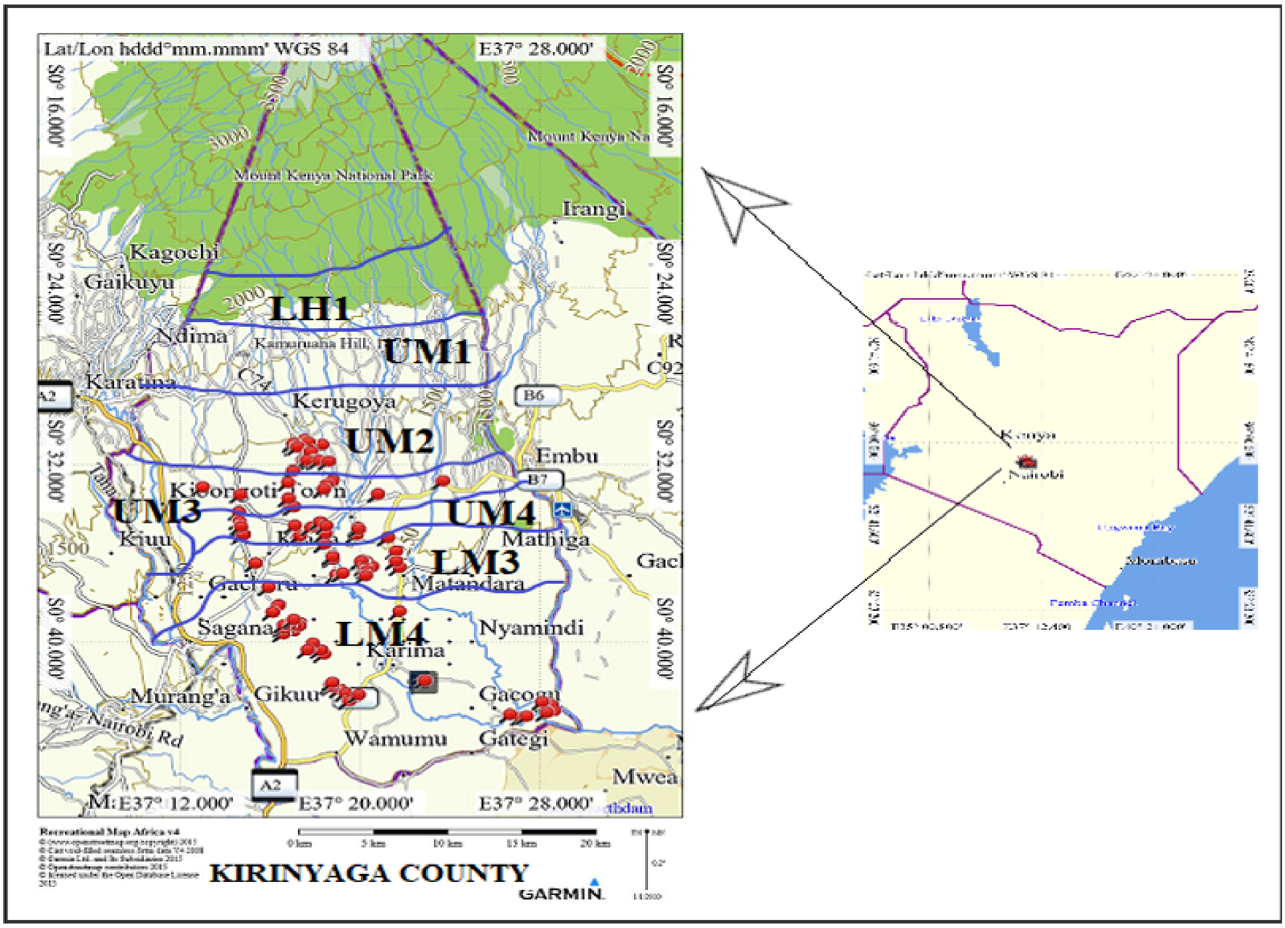

Figure 1. Map of Kirinyaga County showing agro-ecological zones (UM2, UM3, UM4, LM3 and LM4) surveyed for foliar diseases of tomato; where UM = Upper midland (1, 2 and 3), LM = Lower midland (3 and 4)

target population farmers with tomato farms measuring over 0.5 acres. The number of farms surveyed in AEZ LM4 was 32, AEZ LM3 had 23 farms, AEZ UM4 had 16 farms, AEZ UM3 had 19 farms and AEZ UM2 had 13 farms. In each tomato farm, three macro plots (10 ×10 m^2) were laid across the farms diagonally from both sides of the farm. The first and the last macro plots were established 5 m away from the farm margin to avoid the edge effect. The distance between one macro plot to the next was 10 m apart along the diagonal line. In each macro plot, nine tomato plants were randomly selected and assessed for disease incidence and severity. Further, assessments for individual diseases (Early blight, *Septoria* spot and late blight) were done on the same day assessing each disease at a time.

2.3 Data collection

Disease assessment was done in April and May 2020. Four-month old tomato plants were selected given that foliar diseases become visible as the plants mature (Cabral et al., 2013). Sampling for disease incidence was done by counting nine plants in each grid and assessing the incidence of early blight, late blight and *Septoria* spot in every plant. The symptoms used to identify early blight in tomatoes included the presence of blight with concentric rings according to the description of Gulzar et al. (2018). *Septoria* spot in the farms was identified using descriptions earlier reported by Douglas (2008). In addition, late blight symptoms were identified using descriptions given by Nelson (2008). The result was recorded as 1 (If blight symptoms existed) or 0 (If blight symptoms were absent). The procedure was repeated for all the laid grids in every farm studied. Disease incidence was calculated using the formula below, adopted from Mahantesh et al. (2017).

$$DI\ (\%) = \frac{P_D}{P_T} \times 100 \quad (1)$$

where DI = disease incidence (%), P_D = number of diseased plants, and P_T = number of total plants assayed.

To determine the disease severity, 9 tomato plants were randomly selected from each established macro plots. Rating scale of 1 - 6 was used to score diseases severity for the early blight and late blight (Yesuf, 2015). In the scale, 1 = trace to 20% leaf infection, 2 = 21 - 41% infection, 3 = 41 - 60% infection, 4 = 61-80%

infection, 5 = 81 - 99% infection and 6 = 100% leaf infection or the entire plant defoliation. *Septoria* spot were scored using a scale of 1 – 8 (Gyenis et al., 2003). *Septoria* scoring scale was as follows 1 = 0, 2 = 1 to 3, 3 = 4 to 8, 4 = 9 to 17, 5 = 18 to 25, 6 = 26 to 50, 7 = 51 to 75, and 8 = 76 to 100% necrosis. The percentage severity index was calculated using the formula below as used by Negesa Dabesa and Ayana (2021):

$$DS\ (\%) = \frac{R_i}{P_T} \times \frac{100}{R_{max}} \qquad (2)$$

where DS = disease severity, R_i = number of individual rating, P_T = number of total plants assayed, and R_{max} = maximum scale.

2.4 Data analysis

Data on percentages of disease incidence and severity of early blight, late blight and *Septoria* spot was visualized using the Principal Component (PC1 and PC2) and Bi-plot constructed using factor Minor package in R studio version 4.0.3 with 1st and 2nd eigenvectors. Inter correlation between disease incidences and disease severity was determined by Spearman's rank correlation coefficient using the 'spearman' package in R studio version 4.0.3. Data collected on disease incidence and severity was subjected to Analysis of Variance (ANOVA) using Kruskal Wallis test and significance Median were compared using Steel-Dwass-Critchlow-Fligne with Bonferroni adjusted alpha level (α=0.05) in SAS version 9.4. The Kruskal Wallis test was preferred following the significance ($p<0.05$) result of Kolmogorov–Smirnov normality test results even after the data was log-transformed.

3 Results

3.1 Incidences of fungal foliar diseases

Variation in incidence and severity of early blight, late blight and *Septoria* spot in different AEZ was explained by PC1 (49.6%) and PC2 (24.1%) respectively (Fig. 2). The PC1 was highly influenced by the severity of *Septoria* spot which had an eigenvector loading of 0.467 while PC2 was highly influenced by the severity of late blight with eigenvector loading of 0.649. The AEZ UM3 was associated with high incidences of early blight, *Septoria* spot and maximum severity of late blight and *Septoria* spot (Fig. 2).

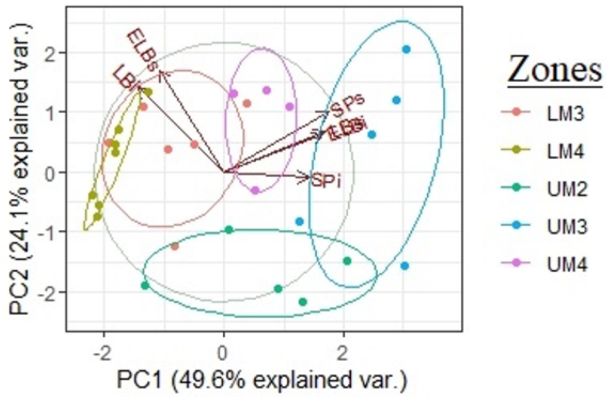

Figure 2. Correspondence visualization plot for incidence and severity of folia diseases of tomato in Kirinyaga County; where EBLs = Early blight severity, LBLs = Late blight severity, SEPs = *Septoria* spot severity, EBLi = Early blight incidence, LBLi = Late blight incidence and SEPi = *Septoria* spot incidence

3.1.1 Early blight, *Septoria* spot and late blight

The study revealed a significant (H (26) = 669.469, $p<0.0001$) difference in the incidences of early blight among the villages in different AEZ, with a Median ranged of 33.33% to 75%. In AEZ LM4, the incidence of early blight was significantly (H (5) = 82.01, $p<0.0001$) different among villages.

Kiumbu and Nguka villages had lower incidences (Median = 41.67%) of early blight compared to Kandongu, Kiaminiki, Kiamukuyu, Mugo and Ndindiruki which had similar Median of 58.33% (Table 1). In AEZ LM3, the incidence of early blight incidence was significantly (H (6) = 62.412, $p<0.0001$) different among villages. The incidence was higher at Kinya and Siranga (Median = 58.33%) while lower at Chemise and Kionya villages (Median = 33.33%). In AEZ UM2, the incidence of early blight was significantly (H (4) = 57.811, $p<0.0001$) different among villages. The incidence was higher at Geotheri village (Median = 75%) while lower (Median = 50%) at Kerigo village (Table 1). In AEZ UM3, the incidence of early blight was significantly (H (4) = 11.787, p = 0.019) different among villages. The incidence was higher at Geotheri, Kidaruini and Kamathori villages (Median = 75%) while lower at Kiangungu village (Median = 66.67%). In AEZ UM4, the incidence of early blight was significantly (H (3) = 52.31, $p<0.0001$) different among villages. The incidence was higher at Gechenjo village (Median = 75%) while lower (Median = 58.33%) at Thumaita village (Table 1).

A significantly (H (26) = 1166.01, $p<0.0001$) different incidence of *Septoria* spot was observed among the villages in different AEZ with Median range of 25% to100%. The incidence of *Septoria* spot in AEZ LM4 differed significantly (H (6) = 34.552, $p<0.0001$) among villages where higher incidence was observed at Kandongu village (Median 91.67%). Nguka and Kiumbu villages both had lower incidences with a Median of 75% in AEZ LM4 (Table 2). In AEZ LM3, the incidence of *Septoria* spot differed significantly (H (5) = 120, $p<0.0001$) among the villages (H (5) = 120, $p<0.0001$). Kionya village had higher incidence (Median 91.67%) while Kathiga village recorded lower incidence [(Median 50%) Table 2]. The incidence of *Septoria* spot in AEZ UM2, differed significantly (H (4) = 43.797, p<0.0001) among villages and was higher at Kerigo village (Median 62.50%) while lower (Median = 25%) at Keria village (Table 2). *Septoria* spot incidence in AEZ UM3, differed significantly (p<0.05) among villages (F (H (4) = 79.567, p<0.0001). Kiangungu village had higher incidence (Median = 83.33%) while Gachai, Kamathori and Kidaruini villages which had equal median (Median = 50%) had lower incidences of *Septoria* spot in AEZ UM3 (Table 2). Incidence of *Septoria* spot in AEZ UM4, differed significantly (H (3) = 20.7, p<0.0001) among villages where Kamigwi village had higher (Median = 100%) incidence while Thumaita village had lower (Median = 66.67%) incidence (Table 2).

The study showed that the incidences of late blight among the villages in different AEZ differed significantly (H (26) = 419.427,p<0.0001) with Median range of 33.33% to 91.67%. In AEZ LM4, the incidence of late blight disease that differed significantly (H (6) = 49.24, p<0.0001) among the villages was high at Nguka village (Median = 50%) while lower at Kandongu, Kiaminiki, Kiamukuyu and Ndindiruki villages all having Median of 33.33%. In AEZ LM3, the incidence of late blight that differed significantly (H (5) =109.07, p<0.0001) among villages was high at Kionya village with a Median of 91.67% while lower at Kathiga and Yaboi villages which had the same Median of 33.33% for the incidence. The AEZ UM2 which had a significantly (H (3) = 140.45, p = 0.0002) different incidence of late blight among the villages recorded higher incidence at Kiangunga village (Median = 48.89%) and lower incidence at Kemicha, Keria and Kerigo villages all of which had similar Median of 33.33%. In AEZ UM3, incidence of late blight differed significantly (H (3) = 140.45, p = 0.0002) among the villages. Kiangungu village had higher incidence of late blight with a Median of 83.33% while Gachai, Kamathori and Kidaruini which had similar Median of 50% recorded lower incidence. In AEZ UM4, late blight incidence among the villages differed significantly (H (4) = 79.567, p<0.0001) with higher incidence being observed at Kianganga and Thumaita villages both having a Median of 50% and was lower (Median = 33.33%) at Kamigwi village (Table 3).

The incidences of early blight in tomato farms were significantly (H (4)= 546.3, p <0.0001) different among the AEZ. The AEZ zone UM3 had significantly higher incidence (Median = 75%) while AEZ LM3 and LM4 had significantly lower incidence [(Median = 75%) Table 4]. Median separation indicated that except for the difference between LM3 and UM3, all the comparisons for early blight in remaining AEZ were significantly different as shown in Table 4.

A significantly (p<0.05) different incidences of *Septoria* spot in tomato farms was observed among the AEZ (H (4) =640.667, p<0.0001). The AEZ LM4 had significantly higher incidence (Median = 83.33%) while AEZ UM2 had significantly lower incidence [(Median = 41.67%). Median separation indicated that except for the difference between LM3 and UM4, all the Median comparisons for *Septoria* spot in remaining AEZ were significant (Table 4). This study showed that the incidences of late blight in tomato farms were significantly (H (4) = 107.806, p<0.0001) different among the AEZ with Median ranging from 41.67% to 50%. AEZ UM3 had a significantly higher incidence (Median = 50%) compared to LM3, LM4, UM4 and UM2. Median separation indicated only the Median of AEZ UM3 was significantly different when compared to other AEZ (Table 4).

Incidence of early blight, *Septoria* spot and late blight in tomato farms were significantly (H (2) =1752.068, p<0.0001) different. The incidence of *Septoria* spot was significantly higher (Median = 75%) than those of early blight (Median = 58.33%) and late blight (Median = 41.67%) as shown in Figure 3. Median separation revealed significance difference between incidences of late blight, *Septoria* spot and early blight (Fig. 3).

3.2 Disease severity

There was significant (H (26) =1323.426, p<0.0001) difference in the severity of early blight among villages in different AEZ of Kirinyaga County where Median range of 16.67% to 49.63% was observed (Table 5). The AEZ LM4, had significantly (H= 62.693, df = 5, p<0.0001) different severity of early blight among villages where Kangondu village recorded higher severity (Median= 29.63%) and Kiaminiki village as well as Nguka village recorded lower severity both having recorded equal median (Median = 16.67%). The AEZ LM3, which had significantly (H (6) =247.78, p<0.0001) different severity of early blight among villages (H (6) =247.78, p<0.0001) had higher severity (Median = 31.48%) at Siranga village and lower severity (Median = 20.37%) at Chemise village. The AEZ UM2 had significantly (H (4) =127.42, p<0.0001) different severity of early blight among villages with higher severity (Median = 33.33%) being observed at Keria village and lower severity (Median = 16.67%) occuring at Kerigo village (Table 5). The AEZ UM3 which had significantly (H (4) =234.89, p<0.0001) different severity of early blight among villages had higher severity at Kidaruini village (Median = 49.63%) and lower severity at Kiangungu village as well as at Kiamathambi village both of which had equal Median (Median = 29.63). Lastly, severity of early blight in AEZ UM4 differed significantly (H (3) =64.83, p<0.0001) among villages with higher severity of early blight being observed at Gechenjo village (Median = 61.11%) and lower severity Median = 24.07%) occurring at Thumaita village (Table 5).

Table 1. Incidence of early blight in tomato farms in villages within different AEZ of Kirinyaga County

AEZ	Village	N	Incidence (%)				Kruskal-Wallis test
			Mean	Med.	Min.	Max.	
LM4	Kandongu	58.02	58.02	58.33	16.67	81	
	Kiaminiki	81	55.04	58.33	25	83.33	
	Kiamukuyu	135	56.11	58.33	8.33	100	H = 62.412
	Kiumbu	189	44.93	41.67	8.33	83.33	df = 6
	Mugo	162	56.74	58.33	16.67	100	p<0.0001
	Ndindiruki	81	56.48	58.33	25	91.67	
	Nguka	135	45.25	41.67	16.67	83.33	
LM3	Chemise	108	35.7	33.33	8.33	100	
	Kathiga	81	35.7	33.33	8.33	100	H = 82.01
	Kionya	81	58.02	58.33	16.67	91.67	df = 5
	Nguvaine	108	47.84	50	8.33	100	p<0.0001
	Siranga	108	59.34	58.33	16.67	100	
	Yaboi	135	49.38	41.67	16.67	91.67	
UM4	Gechenjo	81	76.65	75	33.33	91.67	H= 52.31
	Kamigwi	81	65.54	66.67	25	91.67	df = 3
	Kianganga	135	68.89	75	25	100	p<0.0001
	Thumaita	117	60.33	58.33	25	91.67	
UM3	Gachai	108	73.77	75	25	100	
	Kamathori	162	72.04	75	25	100	H= 11.787
	Kiamathambi	81	68	66.67	33.33	75	df = 4
	Kiangungu	81	69.65	75	25	100	p = 0.019
	Kidaruini	81	76.03	75	33.33	100	
UM2	Geotheri	53	73.27	75	41.67	100	
	Kemicha	108	61.11	58.33	25	83.33	H = 57.811
	Keria	81	53.53	58.33	33.33	66.67	df = 4
	Kerigo	53	51.7	50	25	100	p <0.0001
	Kiangunga	45	63.7	58.33	33.33	100	
Kruskal-Wallis test		H (26) = 669.469		P<0.0001			

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

The severity of *Septoria* spot disease among the villages in different AEZ of Kirinyaga County was significantly (H (26) =1149.685, p<0.0001) different with Median ranging from 16.67% to 44.44%. The severity of *Septoria* spot was significantly (H (6) =172.98, p<0.0001) different among villages in AEZ LM4 with higher severity occurring at Kiangungu and Kiamukuyu villages (Median = 44.44%) while lower severity occurred at Kiumbu village (Median = 34.72%). The severity of *Septoria* spot disease was significantly (H (5) =140.712, p<0.0001) different among villages in AEZ LM3 recording higher severity at Kionya village (Median = 44.44%) and lower severity was recorded at Kathiga village (Median = 34.740%). AEZ UM2 which had significantly (H (4) =83.493, p<0.0001) different severity of *Septoria* spot among the villages had higher severity at Keria and Kemicha villages which had equal Median of 29.63% while lower severity with a Median of 23.61% was at Kiangunga village (Table 6). In AEZ UM3, the severity of *Septoria* spot was significantly (H (4) =53.364, p<0.0001) different among the villages. The severity of *Septoria* spot in AEZ UM3 was higher at Kamathori and Kidaruini villages with equal Median of 33.33% and was lower at Kiamathambi village (Median = 22.22%). The AEZ UM4 had significantly (H (3) =33.598, p<0.0001) different severity of *Septoria* spot among the villages with higher severity occurring at Kiangaga village (Median = 38.89%) and lower severity (Median = 31.94%) occurring at Thumaita village (Table 6).

The study showed a significant (H (26) =1170.66, p<0.0001) different severity of late blight among villages in different AEZ of Kirinyaga County with Median ranging from 16.67% to 33.33%. In AEZ LM4, the severity of late blight was significantly (H (6) =188.529, p<0.0001) different among the villages. The severity was higher at Ndindiruki village (Median = 20.37%) while lower at Kiaminiki and Nguka villages (Median = 16.67%). In AEZ LM3, the severity of late blight was significantly (H (5) =155.45, p<0.0001) dif-

Table 2. Incidence of Septoria spot in tomato farms in different villages within different AEZ of Kirinyaga County

AEZ	Village	N	Incidence (%)				Kruskal-Wallis test
			Mean	Med.	Min.	Max.	
LM4	Kandongu	81	87.55	91.67	50	66.67	
	Kiaminiki	81	81.79	83.33	41.67	100	H = 34.552
	Kiamukuyu	135	80.49	83.33	33.33	100	df = 6
	Kiumbu	189	78.53	75	25	100	p<0.0001
	Mugo	162	82.1	83.33	41.67	100	
	Ndindiruki	81	79.01	83.33	41.67	100	
	Nguka	135	75.49	75	16.67	100	
LM3	Chemise	108	80.8	83.33	50	75	H = 120
	Kathiga	81	51.24	50	8.33	75	df = 5
	Kionya	81	86.63	91.67	58.33	100	p<0.0001
	Nguvaine	108	81.17	83.33	41.67	100	
	Siranga	108	78.86	83.33	41.67	100	
	Yaboi	135	72.16	75	33.33	100	
UM4	Gechenjo	81	76.23	83.33	33.33	100	
	Kamigwi	81	93.42	100	58.33	100	H = 20.7
	Kianganga	135	87.55	91.67	50	66.67	df = 3
	Thumaita	117	60.68	66.67	25	100	p<0.0001
UM3	Gachai	108	67.05	75	25	100	
	Kamathori	162	64.3	66.67	8.33	100	H = 79.567
	Kiamathambi	81	32.61	33.33	8.33	100	df = 4
	Kiangungu	81	40.95	33.33	16.67	83.33	p<0.0001
	Kidaruini	81	80.86	83.33	33.33	100	
UM2	Geotheri	53	34.24	33.33	8.33	100	H = 43.798
	Kemicha	108	52.08	50	25	91.67	df = 4
	Keria	81	23.56	25	8.33	91.67	p<0.0001
	Kerigo	54	61.24	62.5	16.67	91.67	
	Kiangunga	45	58.33	58.33	25	83.33	
Kruskal-Wallis test		H (26) = 1166.01			p<0.0001		

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

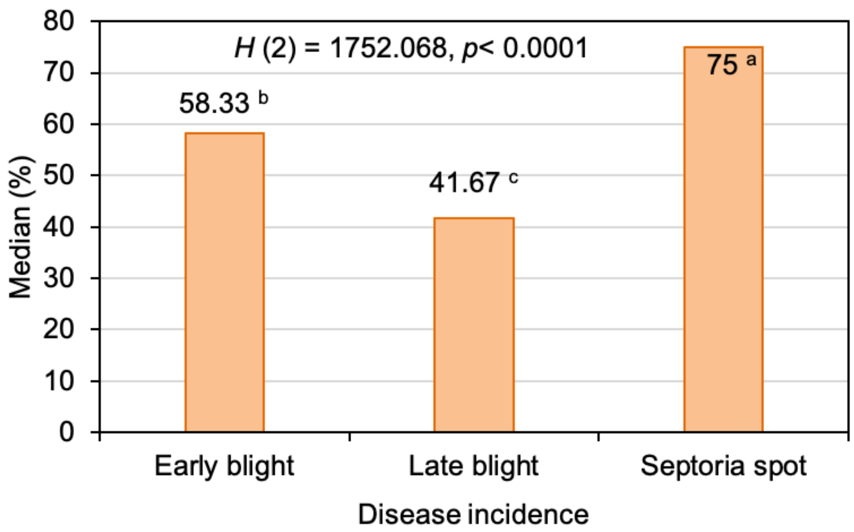

Figure 3. Comparison of incidence of early blight, *Septoria* spot and late blight in Kirinyaga County

Table 3. Incidence of late blight in tomato farms in different villages within different AEZ in Kirinyaga County

AEZ	Village	N	Incidence (%)				Kruskal-Wallis test
			Mean	Med.	Min.	Max.	
LM4	Kandongu	81	39.81	33.33	16.67	91.67	
	Kiaminiki	81	37.96	33.33	16.67	66.67	H = 49.24
	Kiamukuyu	135	39.26	33.33	16.67	66.67	df = 6
	Kiumbu	189	40.3	41.67	16.67	66.67	p<0.0001
	Mugo	162	39.66	37.5	16.67	66.67	
	Ndindiruki	81	33.64	33.33	16.67	66.67	
	Nguka	135	47.47	50	16.67	91.67	
LM3	Chemise	108	50.01	50	16.67	83.33	
	Kathiga	81	37.86	33.33	8.33	66.67	H = 109.07
	Kionya	81	86.63	91.67	58.33	75	df = 5
	Nguvaine	108	47.84	50	8.33	75	p<0.0001
	Siranga	108	55.48	58.33	16.67	75	
	Yaboi	135	35.32	33.33	16.67	75	
UM4	Gechenjo	81	41.4	41.67	16.67	83.33	
	Kamigwi	81	39.51	33.33	16.67	75	H = 140.45
	Kianganga	135	48.89	50	16.67	91.67	df = 3
	Thumaita	117	47.08	50	16.67	75	p = 0.0002
UM3	Gachai	108	52.86	50	16.67	100	
	Kamathori	162	51.23	50	16.67	100	H = 79.567
	Kiamathambi	81	66.87	75	16.67	100	df = 4
	Kiangungu	81	80.86	83.33	33.33	100	p<0.0001
	Kidaruini	81	50.1	50	16.67	91.67	
UM2	Geotheri	53	42.24	41.67	16.67	75	
	Kemicha	108	37.42	33.33	16.67	100	H = 140.45
	Keria	81	40.23	33.33	16.67	91.67	df = 3
	Kerigo	54	41.27	33.33	16.67	91.67	p = 0.0002
	Kiangunga	45	59.63	58.33	33.33	91.67	
Kruskal-Wallis test		H (26) = 419.427			p<0.0001		

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

ferent among village with higher severity recorded at Yaboi (Median = 31.14%) and lower severity recorded at Kionya (Median = 18.51%). In AEZ UM2, severity of late blight was significantly (H (3) =21.418, p = 0.0002) different among villages. The severity was higher at Kemicha, Keria and Kiangunga villages that had equal Median of 24.07% while lower at Kerigo (Median = 16.67%). In AEZ UM3, the severity of late blight was significantly (H (4) =32.502, p<0.0001) different among villages. The severity was higher at Gachai village as well as Kamathori villages that had equal Median of 33.33% while lower at Kiangungu village (Median = 24.07). In AEZ UM4, late blight severity was significantly (H (3) =10.802, p= 0.0128) different among the villages. The severity was higher at Thumaita village (Median = 27.77%) while lower at Kamigwi village as well as Gechenjo village where both had equal Median of 24.07% (Table 7).

The severity of early blight of tomatoes differed significantly (H (4) =845.414, p<0.0001) among the AEZ of Kirinyaga County. Significantly higher disease severity (Median = 38.89%) was observed in AEZ UM3 while AEZ LM3 had significantly lower severity [(Median = 27.28%) Table 8]. Median separation indicated that the severity of early blight between AEZ was significance except for difference between AEZ LM3 and UM2 (Table 8). The severity of *Septoria* spot was significantly (p<0.05) different in five AEZ of Kirinyaga County (H (4) =864.01, p<0.0001). The AEZ LM4 had higher severity (Median = 40.28%) while AEZ UM2 had lower severity [(Median = 24.93%) Table 8]. Median separation revealed that the difference between AEZ was significantly different but not for LM3 and LM4 (Table 8). There was significant (H (4) =818.379, p<0.0001) different severity of late blight among the villages in the AEZ of Kirinyaga County. The AEZ UM3 had higher severity (Median = 32.72%) while AEZ LM4 had lower severity [(Median = 18.51%) Table 8]. The severity of late blight in AEZ were all significantly different (Table 8).

Table 4. Incidence of early blight, Septoria spot and late blight in different AEZ of Kirinyaga County

AEZ	N	Incidencne (%)			
		Mean	Med.	Min.	Max.
Incidence of early blight					
LM3	621	51.05	50.0 c	8.33	100
UM4	414	67.33	75.0 a	25	100
UM2	341	60.05	58.33b	25	100
UM3	513	72.02	75.0 a	25	100
LM4	864	52.2	50.0 c	8.33	100
Kruskal-Wallis test		H (4) = 456.33; p<0.0001			
Incidence of Septoria spot					
LM3	621	75.55	75.00b	8.33	100
UM4	414	73.93	75.00b	25	100
UM2	341	44.81	41.67d	8.33	100
UM3	513	58.8	58.33c	8.33	100
LM4	864	80.23	83.33a	16.67	100
Kruskal-Wallis test		H (4) = 640.667; p<0.0001			
Incidence of late blight					
LM3	621	42.95	41.67b	8.33	75.00
UM4	414	45.08	41.67b	16.67	91.67
UM2	341	42.38	41.67b	16.67	91.67
UM3	513	51.77	50.0 a	8.33	100
LM4	864	40.25	41.67 b	16.67	91.67
Kruskal-Wallis test		H (4) = 107.806; p<0.0001			

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

The severity of early blight, *Septoria* spot and late blight in tomato farms was significantly (H(2) = 1592.98, p<0.0001) different in Kirinyaga County. Severity of *Septoria* spot was significantly higher (Median = 36.11%) than those of early blight (Median = 28.21%) and late blight (Median = 24.34%). Median separation indicated a significant difference severity between late blight, *Septoria* spot and early blight of Kirinyaga County (Fig. 4).

4 Discussion

Early blight disease incidences in different AEZ of Kirinyaga County differed significantly. Our results on the incidence of tomato early blight disease were similar to the results of Negesa Dabesa and Ayana (2021) in Ethiopia where a significantly different incidence of early blight with a range of 48.8 to 72.7% was reported. Additionally, our results are comparable to those reported by Rao et al. (2016) in Eritrea where early blight incidence ranging from 57.7 to 97.8% was reported. In contrary, early blight incidences reported in this study were higher than those of Hussain et al. (2019) who reported incidence range of 10-49.16% in Pakistan. Incidences of early blight herein were lower than the range of 3.3 to 38.6% reported by Safi (2020) in Peshawar. Variation of its incidences across AEZ surveyed in this study may be attributed to factors such as field humidity, temperature, tomato varieties grown, source of planting material as well as fungicides use practices. Earlier studies have shown that early blight development is affected by temperature and humidity (He et al., 2012; Riaz et al., 2021). Optimal temperature for its causal pathogen such as *A. solani* has been reported to range from 25–30 °C (He et al., 2012). Incidences above 50% observed in AEZ LM4 which is a semi-arid area with average temperature range of 21.2 to 22 °C may be attributed to high variability of early blight pathogens. According to Chaerani et al. (2006), early blight pathogens such as *A. solani* is capable of adapting to changing environment easily and developing resistance towards fungicides as well as evading host resistance. Variation in environmental conditions and farming activities that include continuous application of fungicides may induce a genetic shift in the pathogens' genetic structure and the occurrence of new pathogen strains (Pachori et al., 2016). The new strain of the pathogen may mostly acquire resistant against recommended fungicides thus, increasing frequency in pathogenicity (Chaerani and Voorrips, 2006).

Septoria leaf spot is among foliar destructive tomato disease that is favored by mild temperatures, humid weather and wet period conditions (Bitew, 2019). Incidences of *Septoria* leaf spot in tomato farms

Table 5. Severity of Early blight in tomato farms in villages and different AEZ of Kirinyaga County

AEZ	Village	N	Severity (%)				Kruskal-Wallis test
			Mean	Med.	Min.	Max.	
LM4	Kandongu	81	28.09	29.63	16.67	34.72	
	Kiaminiki	81	18.02	16.67	16.67	22.22	H = 247.78
	Kiamukuyu	135	23.87	24.07	16.67	31.48	df = 6
	Kiumbu	189	19.67	18.52	8.33	33.33	P<0.0001
	Mugo	162	22.69	22.22	16.67	31.48	
	Ndindiruki	81	24.85	24.07	16.67	38.89	
	Nguka	135	18.67	16.67	14.81	29.63	
LM3	Chemise	108	22.21	20.37	16.67	33.33	
	Kathiga	81	26.46	29.63	16.67	38.89	
	Kionya	81	28.4	25.92	16.67	40.74	H= 62.693
	Nguvaine	108	25.44	25.92	16.67	35.27	df = 5
	Siranga	108	29.41	31.48	16.67	40.74	P<0.0001
	Yaboi	135	28.42	29.63	14.81	48.15	
UM4	Gechenjo	81	34.83	29.63	16.67	61.11	H = 64.83
	Kamigwi	81	32.93	33.33	18.52	48.18	df = 3
	Kianganga	135	34.78	33.33	22.22	51.85	P<0.0001
	Thumaita	117	26.43	24.07	16.67	46.29	
UM3	Gachai	108	34.11	33.33	16.67	51.85	
	Kamathori	162	42.46	46.29	19.21	61.11	H = 234.89
	Kiamathambi	81	29.88	29.63	16.67	46.29	df = 4
	Kiangungu	81	30.81	29.63	20.37	48.18	P<0.0001
	Kidaruini	81	50.88	49.63	38.89	68.52	
UM2	Geotheri	53	28.14	27.78	18.52	37.04	
	Kemicha	108	27.27	27.77	16.67	40.74	H = 127.42
	Keria	81	31.59	33.33	15.28	40.74	df = 4
	Kerigo	53	17.15	16.67	14.81	24.07	P <0.0001
	Kiangunga	45	31.03	29.63	16.67	83.33	
Kruskal-Wallis test		H (26) = 1323.426			P<0.0001		

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

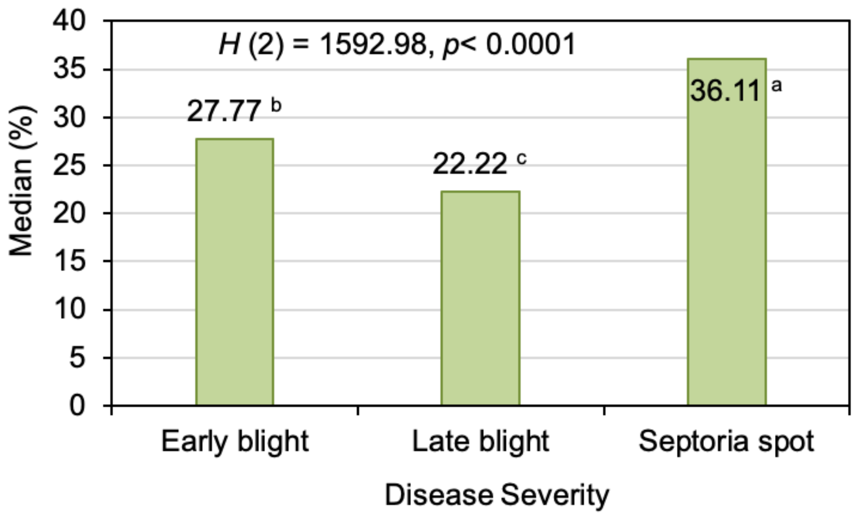

Figure 4. Severity of early blight, *Septoria* spot and late blight in Kirinyaga County

Table 6. Severity of Septoria spot in tomato farms in different villages within different AEZ of Kirinyaga County

AEZ	Village	N	Severity (%)				Kruskal-Wallis test
			Mean	Med.	Min.	Max.	
LM4	Kandongu	81	44.53	44.44	30.55	54.16	
	Kiaminiki	81	36.19	38.88	15.27	52.77	
	Kiamukuyu	135	44.62	44.44	16.67	75	H = 172.98
	Kiumbu	189	35.76	34.72	22.22	44.44	df = 6
	Mugo	162	40.9	40.27	24.07	51.39	p<0.0001
	Ndindiruki	81	41.27	41.67	31.94	51.65	
	Nguka	135	37.54	37.5	23.61	51.39	
LM3	Chemise	108	40.11	40.28	29.17	54.16	
	Kathiga	81	31.73	34.74	13.89	46.28	H = 140.712
	Kionya	81	43.43	44.44	34.74	54.16	df = 5
	Nguvaine	108	42.09	43.05	27.78	54.16	p<0.0001
	Siranga	108	41.57	41.67	29.19	54.17	
	Yaboi	135	36.51	37.03	29.63	48.61	
UM4	Gechenjo	81	38.13	36.11	18.05	54.17	
	Kamigwi	81	32.86	33.33	15.27	44.44	H = 33.598
	Kianganga	135	37.09	38.89	22.22	51.85	df = 3
	Thumaita	117	32.33	31.94	13.89	44.44	p<0.0001
UM3	Gachai	108	28.32	31.26	12.05	38.89	
	Kamathori	162	31.06	33.33	12.05	59.23	H = 53.364
	Kiamathambi	81	23.61	22.22	12.05	34.74	df = 4
	Kiangungu	81	28.03	30.55	15.28	38.89	p<0.0001
	Kidaruini	81	29.51	33.33	12.05	48.61	
UM2	Geotheri	53	19.36	16.67	8.33	66.67	
	Kemicha	108	29.02	29.63	15.27	47.22	H = 83.493
	Keria	81	27.18	29.63	8.33	40.74	df = 4
	Kerigo	54	26.26	23.61	8.33	43.06	p <0.0001
	Kiangunga	45	16.07	16.67	8.33	36.61	
Kruskal-Wallis test		H (26) = 1170.66			p<0.0001		

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

in different AEZ in Kirinyaga County were significantly different (p<0.05). Whereas the incidence of *Septoria* leaf spot was high in AEZ LM4, AEZ UM2 had low *Septoria* spot incidences. The incidence reported in this study differed from those of Lumumba (2001) in Zambia where the incidences ranged of 3% to 10% for all the regions surveyed was reported. Higher incidences of *Septoria* spot in AEZ LM4 may be attributed to the impact of irrigation water as well as the frequency of irrigating tomato farms. For instance, during the current study (Unpublished report), it was established that in AEZ LM4 and LM3 irrigation of tomato farms is carried out frequently with water flowing on the surfaces rapidly. According to 2015 (Lopes, C. and Reis, A. and Boiteux, L.) and Šubić (2016) dissemination of *Septoria* conidia may be sufficiently facilitated by the impact of water droplets around the plant outlining the significance of irrigation system in the development of *Septoria* spot. According to Cabral et al. (2013), minimizing the impact of water droplets may reduce *Septoria* spot disease severity. High soil moisture due to continual heavy irrigation in AEZ LM3 and LM4 may have probably contributed to higher incidences. This fact is supported by the study of Cabral et al. (2013) where greater frequency and a large amount of irrigation water were observed to accelerate the severity of *Septoria* spot. It may also be possible that differences of tomato varieties grown in different AEZ may have contributed to variation in *Septoria* spot observed. The effect of tomato variety on the pathogenicity of *Septoria* spot is documented (Gul et al., 2016). The higher percentage of late blight was observed in AEZ UM3 while AEZ LM4 and UM2 recorded a lower percentage respectively. Incidences of late blight observed in this study were lower than those reported by Testen et al. (2018) in Tanzania where severity of late blight reported ranged from 0 to 50%.

Table 7. Severity of late blight in tomato farms in different villages within different AEZ of Kirinyaga County

AEZ	Village	N	Severity (%)				Kruskal-Wallis test
			Mean	Med.	Min.	Max.	
LM4	Kandongu	81	22.89	18.52	16.67	33.33	
	Kiaminiki	81	17.09	16.67	14.81	22.22	
	Kiamukuyu	135	20.77	18.52	16.67	29.63	H = 188.529
	Kiumbu	189	19.51	16.86	16.11	33.33	df = 6
	Mugo	162	18.66	18.52	16	29.63	p<0.0001
	Ndindiruki	81	20.05	20.37	16.67	29.63	
	Nguka	135	16.82	16.67	14.81	29.63	
LM3	Chemise	23.38	23.38	20.37	16.67	37.04	
	Kathiga	26.74	26.74	29.63	16.67	37.04	
	Kionya	20.28	20.28	18.51	16.67	35.19	H = 155.45
	Nguvaine	21.22	21.22	19.44	16.67	33.33	df = 5
	Siranga	27.85	27.85	29.63	16.67	37.04	p<0.0001
	Yaboi	30.08	30.08	31.14	16.67	37.04	
UM4	Gechenjo	81	24.81	24.07	16.67	35.19	
	Kamigwi	81	26.12	24.07	16.11	37.04	H = 10.802
	Kianganga	135	27.3	25.92	18.52	35.19	df = 3
	Thumaita	117	27.21	27.77	16.11	48.18	p = 0.0128
UM3	Gachai	108	32.46	33.33	16.67	48.14	
	Kamathori	162	33.72	33.33	16.11	57.4	H = 32.502
	Kiamathambi	81	28.68	30.55	16.67	46.29	df = 4
	Kiangungu	81	27.07	24.07	18.52	41.67	p<0.0001
	Kidaruini	81	30.64	31.32	16.86	57.4	
UM2	Geotheri	53	19.95	18.52	0	33.33	
	Kemicha	108	23.51	24.07	16.67	33.33	H = 21.418
	Keria	81	25.39	24.07	15.28	40.74	df = 3
	Kerigo	54	17.93	16.67	14.81	25.92	p = 0.0002
	Kiangunga	45	23.68	24.07	8.33	37.04	
Kruskal-Wallis test		H (26) = 1149.685			p<0.0001		

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

A significant severity of early blight disease was observed in this study where the highest severity was in AEZ UM3, while lower severity was observed in AEZ LM4. Severity of early blight observed in this study was comparable to the severity range of 11.4% to 50% reported by Negesa Dabesa and Ayana (2021) in Ethiopia. However, early blight severity reported in this study was higher than those reported by Safi (2020) in Pakistan where severity range of 7.66 to 8.66 °C was reported. Moderate severity of early blight disease in AEZ UM3 may be attributed to moderate temperature and higher humidity (Jaetzold et al., 2007). Despite continual use of fungicides to manage early blight by the farmers, severity in all the AEZ was above 20%. Moderately higher severity may have resulted from overwintered virulent pathogen strain that continually sustain infection (Ahmad et al., 2014). The difference in severity across AEZ may be explained by differences in environmental conditions (Gupta et al., 2020). Additionally, differences in tomato varieties grown in different AEZ may account for the differences in the severity observed across AEZ (Kumar and Praveen, 2019). Early blight is a seed borne disease, thus, impact of tomato seeds and seedlings used in Kirinyaga County on severity of early blight should be assesed in future studies as a mitigation approach.

Severity of *Septoria* spot was higher in AEZ LM4 and lower in AEZ UM2. High soil moisture due heavy irrigation in AEZ LM3 and LM4 are thought to be contributing factor for higher severity of *Septoria* spots in these zones. Cabral et al. (2013) showed that enhanced frequencies of irrigation favours development of *Septoria* spot in tomato. Differences in tomato varieties and their sources as observed during the study (Unpublished report) may account for differences in severity of *Septoria* spot across AEZ surveyed (Gul et al., 2016). Further, a varied climatic condition that exists across AEZ as documented by Jaetzold et al. (2007) may explain differences in *Septoria* spot sever-

Table 8. Severity of early blight, Septoria spot and late blight in different AEZ of Kirinyaga County

AEZ	N	Severity (%)			
		Mean	Med.	Min.	Max.
Severity of early blight					
LM3	621	26.74	27.28c	14.81	48.15
UM4	414	32.07	31.48b	16.67	61.11
UM2	341	27.32	27.77c	14.81	83.33
UM3	513	38.21	38.89a	16.67	68.52
LM4	864	21.86	20.37d	8.33	38.89
Kruskal-Wallis test		H (4) = 845.414; p<0.0001			
Severity of Septoria spot					
LM3	621	39.27	38.89a	13.89	54.17
UM4	414	35.12	33.33b	13.89	54.17
UM2	341	24.93	24.07d	8.33	66.67
UM3	513	28.58	30.57c	12.05	59.23
LM4	864	39.77	40.28a	15.27	75
Kruskal-Wallis test		H (4) = 845.414; p<0.0001			
Severity of late blight					
LM3	621	25.27	24.07c	16.67	37.04
UM4	414	26.56	25.92b	16.11	48.18
UM2	341	22.54	22.22d	0	40.74
UM3	513	31.12	32.72a	16.11	57.4
LM4	864	19.27	18.51e	14.81	33.33
Kruskal-Wallis test		H (4) = 845.414; p<0.0001			

AEZ: Agro-ecological zones, Min.: Minimum, Max.: Maximum, Med.: Median

ity observed in Kirinyaga County.

The AEZ UM3 had high late blight severity while AEZ LM4 had low early blight severity. Variations of its incidence and severity across AEZ may be attributed to differences in meteorological factors. Meteorological factors play key role in late blight development and distribution (Raza et al., 2019). Factors such as humidity, temperature, rainfall and leaf wetness interval influence growth and development of the pathogen. The humidity of about 90% and temperature range of between 17 to 22 °C have been reported to favour late blight development (Modesto et al., 2016). In deed, according to Jaetzold et al. (2007), AEZ in Kirinyaga County have temperature range of 19 °C to 22 °C and annual rainfall ranging from 350 to 1250 mm which makes the area suitable for development of late blight disease. The severity of late blight in AEZ LM4 and LM3 which is chararacterised with very short rainfall periods (Jaetzold et al., 2007), may be attributed to the tolerance ability of the pathogen. According to Caubel et al. (2012), though humidity is a significant requirement in the pathogenicity of *P. infestans*, the pathogen may develop tolerance for areas with low humidity. The differences in severity observed in this study may further be attributed to differences in the tomato varieties grown across AEZ. As reported by Meya et al. (2014) different tomato varieties respond differently to attack by *P. infestans*.

5 Conclusion

Early blight, late blight and *Septoria* spot diseases in tomato significantly differ across different AEZ. Early blight and late blight appeared to have high incidence in AEZ UM3 while *Septoria* incidences were higher in AEZ LM4. Comparatively, *Septoria* spot had a higher incidence while late blight had lower incidences. Severity of early blight and late blight was higher in AEZ UM3 while late blight and *Septoria* spot had higher severity in AEZ LM4 and LM3. Comparatively, the severity of *Septoria* spot fungal disease was found to be higher while the percentage severity of late blight was lower. Higher incidences and severity of foliar fungal diseases observed in this study indicate the need carry out cost-benefit analysis of foliar diseases of tomatoes and development of a risk management model to manage tomato fungal diseases outbreak in the study area. Further, studies that will investigate disease predisposing factors in different AEZ are recommended.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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