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PREVALENCE AND DISTRIBUTION OF EARLY BLIGHT, LATE BLIGHT AND SEPTORIA SPOT IN DIFFERENT AGRO-ECOLOGICAL ZONES OF KIRINYAGA COUNTY, KENYA

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ABSTRACT
Tomato production is characterized by inconsistence quality and yields that result from biotic constraints such as foliar fungal diseases that include septoria spot, early and late blights. Despite of disease constraints, information on prevalence of tomato foliar fungal diseases in different agro-ecological zones in Kenya is scanty. Therefore, this study assessed prevalence and distribution of early blight, late blight and septorial spot fungal diseases of tomatofive different agro ecological zones (UM2, UM3, UM4, LM3 and LM4) of Kirinyaga County in Kenya. Study was carried out using cross sectional survey method. At the farm, transects were laid diagonally from where micro plot was established for assessment of foliar fungal diseases of tomato. Percentage incidences and severity data were subjected to analysis of variance using Generalized Linear Model (GLM) and significant means separated using Least Significant Difference (LSD) at $\alpha = 0.05$. Statistical Analysis Software (SAS) version 9.4 was used for the analysis. Incidences and severity of early blight, late blight and septoria spot in tomato farms in different agro- ecological zones were significantly different ($p < 0.05$). Incidence of early blight was high 72.09 % in zone UM3and lower in zones LM4 52.32 %. Incidence of late blight was high 51.77% in zone UM3 and lower in zones LM4 40.25 %. Incidence of Septoria spot was high 80.22% in zone LM4 and lower in zones UM4 44.81 %. Severity of Early blight was high 38.21 % in zone UM3 and lower in zones LM4 21.86 %. Severity of late blight was high 31.12% in zone UM3 and lower in zones LM4 19.27 %. Severity of septoria spot was high 39.76% in zone LM4 andlower in zones UM2 at 24.93 %. Incidences and severity of the three foliar fungal diseases of tomato differed in different agro ecological zones of Kirinyaga County. Future studies should consider evaluation of cost benefit analysis to determine economic impact of foliar fungal diseases of tomatoes in Kirinyaga County.
Keywords: Tomato, Early blight, Late blight, Septoria spot

INTRODUCTION
Tomato is the world's second highest produced vegetable crop after potatoes with an estimate of 126 million ton per annum (0; Kanneh *et al.*, 2016). Tomato is widely grown due to its nutritive value, short duration and high yield (Olanrewaju *et al*., 2017). The world's leading producers of tomatoes are China (30.4%), India (10.0%), USA (7.9%), Turkey (7.1%), Egypt (5.0%), Spain (2.4%), Brazil (2.4%) and Mexico (1.9%) accounting for 74.2% of the total production (Olanrewaju *et al*., 2017). In Africa, Kenya is the sixth highest producer with up to 509,465 metric tons whereas Egypt and Nigeria ranks first and second producing over 7,297,108 and 4,100,000 metric tonsrespectively (Paul, 2018; Kansiime *et al.,* 2020; Dube *et al*., 2020). Tomato yields East Africa is far below the potential yield (Bio vision). In Tanzania and Uganda low yields averaging to 7 t/ha and 10 t/ha from Uganda have been reported compared to higher yields of over 100 t/ha reported in Zimbabwe (FAOSTAT, 2019; Bio vision, 2021). Though potential of Kenya's tomato production is 30.7 t/ha, actual yield as per 2018 was 12 t/ha (Masinde *et al.*, 2011; Ochilo *et al.,* 2019). Low tomato production challenges the effort of ensuring a food secure nation a mandate of her Big Four Agenda initiative (GoK, 2020).

Tomato is important for sustenance of food security, income generation, government revenue from foreign exchange and creation of employment (FAO, 2017). The leading counties in tomato production include Kirinyaga, Kajiado, Taita Taveta, Meru, Bungoma, Kiambu, Kisii, Kisumu, Trans Nzoia and Migori (HCDA, 2013). In 2016-2017, up to 509,465 metric tons of tomatoes was produced in Kenya. The highest production was reported in Kajiado (14%), Narok (11%), Kirinyaga (7%), Machakos 7% (Paul, 2018). However, a substantial tomato yield gap still exists in

Kenya resulting from infectious diseases (Birgen, 2017), which may result in crop losses beyond 50% (Lengai, 2016). Yield loses due to diseases may explain seasonal shortage and hiked prices (Masinde *et al.,* 2011; Birir, 2020;Imbayi, 2020). Globally, losses due to diseases of tomato are approximated to stand at 21.8% (Work u and Sahe, 2018). Studies on incidences and prevalence of tomato foliar fungal diseases have been reported globally (El- Mohamady *et al.*, 2014; Soni *et al.*, 2017). In South Gujarati in Indian, a survey by Patel *et al.* (2016) observed earlyblight disease incidences of 43.33% - 56.67% and lower cases of late blight 10.56% - 16.67%. In Ghana, incidenceof early blight of 63.9, 43.5 and 38.2 % were reported for Agogo, Offinso and Techiman regions respectively by

Opuku (2012). In Eritrea farm survey by Naqvi *et al.* (2014) reported varied regional early blight incidences (Awrari 27.27, Abderes 25.11, A water 56.28 and Tsebab 49.35-52.38 and Genfelom 32.90%). In Morogoro, Tanzania, a survey by Hayes (2015) reported low incidences of tomato early blight when compared to other diseases while a survey by Testen *et al.* (2018) in Morogoro reported higher early blight (88 of 100 %) and Septoria leaf spot (34 %) incidences. However, information of foliar fungal diseases in tomato farms in Kenya have depended on use of structured questionnaires Mwangi *et al.* (2015), and Ochilo *et al.* (2019). There exists scarce information on prevalence and distribution of early blight, late blight and septoria spot in tomato production regions such as Kirinyaga County.

MATERIALS AND METHODS

Study Area

The study was carried out in Kirinyaga County (Figure 1). Kirinyaga County is located in the Southern outskirts of Mt. Kenya and about 100 km North East of Nairobi (Serede *et al.,* 2015). Kirinyaga County was suitable for this study since it is one of the leading tomato production Counties in Kenya. Geographically, Kirinyaga County lies between latitudes 0° 37'S and 0° 45'S and between longitudes 37° 14'E and 37° 26'E. It lies between 1,100 m and 1,200 m above sea level. The area 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 temperature ranges from a minimum of 12°C to a maximum of 26°C with an average of 20°C (Kaggikah, 2017). Kirinyaga County have six agro ecological zones that include LH 1 (Tea Dairy Zone), UM 1, UM 2, UM 3 (three coffee zones), LM 3 and LM 4 (Marginal Cotton Zone). Preliminary studies carried out prior to actual study showed that tomato is grown in coffee zones, tea zones and largely in cotton zones through irrigation. Specifically, the study was conducted in five tomato growing agro- ecological zones of Kirinyaga: LM 3, LM 4, UM 3 and UM 3 (Figure 1, Table 1).

Table 1: Details of agro-ecological areas of surveyed in Kirinyaga County

Agro-ecol zone	Altitude (m)	Temp (°C)	Subzone	Rainfall (mm)
UM2			m/l i m/s	1220-1500
	1400-1580	20.1-19.0	m + s/m	1200-1250
UM3	1340 - 1400	20.6-20.1	m/s + s	1100 - 1250
UM4	1280 - 1340	20.9-20.4	s/m + s	950 - 1200
			s + s	350 - 960
LM3	1220 - 1280	21.2 - 20.9	s /m+ s	950 -1200
			s + s	350 -960
LM4	1090 - 1220	22.0 - 21.2	s + s/vs	850 - 950

Study designs

The study was conducted using a cross sectional survey design. The agro ecological zones were purposively selected based on their tomato production status. Farms for the study were selected through multistage sampling method to ensure adequate mapping and coverage of study area. Only farms measuring ¼ an acre and above were surveyed for diseases. At the farm, systematic ecological survey design was used. Transects were laid diagonally from where micro plots (10 x 10 m^2 area) at equidistance of 10 m were established for assessment of foliar fungal diseases of tomato. Systematic ecological survey design was preferred to ensure uniform coverage of the target population.

Target population, sample size and sampling procedure and sample size

Prevalence and distribution of Early blight, late blight and Septoria spot was carried out using a cross sectional survey study design across the five different agro ecological zones of Kirinyaga County between the months of March to July 2020. In agro ecological zone LM4 (Gachogu, Gategi, Kiumbu, Wanguru and Nguka villages), LM3 (Kandongo, Kagio, Siranga, and Nyangate villages), UM4 (Ndoma, Kianganga, Njiris), UM3 (Gatheri and Kamuthambi villages) and UM2 (Kerigo, Karia, Keria and Geotheri villages). The villages above were selected because they have many farmers who grow tomatoes. The sample size of 112 farmers was drawn using, Cochran (1963) formula from 1000 tomatoes farmers who grow tomatoes in over ¼ acres of land in Kirinyaga County.

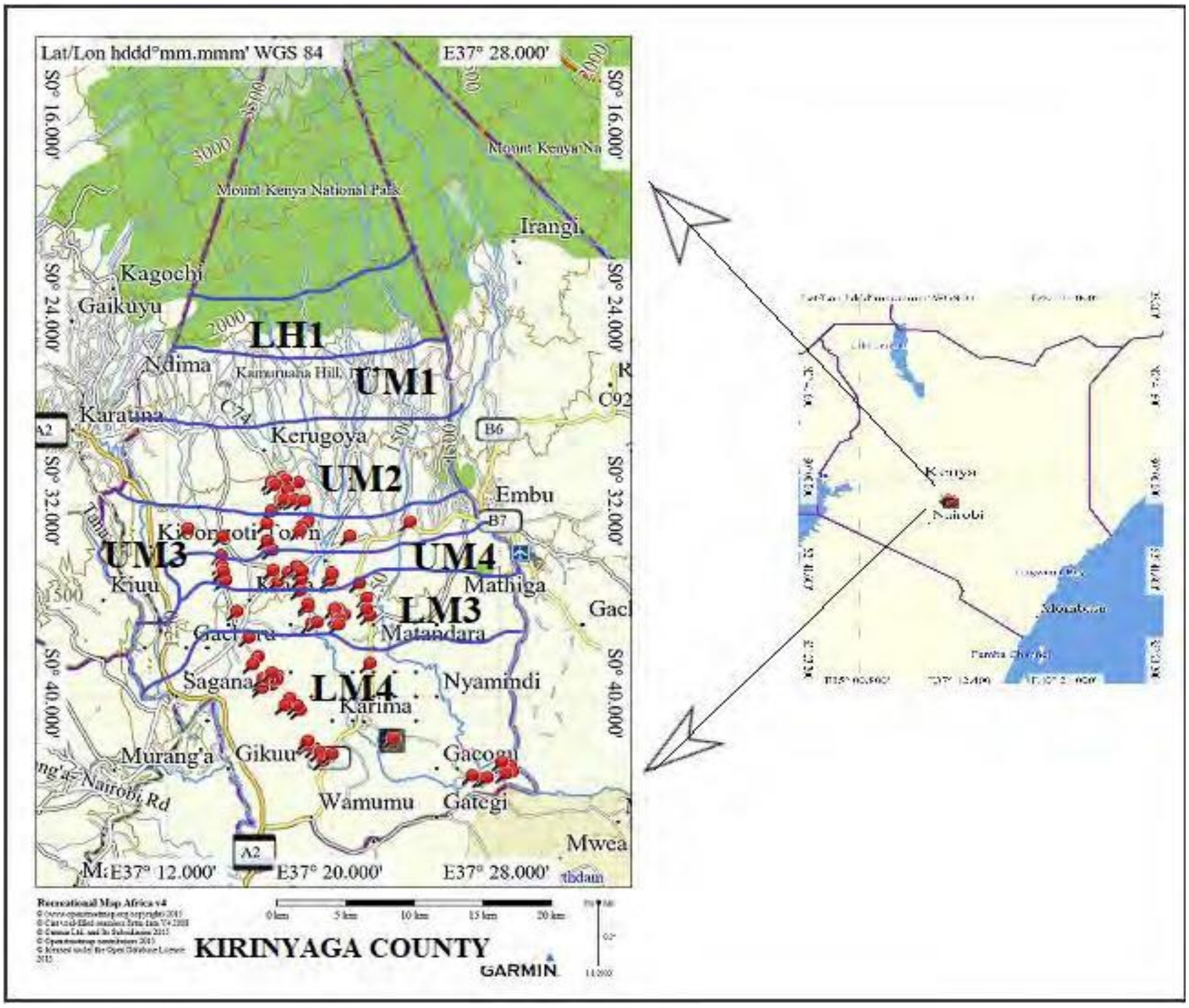

Figure 1: Map of Kirinyaga County Showing agro ecological zones UM2, UM3, UM4, LM3 and LM4Surveyed for tomato foliar diseases

Data Collection

Assessment of the fungal diseases in tomato and sample collection

Survey procedure method used by Olawale (2015) was used to collect information on the incidences of early blight in tomato farms in Kirinyaga County. In each tomato farm especially where the farm was large enough (100 x 100 m), three micro plots (10 x 10 m^2) laid a cross the farms diagonally were established from both side of the farm. Where the farm was less than an acre the size the micro plots were adjusted appropriately. The first and the last plotsmicro plots were established 5 m away from the farm margin to avoid edge effect. The distance between one micro plot to the next was 10 m apart along the diagonal line in an acre farm.

Determination of incidence and severity of early blight and late blight and septoria spot

In every micro plot established, sampling of the plot for incidence of early blight diseases was done by counting ten plants in each grid and assessing the incidence of early blight, late blight and septoria spot in every plant. The result was recorded as 1 (If blight symptom 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 (Mayee and Datar, 1986; Mahantesh *et al.,* 2017).

$$\%\ \text{Disease incidence}\ (DI) = \frac{Number\ of\ diseased\ plants}{Total\ number\ of\ plants\ assesed\ plants} x\ 100$$

To determine the disease severity, five plants were randomly selected from each micro plots. From each of the five tomatoes selected in every plot, five leaves were randomly picked and used for disease severity determination. Rating scale of 1 - 6 used by was used to score diseases severity for the Early blight and Late blight (Desta and 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 per cent severity index was calculated using the formula below:

$$\text{Percent Disease Severity} = \frac{\text{Number of individual ratings}}{\text{Total number of leaves assessed}} x \frac{100}{\text{Maximum scale}}$$

RESULTS

Prevalence and distribution of foliar fungal diseases of tomato

Spearman correlation was conducted to examine the correlation between different tomato foliar fungal diseases at 95% significant level. Table 2 presents intercorrelations and descriptive statistics. There was weak negative non-significant correlation of early blight incidence with septoria spot incidence (r = -0.134, p > 0.59, n=27; Table 2). However, there was strong positive significant correlation between Early blight incidence and Early blight severity (r = 0.707, p <.0001, n= 27; Table 2). The minimum and maximum early blight percentage incidence was 36.69% was 76.65 respectively. Early blight severity had minimum and maximum percent of 17.15% was 50.88 % respectively (Table 1). A strong positive correlation was observed between septoria spot incidence and septoria spot severity (r = 0.743, p <.0001, n=27; Table 2). The maximum and minimum percentage score for septoria spot incidence was 23.56% and 66.89% respectively. Likewise, the maximum and minimum percentage score for septoria spot severity was 16.07% and 44.62% respectively. Late blight incidence and late blight severity had strong positive correlation and was significant (r = 0.783, p <.0001, n=27; Table 2). Early blight incidence had minimum and maximum percentages of 33.64% and 66.87% respectively (Table 2).

Table 2: Correlation matrix between different tomato foliar fungal diseases

	EBI	SPI	LBI	EBS	SPS	LBS
EBI	1					
SPI	-0.134 (0.509)	1				
LBI	0.405 (0.036)	-0.212 (0.288)	1			
EBS	0.707 (<.0001)	-0.087 (0.665)	0.339 (0.083)	1		
SPS	-0.350 (0.073)	0.743 (<.0001)	-0.402 (0.038)	-0.256 (0.197)	1	
LBS	0.481 (0.011)	-0.221 (0.268)	0.428 (0.026)	0.783 (<0.0001)	-0.263 (0.186)	1
Minimum	36.69	23.56	33.64	17.15	16.07	16.82
Maximum	76.65	93.42	66.87	50.88	44.62	33.72
Mean ± SD	59.7±10.4	67.9±18.4	44.1±8	28.4±7.3	33.8± 7.6	24.2±4.7

Where EBI = Early Blight incidence, SPI = Septoria spot incidence, EBS = Early blight severity, SPS = Septoria spot severity, LBS = Late blight severity. Figures in parenthesis represent *p*-values.

Incidences of early blight, late blight and septoria spots

Early blight incidences in different villages within different agro ecological zones of Kirinyaga County differed significantly ($F(26, 2726) = 34.55$, $p < .0001$) at $\alpha = 0.05$. In zone UM3, the higher early blight percentage incidence was 76.6% at Kamigwi village and with low incidence percentage of 68.01% at Kiamathambi village. All the percentages of early blight incidences observed in this zone were above the average mean (Table 3). The higher and lower percentage of early blight incidence in Zone LM3 was 59.34% and 35.69% at Siranga and Chemise respectively. Except for Siranga village early blight incidences were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone LM2, higher and lower percentage of incidence early blight was 72.27% and 51.69% at Geotheri and Kerigo villages respectively. Zone LM4 had higher and lower percentage of early blight incidence of 58.02% and 44.93% at Kandongu and Kiumbu villages respectively. All the per cent incidences of early blight in zone LM4 were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone UM4, Gechenjo and Thumaita villages had higher and lower early blight incidences of 76.65% and 60.33% respectively.

Table 3: Incidence of early blight, septoria spots and late blight in tomato farms in Kirinyaga

Agrozone	Village	Early blight Incidence (%)	Septoria spot Incidence (%)	Late blight Incidence (%)
LM3	Chemise	54.32 lm	80.79 c	50.01 def
	Kathiga	35.69 q	51.24 i	37.86 gij
	Kionya	58.02 ijkl	86.63 b	41.87 gh
	Nguvaine	47.84 op	81.17 c	37.55 ijk
	Siranga	59.34 hijk	78.86 cd	55.48 c
	Yaboi	49.38 nop	72.16 e	35.32 ijk
LM4	Kandongu	58.02 ijkl	87.55 b	39.81 ghi
	Kiaminiki	55.04 klm	81.79 c	37.96 gij
	Kiamukuyu	56.11 jklm	80.49 c	39.26 gij
	Kiumbu	44.93 p	78.53 cd	40.3 ghi
	Mugo	56.74 ijkl	82.09 c	39.66 ghi
	Ndindiruki	56.48 ijkl	79.01 cd	33.64 k
	Nguka	45.25 p	75.49 de	47.47 ef
UM2	Geotheri	73.27 abc	34.24 k	42.24 g
	Kemicha	61.11 ghi	52.08 i	37.42 ijk
	Keria	53.53 lmn	23.56 l	40.23 ghi
	Kerigo	51.69 mno	61.24 gh	41.27 ghi
	Kiangunga	63.7 fgh	58.33 h	59.63 b
UM3	Gachai	73.77 ab	67.05 f	52.86 cd
	Kamathori	72.04 abcd	64.309 fg	51.23 de
	Kiamathambi	68.01 bcde	32.61 k	66.87 a
	Kiangungu	69.65 bcde	40.95 j	37.96 gij
	Kidaruini	76.04 a	80.86 c	50.1 def
UM4	Gechenjo	76.65 a	76.23 de	41.4 ghi
	Kamigwi	65.54 efg	93.42 a	39.51 ghi
	Kianganga	68.89 edf	72.35 e	48.89 def
	Thumaita	60.33 hij	60.68 gh	47.08 f
	Mean	58.88	69.85	43.99
	LSD (p<0.05)	5.222	4.786	4.807
	CV (%)	30.468	23.54	37.532

[a]Means followed by the same letters in columns are not significantly different at α = 0.05

Incidences of septoria spots foliar disease in different villages within different agro ecological zones differed significantly ($F (26, 2726) = 103.63$, p <.0001) at α = 0.05. Higher and lower percentage incidence of 93.42% and 72.35 were recorded at Kamigwi and Thumaita villages respectively (Table 3) in zone UM4. The higher and lower percentage of septoria was 86.63% and 51.24% at Kionya and Kathiga villages respectively in Zone LM3. Higher and lower percentage of septoria spot incidence was 61.24% and 23.56% at Kerigo and Keria villages respectivelyin zone LM2. All septoria incidences in LM2 were below the overall mean (Table 3). Zone LM4 had its higher and lower percentage of septoria incidence of 87.55% and 75.49% at Kandongu and Nguka villages respectively. All the per cent septoria spot incidences in zone LM4 were above the overall mean ((Incidences of **early blight, late blight and septoria spots**

Early blight incidences in different villages within different agro ecological zones of Kirinyaga County differed significantly ($F(26, 2726) = 34.55$, $p < .0001$) at $\alpha = 0.05$. In zone UM3, the higher early blight percentage incidence was 76.6% at Kamigwi village and with low incidence percentage of 68.01% at Kiamathambi village. All the percentages of early blight incidences observed in this zone were above the average mean (Table 3). The higher and lower percentage of early blight incidence in Zone LM3 was 59.34% and 35.69% at Siranga and Chemise respectively. Except for Siranga village early blight incidences were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone LM2, higher and lower percentage of incidence early blight was 72.27% and 51.69% at Geotheri and Kerigo villages respectively. Zone LM4 had higher and lower percentage of early blight incidence of 58.02% and 44.93% at Kandongu and Kiumbu villages respectively. All the per cent incidences of early blight in zone LM4 were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone UM4, Gechenjo and Thumaita villages had higher and lower early blight incidences of 76.65% and 60.33% respectively.

Table). In zone UM3, Kidaruini and Kiamathambi villages had higher and lower septoria incidences of 80.86% and 32.61% respectively.

Incidences of late blight disease in different villages within different agro ecological zones differed significantly ($F(26, 2726) = 20.99$, $p < .0001$) at $\alpha = 0.05$. In zone UM4, higher and lower percentage incidence was 48.89% and 39.51% at Kianganga and Kamigwi villages respectively (Incidences of **early blight, late blight and septoria spots**

Early blight incidences in different villages within different agro ecological zones of Kirinyaga County differed significantly ($F(26, 2726) = 34.55$, $p < .0001$) at $\alpha = 0.05$. In zone UM3, the higher early blight percentage incidence was 76.6% at Kamigwi village and with low incidence percentage of 68.01% at Kiamathambi village. All the percentages of early blight incidences observed in this zone were above the average mean (Table 3). The higher and lower percentage of early blight incidence in Zone LM3 was 59.34% and 35.69% at Siranga and Chemise respectively. Except for Siranga village early blight incidences were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone LM2, higher and lower percentage of incidence early blight was 72.27% and 51.69% at Geotheri and Kerigo villages respectively. Zone LM4 had higher and lower percentage of early blight incidence of 58.02% and 44.93% at Kandongu and Kiumbu villages respectively. All the per cent incidences of early blight in zone LM4 were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone UM4, Gechenjo and Thumaita villages had higher and lower early blight incidences of 76.65% and 60.33% respectively.

Table). In Zone LM3 higher and lower percentage of Late blight incidence of 86.63% and 51.24% were observed at Siranga and Yaboi villages respectively. In zone LM2, higher and lower percentage incidence of late blight was 59.63% and 37.42% at Kiangunga and Kemicha villages respectively (Incidences of **early blight, late blight and septoria spots**

Early blight incidences in different villages within different agro ecological zones of Kirinyaga County differed significantly ($F(26, 2726) = 34.55$, $p < .0001$) at $\alpha = 0.05$. In zone UM3, the higher early blight percentage incidence was 76.6% at Kamigwi village and with low incidence percentage of 68.01% at Kiamathambi village. All the percentages of early blight incidences observed in this zone were above the average mean (Table 3). The higher and lower percentage of early blight incidence in Zone LM3 was 59.34% and 35.69% at Siranga and Chemise respectively. Except for Siranga village early blight incidences were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone LM2, higher and lower percentage of incidence early blight was 72.27% and 51.69% at Geotheri and Kerigo villages respectively. Zone LM4 had higher and lower percentage of early blight incidence of 58.02% and 44.93% at Kandongu and Kiumbu villages respectively. All the per cent incidences of early blight in zone LM4 were below the overall mean (**Error! Not a valid bookmark self-reference.**). In zone UM4, Gechenjo and Thumaita villages had higher and lower early blight incidences of 76.65% and 60.33% respectively.

Table).

Incidences of early blight in tomato farms in different agro ecological zones in Kirinyaga County were significantly different ($p < .05$). Higher percentage of tomato early blight of 72.09% was observed in Agro-zone UM3 followed by UM4 at 67.33%. A lower percentage of early blight was recorded in agro ecological zone UM2 (Table 4).

Percentages of tomato blight in zones UM3 and UM4 were above the overall mean of 62.52%. Except for LM3 and LM4 whose mean differences were not significantly different, all differences mean between other zones were significant (
Table).

Table 4: Percentages of incidence of Septoria spots, Early and Late blight in tomato in different agro ecological zones of Kirinyaga County

Agro Ecological zone	Early Blight Incidence (%)	Incidence of Septoria spots (%)	Late Blight Incidence (%)
UM3	72.09 [a]	58.80 [c]	51.77 [a]
UM4	67.33 [b]	73.93 [b]	45.08 [b]
LM3	61.05 [d]	75.55 [b]	42.95 [c]
LM4	52.319 [d]	80.22 [a]	40.25 [d]
UM2	60.05 [c]	44.81 [d]	40.38 [c]
Means	58.88	69.85	43.58
LSD (p<.05)	2.339	2.454	2.184
Cv (%)	31.927	28.236	39.901

[a] Means followed by the same letters in columns are not significantly different at $\alpha = 0.05$

Incidences of septoria spot in tomato farms in different agro-ecological zones in Kirinyaga County were significantly different ($p < 0.05$; Appendix III). Higher percentage of septoria spot at 80.22% was observed in Agro- zone LM4 and was followed by LM3 at 75.55%. The mean percentage difference of septoria incidence between UM4 and LM3 were not significantly different. Agro ecological zone UM2 with septoria spot percentage of 44.81% was the lowest (
Table). Two agro ecological zones (UM2 and UM3) had septoria incidence percentage lower than the overall mean of 71.02% (
Table).

Incidences of late blight in tomato farms in different agro-ecological zones in Kirinyaga County were significantly different ($p < 0.05$). Higher percentage of late blight of 51.77% was observed in Agro ecological zone UM3 followed by UM4 with 45.08%. Agro ecological zones LM4 and UM2 recorded lower percentage of late blight of 40.25% and 40.38% respectively (
Table). Mean late blight percentages in zones UM3 and UM4 were above the overall mean of 43.58%. Comparatively, septoria spot fungal disease was found to be higher at 69.84% and was followed by Early blight per cent incidence at 58.89% while per cent incidence of Late blight was lower at 44.02% (Figure 16). Overall mean percent of fungal disease incidence was 57.58%, LSD of 0.99% and CV of 32.59.

Severity of early blight, septoria spots and late blight

Severity of Early blight disease tomatoes farms in different villages within different agro ecological zones of Kirinyaga County differed significantly ($F(26, 2726) = 117.24$, $p < .0001$) at $\alpha = 0.05$. In zone LM4, 28.09% and 18.01% was observed as the higher and lower percentage severity mean at Kandongi and Kiaminiki villages. All of the severity means for early blight in zone LM4 were below the overall mean of 28.22% (
Table). In zone LM3, higher and lower Early blight severity were 29.41% and 22.21% at Siranga and Chemise respectively. Severity for Kionya, Siranga and Kathiga villages were below the overall mean of 28.22 (
Table). In zone UM4, higher and lower severity of early blight was 34.83% and 26.43% at Gechenjo and Thumaita villages respectively.

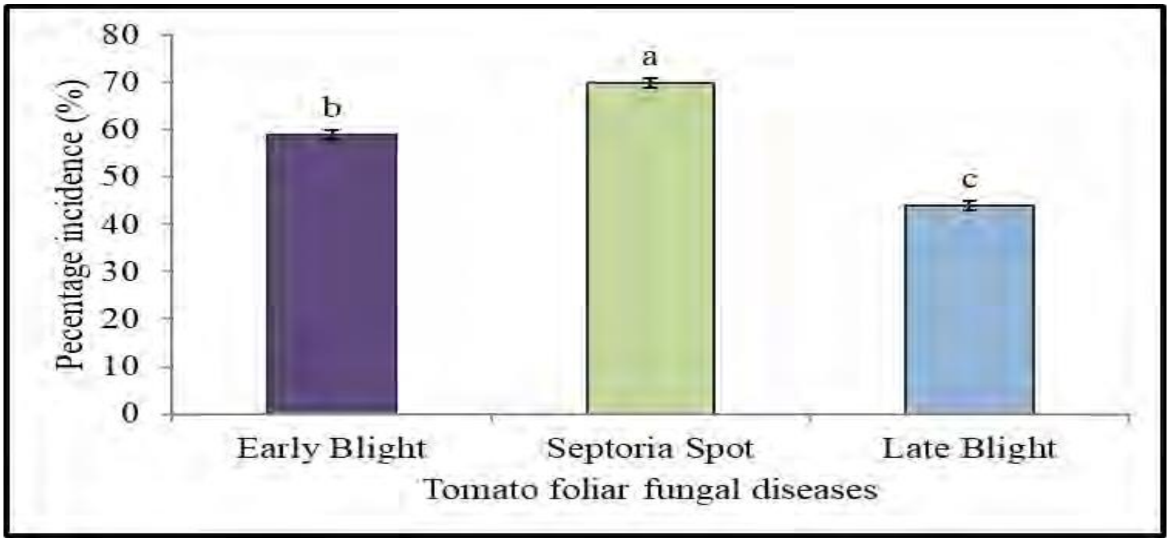

Figure 16: Overall per cent incidences of tomato foliar diseases in Kirinyaga County

Table 5: Severity of septoria spots, early and late blight in tomato farms in Kirinyaga County

Agro-zone	Village	Early blight Severity (%)	Septoria spot Severity (%)	Late blight Severity (%)
LM3	Chemise	22.21 ^{n}	40.11 ^{d}	23.38 ^{jh}
	Kathiga	26.46 ^{kl}	31.73 ^{hi}	26.74 ^{eg}
	Kionya	28.39 ^{hij}	43.43 ^{ab}	20.28 ^{kl}
	Nguvaine	25.45 ^{lm}	42.09 ^{bc}	21.22 ^{k}
	Siranga	29.41 ^{gh}	41.57 ^{cd}	27.85 ^{ed}
	Yaboi	28.42 ^{hij}	36.51 ^{efg}	30.08 ^{bc}
LM4	Kandongu	28.09 ^{ijk}	44.53 ^{a}	22.89 ^{j}
	Kiaminiki	18.01 ^{op}	36.19 ^{eg}	17.09 ^{o}
	Kiamukuyu	23.87 ^{mn}	44.62 ^{a}	20.77 ^{kl}
	Kiumbu	19.67 ^{o}	35.76 ^{g}	19.51 ^{lm}
	Mugo	22.69 ^{n}	40.90 ^{cd}	18.66 ^{mn}
	Ndindiruki	24.85 ^{lm}	41.27 ^{cd}	20.05 ^{klm}
	Nguka	18.67 ^{op}	37.54 ^{ef}	16.82 ^{0}
UM2	Geotheri	28.14 ^{ij}	19.36 ^{o}	19.95 ^{klm}
	Kemicha	27.27 ^{jk}	29.02 ^{k}	23.51 ^{ij}
	Keria	31.59 ^{ef}	27.18 ^{lm}	25.39 ^{gh}
	Kerigo	17.15 ^{p}	26.26 ^{m}	17.93 ^{no}
	Kiangunga	31.04 ^{fg}	16.07 ^{p}	23.68 ^{ij}
UM3	Gachai	34.11 ^{cd}	28.32 ^{kl}	32.46 ^{a}
	Kamathori	42.46 ^{b}	31.06 ^{kj}	33.72 ^{a}
	Kiamathambi	29.88 ^{gh}	23.61 ^{n}	28.68 ^{cd}
	Kiangungu	30.811 ^{fg}	28.03 ^{klm}	27.07 ^{ef}
	Kidaruini	50.88 ^{a}	29.51 ^{kj}	30.64 ^{b}
	Gechenjo	34.83 ^{c}	38.13 ^{e}	24.81 ^{hi}
UM4	Kamigwi	32.93 ^{de}	32.86 ^{n}	26.12 ^{fgh}
	Kiangaga	34.78 ^{fg}	37.09 ^{efg}	27.30 ^{ed}
	Thumaita	26.43 ^{kl}	32.33 ^{hi}	27.21 ^{edf}
	Mean	28.22	35.03	24.33
	LSD ($p<0.05$)	2.018	2.187	1.778
	CV (%)	24.576	21.45	25.112

[a]Means followed by the same letters in columns are not significantly different at $\alpha = 0.05$

Agro ecological zone UM3 had higher and lower percentage of early blight severity of 50.88% and 29.88% at Kidaruini and Kiamathambi villages respectively. All the per cent severities of early blight in UM3 were above the overall mean. In zone UM2, Keria and Kerigo villages had higher and lower early blight incidences of 31.59% and 17.15% respectively (
Table). Severity of septoria spot on tomato leaves in different villages within different agro ecological zones of Kirinyaga County differed significantly (F (26, 2726) = 80.69, p <.0001) at α = 0.05. Septoria severity of 44.62% and 35.76% at Kiamukuyu and Kiaminiki villages were the highest and lowest respectively in zone LM4, (
Table). In zone LM3, higher and lower septoria spot severities were 43.43% and 31.73% at Kionya and Kathiga respectively. In zone UM4, higher and lower septoria spot severity were 38.13% and 32.33% at Gechenjo and Thumaita villages respectively. Zone UM3 had higher and lower septoria severity of 31.06% and 23.61% at Kamathori and Kiamathambi villages respectively (
Table). In zone UM2, Kemicha village had higher severity of 29.02% followed by Keria village at 27.18% while Kiangunga with 16.07% was the least (
Table).

Severity of late blight on tomato leaves in different villages within different agro ecological zones of Kirinyaga County differed significantly (F (26, 2726) = 68.22, p <.0001) at α = 0.05. In agro ecological zone LM4, higher late blight severity of 22.89% was observed at Kandongu village and was followed by Kiamukuyu village at 20.77% while Nguka had the lower severity of 16.82% (
Table). Yaboi had the higher late blight severity of 30.08% in zone LM3 and was followed by Siranga at 27.85% while Nguvaine with 21.22% was the least. In zone UM4, higher Late blight severity was 27.3% at Kianganga and was followed by 27.21% at Thumaita while Gechenjo village had low severity of 24.81%. Late blight severity in Zone UM3 was higher at Kamathori village with 33.72% followed by 32.46% at Gachai while Kiangungu recorded lower late blight severity with 27.07%. In agro ecological zone UM2, late blight severity was high at Keria with 25.39% which was followed by Kiangunga village at 23.69. Kerigo village had low severity of late blight at 17.93% (
Table).

Severity of tomato diseases early blight, septoria spot and late blight

Severities of early blight of tomato in different agro-ecological zones of Kirinyaga County were significantly different ($p < 0.05$). High percentage of early blight severity of 38.21% was recorded in Zone UM3 followed by 32.07% in zone UM4 and was low at 21.86% in zone LM4. Mean differences of early blight severity in zones LM3, LM4 and UM2 were not significantly different (LSD of 0.434% and CV of 28.19.

Table 46). Septoria spot severities in different agro-ecological zones were significantly different ($p < 0.05$). Higher percentage of septoria spot severity of 39.76% was observed in Agro-zone LM4 and was followed by 39.27% in zone LM3 (LSD of 0.434% and CV of 28.19.

Table 46). However, the mean difference of septoria severity between UM4 and LM3 were not significantly different. Lower septoria spot severity was observed in zone UM2 with 24.93%. Agro ecological zone UM2 with 43.45% was the lowest in septoria severity. Agro ecological zones UM2 and UM3 recorded severity of septoria percentage lower than the overall mean of 35.03% (LSD of 0.434% and CV of 28.19.

Table 46). Tomato late blight severities in different agro-ecological zones in Kirinyaga were significantly different ($p < 0.05$). Higher late blight severity percentage was recorded in zone UM3 with 31.12% and was followed by zone UM4 at 26.56% while zone LM4 had lower percentages of severity at 19.27%. Generally, severity of septoria spot fungal disease was found to be higher at 35.01% and was followed by early blight per cent severity at 28.21% while per cent severity of Late blight was lower at 24.34% (Figure). Overall mean percentage of tomato foliar fungal disease incidence was 29.14%, LSD of 0.434% and CV of 28.19.

Table 46: Severity of septoria spots, early and late blight in tomato in different agro ecological zones of Kirinyaga County

Agro Ecological zone	Early Blight Severity (%)	Septoria spots Severity (%)	Late Blight Severity (%)
UM3	38.21 [a]	28.58 [c]	31.12 [a]

UM4	32.07 [b]	35.12 [b]	26.56 [b]
LM3	27.32 [c]	39.27 [a]	25.27 [c]
LM4	21.86 [c]	39.76 [a]	19.27 [d]
UM2	26.74 [c]	24.93 [d]	22.54 [d]
Means	28.22	35.03	24.33
LSD (p<.05)	1.017	1.023	0.817
Cv (%)	28.982	23.472	26.985

[a]Means followed by the same letters are not significantly different at α = 0.05

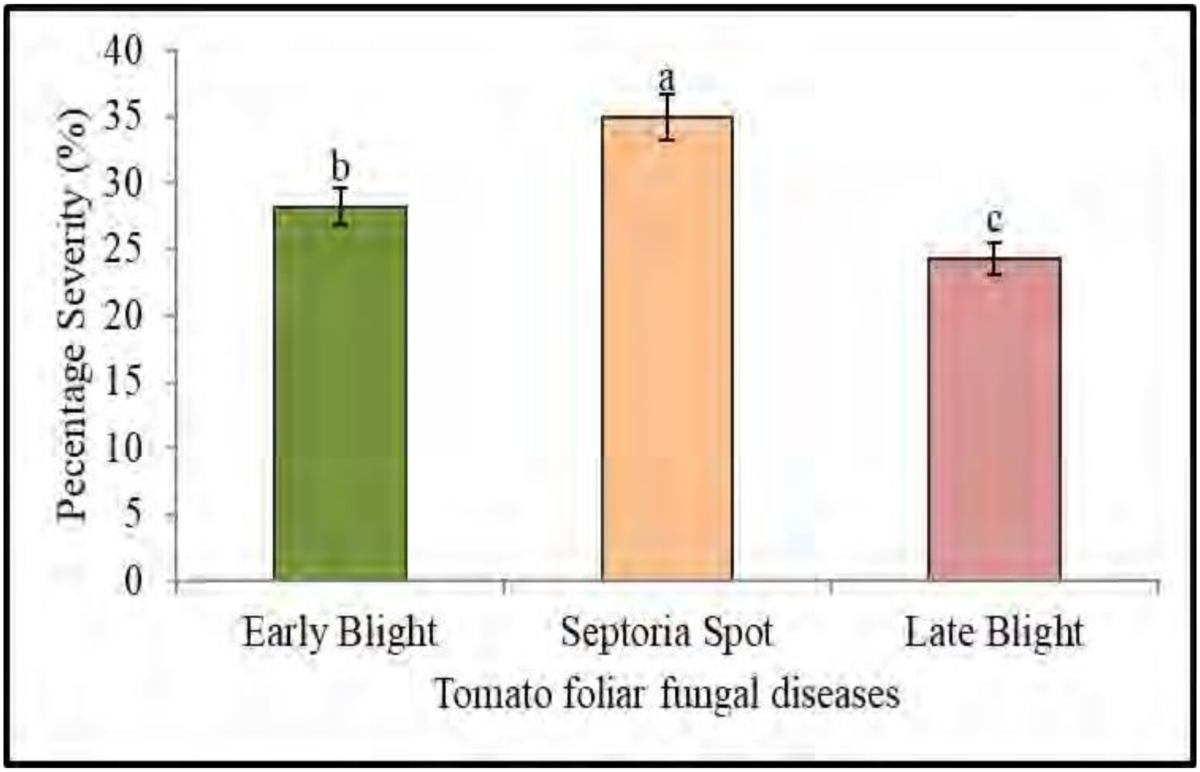

Figure 17: Overall percent severity of tomato foliar diseases in Kirinyaga County

Field Observation on tomato diseases and Other constraints in Tomato Farms

Distinctive Early blight symptoms were observed in tomato farms and were present in different parts of the plant. Lesions characterized by concentric rings were observed on leaves, stem and on fruits (Figure 18). Leaf blight symptoms were observed to cause collar rot, blighted leaf as well as fruit rot. The lesion on leaves and on fruits was more circular than that caused by the late blight. The Early blight symptoms were more pronounced on the lower older leaves than on the upper younger tomato leaves.

Figure 18: Early blight symptoms on developing on tomato fruit (Left) fruit and leaf (Right)

Symptoms of Late blight observed in tomato farms were water-soaked lesions appearing pale greenish. Blight margin were irregular unlike those of early blight greyish to whitish moulds growth observed on lower leaf surface with visible sporangiophores. Heavy infection turned the green photosynthetic leaf into brown non photosynthetic leaf. Symptoms were also observed on petioles, stem on fruits (Figure 19).

The lesions caused by the *Septoria lycoperscici* on tomato leaves in farms were observed. The lesions developed from the lower part of the leaves and were visible on both sides of the leaf. Freshly developing lesions appeared as dark green spots and water soaked. As they mature, the lesions became circular, angular or elliptical in shape and dark coloured with characteristic greyish whitish center. Septoria spot lesions were surrounded by yellow hallo. The lesions coalesced as they increased in numbers leading to a larger blight on the leaf. Heavy infestation of the tomato leaves with septoria spots made the entire leave to turn yellow (Figure 20). Large and black coloured pycnidia were visible on the upper side of lesions when the lesion was observed using dissecting light microscope. Other than symptoms on the leaves septoria spots were also observed on the stem of tomato plants in the farms.

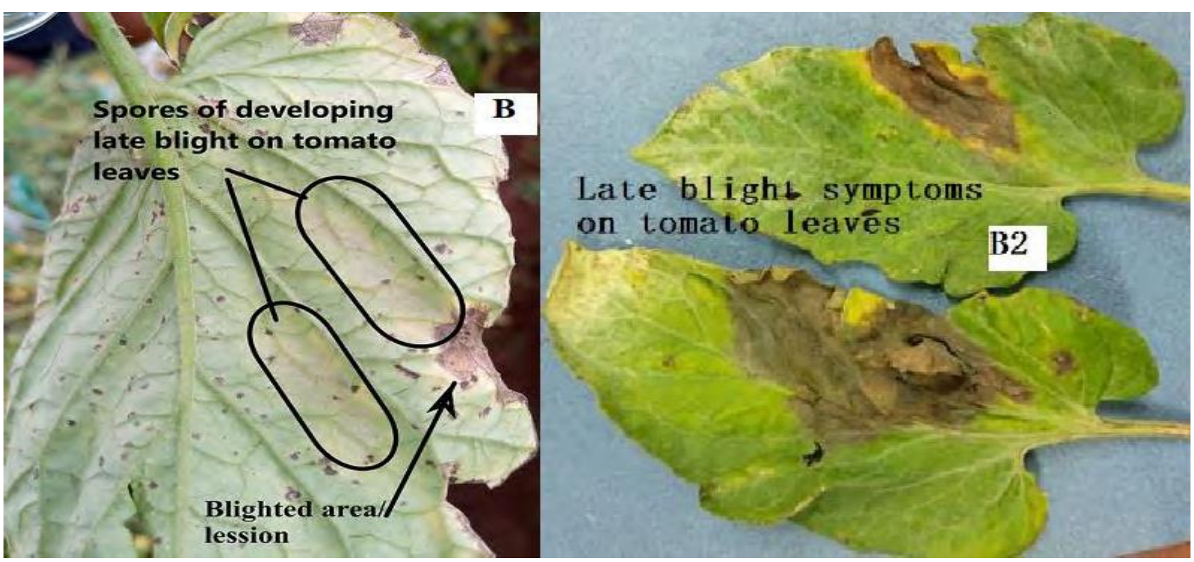

Figure 19: Late blight symptoms - pathogen's spore (B) lesions (B2)

Figure 20: Symptoms of Septoria leaf spot observed in tomato farms

Other Constraints in Tomato Farming Observed during Farm Survey

Symptoms associated with wilting particularly *Fusarium* wilt and *Ralstonia* wilt were observed in different farms. Whereas the plant reaction was similar for the two type of wilt the observation in the vascular system was distinctive. Bacteria wilt (*Ralstonia* wilt) had watery sticky oozing when the stem was split into two while Fusarium wilt had brownish dry vascular system. When the disease was advances Fusarium wilt had dark brown dry vascular rot (Figure 21). Bacteria spot, *Canker* and Damping off (Figure 22).

Figure 21: Fusarium wilt (I) Bacterial wilt infested tomato roots - vascular systems

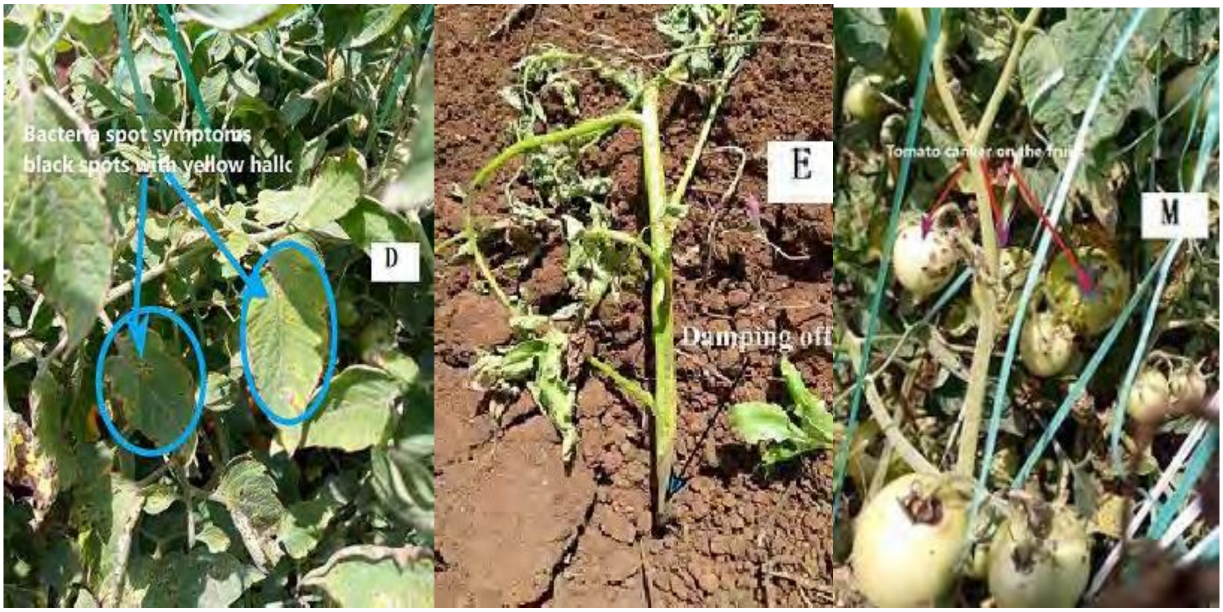

Figure 22: Bacteria spot (D), Canker (M) and Damping off (E) diseases of tomato

Some of the viral diseases observed were leaf mosaic and bunchy top viral diseases (Figure 23). Insects included *Tuta absoluta*, spider mites and white flies (Figure 24).

Figure 23: Tomato leaf mosaic (H) and bunchy top (J) viral diseases

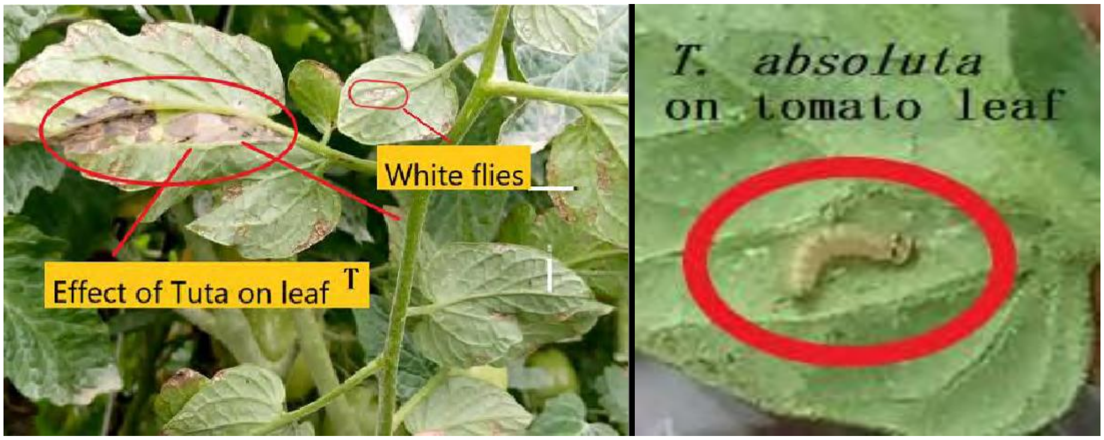

Figure 24: **Tota absoluta** ***effect on tomato leaf (T) and*** **Tuta absoluta** ***(Left)***

DISCUSSION

Prevalence and Distribution of Foliar Fungal Diseases of Tomato

Incidences of Foliar Fungal Diseases of Tomato

Early blight disease incidences in different agro ecological zones of Kirinyaga County differed significantly ($p < 0.05$). Compared to other agro ecological zones in the study area, zone LM4 had low incidences of early blight at 52.319% while zone UM3 had higher incidences of 72.09%. Early blight incidences reported in this study were higher than those reported by Naqvi *et al.* (2016) and Hussain *et al.* (2019) who reported incidence range of 5-56%. The incidence reported here are comparable to those reported by Rao *et al.* (2016). However, incidences of early blight herein are lower than those reported by Ahmad *et al.* (2014). Variation of early blight incidences across agro ecological zones surveyed may have been attributed for by a number of factors. Factors that may explain such variation include differences in field humidity, temperatures, tomato varieties grown, source of planting material as well as fungicides use practices. Studies have shown that early blight development is affected by temperature and humidity (He *et al.*, 2012). Optimal temperature for growth of early blight pathogen such as *A. solani* has been reported to range from 25–30°C (Naik and Sinha, 1997; He *et al.,* 2012). Incidences above 50% observed in zone LM4 a semi-arid area may be attributed to high variability of early blight pathogens. For instance, according to Pasche *et al.* (2004) and Chaerani *et al.* (2007), early blight pathogens *Alternaria solani* is capable of adapting to changing environment easily and develop resistance towards fungicides as well as evading host resistance. Variationin factors like environmental conditions and farming activities that include continuous application fungicides may induce genetic shift in the pathogens' genetic structure and occurrence of new pathogen strains (Pachori *et al.,* 2016). New strain of the pathogen may mostly be resistant to recommended fungicides thus, increased frequency in pathogenicity (Van der Waals *et al.,* 2004; 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 sport in tomato farms in different agro ecological zones in Kirinyaga County were significantly different ($p < 0.05$). Whereas the incidence of septoria leaf spot was high (80.22%) in agro ecological zone LM4, zones UM2 had low septoria spot incidences at 44.81%. The incidence reported in this study differed with those of Lumumba (2001) in Zambia where septoria spot incidences ranged from 3% to 10% for all the regions surveyed. Higher incidences of septoria spot in zone LM4 may be attributed to impact of irrigation water as well as the frequency of irrigating tomato farms. For instance, during the study, it was established that in zone LM4 and LM3 irrigation of tomato farms is carried out frequently with water flowing on the surfaces rapidly. According to Lopes *et al.* (2005) and Šubić *et al.* (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 development of septoria spot.

According to Cabral *et al.* (2013), minimizing impact of water droplets may reduce septoria spot disease severity. High soil moisture due to continual heavy irrigation in zone LM3 and LM4 may have probably contributed to higher incidences. This fact is supported by Cabral *et al.* (2013) where greater frequency and large amount of irrigation water increased severity of septoria spot. It may also be possible that differences of tomato varieties grown in different agro ecological zones 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). Incidences of late blight in tomato farms in different agro ecological zones in Kirinyaga County were significantly different ($p < 0.05$). Higher percentage of late blight of 51.77% was observed in Agro ecological zone UM3 while agro ecological zones LM4 and UM2 recorded lower percentage at 40.25% and 40.38% respectively. Incidences of late blight observed in this study are lower than those reported by Tripathi *et al*. (2017) and Testen *et al.* (2018). On the other hand, late blight incidences reported in here are higher than those reported by Hayes (2015) and are comparable to the findings of Patel *et al.* (2016).

Severity of foliar fungal diseases of tomato

Early blight severity differed from one agro ecological zone to the next ($p <.05$). High severity of up to 38.21% was observed in zone UM3 while lower severity was observed in zone LM4 with 21.86%. Severity of early blight observed in this study was comparable to other studies (Rao *et al*., 2016 ; Hussain *et al.*, 2019; Iqbal *et al*., 2019). However, early blight severity reported in this study were higher than those reported by Safi *et al*. (2020) where severity lower than 10% were reported. Moderate severity in Zone 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 agro ecological zones was above 20%. Moderately higher severity may have resulted from overwintered virulent pathogen strain that continues to sustained infection (Naik *et al.*, 2010; Ahmad *et al.*, 2014). Difference in severity across agro ecological zones may be explained by differences in environmental conditions (Gupta *et al.*, 2020). Further, differences in tomato varieties grown in different agro ecological zones mayaccount for the differences for the severity observed across agro ecological zones (Kumar and Praveen, 2019).

Severity of septoria spot was higher in zone LM4 at 39.76 % and lower in zone UM2 at 24.93%. High soil moisture due to continual heavy irrigation in zone LM3 and LM4 are thought to be contributing factor for higher severity of septoria spots in these zones (Lopes *et al.*, 2005; Cabral *et al.*, 2013). Differences in tomato varieties and their sources as observed in this study may account for differences in severity of septoria spot across agro ecological zones surveyed (Gul *et al*., 2016). Further, varied climatic condition that exists across agro ecological zones as documented by Jaetzold *et al*. (2007) may explain differences in septoria spot severity observed in different agro ecological zones.

Late blight severity significantly ($p < 0.05$) differed from one agro ecological zone ($p<.05$). Agro ecological zone UM3 had high Late blight severity of 38.21% while agro ecological zone LM4 had low early blight severity of 21.86%. Variations in the Late blight incidence and severity across agro ecological zones may be attributed to differences in metrological factors. Studies show that meteorological factors play role in Late blight development and distribution (Raza *et al.*, 2019). Factors such as humidity, temperature, rainfall and leaf wetness interval influences growth and development of the pathogen. For instance, 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). The severity of late blight in agro ecological zones zone LM4 and LM3 which are drier maybe attributed to the tolerance ability of the pathogen. According to Caubel *et al.* (2013), though of humidity is a significant requirement in pathogenicityof *P. infestans*, the pathogen may developed tolerance for areas with low humidity. The different severity observed may be attributed to differences on the tomato varieties grown across agro ecological zones. As reported by Meya *et al.* (2014) different tomato varieties responds differently to attack by *P. infestans*.

Foliar fungal diseases symptoms

Symptoms of early blight were observed to first appear on the lower leaves and were characterized by small scattered spots which were dark brown to black and were enlarged in advanced stage with concentric rings. The symptoms correspond with those earlier reported (Walker, 1969). The observations are further supported by Babu *et al.* (2000). Walker (1969) and Babu *et al.* (2000) distinctive characteristics of early blight symptoms in tomato to includes as dark brown to blackish spots which are circular to angular but have concentric rings within necrotic lesions. Studies by Sonali (2006) outlined 122 early blight symptoms in tomato as small, oval or angular, darkbrown to black, necrotic, leathery spots with concentric rings, producing a characteristic shooting target board effect.Development of symptomatic lesion in early blight infected tomato is due to production of secondary metabolites such as alternariol monomethyl ether (AME), ten azonic acid (TeA), ten toxin (TEN), altenuene (ALT) and altertoxin I (Garganese *et al.,* 2016; Ramires *et al*., 2018). The symptoms of Septoria spot observed in this study were similar to those observed by (Kashyap, 2013) while symptoms observed for late blight were similar to the onesdocumented by (Schumann and D'Arcy, 2000).

CONCLUSION AND RECOMMENDATIONS

This study has confirmed occurrence of tomato early, late and septoria spot foliar diseases in tomatoes thatsignificantly differ across different agro ecological zones of Kirinyaga County. Early blight and Late blight appearedto be higher in its incidence in agro ecological zone UM3 while Septoria incidences were higher in agro ecological zone LM4. Comparatively, septoria spot fungal disease was had higher incidence at 69.84% while percentage incidence of Late blight was lower at 44.02%. Severity of Early blight and Late blight was higher in agro ecological zone UM3 while Late blight and Septoria spot had higher severity in agro ecological zone LM4 and LM3.Comparatively, severity of Septoria spot fungal disease was found to be higher at 35.01% while percentage severity of Late blight was lower 24.34%. Higher incidences and severity of foliar fungal diseases observed in this study indicate the need carry out cost benefit analysis of foliar diseases of tomato and development of risk management model to manage tomato fungal diseases outbreak in the study area.

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