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Epidemiological factors of septoria tritici blotch (*Zymoseptoria tritici*) in durum wheat (*Triticum turgidum*) in the highlands of Wollo, Ethiopia

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Abstract

Background: Septoria tritici blotch (STB) (*Zymoseptoria tritici*) is a major disease of durum wheat, an economic crop grown in the highlands of Wollo in Ethiopia.

Methods: To determine the status of this disease, we conducted surveys in five districts of Wollo (Meket, Woreilu, Wadila, Jama, and Dessie Zuria) during the 2015 cropping season. We visited 75 farm plots to determine the prevalence, incidence, and severity of STB.

Results: STB prevalence varied among locations, genotypes, planting dates, growth stages, previous crops, plant population, weed population, and soil types. Similarly, disease intensity also varied along all independent variables. The level of incidence was high in all the visited districts, and the level severity ranged from 9.9 to 59.3% while the incidence varied from 50 to 100%. The mean differences in incidence and severity within the districts' variable classes, altitude, varieties, growth stage, plant population, planting date, previous crop, weed population, and soil type were high. The independent variables, districts, altitude, varieties, growth stage, plant population, planting date, previous crops, weed population, and soil type, were significantly associated with high incidence and severity of STB as single predictor in the logistic regression model. A reduced multiple variable model was fitted using districts, altitude, varieties, growth stage, plant population, planting date, previous crop, weed population, and soil type as independent variables. High incidence (> 50%) and severity (> 25%) had a high probability of association to all independent variables, except previous crop. Low disease incidence (≤ 50%) and low disease severity (≤ 25%) had high probability of association to the previous crop.

Conclusion: Environmental variables, cultivation practice, and responses were important for the development of STB. Therefore, these factors must be considered in designing strategies for the effective management of STB.

Keywords: Durum wheat, *Zymoseptoria tritici*, Septoria tritici blotch

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Introduction

Zymoseptoria tritici is the causal agent for septoria tritici blotch (STB) that attacks durum wheat (*Triticum turgidum* L. subsp. *durum*) (Eyal et al. 1985). It is widely distributed in the Mediterranean basin, East Africa, South America, Australia, and Western Europe (Saari and Wilcoxson 1974; Rajaram and Dubin 1977; Polley and Thomas 1991). In the USA, septoria tritici blotch is second only to wheat stem rust in terms of importance, and it is the number one disease of wheat in Russia and many countries of Western Europe (Ponomarenko et al. 2011). This fungus is essentially a leaf pathogen and rarely causes blotches on glumes. In the initial stages of the disease, the blotches are clear yellow, small, globular, or oblong, sometimes narrower than the spots. Severe epidemics of septoria tritici blotch can reduce wheat yields by 35 to 50% worldwide (Ponomarenko et al. 2011).

Studies focusing on septoria tritici blotch of durum wheat have not been conducted in the highlands of Wollo, where durum wheat is grown in large scale. Further, cultural practices, altitude, and soil types, which affect septoria tritici blotch development and response of genotypes to the disease, are seldom reported in the region. Information on occurrence, distribution, and factors affecting the disease is important to develop management options.

The improvement of durum wheat based on improved varieties of local collections is the main component for the management of septoria tritici blotch (Blixt 1988; Damania et al. 1992). These genetic resources contain several important agronomic and resistance genes (Grausgrubera et al. 2005; Yahyaoui et al. 2006). The availability of such germplasm depends on the identification of the sources of diversification (Devra and Hodgkin 1999; Ganeva et al. 2011), especially within the primary and secondary diversity centers which are characterized by large diversity. Ethiopia is one of the centers of diversity for durum wheat (CSA (Central Statistical Agency) 2009). The local germplasm is adapted to a wide range of environments and carries a large reservoir of useful genes (Zelalem 1989; Cherdouh et al. 2005). Resistance to septoria tritici blotch (*Zymoseptoria tritici*) is generally expressed through the reduction of the foliar area covered with pycnidia and/or necrosis.

Given the economic relevance, the development of strategies to manage septoria tritici blotch is of great importance. Generating strategies and information on occurrence, distribution, and factors affecting the disease

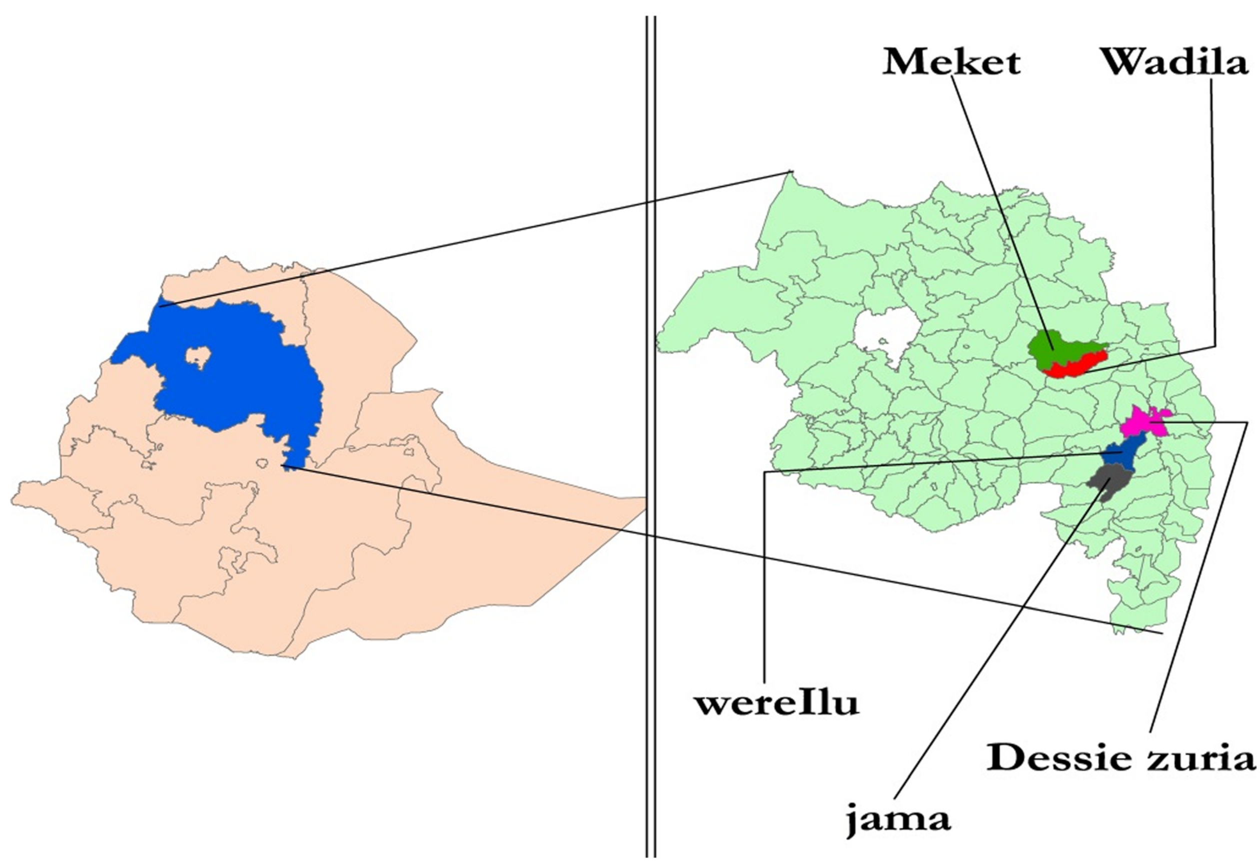

Fig. 1 Map of Ethiopia showing the study sites

are important to develop disease management options. Among the strategies to combat diseases, genetic resistance stands out as the most appropriate disease management option in terms of stability, economy, and environmental impact.

The high level of diversity in *Triticum turgidum* subsp. *durum* landraces allows breeders and pathologists to make selection for different traits of economic importance. However, information about the septoria tritici blotch and the reaction of genotypes to the disease in the highlands of Wollo is not available. Therefore, the objective of this study was to determine the incidence and severity of septoria tritici blotch on durum wheat in the highlands of Wollo.

Materials and methods

Survey area and sampling procedures

Field surveys were conducted in five districts of Wollo highlands, namely Jama, Dessie Zuria, Wadila, Woreilu, and Meket (Fig. 1). The surveys were conducted in the area, from October to November 2015, which covers the main cropping season. From each district, 15 representative farm plots were assessed and plant samples were taken randomly at fixed interval of 5 up to 10 km. A total of 75 fields (15 per district) were assessed.

Crop and disease assessments

The prevalence of septoria tritici blotch was computed based on the presence and absence of disease within the farm plot. Disease incidence and severity were assessed visually by walking in each field in an "X" fashion and taking 10 random plants within a quadrat (0.5 m × 0.5 m). Disease incidence was calculated as the percentage of the number of infected plants by the total number of plants assessed. Disease severity was scored based on the double-digit recording system (00 to 99), modified version of Saari and Prescott's scale (Saari and Prescott 1975; Eyal et al. 1987; Sharma and Duveiller 2007) for wheat foliar diseases. The first digit ($D1$) indicates disease progress in plant height, and the second digit ($D2$) refers to severity measured as the diseased leaf area.

In addition to disease data, other supplementary information was collected, including soil type, durum wheat variety name, planting date, altitude, plant population, weed population, previous crop, and growth stage. The plant and weed population was counted in each quadrat. The mean plant and weed population density was obtained by averaging five quadrats, and the weed density was recorded as low (20–40 weeds), medium (41–60 weeds), and high (61–110 weeds m^{-2}) and plant population as high (> 210 plants m^{-2}), low (< 140 plants m^{-2}), and medium (141–210 plants m^{-2}) (Woldeab et al. 2007). Information on variety type, previous crop, and planting date was obtained from growers through interview. The growth stage of the crop was recorded using Zadoks' scale. It consists of a two-digit code: the first digit referring to the principal stage of development (from 0 to 9, germination to kernel ripening) and the second digit allowing subdivision of the bespoke principal (Zadoks and Schein 1979; Eyal et al. 1987).

Disease and crop parameters

Disease severity was assessed on five randomly taken plants in the two rows of every plot, and data were recorded and assessed at late milk stage of the crop (Eyal et al. 1987).

The disease severity was scored visually using a double-digit (00 to 99) recording system. The first digit ($D1$) indicates disease progress in plant height, and the second digit ($D2$) refers to severity measured as the diseased leaf area.

Statistical analysis

For each score, percentage of disease severity was estimated based on the following formula (Sharma and Duveiller 2007):

$$\text{Severity} = (D1/9) \times (D2/9) \times 100$$

where $D1$ = the disease progress in plant height and $D2$ = the severity measured as the diseased leaf area.

Simple descriptive statistics were used to summarize data obtained from field surveys by using proc mean SAS procedure (SAS Institute 2003). The values corresponding to each independent variable represented the frequency of fields falling in the different boundaries and were used to analyze the association of septoria tritici blotch incidence and severity with the independent variables and variable class using stepwise logistic regression of SAS procedure (SAS Institute 1993; 2003). The procedure has been used by many authors to evaluate the association of disease incidence and severity of the different independent variables (Fininsa and Yuen 2001a; Woldeab et al. 2007; Zewde et al. 2007). The logit link function was used in this binomially distributed data to determine the association of the independent variable to the response variable (Fininsa and Yuen 2001b; Zewde et al. 2007). The binary outcome was the probability that durum wheat septoria tritici blotch incidence exceeds 50% and severity exceeds 25% in a given durum wheat field (Table 1). The likelihood ratio statistic was used to examine the importance of variables and was tested against a chi-square (McCullagh and Nelder 1989).

Results

Prevalence of septoria tritici blotch

We found STB in all our study sites (Table 2), but the highest prevalence was recorded at Wadila (87% of the fields showing the disease), followed by Jama (80%),

Table 1 Independent variables by disease contingency for logistic regression analysis of durum wheat septoria tritici blotch in the highlands of Wollo

Variable	Variable class	Incidence		Severity		Variable	Variable class	Incidence		Severity	
		≤ 50	> 50	≤ 25	> 25			≤50	>50	≤25	> 25
District	Dessie Zuria	15	0	15	0	Plant population	High	12	13	16	9
	Jama	13	2	15	0		Low	14	1	15	0
	Meket	7	8	8	7		Medium	28	7	31	4
	Wadila	9	6	11	4	Planting date	August	13	2	14	1
	Woreilu	10	5	13	2		Early July	13	6	14	5
Altitude	≤ 2700 masl	32	9	38	3		June	5	7	6	6
	> 2700 masl	22	12	24	10		Late July	12	3	15	0
Variety	Abesha	3	3	6	0		Mid-July	11	3	13	1
	Enat	6	0	6	0	Previous crop	Barley	8	0	8	0
	Enzosh	5	2	6	1		Legume	18	2	19	1
	Firno	1	6	2	5		Tef	7	2	8	1
	Gojam	3	0	3	0		Wheat	21	17	27	11
	Gundile	5	1	5	1	Weed population	High (> 61 weeds m^2)	2	9	4	7
	Key sindie	9	4	9	4		Low (< 40 weeds m^2)	39	5	41	3
	Laste	6	3	7	2		Medium (41–60 weeds m^2)	17	7	17	3
	Nesh	3	0	3	0	Soil type	Red	8	10	11	7
	Nich jiru	9	1	10	0		Gray	12	7	14	5
	Tikur jiru	4	1	5	0		Black	34	4	37	1
Growth stage	Early flower	14	3	16	1						
	Flower	1	0	1	0						
	Late milk	8	0	8	0						
	Milk	31	18	37	12						

Woreilu (80%), and Meket (80%) while the lowest (40%) was recorded at Dessie Zuria. Septoria tritici blotch prevalence varied among genotypes, planting dates, growth stages, previous crops, plant populations, weed populations, and soil types. The highest STB prevalence (100%) was recorded on Abesha sindie and Firno local varieties, while the lowest STB prevalence (33%) was registered in Enat, Gojam gura, and Nech sindie varieties.

Previous crops were important in determining the prevalence of STB. Highest STB prevalence (92%) was recorded on previously grown wheat field, while the lowest prevalence (50%) was recorded on previously legume and barley grown fields. Varied levels of STB prevalence were registered in different planting times, where highest STB prevalence (92%) was recorded in June, while lowest prevalence (53%) in August planting time.

Highest (100%) STB prevalence was recorded on the high plant population compared to a low plant population (47%). Similarly, highest (100%) weed population resulted in high STB prevalence compared to low weed population (59%). Varied levels of STB prevalence were also recorded among soil types that red soil type showed the highest STB prevalence (94%), while black soil showed the lowest prevalence (60%).

Intensity of septoria tritici blotch

Mean incidence and severity of septoria tritici blotch on durum wheat for different independent variables were presented (Table 2). The survey results showed that the highest (55.3%) STB mean incidence was recorded at Meket, followed by Wadila (42.7%), while the lowest (16%) was recorded at Dessie Zuria. Similarly, the maximum mean STB severity (21.7%) was recorded at Meket, followed by Wadila (14.2%), while Dessie Zuria showed the least STB severity (2.5%).

The disease intensity varied along altitudinal range. When altitude increased, the level of mean STB incidence as well as severity increased. Generally, it was more severe in districts with altitude > 2700 masl than lower elevations and the maximum severity level (59%) was recorded in areas with altitude > 2700 masl (Table 2). Similarly, there was an increased incidence level with increase in altitude. The maximum incidence was recorded in areas with > 2700 masl (Table 2).

Table 2 Prevalence, mean incidence, and severity of septoria tritici blotch on durum wheat under different independent variables

Variable	Variable class	Prevalence (%)	Septoria tritici blotch							
			Incidence				Severity			
			Mean	SD	Min	Max	Mean	SD	Min	Max
District	Dessie Zuria	40	16.7	21.9	0	50	2.5	3.6	0	9.9
	Jama	80	34.0	22.0	0	70	6.2	5.2	0	14.8
	Meket	80	55.3	40.7	0	100	21.7	22.1	0	59.3
	Wadila	87	42.7	27.1	0	90	14.2	12.7	0	39.5
	Woreilu	80	38.0	26.2	0	80	12.3	13.2	0	49.4
Altitude	≤ 2700 masl	75.6	35.36	25.40	0	80	8.35	9.72	0	49
	> 2700 masl	70.6	39.70	35.80	0	100	15.0	18.0	0	59
Variety	Abesha	100	50.0	12.6	30	60	11.0	4.7	3.7	17.3
	Enat	33	10.0	15.5	0	30	0.8	1.3	0	2.5
	Enzosh	71	32.9	29.3	0	70	9.9	10.8	0	29.6
	Firno	100	74.3	17.2	50	100	28.4	13.0	9.9	49.4
	Gojam gura	33	10.0	17.3	0	30	0.8	1.4	0	2.5
	Gundile	67	31.7	27.1	0	70	11.1	11.9	0	29.6
	Key sindie	77	41.5	37.8	0	100	16.2	20.8	0	59.3
	Laste	89	51.1	28.5	0	100	16.7	18.8	0	49.4
	Nech	33	6.7	11.5	0	20	0.8	1.4	0	2.5
	Nech jiru	70	28.0	24.4	0	60	5.6	5.8	0	14.8
	Tikur jiru	80	34.0	26.1	0	70	5.2	4.5	0	12.3
Planting date	August	53	24.0	25.9	0	70	6.2	8.8	0	29.6
	Early July	84	43.2	28.7	0	100	13.7	14.5	0	49.4
	June	92	66.7	32.0	0	100	27.1	21.0	0	59.3
	Late July	67	28.7	23.9	0	60	4.6	5.3	0	17.3
	Mid-July	71	27.9	26.4	0	70	7.6	8.6	0	29.6
Previous crop	Barley	50	17.5	20.5	0	50	2.6	37	0	9.9
	Legume	50	17.5	23.4	0	80	4.0	6.5	0	25.9
	Tef	67	30.0	28.7	0	70	7.4	9.1	0	25.9
	Wheat	92	53.7	27.0	0	100	18.0	16.7	0	59.3
Growth stage	Early flower	65	27.1	24.9	0	70	6.1	8.1	0	29.6
	Flower	100	30.0		30	30	7.4		7.4	7.40
	Late milk	37	17.5	24.3	0	50	3.1	4.3	0	9.9
	Milk	82	44.3	31.3	0	100	14.6	16.2	0	59.3
Plant population	High (> 210 plants m^{-2})	100	60.0	23.2	20	100	18.9	17.2	2.5	59.3
	Low (< 140 plants m^{-2})	47	26.5	29.2	0	70	6.0	8.8	0	25.9
	Medium (141–210 m^{-2})	66	32.3	32.2	0	100	10.7	16.0	0	59.3
Weed population	High (> 61 weeds m^{-2})	100	73.6	22.9	30	100	29.7	17.6	7.4	59.3
	Low (< 40 weeds m^{-2})	59	23.4	23.6	0	70	5.4	7.8	0	29.6
	Medium (41–60 weeds m^{-2})	90	48.0	27.1	0	100	14.5	14.9	0	49.4
Soil type	Red	94	58.3	30.0	0	100	18.9	15.7	0	49.4
	Gray	79	44.2	31.5	0	100	17.3	18.8	0	59.3
	Black	60	23.9	23.1	0	70	4.8	6.4	0	29.6

SD standard deviation

In this field survey, varied levels of mean STB incidence and severity reaction were registered among durum wheat varieties. Firno local variety scored the highest (74.3%) mean disease incidence, while Nech sindie scored the lowest (6.7%) mean disease incidence. Nech sindie, Enat sindie, and Gojam gura varieties showed low disease incidence, and the highest disease severity was observed in Firno variety.

Cultural practices also significantly affected the incidence and severity of STB disease on durum wheat. The highest mean disease incidence (60.0%) and severity (18.9%) of STB were recorded in higher plant population, whereas lower plant population showed 26.5% incidence and 6% severity. Similarly, the highest mean disease incidence (73.6%) and severity (29.7%) of STB were recorded in high weed density compared with low weed density (23.4% incidence and 5.4% disease severity). Previous crops, viz. wheat, tef, barley, and legumes, showed variation in STB. The highest disease incidence (53.7%) and severity (18%) were observed in previously wheat grown fields.

In this study, the planting time affected the development STB on durum wheat. Higher disease incidence (66.7%) and severity (18%) were observed in early durum wheat planted fields than late planted fields.

Durum wheat fields sown on red soil type showed the highest STB mean incidence (53.3%) and severity (18.9%) while black soil type showed the lowest disease incidence (23.9%) and severity (4.8%).

Association of durum wheat septoria tritici blotch intensity with environmental factors and cultural practices

The probability of septoria tritici blotch (STB) associated with the independent variables was presented (Table 3). Durum wheat STB mean incidence and severity were significantly associated with all independent variables: district, altitude, variety, growth stage, plant population, planting date, previous crop, weed density, and soil type as single predictors in the logistic regression (Table 3). Analysis of deviance, natural logarithms of odds ratio, and standard error of added variables in a reduced model analyzing durum wheat STB incidence and severity were also presented (Tables 4 and 5). All independent variables were tested in a reduced multiple model.

Association of septoria tritici blotch with districts and altitude

This septoria tritici blotch (STB) survey result indicated that the disease was widely distributed in all districts and showed variation. The probability of association of district and altitude range to high STB incidence (> 50%) and high severity (> 25%) was significant with low (≤ 0%) disease incidence and low (≤ 25%) severity (Table 3). Meket district and lower altitude (≤ 2700 masl) had a high probability of association to high STB incidence and severity. The probability of occurrence of > 50% incidence was 1.8 times higher in ≤ 2700 masl altitude than in > 2700 masl altitude (Table 4). However, > 25% severity was more associated with Woreilu and Jama district than Meket and ≤ 25% severity positively associated with ≤ 2700 masl than > 2700 masl altitude (Table 5).

Association of septoria tritici blotch with varieties and growth stage

Different durum wheat varieties were analyzed by logistic regression model as a single predictor, and the result showed that there was a highly significant association with more than 50% incidence and above 25% severity (Table 3). In the reduced model, Abesha, Enat, Enzosh, Firno, and Lastie wheat varieties were associated with the probability of high incidence occurrence, but Gojam gura, Gundile, Key sindie, Nech sindie, and Nech jiru

Table 3 Independent variables used in logistic regression modeling durum wheat incidence and severity and likelihood ratio test (LRT) for nine variables as single predictors of disease outcome

Independent variable	df	Septoria tritici blotch incidence LRT > 50%		Septoria tritici blotch severity LRT > 25%	
		DR	Pr > χ^2	DR	Pr > χ^2
District	4	534.21	< .0001	356.02	< .0001
Altitude	1	128.55	< .0001	6.10	0.0135
Variety	10	931.59	< .0001	372.15	< .0001
Growth stage	3	53.77	< .0001	16.18	0.001
Plant population	2	474.36	< .0001	165.41	< .0001
Planting date	4	33.04	< .0001	15.49	0.0038
Previous crop	3	222.05	< .0001	181.28	< .0001
Weed population	2	13.88	0.001	32.06	< .0001
Soil type	2	59.69	< .0001	11.45	0.0033

df degrees of freedom, *DR* deviance reduction, *Pr* probability of a χ^2 value exceeding the deviance reduction

Table 4 Analysis of deviance, natural logarithms of odds ratio, and standard error of added variables in a reduced model analyzing septoria tritici blotch incidence

Added variable	Residual deviance	df	Deviance reduction	Pr > χ^2	Variable class	Estimate loge	SE	Odds ratio
Intercept	3752.19					− 0.73	0.37	0.48
District	3217.99	4	534.21	< .0001	Jama	− 0.74	0.34	0.48
					Wadila	− 0.35	0.15	0.70
					Woreilu	− 0.39	0.31	0.68
					Dessie Zuria	− 1.92	0.31	0.15
					Meket	0.00	0.00	1
Altitude	3089.44	1	128.55	< .0001	≤ 2700 masl	0.61	0.12	1.85
					> 2700 masl	0.00	0.00	1
Variety	2157.84	10	931.59	< .0001	Abesha	0.36	0.28	1.43
					Enat	0.34	0.33	1.41
					Enzosh	0.10	0.35	1.10
					Firno	0.42	0.37	1.52
					Gojam	− 0.10	0.36	0.91
					Gundile	− 0.07	0.23	0.93
					Key	− 0.21	0.33	0.81
					Laste	0.38	0.24	1.47
					Nech	− 1.12	0.46	0.33
					Nech jiru	− 0.32	0.13	0.73
					Tikur jiru	0.00	0.00	1
Growth stage	2104.07	3	53.77	< .0001	Early flowering	− 0.35	0.12	0.70
					Flower	− 0.20	0.31	0.82
					Late milk	0.15	0.19	1.16
					Milk	0.00	0.00	1
Plant population	1629.71	2	474.36	< .0001	High (> 210 plants m^{-2})	0.44	0.09	1.56
					Low (< 140 plants m^{-2})	− 0.93	0.12	0.39
					Medium (141–210 m^{-2})	0.00	0.00	1
Planting date	1596.67	4	33.04	< .0001	August	0.41	0.13	1.50
					Early July	0.02	0.12	1.02
					June	0.77	0.15	2.16
					Late July	0.13	0.14	1.14
					Mid-July	0.00	0.00	1
Previous crop	1374.62	2	222.05	< .0001	Barley	− 1.75	0.18	0.17
					Legume	− 1.18	0.12	0.31
					Tef	− 0.59	0.12	0.56
					Wheat	0.00	0.00	1
Weed population	1360.73	2	13.88	0.001	High (> 61 weeds m^{-2})	0.58	0.14	1.79
					Low (< 40 weeds m^{-2})	0.42	0.11	1.53
					Medium (41–60 weeds m^{-2})	0.00	0.00	1
Soil type	1301.05	2	59.69	< .0001	Red	0.94	0.15	2.55
					Gray	0.79	0.11	2.21
					Black	0.00	0.00	1

df degrees of freedom, *Pr* probability of a χ^2 value exceeding the deviance reduction, *SE* standard error

Table 5 Analysis of deviance, natural logarithms of odds ratio, and standard error of added variables in a reduced model analyzing septoria tritici blotch severity

Added variable	Residual deviance	df	Deviance reduction	Pr > χ^2	Variable class	Estimate loge (odds ratio)	SE	Odds ratio
Intercept	1378.9					− 3.42	0.54	0.03
District	1022.9	4	356.02	< 0.0001	Jama	0.45	0.50	1.56
					Wadila	0.69	0.19	0.50
					Woreilu	1.19	0.38	3.30
					Dessie Zuria	− 1.64	0.50	0.19
					Meket	0.00	0.00	1
Altitude	1016.81	1	6.10	0.0135	≤ 2700 masl	− 0.30	0.16	0.74
					> 2700 masl	0.00	0.00	1
Variety	644.66	10	372.15	< .0001	Abesha	0.85	0.50	2.33
					Enat	0.55	0.70	1.73
					Enzosh	2.58	0.50	13.14
					Firno	2.57	0.56	13.10
					Gojam	− 1.27	0.83	0.28
					Gundile	0.40	0.45	1.50
					Key	1.32	0.50	3.75
					Laste	0.98	0.41	2.67
					Nech	1.37	0.88	3.95
					Nech jiru	0.00	0.27	1.00
					Tikur jiru	0.00	0.00	1
Growth stage	628.48	3	16.18	0.001	Early flowering	− 0.30	0.21	0.74
					Flower	0.69	0.51	1.99
					Late milk	0.86	0.42	2.37
					Milk	0.00	0.00	1.00
Plant population	463.07	2	165.41	< .0001	High (> 210 plants m^2)	0.32	0.16	1.38
					Low (< 140 plants m^2)	− 0.80	0.23	0.45
					Medium (141–210)	0.00	0.00	1.00
Planting date	447.58	4	15.49	0.0038	August	0.13	0.21	1.14
					Early July	− 0.29	0.21	0.75
					June	0.81	0.23	2.24
					Late July	− 0.64	0.26	0.53
					Mid-July	0.00	0.00	1.00
Previous crop	266.30	3	181.28	< .0001	Barley	− 3.07	0.34	0.05
					Legume	− 1.55	0.20	0.21
					Tef	− 0.82	0.23	0.44
					Wheat	0.00	0.00	1.00
Weed population	234.24	2	32.06	< .0001	High (> 61 weeds m^2)	0.50	0.17	1.65
					Low (< 40 weeds m^{-2})	0.91	0.18	2.48
					Medium (41–60 weeds m^{-2})	0.00	0.00	1.00
Soil type	222.7967	2	11.45	0.0033	Red	0.30	0.24	1.34
					Gray	0.52	0.17	1.69
					Black	0.00	0.00	1.00

df degrees of freedom, *Pr* probability of a χ^2 value exceeding the deviance reduction, *SE* standard error were associated with the probability of lower disease incidence than that of Tikur jiru (Table 4).

Durum wheat severity was analyzed with reference to deviance, natural logarithms of odds ratio, and standard error of added variables in a reduced model (Table 4). Varieties were also tested in a reduced multiple model. High STB severity (> 25%) had a high probability of association to Firno, Enzosh, and Nech sindie with 13.14, 13.1, and 3.95 times, respectively, greater probabilities that STB severity occurred than Tikur jiru.

Association of septoria tritici blotch with cultural practices

Cultural practices varied in their association to septoria tritici blotch incidence and severity. Cultural practices, such as previous crop, planting date, plant population, and weed density, were highly associated with incidence and severity when first entered as single variables into the model (Table 4).

The parameter estimates resulting from the reduced regression model and their standard errors were depicted (Table 4). There were about 1.56, 2.16, and 1.79 times higher probabilities that STB incidence exceeded 50% in high plant population compared to medium plant population, June planting date compared to mid-July planting date, and high weed density fields compared to medium weed density fields, respectively. Low STB incidence (≤ 50%) and severity (≤ 25%) had a higher probability of association to legume, barley, and tef previous crop than wheat. Similarly, high STB severity (>25%) had a high probability of association to high plant population, June planting, and high weed population.

Association of septoria tritici blotch with soil type

In this survey, highly significant association of STB with soil type was observed. Septoria tritici blotch incidence and severity were positively associated with red soils compared to black soil type. The parameter estimates resulting from the reduced regression model indicated that high STB incidence (>50%) had a high probability of association to red and gray soils than black soils (Table 4). There were about 2.55 and 2.21 times greater probabilities that STB incidence will exceed 50% in the red and gray soil types compared to black soil types, respectively.

Discussion

In this study, the prevalence and intensity of septoria tritici blotch varied among agronomic and environmental factors. This might be attributed to higher level of humidity at higher altitude (Janet and Tammy 2008) and highest level of infection on rainy cloudy with high relative humidity (Magboul et al. 1992; Kema et al. 1996; Dancer et al. 1999). Brown and Caligari (2008) stated that environmental variables of a macro nature have to be considered (Schulthesis et al. 1997), as well as other possible differences in the environment micro ones that affect individual plants, which leads to disease variation in district and altitude range.

A wide disease resistance variation occurred in different wheat genotypes for septoria tritici blotch (Gough 1978) and common bean genotypes for CBB (Fininsa and Yuen 2001a). In this regard, durum wheat genotypes had different disease resistance capacities with different agronomic features. This variation is important for breeding program to develop high yielder and STB resistant varieties (Gough 1978). In addition to genotype variability (Nadeem et al. 2008; Kahrizi et al. 2010), planting time also affects the development of septoria tritici blotch. The result of this study is in agreement with Shaw and Royle (1993) that crops sown at early times pose greater risks of infection. This may be due to the fact that early sown plants produce more leaves and result in greater presence of inoculums (Shaw and Royle 1993). In addition, slower stem extension in early sown crops gives more time for the infection to move from older to younger leaves (Shaw and Royle 1993; Lovell et al. 2004).

The result of this study is in accordance with Agrios (2005); some plants escape disease because they are susceptible to a pathogen only at a particular growth stage (young leaves, stems, or fruits; at blossoming or fruiting; at maturity and early senescence); therefore, if the pathogen is absent or inactive at that particular time, such plants avoid becoming infected, but latent infection may occur.

The result of present survey showed that high plant population, high weed density, wheat as a previous crop, and early planting favor the development of STB disease. A number of studies reported that crop rotation is important in reducing the incidence and severity of diseases. Previously, Krupinsky (1999) recommended crop rotation as a means to increase decomposition of the infected crop residue while non-host crops are grown. The author stated that crop rotation might not eliminate the disease; however, they would reduce the inoculum level of the pathogen. In addition, Pedersen and Hughes (1992) reported that crop rotation of at least 2 years between wheat crops was required to achieve adequate control of the septoria disease complex under ideal environmental conditions, while a 1-year break between wheat crops was effective in reducing disease severity under conditions that were unfavorable for the pathogen. The reduction of the disease is attributed to the contribution of wheat or related crops to the build of STB pathogen, while rotation with a non-susceptible crop reduces the pathogen inoculum levels as it helps to break the cycle. The disease severity of leaf spot pathogens is higher in wheat grown after wheat than after flax or lentil although the effects are only obvious in years with high disease pressure (Fernandez et al. 1998).

It demonstrated the effect of planting date on the diseases that corresponded with previous reports (Shaner et al. 1975; Thomas et al. 1989; Shaw and Royle 1993) that crops sown at early times pose greater risks of infection. A higher disease intensity in early sown fields might be attributed to much amount of leaves in early sown plants (Shaw and Royle 1993; Tesfaye 1988; Zelalem 1989), which, in turn, results in greater presence of inocula (Shaner et al. 1975; Shaw and Royle 1993), and slower stem extension gives more time for the infection to move from older to younger leaves (Shaw and Royle 1993; Lovell et al. 2004). In addition, too longer maturation time gives rise to another STB cycle of multiplication in diseased plants (Shaw and Royle 1993).

In accordance to the result of the present study, previous reports showed that high plant population favors the development of plant pathogen. Fininsa and Yuen (2001a) reported low maize rust incidence had a high probability of association to low maize crop density. This is attributed to high seeding rates, and narrow row spacing creates a favorable microclimate for the development of stagonospora nodorum blotch and septoria tritici blotch (Tompkins et al. 1993). On the contrary, reduced plant density in the field increased nutrient availability, which, in turn, aggravating the disease (Rodgers-Gray and Shaw 2000), and increased the dispersal ability of STB spores by rain-splash (Shaw and Royle 1993).

The influence of weed density on the intensity of the disease was observed in this study. The result of this study is supported by the previous work (Woldeab et al. 2007) which reported that barley leaf rust (*Puccinia hordei*) incidence increases with an increase in weed population. In this connection, Duczek et al. (1996) discussed that dense population of weeds in a field may contribute to disease development by increasing the density of the plant canopy or serving as an inoculum reservoir in the absence of a susceptible host crop.

Similarly, STB severity was significantly associated with soil type (Table 5). Walters and Bingham (2007) and Ruska et al. (1997) discussed that soil factors, such as organic matter, red content, nutrients, and soil pH, have an impact on yield, plant diseases, and interactions. Similarly, Saito et al. (2006) reported the availability of moisture in heavy soils (red soils) due to high water holding capacity favors the development of the disease.

Conclusions

Our results show environmental variables, cultural practice, and responses were important for the development of STB. These findings indicate that proper plant density, weed management, and plant growth stage are crucial to reduce the impact of septoria tritici blotch in wheat. Disease intensity of septoria tritici blotch varied among districts, altitude, varieties, growth stage of the crop, cropping practices, and soil type. High STB incidence and severity were positively associated with varieties, high plant population, high weed density, early (June) planting, late milk stage, and red soil type, whereas previous crop was positively associated with low disease incidence and severity. As a result, different epidemiologically relevant factors must be considered to manage STB disease. Therefore, these factors must be considered in designing strategies for the effective management of septoria tritici blotch.

Abbreviations

DR: Deviance reduction; LRT: Likelihood ratio test; masl: Meter above sea level; Pr: Probability; STB: Septoria tritici blotch; Subsp.: Subspecies; χ^2: Chi-square

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Authors' contributions

BN, YG, and AA designed the experiment. BN conducted the data collection, analyzed the data, and wrote the manuscript. YG and AA revised the manuscript. All authors read and approved the final manuscript.

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