American Journal of Biological and Environmental Statistics
2022; 8(3): 70-80
http://www.sciencepublishinggroup.com/j/ajbes
doi: 10.11648/j.ajbes.20220803.14
ISSN: 2471-9765 (Print); ISSN: 2471-979X (Online)

Spatial Distribution and Intensity of Wheat Stem Rust (*Puccinia graminis* f.sp. *tritici*) in Western and South-Western Ethiopia

Mosisa Tolossa[1, 2, *], Girma Adugna[2], Bekele Hundie[3]

[1]Department of Plant Pathology, Ethiopian Institute of Agricultural Research, Assosa, Ethiopia

[2]Department of Plant Pathology, College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia

[3]Department of Plant Pathology, Ethiopian Institute of Agricultural Research, Kulumsa, Ethiopia

Email address:

mosisatolossa2016@gmail.com (M. Tolossa)

[*]Corresponding author

To cite this article:

Mosisa Tolossa, Girma Adugna, Bekele Hundie. Spatial Distribution and Intensity of Wheat Stem Rust (*Puccinia graminis* f.sp. *tritici*) in Western and South-Western Ethiopia. *American Journal of Biological and Environmental Statistics.* Vol. 8, No. 3, 2022, pp. 70-80. doi: 10.11648/j.ajbes.20220803.14

Received: May 22, 2022; **Accepted**: July 1, 2022; **Published**: July 28, 2022

Abstract: Wheat is one of among major staple food crop in Ethiopia. However, several wheat stem rust diseases out break had been caused significant losses of crops in many parts of the country. This research was undertaken to quantify spatial distribution and intensity of *Puccinia graminis* f.sp.*tritici* in western and southwestern Ethiopia. The disease parameters were measured from 105 farmer's fields of 6 districts in four zones. The survey was carried out by purposive multistage sampling methods depending on the importance of the crops at areas. Stem rust was prevalent and widely distributed in all study areas. Analysis of variance indicates fields, districts, and zones significant ($p < 0.01$) by disease incidence and severity %. ANOVA of disease intensity with altitude, weed management, a wheat variety is grown and growth stage also significant at ($p < 0.01$). Disease means prevalence ranged from 66.7%-92%in zones and the lowest and the highest being at Jimma and in Assosa zones, respectively. Mean % incidence was in the range of 3.7-47.9, the lowest and the highest being in Dedo and Begi districts in a given order, with the corresponding severities of 4.866.5%. The disease was severe in mid altitude with warmer weather conditions. Correlation analysis indicates, a significant ($P < 0.05$) and positive association between crop growth stages and disease intensity, incidence ($r = 0.10$) and severity ($r = 0.15$) indicating that stem rust is more intense in the later wheat crop growth stages. Stepwise multiple regression in the current study indicates, the strongest predictor for disease severity was the growth stage with the highest β value which is 0.47 and with its highest shared; $(0.455)^2 = 20.1\%$ and unique $(0.429)^2 = 18.4\%$ contribution for disease severity. In conclusion, wheat stem rust disease was widely distributed and intense in wheat farms of the west and southwestern Ethiopia and the need to undertake regular monitoring across the study areas.

Keywords: Correlation, Distribution, Intensity, Stem Rust, Stepwise Regression, Wheat

1. Introduction

Wheat (*Triticum* spps.) is one of staple food crops across the world and primarily a high source of protein [9, 22]. In terms of areas of production, it is the second-ranked crop in the world next to rice [3]. Bread wheat (*Triticum aestivum* L. Thell) and durum wheat (*Triticum turgidum*L.var. durum) are the two wheat species being grown in Ethiopia [17]. It is grown primarily as a rain-fed and irrigated offseason at mid to high land areas that range from 1500 to 3000m [25].

Wheat took up to 13.38% of the grain crop area, next to Teff (23.85%), sorghum (16.79%) and maize (14.96%). As per production, cereals contributed 87.48% of the grain production out of which wheat contribute 15.17% of total grain production next to maize (27.43%), teff (17.26%), wheat and sorghum (16.89%) production [5]. Wheat crop production in study areas viz southwestern; Bunobedele and Jimma Zones in a season of 2017/18 were 300.6 and 20925.2 ton respectively and West wellega and Benishangulgumuz; 430.5 ton and 5908.3 ton of wheat productions were recorded in aforementioned year, respectively. The wheat yield in Western and Southwestern Ethiopia including Benishangul Gumuz regional state is 2.0-2.4ton/ha which is low as compared with central Oromia, 2.9 tons [5].

Even though wheat is one of stable crops in Africa, it is increasingly in demand in as a result of income growth and rapid population growth [16 and 17]. However, wheat production levels have not been satisfying the demand emanated from world population increase and high demands for wheat consumption, thus, triggering price instability and hunger riots worldwide and Ethiopia.

Wheat productivity in Ethiopia, in general, is very low as compared to other Sub-Saharan African countries [16]. It is attributed to a number factors like biotic (diseases, insects, and weeds), abiotic, and socioeconomic constraints [13]. For instance there is a need to increase wheat yield, tolerance to abiotic stresses, pathogen and pests, as well as improve input use efficiency of crops [17, 23].

Among biotic factors, the incidence of disease and pest infestations is a major one. The most important disease reported so far includes rusts (*Puccinia spp*.), Septoria leaf blotches (*Septoria tritici*), Fusarium head blight (*Fusarium graminearum*), Tanspot (*Pyrenophora tritici repentis*), Smut (*Ustilago tritici*) and Powdery mildew (*Erysiphe graminis* f.sp. *tritici*) [2]. Wheat stem rust (*Puccinia graminis* f.sp.*tritici*) has been devastating disease of wheat in Ethiopia causing up to more than 90% yield losses during the epidemic year [13].

Wheat stem rust survey is regularly conducted in Ethiopia in areas where wheat is cultivated in large areas mainly in rain-fed and central highland agro-ecologies and the pathogenic variability in terms of virulence and diversity in different parts of wheat-producing areas are being reported. However, new virulent stem rust races continue to evolve in the pathogen population in space and time and therefore, monitoring the pathogen distribution in time and space and keeping the records is very crucial for rust resistance breeding program.

However, despite considerable wheat crops also produced in some parts of western and southwestern Ethiopia, the status of stem rust disease intensity is not well studied [5]. Under such circumstances, resistance breeding against an epidemic of stem rust races cannot target the actual problem. In addition absence of information about the pathogen across the location can lead to loss of crops and spread of the pathogen to neighboring districts, fortunately, can lead to a decrease in GDP of the country.

Moreover, avoiding rust is not possible because of constant changes in the races of pathogens. Despite that, it is possible to prevent by using host plant resistance, but whenever there is a lack of information on the distribution of pathogen, it is not possible to undertake such preventive measures to control the epidemic of wheat stem rust. Therefore, knowing the pathogen's distribution and intensity is very important in the management strategy of the diseases. Hence, the present study is aimed to assess spatial distribution and intensity of wheat stem rust in the western and southwestern Ethiopia.

2. Materials and Methods

2.1. Description of Study Areas

This study, viz Spatial distribution and intensity of rust disease was assessed and quantified from major wheat-growing districts of Western and Southwestern Ethiopia, namely Maokomo district of Asosa zone of western Ethiopia; Bedele and Gechi districts of Buno-Bedele zone and Dedo and Omonada districts of Jimma zone in southwestern Ethiopia and Begi district in West-Wellaga of Western Ethiopia. More description; coordinate, altitude, Annual RF and Temperature is given in Table 1.

Table 1. *Coordinates, elevations (m), annual rainfall (mm) and mean temperatures (°C) of the study areas.*

Zone	District	Coordinate		Altitude[e] (m.a.s.l)	Rainfall (mm)	Temperature (°C)	
		N	E			Min	Max
Jimma	Omonada	07°33'	37° 16'	-	1820.2	11.7	24.8
	Dedo[a]	07° 28'	37° 00'	880 – 2800	1710.3	12.2	25.6
Buno-Bedele	Bedele	08°27′	36°21′	1750–2162	2001.1	12.7	24.4
	Gechi[c]	08°20′	36°40′	1400–2380	1639.0	18.0	25.0
Assosa[d]	Maokomo[b]	9°15′	34°45′	1465–2100	1134.4	14.9	27.4

Footnote: [a]National Meteorology Agency of Ethiopia, Jimma Meteorological Center, 2019, [b]National Meteorology Agency of Ethiopia, Assosa Meteorological centres, 2019, [c]Obtained from districts agricultural and natural resource development offices of the respective districts, [d] Used to represent both Begi and Maokomo districts in this study and"–"Indicate the altitude of the district not available, [e]Altitude ranges from which sample were collected.

2.2. Disease Assessment

Assessments disease in the field were made along the two diagonals (in an ''X'' pattern) using 0.5m x 0.5m ($0.25m^2$) quadrat. A total of five points, four points on two diagonal and one point at mid points of diagonals were used. In each field, all wheat plants within the quadrat were counted and divided into infected and non-infected plants and incidence were calculated as [6].

$$\text{Disease Incidence} = \frac{\text{Total number of infested plant}}{\text{Total number of assessed plants}} \times 100$$

Disease prevalence is one of the disease parameters and measures the fields infested in Peasant Association, districts, zones from the total assessed fields and calculated as

$$\text{Disease prevalence} = \frac{\text{Total number of infested field}}{\text{Total Number of Assessed Fields}} \times 100$$

Modified Cobb's scale was used to score disease severity [17]. Accordingly, 100% disease severity, the actual leaf/stem area covered by rust pustules is 37 (Figure 1). The severity of the disease was examined randomly from five plants of quadrat and each field disease severity was represented by the mean of five quadrats. Infection response in the field scored using methodology of [21].

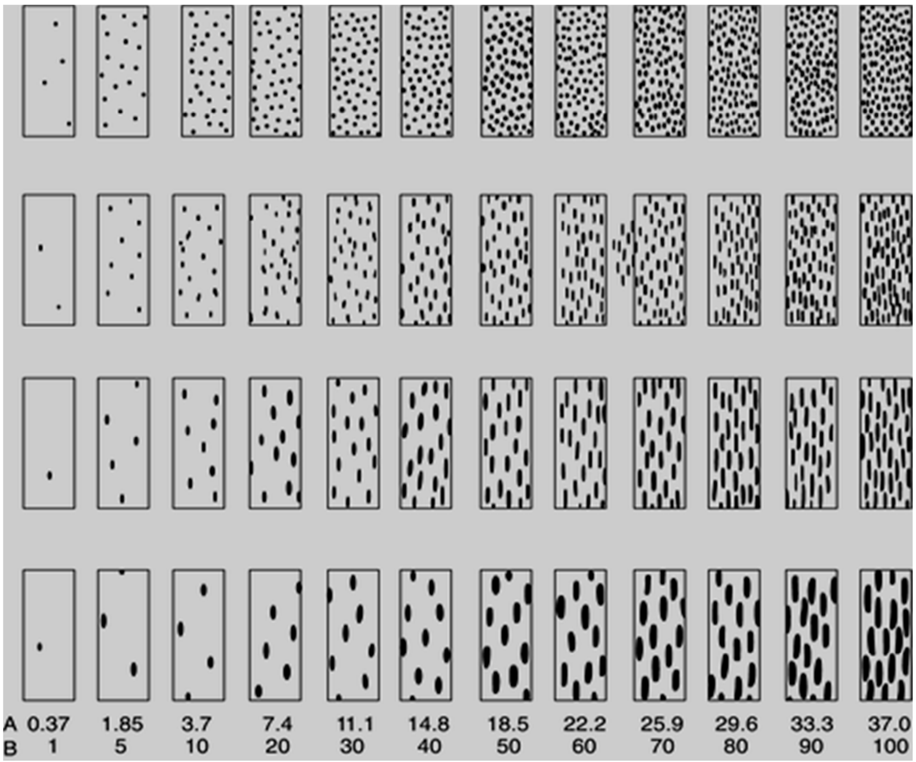

Figure 1. *A diagrammatic scale used for estimating rust severity on leaves and stem of cereal crops (Footnote: A. actual percentage occupied by rust uredinia; B. rust severities of the modified Cobb scale after Peterson [17]).*

2.3. Sampling Methods, Sample Size and Sampling Units

Based on the importance of wheat crops, sampling was made purposively to select main wheat growing zones, districts within zones and peasant associations within districts across western and southwestern Ethiopia. Of each peasant association, five farms were selected at 2 to 5km intervals followed by systematic sampling along with the main and feeder (accessible) road sides on pre-planned routes.

Information such as variety grown was obtained from Farmers or otherwise from a developmental agent of respective kebeles. Finally, a composite of five quadrats samples per field was collected during the survey and 105 farmers' fields were surveyed. All plants in each quadrat were used as sampling units. The sample size per district was determined to suit the crop distribution.

The plant population in each quadrat was counted and the mean plant population was obtained by averaging the plant population in five quadrats. The check list was prepared to record field information such as Wheat type, variety name, and crop growth stage. Information on variety type, and weed and pest control measures were assessed orally from growers through interviews. Altitudes (m) and location coordinates (longitude and latitude) were recorded using a Geographical Positioning Systems (GPS). Crop growth stages were recorded and categorized according to Zadoks (GS73-GS87) cereal growth stage guideline [26]. The disease incidence and severity were used for analysis of variance (ANOVA) and correlation was done to determine disease parameters with crop growth stage, altitude and weed management.

2.4. Statistical Analysis

The nested design was used as a model for data analysis as follows [21].

$$Yijk = \mu + \tau i + \beta j(i) + \gamma k(ij) + \varepsilon l(ijk)$$

Where: Y_{ijk} is the wheat stem rust disease intensity where as peasant association k is nested within district J nested within zone i, μ is the overall mean, τ_i is the effect of the i^{th} zone, $\beta_{j(I)}$ is the effect of the j^{th} districts within the i^{th} zone, and $\gamma k_{(ij)}$ is the effect of the k^{th} peasant association within the j^{th} district and i^{th} zone, and $\varepsilon_{l(ijk)}$ is the error term.

SAS version 9.3 Software packages were used for analysis of variance [24]. Least Significant differences (LSD) were tested at 5% levels of significance. Simple correlation analysis was done for disease incidence and severity with altitude, variety growth stage and weed management. Each of the independent variables was tested with the incidence and severity of stem rust as the dependent variable.

Stepwise regression analysis was done between diseases

Severity against altitude, growth stage and weed infestation level. Regression intercept, slope and coefficient of determination were computed using SPSS [11].

3. Results

3.1. Spatial Distribution of Stem Rust

The overall prevalence across the study area was 78.4%. It was varied by region, zone, districts and peasant associations. All of the dependent variables were significantly affected by disease incidence and severity. Prevalence is a measure of the number of fields infested in various areas and measures a level of disease distribution. The mean prevalence of disease in southwestern Ethiopia was lower than in Western Ethiopia viz. 68.4% and 88.4% respectively. The prevalence of disease in the zone was 70% in Buno Bedele, 66.7% in Jimma, 85% in West Wellaga and 92% in Asosa zones. The high disease prevalence was 92% at Maokomo district and 85% at Begi district and low, 60% at Bedele and Dedo districts (Table 3).

Table 2. *Nested ANOVA table for the intensity of wheat stem rust (Puccinia graminis f.sp. graminis) across study areas.*

Source of variation	Degree of freedom	Mean square	
		Disease Incidence	Disease Severity
Model	1013	13144.71**	21245.54**
Region	1	21772.87**	68483.57**
Zone (Region)	3	58526.97*	109338.73*
Districts (Region*Zone)	24	4850.39**	9939.65**
PA (Region Zone*Distr)	480	7466.22**	7497.92**
Error	504	449.52	541.86
CV%		49.49	36.22

Footnote*, ** Indicates significance and highly significant difference at p≤0.5and 0.01 respectively.

Table 3. *Altitude range and number of fields assessed across zones.*

Zones	Districts	Altitude ranges[a] (m.a.s.l)	No of fields assessed	Prevalence (%)
Buno Bedele	Bedele	1750-2213	15	60
	Gechi	2001-2213	15	80
Mean		1944-2075		70
Jimma	O/Nada	2025-2425	15	73.4
	Dedo	1956-2690	15	60
Mean		2179-2432		66.7
South western (Mean)				68.4
Westwellaga	Begi	1545-1970	20	85
Assosa	M/komo	1595-1902	25	92
Western (Mean)				88.4
Total/Mean		1944-2432	105	78.4

Footnote: B/Bedele=Bunobedele, W/wellega=Westwellega, O/Nada=Omonada, M/komo =Maokomo. [a] Indicates altitude range from which samples were collected

3.2. Incidence and Severity of Rust Disease

Disease incidence, highly significantly ($p<0.001$) different among zones, districts and peasant associations and cultivars in production, crop growth stage and weed management practices. The overall mean incidence in Southwestern, 13.0% and Western parts was 45.6%. It was highest in the Westwellaga zone and Assosa zone having mean of 47.86% and 42.46%, while the lowest incidence being recorded in Bunobedele, 14.4% and Jimma, 11.8% zones in a given order.

The disease severity showed variation, high in the western region with severity of 65.1% and low in the southwestern region with severity of 19.7%. The difference between the two regions for this disease parameter was highly significant ($p<0.001$). Similar to disease incidence, severity also showed variation with zones. The highest disease severity of 66.5% recorded in the west wellaga zone and the lowest disease severity of 10.3% was observed in the Jimma zone (Table 4).

Table 4. *Stem rust Intensity across zones.*

Zones	Disease Incidence (%)		Disease Severity (%)	
	Range	Mean	Range	Mean
West Wellega	0-100	47.86[a]	0-95	66.5[a]
Assosa	0-100	42.46[b]	0-98	63.9[a]
Buno-Bedele	0-80	14.41[c]	0-95	29[b]
Jimma	0-100	11.8[c]	0-85	10.2[c]
LSD (p<0.05)		3.83		3.26
CV		48.3		33.9

Footnote: Means with the same letter(s) with in the column are not significantly different at $p<0.05$.

Highly significant ($p<0.01$) variation among districts for stem rust intensity was observed. Mean of disease incidence ranged of 3.7% to 47.9% within the districts, the highest incidence of 47.9% being recorded in Begi followed by 42.6% in Maokomo district, and the lowest incidence of 3.7% was recorded at Dedo district.

Similar to the aforementioned disease parameters, severity showed variation among districts. The highest severity, 66.5%, being recorded in the Begi district followed by 63.5% severity recorded in the Maokomo district (Table 5). Gechi district had a moderate level of disease severity and was significantly different from lower severity recorded in Omonada, 16.9%, and Bedele 19.3% districts. The severity recorded in Omonada and Bedele districts was not significantly different from each other as showed by LSD value, but significantly differed from the lowest disease severity recorded in the Dedo district with values limited to 4.8% and likewise different value of mean disease severity recorded in the rest of districts.

Table 5. *Intensity of wheat stem rust by districts.*

Regions	Zones	Districts	Disease Incidence (%)		Disease Severity (%)	
			Range	Mean	Range	Mean
South-western	Bunobedele	Bedele	0-80	15.62^{dc}	0-85	19.25^{c}
		Gechi	0-50	13.21^{d}	0-95	38.86^{b}
	Jimma	Omonada	0-100	19.58^{c}	0-85	16.89^{c}
		Dedo	0-50	3.68^{e}	0-35	4.82^{d}
Western	Westwellega	Begi	0-100	47.86^{a}	0-95	66.51^{a}
	Assosa	Maokomo	0-100	42.46^{b}	0-98	63.95^{a}
Mean				23.74		35.18
LSD (0.05)				4.72		4.02
CV%				34.76		27.48

Footnote: Means with the same letter(s) within the column are not significantly different at p<0.05.

3.3. Intensity of Wheat Stem Rust by Peasant Associations

Disease data noted in various peasant associations have confirmed stem rust intensity showed significant differences ($p<0.01$) with peasant association. The peasant associations varied in terms of the mean percent of stem rust incidences. Shoshor, Taja, Lalo and Gebasenbata peasant associations sustained mean higher incidences of 79.33%, 73.5%, 51.8% and 51.2% in the listed order than in others such as Nadadawe, Lalistu, Sito, and Ilala peasant associations that had values of 4.8%, 4.7%, 3.8% and 1.2%, respectively (Table 6).

The highest disease severity was recorded in Shoshor, Dhaladuwabara, Taja and Seko peasant association possessing severity values of 86.2%, 85.84%, 74.5% and 73.5% respectively. However, low disease severity was recorded in peasant association of Garimalamesa, Ilala and Lalistu with mean values of 4.7%, 5.6% and 7.2% respectively and lowest severity was recorded in Sito peasant association (4.1%).

Table 6. *Distribution and Intensity of wheat stem rust across different peasant associations.*

Zone	District	Peasant association	# of Field assessed	Prevalence (%)	Incidence (%)	Severity (%)
Buno Bedele	Bedele	Lalistu	5	40	4.7^{i}	7.2^{ih}
		Digaja	5	60	21.8^{ed}	28.0^{fg}
		Mirgamute	5	80	20.2^{edf}	22.5^{g}
	Gechi	Gixo	5	60	10.8^{ighf}	13.1^{h}
		Seko	5	100	22.0^{ed}	73.5^{b}
		Bidojiren	5	60	6.7^{igh}	29.9^{ef}
Jimma	O/Nada	Nadabidaru	5	40	16.0^{egdf}	10.8^{ih}
		Nadadawe	5	20	4.8^{i}	10.0^{ih}
		Hundatoli	5	60	39.0^{c}	26.2^{fg}
	Dedo	Garimalamesa	5	60	6.0^{ih}	4.7^{i}
		Sito	5	40	3.8^{i}	4.1^{i}
		Ilala	5	20	1.2^{i}	5.6^{i}
West wellega	Begi	Gabasenbata	5	100	51.2^{b}	64.7^{c}
		Lalo	5	80	51.8^{b}	63.5^{c}
		Dhaladu Wabara	5	100	40.7^{c}	85.8a
		Rafis	5	100	47.6^{cb}	51.6d
Assosa	Maokomo	Taja	5	100	73.5^{a}	74.5^{b}
		Wetse	5	100	25.4^{d}	54.2^{d}
		Shoshor	5	100	79.3^{a}	86.2^{a}
		Tongo	5	60	15.1^{eghf}	29.9^{e}
		Wanga	5	100	18.8^{edf}	68.6^{cb}
LSD (0.05)					8.65	7.38
CV (%)					37.7	22.4

Footnote: Means with the same letter(s) within the column are not significantly different at p<0.05, CV: coefficient of variation LSD: least significance difference.

3.4. Wheat Stem Rust Status by Altitude

Altitude data record indicates, survey was carried out at altitude ranges of 1545-2690 m.a.s.l, 1545-1970 m.a.s.l in Westwellega zone, 1595-1902 m.a.s.l in Assosa zone, 1750-2213 m.a.s.l in Bunobedele zone, and 1956-2690 m.a.s.l in Jimma zone. Out of the total 105 fields inspected, 18 of the fields assessed were fallen in high altitudes ranging from 2301-2690 m.a.s.l, while the remaining 87 fall in to mid-altitude ranged from 1545 to 2300 m.a.s.l. Eighty-one (81) fields were infested among 105 assessed fields. Of 81 infested fields, the prevalence of the disease by attitude range showed high variation, 72 (82.7%) of fields in the mid-altitude ranging in 1545-2300 m.a.s.l and 9 (50%) of fields in high altitudes ranging in 2301-2690 m. a. s. l.

Analysis of variance (ANOVA) result showed, the two altitude classes highly significant at (p<0.01) by disease incidence and severity of wheat stem rust and prevalence in terms of descriptive mean values (Table 7). The data generated has proved that more infected plants were prevalent in fields surveyed in mid-altitude wheat-producing agro-ecologies as confirmed by the incidence of 30.9% in this altitude and 4.5% incidences in high altitude. High altitudes sustained mean stem rust severity of 8.1% where as the disease was as severe as 45.3% in mid-altitude of wheat-producing areas. Both disease parameters are invariably significantly affected by altitudes.

Table 7. *Prevalence and intensity of wheat stem rust by altitude classes.*

Altitude range	Class	Field Inspected	Field infested	Prevalence (%) **	Incidence (%)		Severity (%)	
					Range	Mean	Range	Mean
1545-2300	Mid-Altitude	87	72	82.7	0-100	30.9a	0-100	45.3a
2301-2690	High-Altitude	18	9	50.0	0-50	4.5b	0-50	8.1b
Total		105	81					
LSD(0.05)						4.89		5.47
CV%						38.90		29.84

Footnote: Means with the same letter(s) with in the column are not significantly different at p<0.05, **: % of prevalence disease at each altitude class.

Mean incidence and severity of wheat stem rust decreased from mid-altitude to high-altitude and very low at high altitude >2600m.a.s.l. The disease severity of 98% and 94% was recorded at 1850 m.a.s.l from Maokomo district and Begi district at a field of Shoshor and Dhaladuwabara locality. In this study complete (100%) disease severity was not recorded. Stem rust incidence of 100% was recorded at mid-altitude ranges of Begi and Maokomo districts of Gabasenbata and Taja localities respectively.

3.5. Distribution and Intensity of Wheat Stem Rust by Wheat Variety

Most of the farmers in the areas are producing wheat, barley, maize, Sorghum, Soybean, Fababean, Teff and field pea. Most of farmers in study areas grow six latter crops in rotation with wheat in small scale farms, ranging from 0.25 ha to 2 ha in size. Few farmers grow wheat without crop rotation. The wheat production is currently expanding to the marginal area of western and southwestern Ethiopia.

Farmers grow both improved and unknown local wheat cultivars of which improved cultivars occupied 91.43% of the total wheat fields. The rests are 2.86% and 5.71%grown man-made crop cultivar called triticale and local wheat cultivar, respectively. The present survey proved that seven improved bread wheat namely; Ogolcho, Hidassie, Danda'a, Digalu, Kingbird, Senate and Shorima grow in the proportion of 28.57%, 6.67%, 30.47%, 14.28%, 0.95%, 3.81% and 6.67% fields in the aforementioned orders, indicating that cultivar Danda'a is most widely cultivated and followed by cultivar Ogolcho. King bird was least spread wheat variety to the area.

Of 105 fields assessed, stem rust was not encountered in all fields. Fields planted to Ogolcho, Hidase, Danda'a, Digalu, Kingbird, Senate, Local, and Shorima were infested in a proportion of 93.34%, 85.71%, 68.75%, 73.34%, 100%, 50%, 50%, 28% in the given orders. No disease was scored in fields planted to Triticale cultivar in the current study as shown in Figure 2. The lowest disease prevalence was recorded in fields planted to triticale cultivar (0%) and followed by fields planted to cultivar Shorima (42.85%).

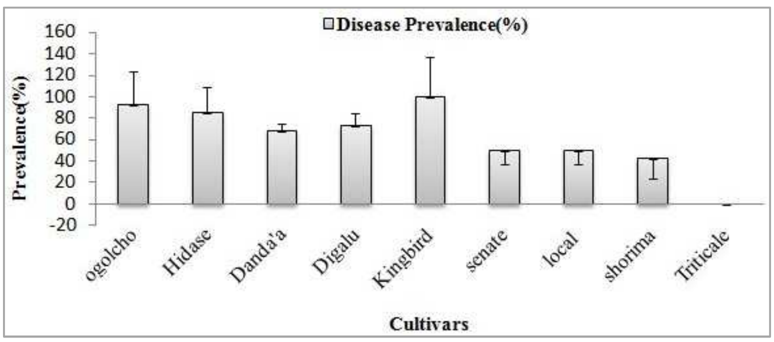

Figure 2. *Disease prevalence's by cultivars.*

Disease Incidence and severity among the grown cultivars was highly significant difference at (p<0.01) levels. The high mean disease incidence was recorded from Ogolcho Cultivar (39.6%) followed by Danda’a and Digalu with a value of 26.6% and 25.7%, respectively. However, Danda’a and Digalu variety were not significantly different statistically. The lowest disease Incidence was recorded from the local (1.5%) variety.

The cultivars also varied for disease severity like that of disease incidence. The highest mean disease severity recorded on Ogolcho cultivar was as high as 61.2% followed by Hidase, Danda’a and Shorima infected to the level of 57.9%, 36.7% and 25.3%, respectively. The zero disease severity was recorded on triticale (0%) cultivar. The most widely grown wheat variety was Danda’a and it covered 30.47% of assessed fields (Table 8).

Table 8. *Incidence and Severity of wheat stem rust by varieties.*

Varieties	Variety Response	Number of field assessed	Disease Incidences (%)	Disease Severity (%)
Ogolcho	MS-S	30	39.6[a]	61.2[a]
Hidassie	MS-S	7	18.6[b]	57.9[a]
Danda’a	MS-S	30	26.6[b]	36.7[b]
Shorima	MR-MS	7	25.0[b]	25.3b
Digalu	MS	15	25.7[b]	24.5[b]
Kingbird	MR-MS	1	7.2[c]	9.2[c]
Senate	MR	4	3.3[c]	7.0[d]
Local	MR	6	1.5[c]	6.1[d]
Triticale	R	3	0.0[c]	0.0[d]
LSD(0.05)			9.72	8.28
CV%			25.92	16.05

Footnote: Means with the same letter(s) with in the column are not significantly different at p<0.05.Where: R-resistant, MR-moderatelyresistant, MS-moderatelysusceptibleandS-susceptible.

However, most interestingly triticale cultivar was not affected by stem rust disease invariably with agro-ecologies and elevation. The typical symptoms of wheat stem rust in the zones of study areas were illustrated below (Figure 3). In Figures 3a, 3b and 3c indicate stem rust spore stage where uredia appears as golden red of its early disease cycle while Figure 3d indicates urediospores brusted out of stem appears as dust in the field of Maokomo districts.

Figure 3. *Typical symptoms of stem rust during a survey in the study field, 2019 cropping season (A, B, C and D indicates picture taken from Westwellega, Jimma, Bunobedele and Assosa Zone respectively (Source: picture taken during disease survey)).*

3.6. Occurrence and Intensity by Wheat Growth Stages

Crop growth stage is essential for comparisons when ever disease surveys are made to study the epidemiology of pathogens. During survey time, crops in 105 fields inspected were in four growth stage categories, flowering, milk, soft dough and hard dough in a proportion of 0.95%, 42.8%, 52.4% and, 3.8% in the listed order. Fields at milk, soft dough and hard dough were infested to the proportion of 37.7%, 27.3% and 100%, respectively. The proportion of growth stage indicates the number of each growth category in percentage form out of total field assessed while the proportion of infestation indicates the prevalence of disease at each growth stage. The highest mean disease incidence (43.73%) and severity (69.98%) recorded from hard dough stage. The lowest disease intensity was recorded from the flowering stage (Table 9).

Table 9. *Occurrence and intensity by wheat growth stage.*

Crop stages	# of Fields**	Proportion of field	Prevalence (%)	Incidence (%)	Severity (%)
				Mean	Mean
Flowering	0.95	1	0	0.00c	0.00 c
Milk	45	42.8	37.7	26.0b	36.4b
Soft dough	55	52.4	27.3	26.4b	40.1b
Hard dough	4	3.8	100	43.7a	69.9a
LSD(0.05)				14.8	16.8
CV (%)				38.6	27.8

Footnote: Means with the same letter(s) within the column are not significantly different at $p < 0.01$. **The high variation in the number of fields inspected is due to survey were carried out once when crops are post of flowering stage.

3.7. Correlation of Rust Intensity, Growth Stage, Altitude and Weed Infestation Level

Disease intensity represented by incidence and severity were significantly correlated between themselves and with altitude, crop growth stage and level of weed infestation (Table 10).

Table 10. *Pearson's correlation coefficients among altitude, crop growth stage, Weed infestation and disease intensity.*

Variables	Disease incidence	Disease Severity	Growth Stage	Weed Infestation	Altitude
Disease Incidence	1	0.72***	0.10*	0.36***	-0.31***
Disease Severity		1	0.15*	0.43***	-0.39***
Growth Stage			1	-0.03^{ns}	0.01^{ns}
Weed Infestation				1	0.10^{ns}
Altitude					1

Footnote:*Significant at $p<0.05$;**significant at $p<0.01$ and *** significant at 0.001, ns: non-significant.

Stepwise multiple regression analysis was performed using stem rust severity as a dependent factor and altitude ranges, weed infestation level and growth stage as an independent factor. The stepwise multiple regression results in SPSS indicate that two predictor variables i.e altitude and growth stage significantly contributed to disease severity while weed infestation level did not significantly contribute to stem rust disease severity and its excluded predictor variable from stepwise regression models (Table 13).

Table 11. *ANOVA of Stepwise multiple regression predictors*.*

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	23689.528	1	23689.528	25.634	.0001
	Residual	81326.109	103	924.160		
	Total	105015.636	104			
2	Regression	31075.593	2	15537.797	18.282	.0001
	Residual	73940.043	102	849.886		
	Total	105015.636	104			

* Dependent Variable is Severity. Model 1 (Predictors: Constant, Growth stage); Model 2 (Predictors: Constant, Growth stage, Altitude).

Table 12. *Stepwise multiple regression coefficients, t-value, significance, shared and unique contribution of growth stage and altitude on disease severity.*

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Contribution	
		B	Std. Error	Beta			shared	Unique
1	Constant	-17.000	8.861	-	-1.919	.058	-	-
	Growth stage	20.131	3.976	.475	5.063	.0001	.475	.475
2	Constant	14.078	13.541	-	1.040	.301	-	-
	Growth stage	18.406	3.858	.434	4.771	.0001	.455	.429
	Altitude	-22.913	7.772	-.268	-2.948	.004	-.301	-.265

Where B: Indicates regression coefficient of predictor variables, Beta: Measure of significance of predictors.

Table 13. *Stepwise multiple regression of disease severity for significant independent variables*.*

Model	Predictors variables	Disease severity	
		Coefficient	Sum square(SS)
1	Intercept	-17.0	
	Growth stage	20.1	223689.5
	R^2		47.5%
	AdR^2		21.7%
	Pr>F		0.001

Model	Predictors variables	Disease severity	
		Coefficient	Sum square(SS)
2	Intercept	14.07	-
	Growth stage	18.4	223689.5
	Altitude	-22.9	31075.9
	R^2		54%
	AdR^2		21.7%
	Pr>F		0.0001

Footnote: *Dependent Variable is Severity, Model 1 (Predictors: Constant (-17.0), growth stage); Model 2 (Predictors: Constant (14.7), growth stage, Altitude).

4. Discussion

Wheat stem rust was widely distributed and important in Western and Southwestern Ethiopia. It is more widespread and important in western Ethiopia, this probably due to climate suitability particularly warm temperature and the wide cultivation of susceptible varieties like Ogolcho which is susceptible to wheat stem rust pathogen. A warmer climate is reported to benefit production of urediniospores [19]. In addition it can create a days with favorable temperatures for sporulation.

Based on agro-ecological zones of Ethiopia; Areas in 500 - 1500m, 1500-2300m and 2300-3200m are classified to lowlands, midlands and highlands respectively [7]. Hence, this finding is in agreement of other works that stem rust is not threatening wheat at higher altitudes where the temperature is commonly very low [16]. High level of stem rust infection also reported from 2001 to 2500m.a.s.l, hence it indicated the rust problem increased with increase of altitude up to certain level of elevation [13]. Inline, complete (100%) disease incidence was recorded from Maokomo districts of Taja localities of higher altitude.

Similar report from Ethiopia indicated, more disease prevalence of 68% stem rust was recorded at altitude range 1494-1800m.a.s.l followed by 66.1% at 1801-2300 m.a.s.l, and none in higher altitudes > 2300 m.a.s.l during 2010 cropping season [1]. The study in northern Ethiopia also found prevalence of rust disease at the mid-altitude range [10]. The importance of stem rust at low to mid-altitude might be associated with appearance of new virulent races due to suitable climate and widely production of wheat crops at mid altitude agro ecology.

Cultivar reaction to stem rust across survey areas varies; none of the wheat cultivars encountered in the survey areas has shown immunity to stem rust. Most improved wheat varieties have shown the susceptibility reaction (MS-S) to wheat stem rust based on the host response at field. Generally, most wheat cultivars succumb to rusts including stem rust shortly after their release to farm for production. This might be due to the climatic change and evolution of the pathogen to the wider environmental conditions [15, 16, and 18]. Moreover, the evolution of new virulent stem rust races infecting commercial cultivars deployed to farmers for production with qualitative type/major gene resistance incorporated is the major reason for the cultivar to become susceptible [14].

Analysis of variance revealed that rust severity along with incidence significantly (p<0.01) differed by crop growth stages. Stem rust intensity was not on crops at flowering stages during the survey. Such effects of crop growth stages are in agreement with a previous study conducted at Tigrayi Region of Ethiopia [10]. Wheat stem rust is more important late in the growing season, on late-sown and late maturing wheat cultivars [23]. Incidence and severity did not significantly differ by milk and soft dough stages as compared to the rest of the crop growth stages that were not significant. Incidence and severity showed the trend of increase with increasing of crop growth stages.

In this study, it was observed that there were various planting dates, early to late plantings. In the survey areas that have been resulted in various crop growth stages, the hard dough stage was found to sustain high stem rust intensity. The wheat-growing agro ecology that varies in planting dates like southwestern and western Ethiopia (July-August), characterized with various planting dates, early to late plantings allow rust spores to spread from advanced growth stages to different late-planted wheat fields mainly by wind. Thus, planting wheat at optimum planting dates and growing early maturing cultivars reported to reduce shifting rust epidemic to near the field [8], and reduces the time for development of urediniospores.

In general, wheat stem rust infestation was increased with increasing in the growth stage of the crops. This finding is supported by various works. For example, the late growth stage of the crop is an important period to reach stem rust disease of wheat at its-maximum severity levels [20]. In addition, wheat stem rust disease severities as high as 80-100% reported at soft dough to hard dough growth stages [4].

In case of correlation analysis, severity linearly and positively associated with disease incidence and signifying that there is high disease incidence wherever there is high disease severity (p<0.0001). Likewise, there was highly significant (P<0.001) and negative association of altitude and stem rust incidence (r = -0.31) and severity (r = -0.39). This finding is in line with previous findings of various authors, who found negative association of rust incidence and altitude [1, 10, 12]. The negative relationship between altitude and severity of wheat stem rust in Ethiopia were also reported [12].

A significant (P<0.05) and positive correlation of growth stages and disease intensity, incidence (r=0.10) and severity (r=0.15) indicating that stem rust is more intense in the later wheat crop growth stages, where the advanced wheat growth stages meet, most probably with increased temperature to the level of optimum temperature favoring the infection and disease development. In agreement with our work, Positive correlation of disease intensity with growth stage, particularly with the late crop growth stages also reported so far [8].

There was highly significant (p<0.001) and positive correlation between weed infestation and disease incidence (r=0.36) and severity (r=0.43). Likewise, wheat stem rust is more severe and intense in the weedy farm than the well-managed field because of canopy [15]. The reason why the disease was more intense in the weedy farm is related to the contribution of the canopy epidemic of rust. In addition weedy farm increases crops canopy consequently creating favorable incubation environment for rust disease. In spite, Moisture in weedy canopy can favors germination and hastening epidemic development.

Moreover, stepwise multiple regression in the current study indicates the strongest predictor for disease severity was the growth stage with the highest β value which is 0.47 and with its highest shared; $(0.455)^2$ = 20.1% and unique $(0.429)^2$ =18.4% contribution for disease severity. In another way stepwise multiple regression results indicate, the low shared and unique contribution for disease severity were from predictor variables of altitudes, $(0.301)^2$=9.1% and $(0.265)^2$=7.0% respectively. This indicates altitude contribute less to disease severity than the growth stage of crops. The regression equation with significant predictors was; $Y=18.4X_1-22.9X_2+14.07+\varepsilon$, where Y=disease severity, X_1=growth stage X_2=Altitude, Intercept=14.07 and ε=13.5. Accordingly, the stepwise regression equation indicates; increase in the growth stage of crops from one growth to the next growth stage, the disease severity increased by 18.4% and an increase of one meter in altitude resulted in a 22.9% (0.22) decrement in disease severity.

5. Conclusion

The result generated in the study has revealed, stem rust was prevalent in western and southwestern Ethiopia at variable levels, 67-92% in range, with an overall mean of 78.4%. Incidence and severity varied significantly by district, the formers ranging from 3.7 to 47.9% and the latter ranging from 4.8 to 66.5%. Analysis of the data collected indicated that all disease parameters were significantly affected by altitude, crop growth stage, locality and weed density.

Correlation analysis in current findings revealed the association between the disease and altitudes in the mid to highland is negative and significant; conversely, the association between growth stages is positive and significant. Furthermore, stepwise multiple regression analysis showed that crop growth stage and altitude was a significant predictor of disease severity.

Furthermore, to get the full depiction of the distribution and importance of wheat stem rust and to design appropriate control techniques, it is worthwhile to conduct similar assessments in different wheat belt areas of the country. The current study was limited to one time monitoring during growth time most probably by synchronization with the growth stage, in case the dough growth stage is a major focus of ours. So that future research should focus on periodically monitoring the epidemic of pathogens throughout the growth stage of the crops.

References

[1] Abebe, T., Woldeab, G. & Dawit, W. 2012. Distribution and physiologic races of wheat stem rust in Tigray, Ethiopia. *Journal of Plant Pathology & Microbiology,* 3, 1-6. https://www.researchgate.net/profile/Teklay-Teferi/publication/269543978,doi:10.4172/2157-7471.1000142.

[2] Admassu, B., Lind, V., Friedt, W. & Ordon, F. 2009. Virulenceanalysis of Puccinia graminis f.sp. tritici populations in Ethiopia with special consideration of Ug99. *Plant Pathology,* 58, 362369. https://doi.org/10.1111/j.1365-3059.2008.01976.x

[3] Ambika R, Meenakshi D (2018). Wheat Stem Rust Race Ug99: A Shifting Enemy. Int. J. Curr. Microbial. App. Sci.7 (01): 12621266. https://doi.org/10.20546/ijcms.2018.701.153.

[4] Bhavani, S., Singh, R., Argillier, O., Huerta Espino, J., Singh, S. & N jau, P. Mapping of durable adult plant stem rust resistance in six CIMMYT wheats to Ug99 group of races. 2011 BGRI technical workshop, St Paul, Minnisota, USA, 2011. 43-53. https://globalrust.org/sites/default/files/2011%

[5] Cochrane, L., & Bekele, Y. W., 2018. Average crop yield (2001–2017) in Ethiopia: Trends at national, regional and zonal levels. *Data in brief*, *16*, 1025. http://dx.doi.org/10.1016/j.dib.2017.12.039

[6] Denbel, W., Badebo, A.& Alemu, T. 2013. Evaluation of Ethiopian commercial wheat cultivars for resistance to stem rust of wheat race 'UG99'. *International Journal of Agronomy and Plant Production,* 4, 15-24. https://www.ijappjournal.com

[7] Ferede, T., Ayenew, A. B., Hanjra, M. A. & Hanjra, M. 2013. Agroecology matters: Impacts of climate change on agriculture and its implications for food security in Ethiopia. *Global food security: Emerging issues and economic implications*, 71-112. http://www.agriverdes.com.br/biblioteca/biblioteca/Agroecologia/Artigos%20de%20Agroecologia

[8] Fetch, T., Mccallum, B., Menzies, J., Rashid, K. & Tenuta, A. 2011. Rust diseases in Canada. *Prairie Soils and Crops,* 4, 87-96. https://doi=10.1.1.690.6329

[9] Figueroa M, Hammond-kosack K, Solomon S (2017). Review of wheat diseases a field perspective. Molecular Plant Pathology. https://doi:10.1111/m:pp.12618.

[10] Gizachew, H. R., Girma, A. S. & Netsanet, B. H. 2019. Evaluation of Ethiopian bread wheat varieties to dominant stem rust races (*Pucciniagraminis*f.sp.*tritici*) at seedling stage under greenhouse condition. *International Journal of Agriculture and Biosciences,* 8, 210-216. http://www.ijagbio.com/.../210-216.pdf

[11] Green, S. & Salkind, N. 2016. Using SPSS for Windows and Macintosh, books alacarte. *Pearson,* 2, 3. http://wwoof.ro/sites/default/files/applications/pdf-using-spss-for-windows-and-macintosh-7th-edition

[12] Hailu A, Woldeab G, Dawit W, Hailu E., 2015. Distribution of Wheat Stem Rust (*Puccinia graminis* f.sp. *Tritici*) in West and southwest shewa zones and Identification of its Physiological Races. Adv Crop Sci Tech 3: 189. doi: 10.4172/2329-8863.1000189

[13] Hei, N., Shimelis, H. A. & Laing, M. 2017. Appraisal of farmers wheat production constraints and breeding priorities in rust prone agro-ecologies of Ethiopia. *African journal of agricultural research,* 12, 944-952. https://doi.org/10.5897/AJAR2016.11518

[14] Krupinsky, J. M., Bailey, K. L., Mcmullen, M. P., Gossen, B. D. & Turkington, T. K. 2002. Managing plant disease risk in diversified cropping systems. *Agronomy journal,* 94, 198-209. https://pubag.nal.usda.gov/catalog/11508

[15] Mideksa, T., Fininsa, C. & Hundie, B. 2018. Analysis of Climate Variability Effects on Wheat Stem Rust (*Puccinia graminis* f.sp *tritici*) Epidemics in Bale and Arsi Zones of Oromia Regional State, Ethiopia. *American Journal of Biological and Environmental Statistics,* 4, 49-65. http://www.sciencepublishinggroup.com/j/ajbesdoi:10.11648/j.ajbes.20180402.12

[16] Negassa, A., Shiferaw, B., Koo, J., Sonder, K., Smale, M., Braun, H., G begbelegbe, S., Guo, Z., Hodson, D.& Wood, S. 2013. The potential for wheat production in Africa: Analysis of biophysical suitability and economic profitability. https://repository.cimmyt.org/xmlui/bitstream/handle/10883/4015/97365.pdf.

[17] Peterson, R. F., Campbell, A.& Hannah, A. 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. *Canadian journal of research,* 26, 496-500. https://doi.org/10.1139/cjr48c-033

[18] Prank, M., Kenaley, S. C., Bergstrom, G. C., Acevedo, M. & Mahowald, N. M. 2019. Climate change impacts the spread potential of wheat stem rust, a significant crop disease. *Environmental Research Letters,* 14, 124053. https://doi.org/10.1088/1748-9326/ab57de

[19] Prescott, J. M., Geleta, A. B., Bowman, J., Burnett, P. A., De Milliano, W., Ransom, J. K., Saari, E. E. and Singh, R. P., 2002. Wheat diseases and pests: a guide for field identification. https://repository.cimmyt.org/xmlui/bitstream/handle/10883/3215/13655.pdf

[20] Roelfs, A. P. 1992. *Rust diseases of wheat: concepts and methods of disease management*, Cimmyty. https://doi.968-6127-4.x https://repository.cimmyt.org/xmlui/handle/10883/1153

[21] Schielzeth, H. and Nakagawa, S., 2013. Nested by design: model fitting and interpretation in a mixed model era. *Methods in Ecology and Evolution*, *4* (1), pp.14-24. https://doi.org/10.1111/j.2041-210x.2012.00251.x

[22] Shiferaw B, S male M, Braun J, Duveiller E, Reynolds M, Muricho G, 2013. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Security, 5 (3): pp.291-317. https://doi.org/10.1007/s12571-011-0140-5

[23] Singh, R. P., Hodson, D. P., Huerta Espino, J., Jin, Y., Njau, P., Wanyera, R., Herrera Foessel, S. A. & Ward, R. W. 2008. Will stem rust destroy the world's wheat crop? *Advances in agronomy,* 98, 271-309. https://doi.org/10.1016/S0065-2113(08)00205-8

[24] Stokes, M. E., Davis, C. S. & Koch, G. G. 2012. *Categorical data analysis using SAS*, SAS institute. https://www.sas.com/catbook

[25] White, J. W., Tanner, D. G. & Corbett, J. D. 2001. An agro-climatological characterization of bread wheat production areas in Ethiopia. https://repository.cimmyt.org/xmlui/bitstream/handle/10883/1022/74272. pdf

[26] Zadoks, J. 1985. Cereal rusts, dogs and stars in antiquity. *Cereal Rusts Bulletin,* 13, 1-10. https://www.cabdirect.org/cabdirect/abstract/19851308787