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Importance and Distribution of Wheat Stem Rust (*Puccinia graminis* f.sp.*tritici*) in Western and Southwestern Ethiopia

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Abstract

Wheat is an important staple food crop in Ethiopia. However, several wheat stem rust disease outbreaks had been caused significant losses of crops in many parts of the country. This study was conducted to quantify the stem rust intensity and distribution of the *Puccinia graminis* f.sp.*tritici* population 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 during the 2019 cropping season. Stem rust was prevalent and widely distributed in all study areas. Analysis of variance indicates fields, districts, and zones significantly ($p<0.01$) varied in disease incidence and severity %. ANOVA of disease intensity with altitude, weed management, a wheat variety is grown and growth stage also showed a significant difference ($p<0.01$). The disease means prevalence was high, 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 4.8-66.5%. The disease was more severe in mid-altitude areas with warmer weather conditions. The current study revealed that wheat stem rust was important in wheat farms of the west and southwest Ethiopia and the need to undertake regular monitoring across the study areas.

Keywords: Distribution; Intensity; Stem rust; Wheat; Urbanization; Weed management; Cereal crops

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Introduction

Wheat (*Triticum* spps.) is the high ranked source of cereal proteins and primary staple food crops across the world [1]. It is the second-ranked crop in the world next to rice in areas of production [2]. Likewise; wheat is the important cereal grain in Ethiopia. Bread wheat (*Triticum aestivum* L. Thell) and Durum wheat (*Triticum turgidum* L. var. durum) are the two wheat species cultivated in Ethiopia [3]. It is grown primarily as a rain-fed crop by subsistence farmers in mid to highland areas that range from (1500 to 3000 m) [4].

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 Westwellega 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- 2.4 ton/ha which is low as compared with central Oromia, 2.9 tons [5].

A key staple food crop in Africa, wheat is increasingly in demand in sub-Saharan Africa as a result of income growth and rapid urbanization [3,6]. 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.

The productivity of wheat in Ethiopia, in general, is very low as compared to other countries. The low production and productivity are attributed to several factors including biotic (diseases, insects, and weeds), abiotic, and socioeconomic constraints [7]. For that, all countries share the need to increase wheat yield, tolerance to abiotic stresses, pathogen and pests, as well as improve input use efficiency for more sustainable wheat production [3,6].

Among biotic factors, the incidence of disease and pest infestations is a common one. About 30 diseases have been reported on wheat in Ethiopia. The most important one includes rusts (*Puccinia* spp.), Septoria leaf blotches (*Septoria tritici*), Fusarium head blight (*Fusarium graminearum*), Tan spot (*Pyrenophora triticirepentis*), Smut (*Ustilago tritici*) and Powdery mildew (*Erysiphe graminis* f.sp. *tritici*) [8]. Wheat stem rust has been the most devastating disease of wheat in Ethiopia destroying wheat crops; causing up to 100% yield losses over wide areas during the epidemic year [9,10].

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 and irrigated wheat areas of Ethiopia, the status of wheat stem rust 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 the wheat stem rust distribution and intensity statusin the western and southwestern zones of Ethiopia.

Materials and Methods

Description of study areas

The study was carried out in 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, from October 2019 to January 2019 **(Table 1)**.

Disease assessment

Stem rust assessments were made at five points along the two diagonals (in an ''X'' pattern) of the field using 0.5 m x 0.5 m (0.25 m2) quadrat and used to calculate average values of five points. Four points on two diagonal and one point at midpoints of diagonals were assessed. In each field, all wheat plants within the quadrat were counted and divided into infected and non-infected plants and stem rust incidence was calculated as [10].

$$\text{Disease incidence}\,(\%) = \frac{\text{Total number of infested plants}}{\text{Total number of plants counted}} \times 100$$

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

$$\text{Disease prevalence}\,(\%) = \frac{\text{Total number of infested fields}}{\text{Total number of assessed fields}} \times 100$$

The disease severity was measured as a percentage of stem/leaf area covered by rust disease according to Modified Cobb's scale as developed by [11]. According to this scale, at 100% disease severity, the actual leaf/stem area covered by rust pustules is 37. The severity of the disease was examined randomly by selecting five plants from a single quadrat and each field disease severity was represented by the average of five quadrats. The host response to infection in the field was scored using 'R' to indicate resistance or miniature uredinia; 'MR' to indicate moderate resistance, expressed as small uredinia; 'MS' to indicates moderately susceptible, expressed as moderate-sized uredinia somewhat smaller than the fully compatible type and 'S' to indicate full susceptibility [12] **(Figure 1)**.

Table 1: Coordinates, elevations, annual rainfall and mean temperatures of the study areas by districts, main wheat growing season, 2019.

Zone	District	Coordinate	Altitude[e]	Rainfall	Temperature (°C)	Virulent[b]	Virulent[b]
		N	E	(m.a.s.l)	(mm)	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	18	25
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 district's 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

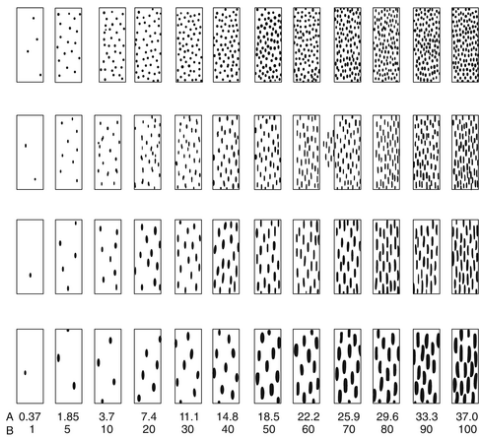

Figure 1 A diagrammatic scale used for estimating rust severity on leaves and stem of cereal crops.
Footnote: A. actual percentage occupied by rust uredinia; B. rust severities of the modified Cobb scale after Peterson 11.

Sampling methods, sample size and sampling units

Based on the importance of wheat crops, purposive multistage sampling was employed 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 5 km intervals followed by systematic sampling along with the main and feeder (accessible) roadsides on pre-planned routes in areas where wheat is predominantly grown.

Field 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 checklist 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 [13]. Disease incidence and severity were used in the analysis of variance (ANOVA) and correlation was done to determine disease parameters with crop growth stage, altitude and weed management.

Statistical analysis

The nested design was used as a model for data analysis. Hence, disease incidence and severity were analyzed using nested design with the model [14].

$$Yijk=\mu+Ti+\beta_{j(i)}+\gamma k_{(ij)}+\varepsilon_{l(ijk)}$$

Where: Yijk is the wheat stem rust disease intensity whereas peasant association k is nested within district J nested within zonei, μ is the overall mean, τi is the effect of the ith 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 kth peasant association within the jth district and i^{th} zone, and $\varepsilon l_{(ijk)}$ is the error term.

Analysis of variance was performed using SAS version 9.3 Software packages [15]. Significant differences across locations were separated using the LSD test at 5% levels of significance. The associations of disease incidence and severity with independent variables *viz*. altitude, variety growth stage and weed management was computed using simple correlation analysis.

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 to know the best predictors of disease Severity. Determination of regression intercept, slope and coefficient of determination were computed using SPSS [16].

Results

Distribution and intensity of wheat 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 was70% 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 2)**.

Incidence and severity of wheat stem rust

Disease incidence, varied significantly ($p<0.001$) 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 with the mean values of 47.86% and 42.46% respectively, 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 a 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% was recorded in the west wellaga zone followed by the Assosa zone with 63.9%. The lowest disease severity was observed in Bunobedele, 29.1% followed by 10.3% in the Jimma zone **(Table 3)**.

There was a significant ($p<0.01$) difference among districts for stem rust intensity. The mean disease incidence was ranged from a minimum of 3.7% to a maximum of 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 4)**. 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.

Distribution and intensity of wheat stem rust by peasant associations

Peasant associations are the unit within the districts in which farmers operating farming. The rust was also invariably found in all peasant associations although differ in the number of fields infested, ranged from 20-100%, the highest prevalence of 100% being recorded in Seko, Taja, Shoshor and Gebasenbeta. 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. 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% in the same order. However, the lowest severity was recorded *in Sito* (4.1%) followed by Garimalamesa, Ilala and Lalistu with mean values of 4.7%, 5.6% and 7.2% respectively.

In the localities of the Dedo district, the disease severity was very low as compared to other districts and recorded only in one wheat field of Ilala locality because wheat stem rust is more important at mid-altitude than at high altitude. In addition, this locality falls in the altitude range of 2212-2389 m.a.s.l **(Table 5)**.

Wheat stem rust status by altitude

Wheat stem rust survey was carried out at altitude ranges of 1545-2690 m.a.s.l, 1545- 1970 m.a.s.l in West wellega zone, 1595- 1902 m.a.s.l in Assosa zone, 1750- 2213 m.a.s.l in Bunobedele zone, 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.as.l, while the remaining 87 fell into 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) showed that there was a significant ($p<0.01$) difference between the two altitude classes in terms of incidence and severity of wheat stem rust and also prevalence in terms of descriptive mean values. 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% whereas 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 6)**.

Table 2: Altitude range and number of fields assessed across zones, 2019 cropping season.

Zones	Districts	Altitude rangesa (m.a.s.l)	No of fields assessed	Prevalence (%)
B/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
Southwestern(Mean)				68.4
W/wellaga	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. aIndicates altitude range from which samples were collected.				

Table 3: Stem rust Intensity across zones, 2019cropping season.

	Incidence (%)		Severity (%)	
Zones	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) within the column are not significantly different at p<0.05.				

Table 4: Incidence and Severity of wheat stem rust across districts, 2019 cropping seasons.

Regions	Zones	Districts	Disease incidence (%)		Disease severity (%)	
			Range	Mean	Range	Mean
	Bunobedele	Bedele	0-80	15.62d[c]	0-85	19.25[c]
		Gechi	0-50	13.21[d]	0-95	38.86[b]
Southwestern	Jimma	O/Nada	0-100	19.58[c]	0-85	16.89[c]
		Dedo	0-50	3.68[e]	0-35	4.82[d]
Western	W/wellega	Begi	0-100	47.86[a]	0- 95	66.51[a]
	Assosa	M/komo	0-100	42.46[b]	0-98	63.95[a]
Overall 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.						

Table 5: Distribution and Intensity of wheat stem rust across different peasant associations of the districts, 2019 cropping season.

Zone	District	PA	# of Field assessed	Prevalence (%)	Inci (%)	Sev (%)
B/Bede	Bedele	Lalistu	5	40	4.7[i]	7.2[ih]
		Digaja	5	60	21.8[ed]	28.0[fg]
		M/mute	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]
Jimma	O/Nada	B/jiren	5	60	6.7[igh]	29.9[ef]
		N/Bidaru	5	40	16.0[egdf]	10.8[ih]
		N/dawe	5	20	4.8[i]	10.0[ih]
		H/Toli	5	60	39.0[c]	26.2[fg]

	Dedo	G/lamessa	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}
W/wellega	Begi	G/senbata	5	100	51.2^{b}	64.7^{c}
		Lalo	5	80	51.8^{b}	63.5^{c}
		Dh/Wabara	5	100	40.7^{c}	85.8^{a}
		Rafis	5	100	47.6^{cb}	51.6^{d}
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}	29.9e
		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.
Where: Inc: incidence, Sev: severity, PA: peasant association, M/mute: Mirgamute, B/jiren: Bidojiren, N/Bidaru: Nadabidaru, N/dawe: Nadadawe, H/toli: Hundatoli, G/lamesa: Garimalamesa, G/senbata: Gebasenbata, B/Bede: Bunobedele, W/wellaga: West Wellaga, O/nada: Omonada, M/komo: Maokomo, Dh/wabara: Dhaladuwabara, LSD: least significance difference

Table 6: Prevalence, Incidence and Severity of wheat stem rust across altitude ranges, 2019 cropping season.

Altitude range	Class name	Field inspected	Field infested	Prevalence (%) **	Incidence (%)		Severity (%)	
					Range	Mean	Range	Mean
1545-2300	Mid-Altitude	87	72	82.7	0-100	30.9^{a}	0-100	45.3^{a}
2301-2690	High-Altitude	18	9	50	0-50	4.5^{b}	0-50	8.1^{b}
Total		105	81					
LSD(0.05)						4.89		5.47
CV %						38.9		29.84

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

The survey results revealed that mean incidence and severity of wheat stem rust decreased from mid-altitude to high-altitude and very low at high altitude >2600 m.a.s.l. The maximum stem rust disease severity recorded at mid-altitude was 97.2% while the maximum disease severity at high altitude was 32% on the farms. The highest disease severity 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.

Prevalence and distribution of wheat stem rust by the wheat variety

The survey results indicated that most of the farmers in the study areas are producing bread wheat, barley, maize, Sorghum, Soybean, Fababean, Teff and field pea. Most farmers grow the 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 obtain wheat seeds from both formal and/or informal sources including non-governmental organizations, governmental organizations and use their seeds of local varieties. The highest seed provider to farming communities were the Agricultural Bureau Offices of the study area, Agricultural Transformation Agency, Jimma Agricultural Research Center, Jimma University and Assosa Agricultural Research Center.

The farmers grow both improved and unknown local wheat cultivars of which improved cultivars occupied 91.43% of the total wheat fields. The restsare 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. Kingbird 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)**.

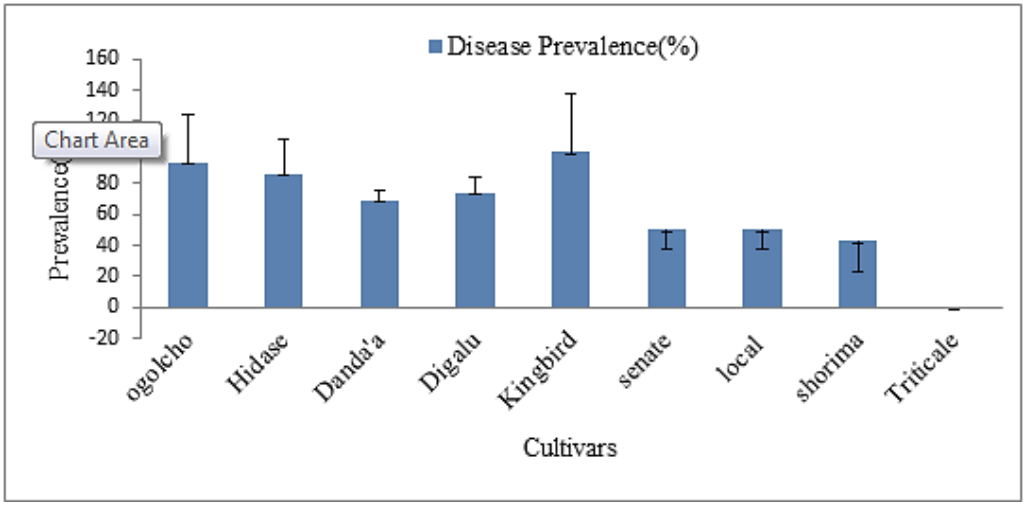

Figure 2 Disease prevalence by cultivars, 2019 cropping season.

There was a significant difference ($p<0.01$) in disease incidence and severity among the grown cultivars. The highest 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 were not significantly different statistically from each other. 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 surveyed wheat fields in the zones of study areas. It showed moderately susceptible to susceptible reactions with 26.6% mean incidence and 36.6% mean severity. The second commonly grown variety was Ogolcho and this variety showed moderately susceptible to susceptible stem rust reaction with mean incidence and severity of 39.6 and 61.2%, respectively **(Table 7)**.

However, most interestingly triticale cultivar was free from stem rust disease invariably with survey agro-ecologies and altitudes, this could be due to there is no virulent stem rust races to the cultivars contained horizontal resistance gene. The typical symptoms of wheat stem rust in the zones of study areas were illustrated below in **Figure 3**. In **Figures 3a-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 **(Figures 3a-3d)**.

Occurrence of wheat stem rust by wheat growth stages

Crop growth stages are essential for comparisons whenever 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 disease incidence (43.73 %) and severity (69.98%) was observed in the hard dough growth stage and followed by soft dough and milk growth stages. The lowest disease intensity was recorded from the flowering growth stage **(Table 8)**.

Association between stem rust intensity, growth stage, altitude and weed infestation

Disease intensity represented by incidence and severity were significantly correlated between themselves and with altitude, crop growth stage and level of weed infestation **(Table 9)**.

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 it's excluded predictor variable from stepwise regression models **(Table 10)**.

Table 7: Mean incidence and severity of wheat stem rust by varieties, 2019 cropping season.

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]	25.3[b]
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) within the column are not significantly different at p<0.05. Where: R- resistant, MR- moderately resistant, MS- moderately susceptible and S- susceptible.

Figure 3 A-D: Typical symptoms of stem rust during a survey in the study field, 2019 cropping season.
Footnote: *A, B, C and D indicates picture taken from Westwellega, Jimma, Bunobedele and AssosaZone respectively.

Table 8: Occurrence of wheat stem rust by wheat growth stage during, 2019 growing season.

Growth stages	Number of fields**	Proportion of field	Prevalence (%)	Incidence (%)	Severity (%)
				Mean	Mean
Flowering	1	0.95	0	0.00[c]	0.00[c]
Milk	45	42.8	37.7	26.0[b]	36.4[b]
Soft dough	55	52.4	27.3	26.4[b]	40.1[b]
Hard dough	4	3.8	100	43.7[a]	69.9[a]
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 at the dough stage

Table 9: 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	-0.03ns	0.01ns
Weed Infestation				1	0.10ns
Altitude					1

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

Table 10: Stepwise multiple regression of disease severity for significant independent variables in south western and western Ethiopia, 2019 cropping season*.

Model	Predictors variables	Disease severity	
		Coefficient	**Sum square (SS)**
	Disease Severity	Disease Severity	Disease Severity
	Growth stage	20.1	223689.5
	R^2		47.50%
	Ad R^2		21.70%
	Pr>F		0.001
2	Intercept	14.07	-
	Growth stage	18.4	223689.5
	Altitude	-22.9	31075.9
	R^2		54%
	Ad R^2		21.70%
	Pr>F		0.0001

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

Discussion

Wheat stem rust was widely distributed and important in Western and Southwestern Ethiopia. It is more widespread and important in western Ethiopia. The reasons for a more widespread of wheat stem rust disease in the western zone than in the Southwestern zones might be 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 and drier climate is predicted to benefit the urediniospores production and escape to a free atmosphere, leading to more spores being released from a similarly infected field [17]. A warmer climate could lead to more days with suitable temperatures for sporulation (between +5°C and +40°C). Thus, a shorter incubation stage and higher spore production rate lead to more spores produced by a similarly infected field.

According to the traditional classification system of agro-ecological zones of Ethiopia; Areas in 500-1500 m, 1500-2300 m and 2300-3200 m are classified to lowlands, midlands and highlands respectively [18]. Hence, this finding is in agreement with that stem rust is not threatening wheat at higher altitudes where the temperature is commonly very low [19]. Other authors reported that the highest level of stem rust infection has been reported in mid-altitude ranges of from 2001 to 2500 m.a.s.l, hence mean incidence and severity increased from low-altitude to mid-altitude and decreased at high altitude [20]. Inline, complete (100%) disease incidence was recorded from Maokomo districts of Taja localities at below 2473 m.a.s.l in the present study.

Similar report from Ethiopia indicate that the highest prevalence of 68% of stem rust was recorded at altitude range 1494-1800 m.a.s.l followed by 66.1% prevalence at 1801-2300 m.a.s.l, and none in higher altitudes >2300 m.a.s.l during 2010 cropping season [21]. The study in northern Ethiopia also stated that stem rust of wheat disease was very important at the mid-altitude range [22]. The importance of stem rust at low to mid-altitude might be associated with the widespread cultivation of susceptible commercial varieties and the appearance of new virulent races due to suitable climate change.

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. Generally, most wheat cultivars succumb to rusts including stem rust shortly after their release to farm for production. The high susceptibility of wheat varieties to stem rust might be due to the climatic change especially, warmer temperature and adaptation of the pathogen to the wider environmental conditions [19]. 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 [7].

Analysis of variance (ANOVA) revealed that the stem rust severity along with incidence was significantly ($p<0.01$) differed by growth stages. Stem rust intensity was not on crops at flowering stages during the survey. Such effects of crop growth stages is in agreement with a previous study conducted at Tigrayi Region of Ethiopia, that higher wheat stem rust disease intensity was reported in the late crop growth stage particularly from the early dough stage to the hard dough stage [22]. 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 significantly different from each other. Both incidence and severity showed the trend of increasing 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 agroecologies that varies in planting dates like southwestern

and western Ethiopia (July-August), characterized with various planting dates, early to late plantings allow stem rust spores to move from advanced growth stages to different late-planted wheat fields mainly by wind. Thus, planting wheat at optimum planting dates as early as possible and growing early maturing cultivars would help to reduce the time of exposure of the crop to the pathogen, and reduces the time frame for establishment of urediniospores and ultimately limits the growth period of the fungus [24].

The importance of wheat stem rust was increasing with mounting in the growth stage of the crop and therefore, the prevalence and intensity of the disease were highest during the soft dough to hard dough development growth stage. The late growth stage of the crop is an important period to reach stem rust disease of wheat at its -maximum severity levels [12]. Wheat Stem rust disease severities as high as 80-100% at soft dough to hard dough growth stage was also indicated [25].

In the case of correlation analysis, disease severity was linearly and positively correlated 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 correlation between 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 that wheat stem rust is more important at mid altitudes than at high altitude [21,22,26]. Similarly, there was a significant ($P<0.05$) and positive correlation between wheat 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, where the advanced wheat growth stages meet, most probably with increased temperature to the level of optimum temperature favoring the infection and disease development. Such a result is in line with the findings that incidence and severity are positively correlated with the growth stage of wheat crops, particularly with the late crop growth stages [24].

The negative relationship between altitude and severity of wheat stem rust in Ethiopia were also reported by [26]. In this study, there was also highly significant ($p<0.001$) and positive correlation between weed infestation levels and disease incidence ($r=0.36$) and severity ($r=0.43$). This implies that the disease became more intense on the weedy farm. Likewise, wheat stem rust is more severe and intense in the weedy farm than the well-managed field because of canopy [27]. The reason why the disease was more intense in the weedy farm is related to the contribution of the canopy for the epidemiology of wheat stem rust. Moisture in the weedy canopy can favor germination and initiation of rust pathogen

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 X2=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.

Present wheat stem rust survey activity implied that stem rust was prevalent in all survey zones of the region at variable levels and was widely distributed in all surveyed areas. Wheat stem rust incidence and severity vary from district to other districts in the west and southwest Ethiopia. Wheat stem rust was prevalent in all wheat producing zones and districts of the west and southwest Ethiopia included in this survey. Wheat stem rust incidence and severity showed a noticeable variation between zones. The current study revealed that wheat farms surveyed in West and southwest Ethiopia are under wheat stem rust pressure and consequently, management should be required to control the disease in an effective, affordable and sustainable approach.

Furthermore, to get the full depiction of the distribution and importance of wheat stem rust disease 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 the 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.

Conclusion

The data 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 confirmed 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 high land 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 and weed infestation is not a significant predictor of disease severity.

Generally, this study investigates the wider spatial distribution of stem rust disease of wheat crops that varies in prevalence,

incidence and severity. It indicates the importance of *Puccinia graminis* f.sp. *tritici* in western and southwestern Ethiopia. Thus, it is beneficial for wheat producers of the study area to monitor and mitigate a newly emerging and reemerged race through the use of fungicide during the epidemic time and by the cultivation of resistant variety for sustainable disease management. This study helps the national rust research program to undertake regular monitoring of the pathogen across the areas.

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Data Availability

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors state that there is no conflict of interest.

Ethical Statement

This study did not engage in any human or animal testing.

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