Distribution of Wheat Stem Rust Disease in the Northern Zone and Southern Highlands of Tanzania: Comparative Epidemiology and Implications for Management

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Abstract

Surveys were conducted in farmers' fields in the northern and southern highlands of Tanzania to determine the distribution of wheat stem rust disease caused by Puccinia graminis f. sp. tritici and response of farmer selected wheat varieties to the disease under their natural habitat. Regions surveyed in the northern zone included Manyara, Arusha and Kilimanjaro, while in the southern highlands; the survey was carried out in Iringa, Njombe and Mbeya. Four quadrants from every corner of the surveyed field and one from the center, 1 m2 each were used to assess rust disease incidence (%) by counting the infected plants divided by total plants per quadrant times one hundred. Rust disease severity was assessed by using a 0-9 scale: 0=healthy plants, 1=1-10% stem area with rust pustules, 3=11-25% stem area with rust pustules, 5=26-50% stem area with rust pustules, 7=51-75% stem area with rust pustules, 9=>75% stem area with rust pustules. Both rust disease incidence and severity was log transformed before analysis of variance. A total of 17 wheat fields were found infected, 10 from the northern zone and 7 from the southern highlands. In the northern zone, 50% of the fields had disease incidence above 40% (P>0.05). In the southern highlands, varieties Sifa and Juhudi were tolerant with disease incidence of 10% in Mbeya and Njombe respectively. However, the disease incidence of 90% was recorded in Mbeya region on the same Juhudi variety. Generally, the mean disease incidence recorded were 33.5% and 35.7% from northern and southern highland zones respectively. Njombe with the same variety Juhudi had 10%, rust disease incidence, indicating presence of a variant of Puccinia graminis f. sp. tritici with higher virulence. The best performing variety in Mbeya was found to be Sifa whose fields had an incidence of 10%. In the northern zone the disease incidence in Manyara, Kilimanjaro and Arusha ranged from 20-60 % with the susceptible variety Mbayuwayu being preferred by most farmers instead of the variety Ngamia grown in Manyara with incidence of 10% (P>0.05). The most tolerant or resistant varieties were Ngamia and Sifa grown in northern and southern highlands zones respectively. There was a distinct difference in disease severity between the two agro-ecological zones with more severity being observed in the northern zone. Disease severity was mostly proportional to disease incidence. The study revealed wheat stem rust potential hotspots, resistant varieties and provides background information for future research and development of management strategies of wheat stem rust disease.

Keywords: disease incidence, disease severity, variety reaction, pathogen variant

Introduction

Wheat stem rust is a fungal disease caused by *Puccinia graminis* f. sp. *tritici* (Roefls and Martins 1998). The disease is largely distributed in wheat growing countries around the globe and is considered as one of the most important diseases associated with the crop (Lemma *et al.,* 2015). Wheat is the fifth most important cereal crop in Tanzania after maize *(Zea mays)*, sorghum *(Sorghum vulgare)*, pearl millet *(Pennisetum glaucum)* and rice *(Oryza sativa)* (MOAC, 2000; FAO, 2010). Diseases of wheat such as stem rust play a role in yield reduction along with other biotic and abiotic factors (Cerda *et al.,* 2017).

Puccinia graminis f. sp. *tritici* is an obligate parasite. The pathogen needs to infect wheat to complete its life cycle (Bettgenhaeuser *et al.,* 2014). Initial infection of wheat begins with wind-blown urediniospores that land on green wheat plants (Lucas *et al.,* 1992). Successful infection of host depends on favourable weather conditions for germination such as warm humid conditions and a temperature range of 15-30°C (Wiese, 1987; Knott, 1989). The fungus infects stems, leaves, sheaths, glumes and awns during the booting stage to three weeks before harvesting (Roefls *et al.,* 1992). It lowers the value of the crop's forage and predisposes the plants to other diseases consequently interfering with its physiological processes (Ghana *et al.,* 2011). The stems weaken and plants lodge. This makes mechanical harvesting impossible leading to reduce or no yield in endemic situations (Steve *et al.,* 2014). Environmental conditions conducive for disease development coupled with growing of susceptible wheat varieties can eventually lead to an epidemic of wheat rust (Singh *et al.,* 2016). Although rare, it's important to assess the potential of a stem rust epidemic occurring and use this information as a background for developing strategies of prevention.

Wheat farming in Tanzania is mainly carried out in the northern zone and southern highlands under rain fed conditions. Major wheat producing regions in the northern zone are Arusha,

Kilimanjaro and Manyara. In the southern highlands, most production is done in Njombe and Mbeya Regions. There is minimum reproducible information on the distribution of stem rust and the level of disease in wheat fields from these regions. Pin-pointing infected areas, determining varieties grown per infected locale and assessing geographical factors influencing infection levels will help develop efficient management schemes tailored to these regions. A comprehensive survey was conducted in the northern zone and southern highlands of Tanzania in order to obtain information that would fill the aforementioned gaps.

Materials and Methods

Field surveys

Surveys were conducted in April 2012 and June 2015. Wheat fields in Manyara were surveyed in mid-April while in Arusha and Kilimanjaro were conducted in mid-May. Regions in the southern highlands (Njombe and Mbeya) were surveyed in early June. The timeline of the surveys was adjusted in this manner to coincide with varying times of booting and ripening stages across the region when disease levels are high. A total of three fields per village, three villages per district across three districts per region were assessed for wheat stem rust disease. The wheat variety found in each field was also recorded. Using a garminetrex global positioning system (GPS) device, GPS coordinates and elevation of each field were determined. The GPS coordinates were plotted on a map using the online software My Maps by Google to provide a map of satellite aerial view of wheat rust disease distribution. Distance between fields grown with the same variety but significantly different severity and incidence levels was estimated on the map scale to determine the potential of a successful urediniospore migration to the field with lower disease levels. The minimum and maximum temperature and humidity were recorded from weather stations from each locality.

Wheat rust disease assessment

Rust disease incidence in each field was assessed in five 1 m^2 quadrants (1 m x 1 m). Four quadrants were from each corner of the field and the fifth one approximately to the center. An average of 10 plants was assessed along a diagonal within a quadrant to make a total of 50 plants and those with symptoms of stem rust disease were counted. The sum of number of infected plants per quadrant was divided by 50 and multiplied by 100% to determine disease incidence per field. Mean rust diseases incidence per district was calculated in Genstat option for computing descriptive statistics and data per district were log transformed and used as replications of the dependent variable in a one-way analysis of variance (ANOVA) with the region as an independent variable. Mean separation was carried out using Bonferroni's' test at $p \leq 0.05$.

Rust disease severity was evaluated using a 0-9 scale developed by McNeal *et al.* (1971) where 0=healthy plants, 1=1-10% stem area with rust pustules, 3=11-25% stem area with rust pustules, 5=26-50% stem area with rust pustules, 7=51-75% stem area with rust pustules, 9=>75% stem area with rust pustules. The rust disease severity scores of each plant assessed per field were added and divided by 50 (total number of wheat plants assessed) to get the mean severity score per field. Mean severity scores per field were log transformed and used as replications of the dependent variable in a one-way ANOVA with the region as the independent variable. Mean separation was done using Bonferroni's' test at $P \leq 0.05$.

Results

Field survey

A total of 17 wheat fields were found with wheat plants infected with *Puccinia graminnis* f. sp. *tritici* (Figure 1). In the northern zone, ten fields had wheat stem rust disease, of which 50% were from Manyara with 40% disease incidence. Variety Mbayuwayu was found grown in 30% of the fields in the northern zone. The other seven infected fields were from the southern highlands with 57.1% coming from Mbeya, hence making disease distribution between the two regions almost even (Table 1). Temperatures in the northern zone ranged from 19-24°C while those in the southern highlands were in the range of 9-12°C. Specifically,

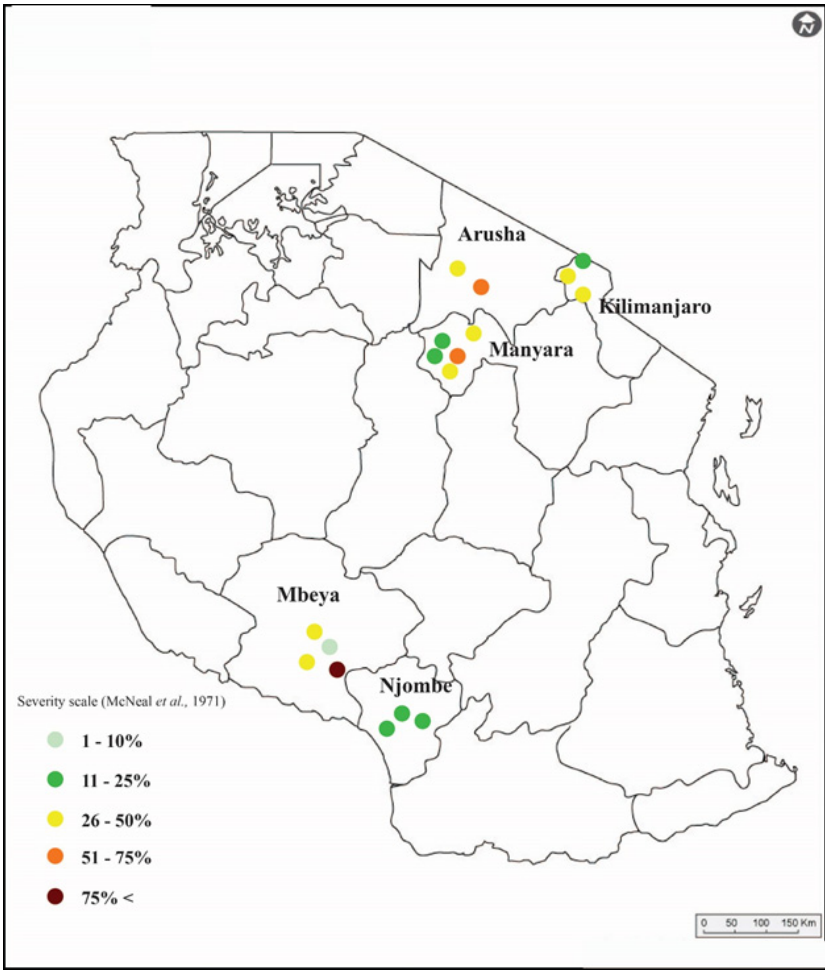

Figure 1: Map of Tanzania depicting distribution and severity of wheat stem rust in wheat fields surveyed in the northern zone and southern highlands in 2012 and 2015.

Table 1: Geographical positions and varieties grown in wheat fields surveyed for stem rust disease in the northern zone and southern highlands of Tanzania

Region	District	Variety	Latitude	Longitude	Elevation (m.a.s.l)
Manyara	Hanang	Kariega	4°28’33’’S	35°00’14’’E	1773.94
	Hanang	Mamba	4°26’32’’S	35°12’25’’E	1776.07
	Hanang	Ngamia	4°37’15’’S	35°12’25’’E	1764.79
	Babati	Mbayuwayu	4°23’24’’S	35°36’21’’E	1398.06
	Katesh	Local	4°53’58’’S	35°28’33’’E	1781.62
Arusha	Karatu	Mbayuwayu	3°21’37’’S	35°33’12’’E	1534.17
	Monduli	Selian	3°32’42’’S	36°10’56’’E	1369.98
Kilimanjaro	Hai	Mbayuwayu	3°55’09’’S	37°43’32’’E	1343.59
	Hai	Selian	3°24’11’’S	37°19’36’’E	1482.61
	Hai	Riziki	3°06’18’’S	37°51’31’’E	1398.27
Mbeya	Mbeya rural	Juhudi	8°73’19’’S	33°42’46’’E	1756.79
	Mbeya urban	Juhudi2	8°56’46’’S	36°53’51’’E	1784.67
	Mbeya urban	Sifa	8°14’27’’S	36°12’53’’E	1801.43
	Mbeya urban	Sifa2	8°01’03’’S	34°53’47’’E	1234.51
Njombe	Njombe	Juhudi	9°33’47’’ S	34°47’31’’E	1581.54
	Njombe	Njombe 7	9°59’58’’S	34°12’08’’E	1965.32
	Makete	Local	9°19’10’’S	34°43’10’’E	2943.33

mean regional temperature range, humidity and annual rainfall were 19.3-20.4°C, >70%, 1052 mm in Arusha, 19.8-21.5°C, 60-75%, 927 mm in Kilimanjaro, 20.3-24.2°C, 50-65%, 983 mm in Manyara, 11.0-12.0°C, >75%, 661 mm in Njombe and 9.0-11.0°C, >75%, 969 mm in Mbeya. In conjunction with humidity values recorded, the general weather description in the southern highlands can be described as cold and humid while the northern zone is warm and humid.

Rust disease incidence and severity assessment

General mean results show rust disease incidence of 33.5% and 35.7% from northern and southern zones respectively. Rust disease incidence clearly demonstrated variation in genotype (variety) interaction to the environment. Wheat fields with the variety Ngamia in Manyara had significantly lower incidence compared to other fields at P>0.05 (Figure 2). The highest disease incidence in the northern zone was observed in Hanang, Manyara in a field with the variety Mamba (60%). All fields growing the varieties obtained from Agriculture Research Institute, Selian (all except Kariega, Ngamia and local varieties) in the northern zone had rust disease incidences above 40% (Figure 2). Surveyed wheat fields across the southern highlands with the variety Sifa had significantly lower rust disease incidence levels suggesting the varieties ability to tolerate infection. The highest disease incidence recorded was in Mbeya (90%). The variety grown in this field was Juhudi which showed a better performance in a field in Njombe where the incidence was 10% (Figure 2).

Generally, many fields in all regions were affected moderately (score 5 on 0–9 scale) at 26–50% disease severity. A large number (35%) of fields affected were those in Manyara, followed by fields in Mbeya (25%), Kilimanjaro

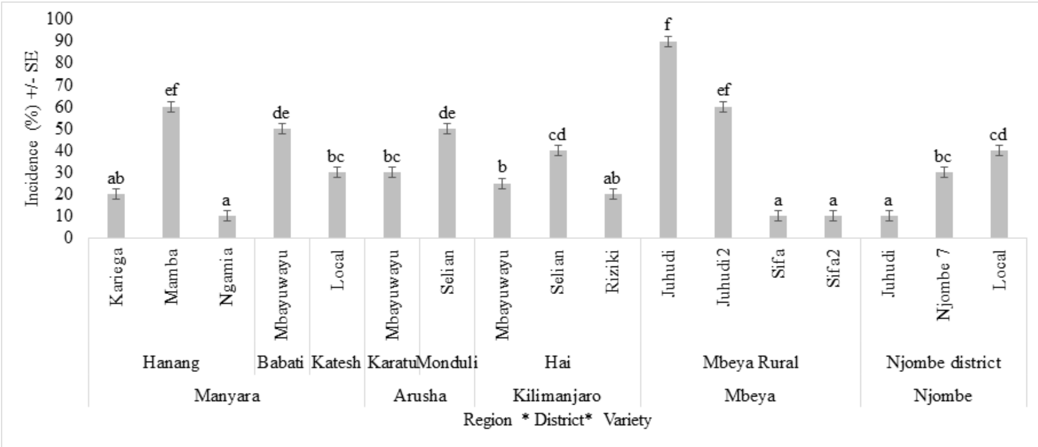

Figure 2: Incidence of stem rust in studied wheat fields showing Ngamia, Sifa and Juhudi varieties being tolerant to disease in Manyara, Mbeya and Njombe regions respectively. The mean rust disease incidence was 33.5% and 35.7% in northern and southern zones respectively.

and Njombe (15%) and Arusha (10%). National wise rust disease severity was higher (26–50%) in 60 % of fields, moderate (11–25%) in 15% and highest (51–75%) in 10% of the fields. Within agro - ecological zones the difference between mean rust disease severities was insignificant at P>0.05.

Mean severity of stem rust in the southern highlands was slightly lower than that of the northern zone. Only 2 fields out of 7 in the southern highlands had disease severity levels above 40% (Figure 3). In the northern zone, 50% of the fields found infected had higher rust disease severity levels in the southern zone.

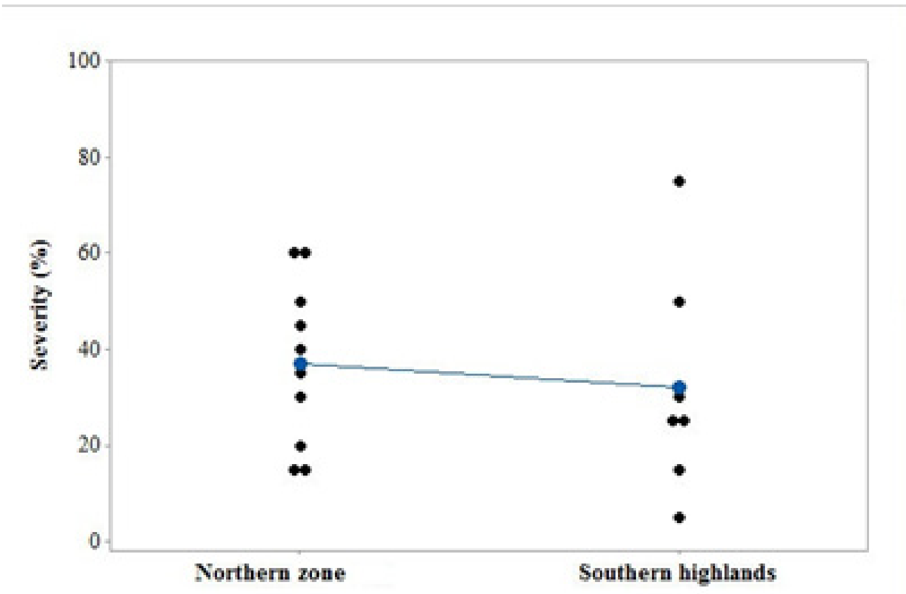

Figure 3: Comparison of individual mean severity levels of wheat stem rust between the northern zone and southern highlands. The blue line connects the grand mean severity scores of the two agro- ecological zones.

Discussion

The observed differences and similarities of disease incidence and severity between surveyed wheat fields can be attributed to variation of parameters of the disease triangle. Successful infection requires interaction between a virulent pathogen and a susceptible host in an environment conducive for pathogenesis (Engering *et al.,* 2013). Variation of severity and incidence within similar agro ecological zones eliminates environment as one of the defining factors hence this may be attributed to variations in host (wheat varieties) and pathogen *(Puccinia graminnis* f. sp. *tritici)* (Burdon and Thrall, 2008). In the southern highlands, wheat fields with the variety Sifa had stem rust incidence of 10% which is by far lower than incidences in fields where Njombe 7 and Local varieties were grown. The variety Sifa is a product of a hybrid cross between NL45 and Jingxuan 9. The Jingxuan 9 variety is a derivative of the variety Veery which contains the gene Yr 7 that confers resistance to rust (Rehman *et al.,* 2013). The variety Ngamia showed a similar reaction in wheat farms in the northern zone and farmers obtained it from Kenya due to its resistance to stem rust. However, there was an interesting pattern of disease incidence and severity in farmers' fields growing the variety Juhudi in the southern highlands. In Mbeya, two fields with Juhudi variety had severity levels of 75% and 50% and were identified as outliers while the same variety grown in Njombe district had stem rust incidence of 15%. The differences in disease severity within the same agro-ecological zone when a similar variety is grown are indication of pathogen variability (Agrios, 2004; Jain *et al.,* 2009). This suggests that there is a variant of Puccinia graminis in Mbeya that has higher pathogenic potential (virulence) than the ones present in Njombe district. The field with Juhudi wheat variety in Mbeya with rust disease severity level of 75% (8°73'19''S 33°42'46''E) and the one with 15% severity in Njombe (9°33'47'' 34°47'31''E) are separated by a distance of 134 km. Urediniospores of *Puccinia graminis* can travel by wind at a distance of over 1700 km (Hovmøllera *et al.,* 2002) hence severity levels in wheat farms in Njombe may increase due to migration of a highly virulent variant from Mbeya. A similar scenario was established by Hodson *et al.* (2012) when disease severity of wheat stem rust in Northern Tanzania increased due to introduction of *Puccinia graminis* race TKSTT of the UG99 race group of Uganda through Southern Kenya to the region.

Humid and warm conditions are favourable conditions for development of wheat stem rust (Agrios, 2004). The optimal temperature range for sporulation of *Puccinia graminis* urediniospores is 15-24°C (Elahinia, 2000). Similar conditions were found in the Northern zone which had more rainfall and humidity than the southern highlands and a temperature range of 19-24°C. Rainfall deposits airborne spores onto leaf surface and provide leaf with wetness preferred by the fungi. The cooler conditions in the southern highlands are favorable for wheat stripe rust disease. However, the main contributing factor to the higher disease levels seen in the northern zone may be due to susceptibility of farmer preferred varieties. Only two out of ten farmers grew the imported varieties Mamba and Kariega. Such conditions cause inoculum build up and risk an epidemic development.

Immediate measures need be taken to prevent disease spread and lower infection. Replacing local varieties with improved high yielding varieties bred to resist rust diseases would reduce risks of epidemics. As this study demonstrated, there is a need for screening and identifying variants of *Puccinia graminis* f. sp. *tritici* causing stem rust in wheat fields in Tanzania. For improved varieties to be effective, their resistance spectrum needs to include variants present in the country (Lemma *et al.,* 2015). There is a possibility of existence of a highly pathogenic variant in Mbeya (8°73'19''S°, 33°42'46''E) which can be isolated and used for resistance screening of imported varieties by local breeders.

The current study also highlights the importance of periodic monitoring stem rust spores migration within agro-ecological zones in attempts to avoid spread and creating intra quarantine zones. This can help reduce disease spread by latently infected seedlings being transported from one region to another and create early warning systems to aid farmers in preparation of control measures.

Local farmers can also reduce disease spread by spraying fungicides approved by Tanzania pesticide research institute (TPRI) at rates described by the manufacturer. Good examples of these include Celest top 313 and Tilt 250 EC (TPRI, 2015). To reduce environmental impact of fungicide levels, cultural practices such as crop rotation, weeding and removal of alternate host barberry *(Berberis vulgaris)* is recommended (Ratnadass *et al.,* 2011). Extension workers need to be more involved in the process of training farmers on management of wheat stem rust on a regular basis.

Conclusion

This study showed that wheat varieties Ngamia, Sifa and Juhudi were tolerant to wheat stem rust disease in Manyara, Mbeya and Njombe regions respectively. The tolerance was location specific per variety, for example, Juhudi was susceptible in Mbeya. The information provided on distribution of wheat stem rust, good performing varieties per agro ecological zone and existing factors influencing disease levels will be very useful in strategizing for monitoring and controlling of the disease. The desired economic impact of wheat farming will be achieved by rigorous research and implementation of solutions to problems that hinder its production. It's therefore, important that further studies be carried out on screening for wheat varietal resistance and pathogenicity test of the wheat stem rust pathogen.

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