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Research Article

Evaluation of Bread Wheat Accessions Conserved in the Ethiopian Biodiversity Institute Genebank for Identification of New Sources of Resistance to Yellow and Stem Rust Diseases

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ABSTRACT

Wheat is an indispensable food crop worldwide, including in Ethiopia. The Ethiopian government is striving to achieve wheat self-sufficiency through initiatives such as expanding production areas, promoting irrigated wheat, and bridging yield gaps. However, stem rust and yellow rust remain the most serious threats to wheat production due to the emergence of virulent races of Puccinia graminis f. sp. tritici and temperature-adapted races of P. striiformis f. sp. tritici, which can cause yield losses of up to 100%. The current study aimed to evaluate 139 bread wheat accessions along with six check varieties under natural infection conditions for both stem rust and yellow rust resistance. The entries were planted in an augmented design across two yellow rust hot-spot locations and one stem rust hot-spot location to assess their slow-rusting characteristics. Slow-rusting resistance at the adult-plant stage was evaluated using final rust severity (FRS) and the average coefficient of infection (ACI). Based on combined FRS and ACI data, most of the tested accessions and all check varieties exhibited high disease severity. However, five accessions viz., 31346, 31405, 31643, 34209, and 34797 consistently showed low FRS and ACI values across locations and years, indicating promising levels of slow-rusting resistance. These accessions, exhibiting durable resistance to both stem and yellow rust, could be backcrossed with high-yielding but susceptible Ethiopian wheat varieties to reduce yield losses and enhance the genetic diversity of the national wheat germplasm.

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Introduction

Wheat (Triticum aestivum L.) is one of the most important staple food crops and a major component of the diet for more than 2.5 billion people worldwide (Adnan et al., 2023). It contributes over 21% of global caloric intake and 20% of the protein supply, with demand steadily increasing in developing countries (Lucas, 2012; Bentley et al., 2022). Globally, wheat is

cultivated on approximately 217 million hectares, making it the most widely grown crop, with an estimated annual production of 752 million tons (FAOSTAT, 2020).

In Ethiopia, common wheat is among the leading cereal crops in both production and consumption and plays a crucial role in national food security (FAOSTAT, 2020; CSA, 2022). It contributes about 12% to the daily per capita calorie intake, ranking third after maize and sorghum (Guush et al., 2011). Wheat is cultivated under rain-fed, irrigated, and belg (short-rain) season conditions, with rain-fed production accounting for the largest share. According to CSA (2022), over five million farmers cultivate wheat on about 2.1 million hectares (1.7 million ha rain-fed and 0.4 million ha irrigated), producing roughly 6.7 million tons annually. The average yield is approximately 3.0 t ha^{-1} under rain-fed and 4.0 t ha^{-1} under irrigated conditions.

Globally, wheat breeding has substantially contributed to yield improvement; however, in recent decades, the annual rate of yield gain has stagnated (Dixon et al., 2009). In Ethiopia, the national average yield (3-4 t ha^{-1}) remains below the experimental potential yield of over 5.1 t ha^{-1} (Tadesse et al., 2022; Alemu et al., 2023). Sustainable wheat production and supply are increasingly constrained by rapid population growth, climate change, and various biotic and abiotic stresses (Dixon et al., 2009). Among the biotic factors, stem rust and yellow (stripe) rust are the most destructive diseases (Hovmøller et al., 2016), causing global yield losses estimated at about 45 million tons annually, valued at approximately USD 9 billion (Oerke, 2006). In Ethiopia alone, wheat rusts are estimated to cause economic losses amounting to tens of millions of USD each year (Meyer et al., 2021).

Stem rust and yellow rust continue to pose major threats to wheat production in Ethiopia. Several epidemics have occurred in recent decades, including a severe yellow rust outbreak in 2010 (Olivera et al., 2015) and a devastating stem rust epidemic caused by race TKTTF in 2013, which resulted in yield losses of up to 100%, with average losses around 50% (Sanders et al., 2011). These epidemics are primarily associated with the breakdown of resistance genes, the emergence of new virulent races adapted to warmer environments, and the pathogen's ability to mutate rapidly, reproduce profusely, and disperse efficiently over long distances through airborne spores (Singh et al., 2005).

Although several management approaches, chemical, biological, and cultural, have been explored, the most effective and sustainable strategy for controlling wheat rusts remains the development and deployment of resistant varieties, which are both cost-effective and environmentally friendly (Chen, 2013). Over the past six decades, more than 102 bread wheat varieties have been released in Ethiopia (MoANR, 2022; Solomon et al., 2022) to enhance yield potential and disease resistance. However, many of these varieties have shown short-lived resistance due to the rapid evolution of virulent pathogen races. Therefore, this study was conducted to comprehensively evaluate the field performance of selected bread wheat genotypes for resistance to stem rust and yellow rust across representative highland and midland agro-ecological zones of Ethiopia.

Materials and Methods

Description of the study area

The experiment was conducted at two yellow rust hotspot locations, Meraro and Bekoji Research Stations, and one stem rust hotspot location, Kulumsa Research Center, all situated in the Arsi Zone of southeastern Ethiopia.

Meraro Research Station is located at 07°24′27″N and 39°14′56″E, at an altitude of 2,990 meters above sea level. The site receives an average annual rainfall of 1,196 mm and represents a highland, frost-prone agroecology. The mean minimum and maximum temperatures are 5.7°C and 18.1°C, respectively (Birhan, 2011).

Bekoji Research Station is situated at 07°32′37″N and 39°15′21″E, at an elevation of 2,780 meters above sea level. It receives an average annual rainfall of 939 mm, with mean minimum and maximum temperatures of 3.8°C and 20.4°C, respectively. Both Meraro and Bekoji are recognized yellow rust hotspot sites, making them suitable for yellow rust screening nurseries and for identifying promising germplasm under natural disease pressure (Birhan, 2011).

Kulumsa Research Center is located at 08°01′10″N and 39°09′11″E, at an altitude of 2,200 meters above sea level. The site receives an average annual rainfall of 820 mm and represents a mid- to highland agroecology with favorable moisture conditions. The mean minimum and maximum temperatures are 10.5°C and 22.8°C, respectively. The predominant soil type is fertile loam, which supports healthy wheat growth. The site provides optimal conditions for screening wheat germplasm against stem rust, facilitated by the use of spreader rows to ensure uniform disease development (Birhan, 2011).

Based on their respective climatic and ecological

characteristics, Meraro and Bekoji were used as screening sites for yellow rust, while Kulumsa served as the primary site for stem rust screening.

Planting materials

A total of 139 bread wheat germplasm accessions, (Table 1) conserved at the National Genebank of the Ethiopian Biodiversity Institute were evaluated, along with six commercial cultivars obtained from the National Bread Wheat Breeding and Improvement Center, Kulumsa. The commercial cultivars were included as susceptible checks for comparison.

Most of the check varieties were previously released and widely cultivated mega varieties in the study areas but have since become susceptible to either stem rust or yellow rust. Therefore, they were used as local susceptible checks during field phenotyping to facilitate the identification of resistant or slow-rusting genotypes under natural infection conditions.

Table 1. List of bread wheat accessions and check varieties used in this study.

Number	Accession ID	Number	Accession ID	Number	Accession ID	Number	Accession ID
1	5011	38	31401	75	34220	112	34688
2	5200	39	31405	76	34225	113	34698
3	5380	40	31406	77	34228	114	34704
4	5548	41	31412	78	34231	115	34706
5	5585	42	31438	79	34233	116	34710
6	5661	43	31443	80	34236	117	34712
7	5694	44	31510	81	34239	118	34714
8	5774	45	31543	82	34245	119	34718
9	6873	46	31554	83	34248	120	34720
10	6883	47	31573	84	34255	121	34722
11	6930	48	31583	85	34267	122	34730
12	7917	49	31585	86	34270	123	34742
13	8390	50	31593	87	34280	124	34745
14	8393	51	31595	88	34284	125	34752
15	31130	52	31596	89	34291	126	34754
16	31134	53	31600	90	34309	127	34786
17	31147	54	31605	91	34311	128	34797
18	31161	55	31619	92	34329	129	34873
19	31164	56	31621	93	34332	130	34900
20	31186	57	31623	94	34335	131	34902
21	31196	58	31627	95	34341	132	34906
22	31204	59	31630	96	34349	133	34909
23	31224	60	31632	97	34362	134	34942
24	31233	61	31635	98	34405	135	206691
25	31244	62	31638	99	34419	136	206693
26	31247	63	31643	100	34435	137	206697
27	31257	64	31792	101	34480	138	213209
28	31258	65	31813	102	34608	139	214716
29	31261	66	31816	103	34621	Check varieties	
30	31270	67	31818	104	34626	140	Kubsa
31	31273	68	31832	105	34633	141	Morocco
32	31301	69	31836	106	34640	142	Digalu
33	31346	70	31841	107	34642	143	PbW343
34	31351	71	31848	108	34655	144	Kingbird
35	31355	72	31856	109	34658	145	Wane
36	31357	73	34209	110	34667	-	-
37	31386	74	34218	111	34676	-	-

Spreader rows and field management

A mixture of three wheat cultivars viz., Morocco, PBW343, and Digalu was used as spreader rows in the field nurseries. Morocco is a universally susceptible cultivar to both stem and yellow rusts, while PBW343 and Digalu are susceptible to most stem and yellow rust races prevalent in Ethiopia. The spreader cultivars were sown ten days before the test entries to ensure uniform disease development and sufficient infection pressure across the experimental field, thereby enabling accurate evaluation of the test accessions.

Field layout and disease assessment

To assess the slow rusting resistance of wheat genotypes under field conditions, the test accessions and check varieties were arranged in an augmented design. Each entry was planted in a two-row plot, 1 m in length, with 0.2 m spacing between rows, 0.5 m between plots, and 1 m between blocks. The seed rate was maintained at 150 kg ha^{-1}, and DAP and urea fertilizers were applied at the recommended regional rates. Weed control was performed manually through hand weeding.

Disease severity was assessed as the percentage of leaf area affected, following the modified Cobb's scale. Scoring commenced when the first yellow or stem rust symptoms appeared on the susceptible checks and continued at 14-day intervals until the early dough stage. Both disease severity and infection type were recorded simultaneously, following the method described by Peterson et al. (1948). Host response types were categorized based on disease severity and infection reaction (Table 2).

Results and Discussions

A wide variation in response to yellow and stem rust was observed among the tested bread wheat accessions, with disease severity ranging from 0 to 90% for yellow rust at Meraro and Bekoji, and from 0 to 80% for stem rust at Kulumsa. Disease pressure was high across all testing seasons, as indicated by the susceptible check varieties 'Kubsa' and 'Morocco', which showed up to 90% disease severity at their respective locations (Table3).

For yellow rust, among the 139 accessions evaluated at Meraro, 3 (2.1%), 0, 9 (6.4%), 2 (1.4%), 7 (5.0%), 20 (14.4%), 42 (30.2%), and 56 (40.1%) accessions exhibited immune, resistant, resistant to moderately resistant, moderately resistant, moderately resistant to moderately susceptible, moderately susceptible, moderately susceptible to susceptible, and susceptible reactions, respectively. Similarly, at Bekoji, 7 (5.1%), 0, 11 (7.9%), 5 (3.6%), 4 (2.8%), 18 (12.9%), 22 (15.8%), and 72 (51.8%) accessions exhibited the corresponding reaction types to yellow rust (Figure 1).

Table 2. Disease severity and infection reaction.

Scale	% Severity	Reaction
TR	Trace	Resistant
10R–MR	10	Resistant to moderately resistant
20MR	20	Moderately resistant
30MR–MS	30	Moderately resistant to moderately susceptible
40MS	40	Moderately susceptible
50MS–S	50	Moderately susceptible to susceptible
70S	70	Fully susceptible

Data on disease severity and host reaction were combined to calculate the Coefficient of Infection (CI) for each genotype.

At Kulumsa, where stem rust was the predominant disease, 7 (5.2%), 4 (2.8%), 14 (10.1%), 3 (2.1%), 7 (5.2%), 23 (16.5%), 35 (25.2%), and 46 (33.1%) accessions showed immune, resistant, resistant to moderately resistant, moderately resistant, moderately resistant to moderately susceptible, moderately susceptible, moderately susceptible to susceptible, and susceptible reactions, respectively, to the prevalent stem rust races across the three seasons.

Considering the mean terminal rust severity and the observed host responses across years, the findings of the present study revealed that only a small proportion of the evaluated lines exhibited promising levels of resistance, while a comparable proportion of accessions showed similar reactions. According to Parlevliet and van Ommeren (1975), final rust severity reflects the cumulative effect of all resistance factors operating throughout the course of an epidemic. Previous studies have also used final rust severity as a key parameter for assessing the slow rusting behavior of wheat genotypes (Ali et al., 2007; Li et al., 2010; Safavi, 2012; Muche et al., 2022). Based on final rust severity, the tested bread wheat accessions exhibited variable reactions to the prevalent yellow and stem rust races. Accessions that demonstrated resistant to moderately resistant responses to both rust diseases are likely to possess multiple minor resistance genes, although this requires confirmation through seedling phenotyping (Rubiales and Nicks, 2000).

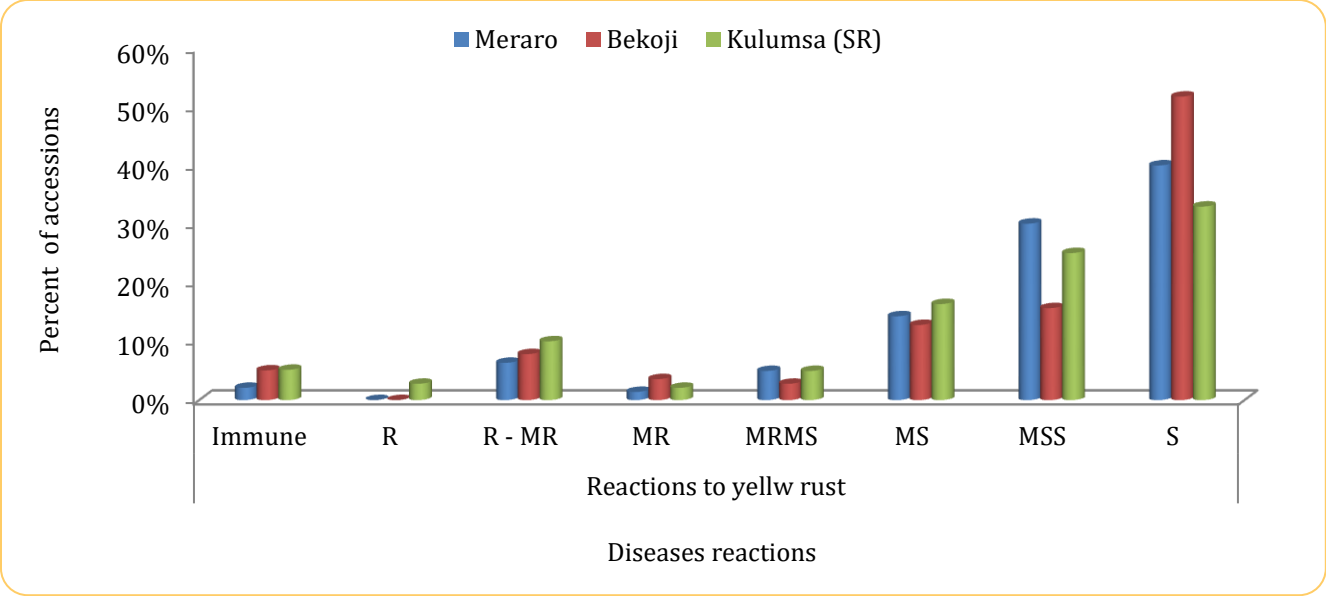


Figure 1. Mean response of 139 bread wheat accessions to yellow and stem rust across three years and locations (Kulumsa, Bekoji, and Meraro).

These findings are consistent with previous reports indicating that partial or slow rusting resistance, governed by the additive effects of minor genes, provides durable protection against rapidly evolving rust pathogen populations (Singh et al., 2005; Herrera-Foessel et al., 2011). Unlike race-specific resistance, which is often short-lived due to the emergence of new virulent pathotypes, slow rusting resistance offers broad-spectrum and long-lasting effectiveness (Johnson, 1988; Singh et al., 2014). The identification of accessions with stable and moderate resistance levels under high disease pressure suggests their potential as valuable parental sources for breeding programs aimed at enhancing durable resistance in Ethiopian wheat germplasm.

Furthermore, the occurrence of resistant accessions under natural epidemic conditions at multiple hot-spot locations implies the presence of horizontal resistance mechanisms that are less influenced by environmental variation (Kaur et al., 2017). This stability across environments is particularly significant for Ethiopia, where climatic diversity and pathogen variability present major challenges to rust management. Incorporating such slow rusting resistance genes into locally adapted, high-yielding cultivars could substantially reduce yield losses and improve the sustainability of wheat production.

Future research should focus on confirming the genetic basis of this resistance through molecular marker-assisted selection and seedling screening under controlled conditions. Combining slow rusting genes with known major resistance genes (e.g., Yr18, Lr34, Sr2) could result in durable, pyramided resistance effective against both stem and yellow rust pathogens (Lagudah, 2011; Bhavani et al., 2022).

Table 3. Three-year mean disease severity and coefficient of infection of check varieties for yellow and stem rusts (2020-2022).

Varieties	Bekoji(yellow rust)		Meraro(Yellow rust)		Kulumsa (Stem rust)	
	FRS	CI	FRS	CI	FRS	CI
Kubsa	90s	90	90s	70	90s	90
Morocco	90s	90	90s	90	90s	90
Digalu	80s	80	70s	70	70s	70
PbW343	90s	90	80	80	80s	80
Kingbird	60s	60	70s	70	30ms	24
Wane	40ms	36	40ms	36	20ms	16

Coefficient of infection

Data on final disease severity were combined with fixed host response values to calculate the Coefficient of Infection (CI). Disease pressure remained high throughout the three-year evaluation period, as evidenced by the susceptible check varieties 'Kubsa' and 'Morocco', both of which consistently exhibited approximately 90% susceptibility.

At the Kulumsa Agricultural Research Center (KARC), the CI values of the tested bread wheat accessions for stem rust ranged from 0 to 90%, indicating wide variability in disease response among the accessions. The three-year mean CI for stem rust across all accessions was 26.3%, reflecting a moderate overall level of disease severity under natural epidemic conditions. Most accessions, along with all check varieties, recorded moderate to high CI values (>20), demonstrating the broad susceptibility of the germplasm to prevailing stem rust races. Specifically, 11 accessions displayed CI values between 0-20, 24 ranged from 21-40, and the remaining 104 exhibited CI values greater than 40. These findings suggest that while a few accessions possess effective slow-rusting or partial resistance genes, the majority of the germplasm remains vulnerable, consistent with earlier reports highlighting the high susceptibility of Ethiopian bread wheat to Puccinia graminis f. sp. tritici under field conditions (Singh et al., 2008; Muche et al., 2022).

At the yellow rust hotspot sites of Bekoji and Meraro, disease pressure was similarly high, allowing accurate and reliable field scoring. At Bekoji, seven accessions had CI values of 0-20, twenty ranged from 21-40, and 112 accessions, including the susceptible checks, showed CI values exceeding 40. At Meraro, four accessions were within the 0-20 range, seventeen ranged from 21-40, and 118 accessions, including the susceptible checks, had CI values above 40. These observations corroborate previous reports of severe yellow rust epidemics at these sites, confirming their suitability for screening and selecting resistant germplasm under natural infection conditions (Olivera et al., 2015; Muche et al., 2022).

Despite the consistently high disease pressure across years and locations, a subset of accessions exhibited resistant or trace reactions (Table 4). These trace reactions likely reflect hypersensitive responses, wherein fungal infection triggers localized cell death that restricts pathogen growth and disease spread (Rubiales and Niks, 2000; Chen, 2013). Accessions expressing such partial or slow-rusting resistance are particularly valuable because they often confer durable, race-nonspecific resistance that remains effective across diverse environments and against evolving pathogen populations (Herrera-Foessel et al., 2011). However, further confirmation through seedling-stage evaluation and molecular characterization of the underlying resistance genes is required to elucidate the genetic basis and inheritance of these traits.

Table 4. Three-year mean coefficient of infection for 139 bread wheat accessions across all experimental locations (2020-2022).

Locations	Reactions to yellow rust		
	Minimum	Maximum	Mean
Meraro	0	90	35.5
Bekoji	0	90	29.7
Kulumsa	0	80	26.3

To enhance the resistance of widely cultivated but highly susceptible Ethiopian bread wheat varieties, several crop improvement strategies can be adopted. These include interspecific and distant hybridization, as well as the introgression of resistance genes through backcrossing with resistant accessions (Bartos et al., 2002). The incorporation of slow-rusting and major resistance genes into locally adapted, high-yielding cultivars can provide durable protection against both stem and yellow rusts while maintaining desirable agronomic performance and adaptability to Ethiopian conditions. Implementing such strategies is crucial to safeguarding wheat productivity, strengthening food security, and minimizing economic losses caused by rust diseases (Oerke, 2006; Singh et al., 2008).

Genotypes exhibiting resistant to moderately resistant responses (Table 5) are of significant importance in breeding programs aimed at developing durable resistance to both stem and yellow rusts. In contrast, accessions that display immune reactions (vertical, race-specific resistance) or host-pathogen compatible reactions are generally considered less suitable for incorporation into breeding programs. This is because vertical resistance can be rapidly overcome by the emergence of new pathogen races, while susceptible reactions offer no value for resistance breeding.

Table 5. Promising bread wheat accessions showing low infection levels of both stem and yellow rust across all experimental locations over three years (2020-2022).

Number	Accession ID	Meraro (YR)		Bekoji (YR)		Kulumsa (SR)	
		MFRS	MCI	MFRS	MCI	MFRS	MCI
1	31346	20MS	16	25MS	20	25MS	20
2	31405	TMR	0.8	5MR	2	TMR	0.8
3	31643	5MR	2	TMR	0.8	TMR	0.8
4	34209	10MR	4	10MR	4	10MS	8
5	34797	25MS	20	20MS	16	5MS	4

Conclusion

Accessions 31346, 31405, 31643, 34209, and 34797 exhibited low disease severity for both stem and yellow rust, indicating their potential as valuable sources of adult-plant resistance. These genotypes are likely to possess multiple minor genes that confer slow-rusting resistance. However, seedling-stage evaluations and molecular characterization of the underlying resistance genes are essential to confirm their genetic basis. Once these specific genes are identified, they can be introgressed into widely cultivated but susceptible Ethiopian wheat varieties through intercrossing with other genotypes carrying minor resistance genes. This strategy will not only enhance durable resistance but also broaden the genetic diversity of the existing wheat germplasm, contributing to more resilient and sustainable wheat production in Ethiopia and other regions with similar agroecological conditions.

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Authors' Contributions

GMA, AAZ, DKM, and TNG conceptualized and designed the study and were responsible for preparing the experimental materials; HT, SR, and HF conducted fieldwork, including data collection and disease assessment; FA, TS, and DZ performed data analysis and interpretation; GMA drafted the manuscript, and all authors critically reviewed, revised, and approved the final version for submission.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 13: Climate Action
SDG 15: Life on Land

References

Adnan, M., Khan, N.A., Ullah, B., Zaman, F., Kaplan, A., Dossou-Yovo, H.O., Sarfraz, M.H., 2023. Proximate composition and mineral content of wheat (Triticum aestivum L.) under boric acid stress via energy-dispersive X-ray fluorescence analysis. Pakistan Journal of Weed Science Research 30(1), 7-17.

Alemu, G., Geleta, N., Dabi, A., Duga, R., Kasahun, C., Delasa, A., Zewdu, D., Bayisa, T., 2023. The agronomic and quality descriptions of Ethiopian bread wheat (Triticum aestivum L.) variety "Boru". International Journal of Bio-Resource and Stress Management 13(10), 1090-1097.

Ali, S., Shah, S.J.A., Ibrahim, M., 2007. Assessment of slow rusting in wheat genotypes against Puccinia striiformis f. sp. tritici. Pakistan Journal of Biological Sciences 10(22), 3440-3444.

Bartos, P., Sip, V., Chrpova, J., Vacke, J., Stuchlikova, E., Blazkova, V., Sarova, J., Hanzalova, A., 2002. Achievements and prospects of wheat breeding for disease resistance. Czech Journal of Genetics and Plant Breeding 38(1), 16-28.

Bentley, A.R., Donovan, J., Sonder, K., Baudron, F., Lewis, J.M., Voss, R., Rutsaert, P., Poole, N., Kamoun, S., Saunders, D.G., Hodson, D., 2022. Near-to long-term measures to stabilize global wheat supplies

and food security. Nature Food, 3(7), 483-486.

Bhavani, S., Singh, R.P., Hodson, D.P., Huerta-Espino, J., Randhawa, M.S., 2022. Wheat rusts: Current status, prospects of genetic control and integrated approaches to enhance resistance durability. In: Wheat improvement: Food security in a changing climate, Springer International Publishing, pp. 125-141.

Birhan, A., 2011. Evaluation of bread wheat (Triticum aestivum L.) varieties for slow rusting resistance to stem rust (Puccinia graminis f. sp. tritici) under field conditions at Kulumsa, Ethiopia. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Chen, X.M., 2013. High-temperature adult-plant resistance: Key for sustainable control of stripe rust. American Journal of Plant Sciences 4, 608-627.

CSA., 2022. Central Statistical Agency, Agricultural sample survey, 2022: Report on area and production of crops (Private peasant holdings, main season) (Statistical Bulletin No. 5:446). Addis Ababa, Ethiopia.

Dixon, J., Braun, H.-J., Crouch, J., 2009. Overview: Transitioning wheat research to serve the future needs of the developing world. In: Dixon, J., Braun, H.-J., Kosina, P., Crouch, J. (Eds.), Wheat facts and futures 2009. CIMMYT.

FAOSTAT, 2020. Database of agricultural production. Food and Agriculture Organization of the United Nations, Rome.

Guush, B., Zelekawork, P., Kibrom, T., Seneshaw, T., 2011. Food grain consumption and calorie intake patterns in Ethiopia (ESSP II Working Paper No. 23).

Herrera-Foessel, S.A., Singh, R.P., Lillemo, M., Huerta-Espino, J., Bhavani, S., Singh, S., Lan, C., Calvo-Salazar, V., Lagudah, E.S., 2014. Lr67/Yr46 confers adult plant resistance to stem rust and powdery mildew in wheat. Theoretical and Applied Genetics 127(4), 781-789.

Hovmøller, M., Walter, S., Bayles, R.A., Hubbard, A., Flath, K., Sommerfeldt, N., Leconte, M., Czembor, P., Rodriguez Algaba, J., Thach, T., 2016. Replacement of the European wheat yellow rust population by new races from the centre of diversity in the near Himalayan region. Plant Pathology 65, 402-411.

Johnson, R., 1988. Past, present and future opportunities in breeding for disease resistance, with examples from wheat. Euphytica 63(1), 3-22.

Kaur, V., Payasi, D.K., Choudhary, R., Kumar, V., Yadav, S.K., Singh, D., Kumar, V., Jat, B., Garg, D., Gupta, V.K., Kumar, S., 2017. Genetic resources for enhancing drought tolerance from National Genebank collection of linseed (Linum usitatissimum L.) in India. Plant and Soil 510(1), 923-946.

Lagudah, E.S., 2011. Molecular genetics of race non-specific rust resistance in wheat. Euphytica 179(1), 81-91.

Li, Z.F., Xia, X.C., He, Z.H., Li, X., Zhang, L.J., Wang, H.Y., Meng, Q.F., Yang, W.X., Li, G.Q., Liu, D.Q., 2010. Seedling and slow rusting resistance to leaf rust in Chinese wheat cultivars. Plant Disease 94, 45-53.

Lucas, H., 2012. The wheat initiative-an international research initiative for wheat improvement. In: Second Global Conference on Agricultural Research for Development (GCARD2), 29 October-1 November 2012, Punta del Este, Uruguay.

Meyer, M., Bacha, N., Tesfaye, T., Alemayehu, Y., Abera, E., Hundie, B., Woldeab, G., Girma, B., Gemechu, A., Negash, T., Mideksa, T., Smith, J., Jaleta, M., Hodson, D., Gilligan, C.A., 2021. Wheat rust epidemics damage Ethiopian wheat production: A decade of field disease surveillance reveals national-scale trends in past outbreaks. PLoS ONE 16(2), e0245697.

MoANR., 2022. Annual report on agricultural development and research activities. Addis Ababa: Ministry of Agriculture and Natural Resources.

Muche, A.G., Ayele, Z.A., Negash, G.T., Kassa, H.D., Tilahun, H.L., Yirga, B.F., 2022. Field assessment of commercial wheat varieties, advanced lines and trap nurseries against yellow rust in south East Ethiopia. Russian Journal of Agricultural and Socio-Economic Sciences 127(7), 104-110.

Oerke, E.C., 2006. Crop losses to pests. Journal of Agricultural Science 144, 31-43.

Olivera, P., Newcomb, M., Szabo, L.J., Rouse, M., Johnson, J., Gale, S., Luster, D.G., Hodson, D., Cox, J.A., Burgin, L., Hort, M., 2015. Phenotypic and genotypic characterization of race TKTTF of Puccinia graminis f. sp. tritici that caused a wheat stem rust epidemic in southern Ethiopia in 2013–14. Phytopathology 105(7), 917-928.

Parlevliet, J.E., van Ommeren, A., 1975. Partial resistance of barley to leaf rust, Puccinia hordei: Relationship between field trials, microplot tests, and latent

period. Euphytica 24, 293-303.

Peterson, R.F., Campbell, A., Hannah, A.E., 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Canadian Journal of Research 26, 496-500.

Rubiales, D., Niks, R.E., 2000. Combination of mechanisms of resistance to rust fungi as a strategy to increase durability. In: CIHEAM-IAMZ Proceedings, pp. 333-339.

Safavi, S.A., 2012. Evaluation of slow rusting parameters in thirty-seven promising wheat lines to yellow rust. Technical Journal of Engineering and Applied Sciences 2, 324-329.

Sanders, R., 2011. Strategies to reduce the emerging wheat stripe rust disease: Synthesis of a dialog between policy makers and scientists from 31 countries. Aleppo, Syria: International Center for Agricultural Research in the Dry Areas (ICARDA).

Singh, R.P., Hodson, D.P., Huerta-Espino, J., Jin, Y., Bhavani, S., Njau, P., Herrera-Foessel, S., Singh, P.K., Singh, S., Govindan, V., 2014. The emergence of Ug99 races of the stem rust fungus is a threat to world wheat production. Annual Review of Phytopathology 52, 465-481.

Singh, R.P., Huerta-Espino, J., William, H.M., 2005. Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. Turkish journal of agriculture and forestry, 29(2), 121-127.

Singh, R.P., Jin, Y., Huerta-Espino, J., Kinyua, M.G., Wanyera, R., Njau, P., Ward, R.W., 2008. Current status, likely migration and strategies to mitigate the threat to wheat production from race Ug99 (TTKS) of stem rust pathogen. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 3(54), 1-13.

Solomon, A., Awet, T., Muluken, A., 2022. K-ERSHA. Retrieved from https://www.agri.kukunetdigital.com

Tadesse, W., Zegeye, H., Debele, T., Kassa, D., Shiferaw, W., Solomon, T., Negash, T., Geleta, N., Bishaw, Z., Assefa, S., 2022. Wheat production and breeding in Ethiopia: Retrospect and prospects. Crop Breeding, Genetics and Genomics 4(3).