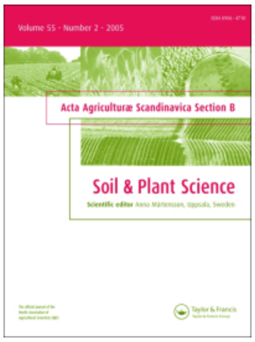

Acta Agriculturae Scandinavica, Section B — Soil & Plant Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/sagb20

Wheat production in the highlands of Eastern Ethiopia: opportunities, challenges and coping strategies of rust diseases

Mulu Nigus, Hussein Shimelis, IsacK. Mathew & Seltene Abady

To cite this article: Mulu Nigus, Hussein Shimelis, IsacK. Mathew & Seltene Abady (2022) Wheat production in the highlands of Eastern Ethiopia: opportunities, challenges and coping strategies of rust diseases, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 72:1, 563-575, DOI: 10.1080/09064710.2021.2022186

To link to this article: https://doi.org/10.1080/09064710.2021.2022186

Published online: 09 Jan 2022.

ACTA AGRICULTURAE SCANDINAVICA, SECTION B — SOIL & PLANT SCIENCE
2022, VOL. 72, NO. 1, 563–575
https://doi.org/10.1080/09064710.2021.2022186

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Wheat production in the highlands of Eastern Ethiopia: opportunities, challenges and coping strategies of rust diseases

Mulu Nigus [a,b], Hussein Shimelis [a], IsacK. Mathew [a] and Seltene Abady [a,b]

[a]African Centre for Crop Improvement, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa; [b]School of Plant Sciences, Haramaya University, Dire Dawa, Ethiopia

ABSTRACT
Ethiopia is the primary wheat producer in Sub-Saharan Africa (SSA) owing to the suitable agro-ecological conditions. Despite wheats economic potential for food security, the actual yield under smallholder farmers conditions is low due to various production constraints. Thus, the objectives of this study were to assess the present wheat production opportunities and constraints and identify farmer-preferred traits to guide variety design with stem rust-resistance and economic traits in eastern Ethiopia. Data on production constraints and trait preferences were collected using structured questionnaires involving 144 wheat-producing farmers. Wheat rust (reported by 97.3% of respondents), small land size (90.4%) and a lack of improved varieties (75.6%) were identified as the major constraints. About 41.7% of respondents in the West-Hararghe and 27.8% in the East-Hararghe zones did not use crop protection strategies to control rusts. Substantial respondent farmers used cultural practices (18.8%), rust-resistant cultivars (13.2%) or, a combination of these (10.4%) to control rust diseases. The essential farmer preferred traits in a wheat variety were rust resistance, high yield potential and good quality grain for bread making. Therefore, there is a need to breed new varieties with high grain yield and quality and durable rust resistance for sustainable wheat production in eastern Ethiopia.

ARTICLE HISTORY
Received 20 November 2021
Accepted 20 December 2021

KEYWORDS
Farmer-preferred traits; participatory rural appraisal; production constraints; variety development; wheat rust

Introduction

Bread wheat (*Triticum aestivum* L.), with an annual global production of 772.6 million tons, is a staple food for more than 35% of the world's population (Statista 2021). Globally, China, India and Russia are the largest wheat producers, while South Africa and Ethiopia are the largest wheat producers in sub-Saharan Africa (SSA) (USDA 2019). Ethiopia's annual production is about 5.8 million tons with mean productivity of 3 tons per hectare (tha^{-1}) (CSA 2021), which is relatively lower than the attainable yield of the crop, reaching up to 5 tha^{-1} (Zegeye et al. 2020). Wheat accounts for about 17% of total grain production in Ethiopia making it the third most important cereal crop after teff [*Eragrostis tef (*Zucc.) Trotter] and maize (*Zea mays* L.) (CSA 2021). The most suitable altitude range for wheat production is between 1900 and 2700 metres above sea level (Hunde et al. 2000). The Hararghe-Highlands in eastern Ethiopia are relatively suitable areas for wheat production due to their cooler temperatures and high rainfall conditions.

Globally, the demand for wheat has increased sharply due to human population pressure, urbanisation and lifestyle changes (Minot et al. 2015). The total per capita consumption of wheat in SSA has increased by 0.35 kg/person/year between 2000–2009 (Sununtnasuk 2013). In Ethiopia, about 29.6 kg/person/year wheat was consumed in 2004/5 and is expected to increase in the future (Berhane et al. 2011). The increased demand for wheat has presented an opportunity for greater production in Ethiopia. The demand for wheat has surpassed its production, and the country had to import an additional 1.5 million tons of wheat to meet the domestic consumption needs (FAOSTAT 2018).

In SSA, including Ethiopia, wheat production and productivity are affected by complex and interactive effects of biotic and abiotic factors and socio-economic challenges, notably in the smallholder farming systems. Wheat diseases, such as stem rust caused by *Puccinia graminis* Pers. f.sp. *tritici* Eriks and Hann, stripe or yellow rust (*P. striiformis* Westend. f.sp. *tritici*) and leaf rust (*P. triticina* Eriks), and insect

CONTACT Mulu Nigus mulufetahi@gmail.com African Centre for Crop Improvement, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa; School of Plant Sciences, Haramaya University, Dire Dawa, Ethiopia

pests such as the Russian wheat aphid (*Diuraphis noxia* Mordvilko) are among the critical biotic factors affecting wheat production in Ethiopia. Other major factors that contributed to low wheat yields in Ethiopia are a lack of access to improved varieties, backward agronomic practices, use of marginal agricultural land, and terminal drought stress, among others (Yami et al. 2012; Belay and Araya 2015; Wheat Atlas 2016; Hei et al. 2017; Semahegn et al. 2021). The occurrence and relative importance of these constraints vary in different agro-ecologies, and farmers may perceive them differently, which affects the wheat breeding goals and hence varietal choices and adoption. It is imperative to assess individual farming systems, and farmers need to understand the prevailing factors and preferred attributes. These conditions affect farmers' varietal choices and variety design for a demand-led wheat breeding programme.

Farmers have subjective preferences, and their trait and variety demands are significantly affected by their perceptions (Dawit and Tekalign 2007; Bishaw et al. 2010). Participatory rural appraisal (PRA) has been widely used to collect information on farmers' varietal preferences, production opportunities and constraints, and traditional knowledge of their production systems (Chambers 1994). Understanding farmers' preferred attributes of wheat varieties and production constraints can enable breeders to prioritise demand-driven breeding (Weltzien and Christinck 2009). Incorporating farmers' needs during variety design and development will deliver new and modern varieties that are acceptable and widely adopted to mitigate the multiple constraints faced by farmers and the wheat value chains (Owere et al. 2014). The PRA is premised on the idea that farmers are not passive recipients of crop varieties and technologies but should be active participants and informants in identifying challenges and proposing suitable solutions. Several studies have used the PRA tools to explore wheat technology adoption in different parts of Ethiopia (Agidie et al. 2000; Shiferaw et al. 2014; Hei et al. 2017; Semahegn et al. 2021). No recent study has been conducted on assessing the major production constraints contributing to low wheat productivity, wheat variety preferences, and adoption of the hitherto released wheat varieties among farmers in eastern Ethiopia. Hence, the objectives of the current study were to assess the present wheat production opportunities and constraints and identify farmer-preferred traits to guide variety design with stem rust resistance and economic traits in eastern Ethiopia.

Materials and methods

Description of the study areas

The study was conducted in East- and West Hararghe Zones situated in the Oromia Regional State of Ethiopia between November 2018 and February 2019. The geographical location and descriptions of the study zones are presented in Figure 1 and Table 1. The study areas spanned across a wide range of agro-ecologies. The farming systems in the two zones include sole and mixed crop and livestock systems (Ademe et al. 2016). The major annual crops grown in the study areas are sorghum, maize, coffee, groundnut, wheat, potato, haricot beans and barley (CSA 2021). The agricultural system in the two zones is highly subsistence. Cereal production in both zones is primarily for home consumption, with only a small part of products marketed (Ademe et al. 2016). Farmers in the study areas are engaged in cash crop production, including coffee, groundnut, Irish potatoes, onions, hops and chat (CSA 2021).

East- and West-Hararghe zones are characterised by two rainy seasons per year; the shorter rainy season (locally referred to as Belg) extends from March to May, and the main rainy season (Meher) extends from the end of June to September. During Belg rains, croplands are prepared to plant long cycle crops such as maize and sorghum in February and March. Following Meher rains, the following major crops are cultivated: barley, teff, wheat and vegetable crops (e.g. onion, shallot) and potatoes. Wheat is commonly grown in the main rainy season in the two zones. The minimum monthly temperatures in East- and West-Hararghe range between 11^{0}C -16 ^{0}C. December to January are the coldest months in a year. The maximum mean monthly temperatures in East- and West-Hararghe zones ranges between 23^{0}C - 36^{0}C in May and June (ICPAC 2019).

Sampling procedures

A multi-stage sampling technique was used through purposive and random sampling of farmers. The technique allowed to the selection of a representative sample of wheat farmers in the study areas. In the first stage, districts were purposively selected by considering wheat production status, area coverage, and intensity of rust diseases with special consideration of stem rust prevalence by consulting zonal and district agricultural officers. Accordingly, three representative districts from each zone were selected. These are Jarso, Malka Ballo, and Meta districts from the East-Hararghe zone, while Gamachis, Masela, and Tulo districts were sampled

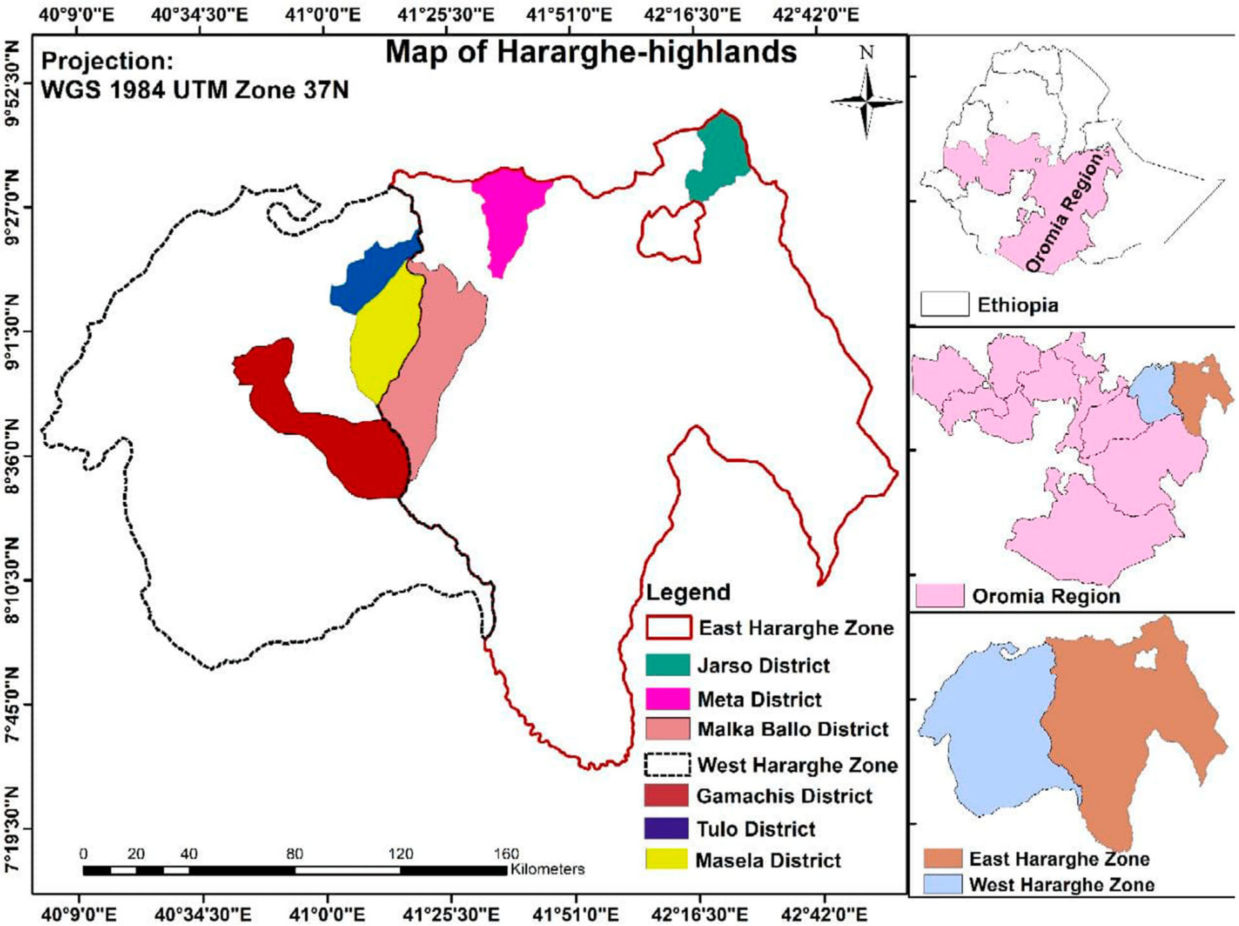

Figure 1. Map of Ethiopia showing the survey districts in East- and West-Hararghe zones of Oromia Region.

from the West-Hararghe zone. In the second stage, two peasant associations were purposively selected from each district, making 12 peasant associations. In Ethiopia, a peasant association is the smallest unit of an administrative structure below a district; it often has 500–1500 households. Finally, 12 farmers were randomly selected from each of the 12 peasant associations providing a total sample of 144 farmers for the study. The sampling structure is presented in Table 2.

Data collection and analysis

Primary data were collected through interviews and observations made by transect walks across the selected villages. Both qualitative and quantitative data were collected as primary data. The questionnaire included topics related to the household's general demographic and socio-economic characteristics, wheat varieties grown, perceived production constraints, wheat rust diseases, and coping mechanisms. Secondary data were obtained from zonal and district agricultural offices in the respective zones and districts. Supplementary information was recorded through observations in a transect walk of the sampled villages. During the transect walk, observations were made on croplands where wheat was planted during the growing season to record the differences of wheat grain and straw use across the villages.

Table 1. Geographical location and climatic characteristics of the study areas.

Descriptions	Unit	Study areas	
		East-Hararghe	West-Hararghe
Annual rainfall	mm	400–1200	660–2000
Temperature range	^{0}C	13–28	20.5-24
Longitudes	d.m.s. in that order	41° 36′ 4.2516′′ E	40° 29′ 59.99″ E
Latitudes	d.m.s. in that order	8° 48′ 28.9008′′ N	8° 39′ 59.99″ N
Altitude range	m.a.s.l.	500–3405	1200–3600

**mm, milli-metres; * d.m.s., Degrees, minutes and second; *^{0}C, degree Celsius; *m.a.s.l, metres above sea level.

Table 2. Names of the study zones, districts and peasant associations and corresponding number and gender of farmers sampled for the study.

Zones	Districts	Peasant associations	PA code	Sex		Total
				Male	Female	
East-Hararghe	Jarso	Afgug	1	6	6	12
		Ifajalala	2	10	2	12
	Meta	Dursitu Bilusuma	3	6	6	12
		Bekelcha Oromiya	4	9	3	12
	Malka-Ballo	Bulle Negaya	5	10	2	12
		Burka Negaya	6	11	1	12
West-Hararghe	Gamachis	Gelgawi Dignat	7	11	1	12
		Abdi Gudina	8	8	4	12
	Masela	Beha Biftu	9	9	3	12
		Aba Nejat	10	7	5	12
	Tulo	Terkemfeta	11	9	3	12
		Garakuffa	12	9	3	12
Total				105	39	144

PA, peasant association.

The primary data collection was undertaken with graduate assistants (GA) and development agents (DA) familiar with the areas, fluent in the local language (Afan Oromo), and who are well acquainted with local and cultural norms. The GA and DA enumerators were trained prior to conducting the interviews and data collection. The questionnaire was pre-tested on non-sample respondents under the supervision of the researcher, and necessary amendments were made. Finally, the formal survey was conducted on 144 farmers after the necessary modifications and adjustments were made according to the pre-test.

The qualitative and quantitative data were coded and subjected to statistical analyses in the Statistical Package for Social Sciences (SPSS) version 20 (SPSS Inc. 2011). Descriptive statistics, such as means, percentages and frequencies, were computed to understand trends and patterns in the quantitative data. Chi-square and independent t-test values were calculated to test differences between frequencies for variables measured between the different study areas. Rank data was subjected to the Kruskal–Wallis non-parametric test to discern the significant differences. The ranking of the major wheat production constraints were weighted by the Rank Based Quotient (RBQ) to identify the most influential constraints in the study areas using the following formula (Sabaratham 1988).

$$\mathrm{RBQ} = \left(\sum \mathrm{fi}\ (\mathrm{n}+1-\mathrm{i})100\right)/\mathrm{N} \times \mathrm{n}$$

where *f* represents the frequency of respondents perceiving a particular constraint under ith rank; *N* the total number of respondents; *n* the number of constraints identified and *i* is the rank of the perceived constraint.

Results

Demographic description of households

There was a non-significant difference ($x^2 = 0.04$; $p = 0.85$) in gender representation (Table 3). Also, the age groups among the sampled farmers had non-significant difference ($x^2 = 48.38$; $p = 0.62$). The largest proportion of farmers were between 30–50 years of age with 62.5 and 61.1% of these found in East- and West-Hararghe zones, respectively. The level of education varied significantly ($x^2 = 1964$; $p = 0.00$) between the two zones. East-Hararghe zone had a significantly lower frequency of farmers (26.4%) without education when compared with West-Hararghe (40.3%). There was a non-significant difference ($x^2 = 0.37$; $p = 0.83$) in family sizes. The majority of the households (63.9%) had a family size of 5–8 individuals. The farmers in the two zones experienced relatively similar access to road services ($x^2 = 1.44$; $p = 0.84$), market ($x^2 = 6.23$; $p = 0.18$) and a development agency centre ($x^2 = 4.87$; $p = 0.30$). The majority of farmers (67.4%) lived within a 30-minute distance to the main road. In terms of access to markets, most farmers in East-Hararghe (63.9%) and West-Hararghe (56.9%) lived within a 200-minute distance from the marketplace. A higher proportion of respondent farmers in East-Hararghe (73.6%) and in West-Hararghe (72.2%) lived up to a distance of 60-minute to a development agency centre.

Farming system

The farming systems in East- and West-Hararghe zones were characterised by mixed crop and livestock production. Most crop production is under rain-fed conditions. The average land size in East and West-Hararghe were 0.52 and 0.56 ha per household, respectively (Table 4). During the study period, all the respondents

Table 3. Demographic characteristics of the interviewed farmers and their access to different facilities.

		Zone							
		EH		WH					
Variable	Category	Freq	%	Freq	%	% mean	*df*	X^2	*P* value
Gender	Male	52	72.2	52	73.6	72.9	1	0.035	0.851
	Female	20	27.8	19	26.4	27.1			
Age (Years)	< 30	17	23.6	14	19.4	21.5	2	48.375	0.616
	30–50	45	62.5	44	61.1	61.8			
	>50	10	13.9	14	19.4	16.65			
Education level	Illiterate	19	26.4	29	40.3	33.35	1	19.643	0.000
	Literate	53	73.6	43	59.7	66.65			
School (Grades)	0	19	26.4	29	40.3	33.35	4	2.044	0.153
	1–4	–	–	2	2.8	1.4			
	5–8	29	40.3	29	40.3	40.3			
	9–12	12	16.7	5	6.9	11.8			
	>12	12	116.7	7	9.7	63.2			
Family size	<5	10	13.9	9	12.5	13.2	2	0.369	0.832
	5–8	47	65.3	45	62.5	63.9			
	>8	15	20.8	18	25	22.9			
Distance to all weather road (minute)	<30	48	66.7	49	68.1	67.4	3	1.436	0.838
	30 - 60	9	12.5	8	11.1	11.8			
	61- 120	13	18.1	3	4.2	11.15			
	121–200	2	2.8	1	1.1	1.95			
Distance to market (minute)	< 30	5	6.9	7	9.7	8.3	4	6.232	0.182
	30 - 60	2	2.8	7	9.7	6.25			
	61- 120	15	20.8	9	12.5	16.65			
	121–200	4	5.6	8	11.1	8.35			
	>200	46	63.9	41	56.9	60.4			
Distance to DA centre (minute)	<30	38	52.8	29	40.3	46.55	4	4.860	0.302
	30 - 60	15	20.8	23	31.9	26.35			
	61- 120	13	18.1	11	15.3	16.7			
	121–200	3	4.2	2	2.8	3.5			
	>200	3	4.2	7	9.7	6.95			

Note EH, East-Hararghe; WH, West-Hararghe; *df*, degrees of freedom; DA, development agent; Freq, frequencies of the respondents.

in the East-Hararghe zone and 98.6% in the West-Hararghe zone allocated more land to wheat as the main crop. In addition to wheat production, farmlands were also allocated to different crops, such as maize (89.9%), chat [*Catha edulis*] (61.1%), barley (50%), sorghum (42.4%), potato (29.1%) and faba bean (12.5%), in decreasing area of production. Of the total cultivated land, on average wheat was allocated to 0.22 ha in East-Hararghe and 0.26 ha in West-Hararghe per household (Table 4). The mean cost of local seed was 12.26 and 11.20 Birr/kg in East- and West-Hararghe Zones, respectively, while improved seed cost 16.72 and 16.64 Birr/kg in East- and West-Hararghe Zones, respectively. There were significant differences among the zones with regards to the price of local seed ($t = 2.3$; $P < 0.023$) and improved seed ($t = 2.93$; $P < 0.004$) (Table 4). The farmers in both areas had relatively the same access to information from government extension agents, with farmers in East-Hararghe having contacts with extension agents at least 17 times per year, while in West-Hararghe, farmers meet extension agents about 15 times a year.

Sources of wheat seed for cultivation

Most respondent farmers (45%) access wheat seed for cultivation mainly from the Bureau of Agriculture (BoA). Alternatively, farmers used farm-retained seeds (23.0%), followed by a farmer-to-farmer seed exchange (17.0%), local markets (6.3%), Haramaya University (4.6%) and donations from various non-governmental organisations (4.2%). The BoA mostly collected the seeds from local farmer cooperatives, which produced old cultivars susceptible to rust, as observed during the transect walk. Almost all of the farmers in East-Hararghe and 94.4% of West-Hararghe farmers had access to improved varieties (Table 5). The majority of farmers in the study areas had more than one source of information to improved varieties, although the sources were not significantly different ($x^2 = 2.17$; $p = 0.54$). About 18.1% of farmers in East-Hararghe and 22.2% in West-Hararghe relied on information solely obtained from the DA centres. The remainder of the farmers in both areas used information obtained from multiple sources, including the DA, listening to the local radio station, neighbours and relatives.

Most respondent farmers in both areas affirmed that they had access to improved varieties ($x^2 = 0.00$; $p = 1.00$) and participated in technology adoption activities ($x^2 = 0.47$; $p = 0.50$). Both zones had considerably high frequencies of farmers who had access to seeds of improved varieties, with 81.9% in the East-Hararghe zone and 86.1% in the West-Hararghe zone. In East-

Table 4. The area allocated to wheat production, local and improved seed costs, and frequency of contact by farmers to extension agents in the two zones.

	Zone							
	EH			WH				
Variable	Mean	Std	SE	Mean	Std	SE	t value	P value
Total land size (ha)	0.52	0.25	0.23	0.56	0.21	0.24	−1.00	0.748
Wheat land size (ha)	0.22	0.15	0.18	0.26	0.19	0.23	−1.37	0.084
Cost of local seed (Birr)	12.26	2.64	0.31	11.2	2.77	0.34	2.3	0.023
Costs of improved seed (Birr)	16.7	4.24	0.50	14.6	3.92	0.49	2.93	0.004
Frequencies of contact to extension agents	17.35	15	1.77	14.7	18.3	2.12	0.99	0.355

Note EH, East-Hararghe; WH, West-Hararghe; Std, standard deviation; SE, standard error, 1 Birr, 0.02 USD; N, number of respondents.

Hararghe, 88.9% attended the Farmer Training Centre (FTC), while 94.1% in West-Hararghe attended these training centres.

Cultivated wheat varieties and farmer preferred traits

The most common wheat varieties widely cultivated in East-Hararghe were Hidase (reported by 34.6% of respondents), Danda′a (26.4%), and Kubsa (19.4%) in decreasing order of importance. In the West-Hararghe, Danda′a (44%), Kakaba (22%) and landraces (12.5%) were the commonly cultivated varieties. Most of the varieties were released between the years 1995 and 2015. The release dates of some of the varieties were unknown. Kubsa and Medawolabo varieties were released 20 years ago, while the rest were more recently released. Kingbird is a recently (2015) released disease-resistant variety grown by a few farmers (4.2%) in East-Hararghe. None of the farmers were growing rust-resistant varieties in the West-Hararghe zone. About 12% of farmers in West-Hararghe used local wheat varieties. About 6.9 and 9% of farmers in East- and West-Hararghe, respectively, cultivated improved varieties, but they could not know the names of these varieties.

Farmers in each PA were cultivating a set of varieties (Table 7). The variety Danda'a was used mainly in the Malka-Ballo district of the East-Hararghe and in the Gamachis and Masela districts of West-Hararghe, while Hidase variety was only grown in Jarso and Meta districts of the East-Hararghe zone. The recently released varieties Kingbird and Ogolcho were cultivated by farmers in East-Hararghe, while none of the farmers used these varieties in West-Hararghe. Some respondent farmers in the study areas had grown more than one wheat variety which makes the proportion of the varieties above 100%. (Tables 6 and 7). Farmers′ ranked their preferred traits in a wheat variety (Table 8). There was a non-significant difference in trait preferences between the farmers in the two areas. The farmers in both areas ranked high yield potential, disease resistance and good bread quality as the most preferred traits, in that order. Farmers in East-Hararghe respectively ranked early maturity, followed by insect pest resistance as their 4th and 5th priority traits. Farmers in West-Hararghe ranked drought tolerance as the 4th important criterion followed by early maturity.

Constraints to wheat production

The major production constraints of wheat identified by farmers in the study areas included diseases (mainly rusts), shortage of arable land, a lack of improved varieties and high cost of inorganic fertilisers (Table 9).

Table 5. Accesses to information and improved seed for wheat production in the study areas.

		Zone							
		EH		WH					
Variable	Category	Frequency	%	Frequency	%	% mean	*df*	X^2	*P* value
Access to information to improved varieties (IV)	Yes	72	100	68	94.4	97.2	1	4.14	0.43
	No	1	1 1.4	6	8.3	8.3			
Sources of information to IV	DA	13	18.1	16	22.2	20.15	3	2.172	0.537
	DA and R	26	36.1	17	23.6	29.85			
	DA, R and neighbour	12	16.7	12	16.7	16.7			
	DA, R, neighbour and relatives	21	29.2	23	31.9	30.55			
Participation in technology evaluation	Yes	64	88.9	64	88.9	88.9	1	0.000	1.000
	No	8	11.1	8	11.1	11.1			
Access to improved wheat varieties	Yes	59	81.9	62	86.1	84	1	0.466	0.495
	No	13	18.1	13.9	13.9	16			

EH, East-Hararghe; WH, West-Hararghe; *df,* degrees of freedom; DA, development agent; R, local radio station.

Table 6. Lists of wheat varieties and proportions of farmers who reported cultivating these in the study areas.

		EH		EW		
Variety	Year of Release	Frequency	%	s	%	% mean
Kingbird	2015	3	4.2	–	–	4.2
Hidase	2012	25	34.6	–	–	34.6
Ogolcho	2012	8	11	–	–	11
Danda'a	2010	19	26.4	32	44.4	35.4
Kakaba	2010	5	6.9	16	22	14.45
Medawolabo	2000	2	2.8	–	–	2.8
Kubsa	1995	14	19.4	7	4.8	12.1
Improved	–	5	6.9	13	9	7.95
Landrace	–	–	–	9	12.5	12.5

EH, East-Hararghe; WH, West-Hararghe; -, unknown or not available.
Note – the varieties are listed based on year of release (latest to old)

Table 7. The proportion farmers (%) in each peasant association using various wheat varieties.

	EH Zone (Districts)						WH Zone (Districts)					
	Jarso		Meta		Malka Ballo		Gamachis		Masela		Tulo	
Variety	1	2	3	4	5	6	7	8	9	10	11	12
Kingbird	–	–	3	–	–	–	–	–	–	–	–	–
Hidase	8	10	–	7	–	–	–	–	–	–	–	–
Ogolcho	8	–	–	–	–	–	–	–	–	–	–	–
Denda'a	–	–	–	–	12	7	7	5	8	12	–	–
Kakaba	–	–	–	–	5	–	–	–	4	–	7	5
Medawolabo	–	2	–	–	–	–	–	–	–	–	–	–
Kubsa	–	–	9	–	–	5	–	–	–	–	–	7
Improved	–	–	–	5	–	–	–	7	–	6	–	–
Landrace	–	–	–	–	–	–	–	–	–	–	9	–

Values from 1 to 12 represent peasant association in East and West-Hararghe zones; see codes 1–12 in Table 2; -, not available.
Note – the varieties are listed based on year of release (latest to old)

The majority of respondents (98.2%) in East-Hararghe and 96.4% in West-Hararghe identified wheat diseases (rusts) as the most important production constraint. The ranking of diseases as production constraints was not statistically significantly different ($p = 0.06$). Shortage of arable land was identified as the second most important constraint reported by 92.9 and 90.4% of East- and West-Hararghe farmers, respectively. A lack of improved variety was identified as the third most important production constraint in both zones reported by 77.2% farmers in East-Hararghe and 75.6% in West-Hararghe. High cost and shortage of inorganic fertilisers and limited supply of improved seeds were also considered as a major limiting factor to wheat production ranked as the fourth, fifth and sixth production challenges in both areas, in that order. Drought stress was the tenth most important production constraint in East-Hararghe zone reported by 39.7% of respondents, while in West-Hararghe zone it ranked eight according to 54.6% of the respondent farmers. The ranking of drought stress as a yield-limiting factor differed significantly between the two zones ($p = 0.013$). In addition, the poor quality of the currently grown varieties was ranked significantly ($p = 0.00$) higher as a production constraint in West-Hararghe (RBQ = 61.8%) compared to East-Hararghe (RBQ = 50.4%).

Table 8. Farmer-preferred traits in a wheat variety in Ethiopia's East- and West-Hararghe zones during 2018.

	Zone					
	EH (N = 72)		WH (N = 72)			
Traits	Mean	Rank	Mean	Rank	*t* *value*	*P* value
Yield potential	1.43	1	1.30	1	1.127	0.262
Disease resistance	1.94	2	2.06	2	−0.940	0.349
Bread making quality	3.38	3	2.90	3	1.893	0.063
Early maturity	3.62	4	3.46	5	0.707	0.482
Insect pest resistance	3.75	5	4.25	8	−1.128	0.281
Drought tolerance	3.79	6	3.45	4	1.125	0.267
High market value	3.82	7	3.73	6	0.393	0.696
Good biomass	4.00	8	4.10	7	−0.250	0.806
White seed colour	4.00	8	4.75	11	−0.728	0.588
Environmental adaptability	4.40	9	4.25	8	0.882	0.382
Big seed size	4.44	10	4.62	10	−0.572	0.580
Good crop stand	4.75	11	4.46	9	0.965	0.345

EH, East-Hararghe; WH, West-Hararghe; N, number of respondents; Rank numbers of 1–11 indicates for farmer-preferred traits of 1 is high preference and 11 low preferences.

Management strategies to wheat stem rust

The wheat stem rust was the most destructive disease in the study areas. The disease was reported by 97.3% of respondent farmers. These farmers observed stem rust symptoms in their wheat fields and ranked it as a number one wheat production constraint. The onset of

Table 9. Major wheat production constraints and proportion of farmers who reported these (%) in East-and West-Haraghe zones.

		EH							WH							
		Score							Score							
Constraints	No of farmers	1	2	3	4	5	RBQ	R	1	2	3	4	5	RBQ	R	*P value*
Diseases (rusts)	72	60	11	1	0	0	98.2	1	56	7	8	1	0	96.4	1	0.06
Shortage of arable land	72	59	7	2	0	0	92.9	2	54	8	4	1	0	90.4	2	0.586
Shortage of improved variety	72	19	26	8	8	2	77.2	3	14	17	14	19	1	75.6	3	0.061
High cost of inorganic fertiliser	72	13	16	13	14	1	66.9	4	14	22	17	6	0	71.7	4	0.228
Shortage of inorganic fertiliser	72	8	15	15	18	2	65.7	5	7	24	11	17	2	70.1	5	0.611
Poor supply of seeds	72	11	19	14	10	1	65.1	6	8	14	11	22	4	65.6	6	0.140
Poor attributes of the current improved variety	72	9	17	14	12	1	61.8	7	1	10	5	31	1	50.4	10	0.000
Poor soil fertility	72	5	11	19	11	1	53.3	8	1	9	16	30	4	62.9	7	0.016
Low yield	72	8	11	13	12	2	52.6	9	2	11	6	31	0	53.3	9	0.003
Moister stress	72	5	10	11	4	5	39.7	10	4	11	7	24	5	54.6	8	0.013

EH, East-Hararghe; WH, West-Hararghe; A score of 1 denotes very important and 5 less important production constraints, RBQ, Rank Based Quotient; R, rank; *P*-values according to the Kruskal Wallis Test; Production constraints ranked based on their importance in East-Hararghe zone.

the disease ranged from August to October. The majority of respondent farmers (44.5%) mentioned that they were detected the first onset of the disease at the flowering stage or later (Table 11). About 70 (97.2%) farmers in East-Hararghe and 69 (95%) in West-Hararghe reported the recurrent occurrences of rust diseases on their farms. A small proportion of farmers (13.9%) did not know how the disease occurred. However, most farmers in both study areas were familiar with the different modes of rust spore dispersal, although there was a significant difference between the zones ($\chi^2 = 8.500$, $p < 0.014$). More farmers in East-Hararghe were familiar with rust dispersal than in West-Hararghe. Farmers in both areas implemented relatively the same rust disease management strategies ($\chi^2 = 3.064$; $p = .080$) (Table 12). About 20.8% of respondent farmers in East-Hararghe and 16.7% in West-Hararghe used rust control strategies that involved better cultural practices, whereas 13.9% in East-Hararghe and 12.5% in West-Hararghe adopted rust-resistant cultivars. The combination of cultural practices and use of resistant cultivars was used by 12.5% of the farmers in the East-Hararghe zone, while some 8.3% of farmers in the West-Hararghe zone used the combination of cultural practice with resistant varieties and resistant varieties with fungicides for each. Only 5.6% of farmers in East-Hararghe used an integrated management approach using cultural practices, resistant cultivars and chemical fungicides compared to 1.4% in West-Hararghe. Conversely, 27.8 and 41.7% of the farmers in East- and West-Hararghe, respectively, did not use any rust management options.

Table 10. Land allocation trends for wheat production between 2014 and 2018 and estimated yield under a diseased and the disease-free situation in Ethiopia's East- and West-Hararghe Zones.

		Zone	
Variable	Unit/statistics	EH	WH
Land allocated trend			
Increase	Percent	33.3	31.4
Decrease	Percent	50.0	41.4
Constant	Percent	16.7	27.2
Estimated Yield			
Disease free (tha^{-1})	Mean	2.60	2.74
	Std.	0.63	1.54
Diseased situation (tha^{-1})	Mean	0.85	0.96
	Std.	0.63	0.68
Yield reduction due to diseases (t/ha)	Mean	1.75	1.78
Yield reduction due to diseases (t/ha)	Percent	67	65

EH, East-Hararghe; WH, West-Hararghe; Std, standard deviations.

Discussion

The majority of the respondents in the study areas were males (72.9%) (Tables 2 and 3). This is consistent with the patriarchal system prevalent in the study areas where men were considered the principal decision-makers in agriculture and society in general (Kassa 2008). Furthermore, most respondent farmers (61.8%) were within the active productive age group (30-50 years old) and had large family sizes (5–8), which is important for the provision of farm labour for wheat production. The age group presents active and productive farmers and could possess valuable agricultural experience and knowledge to carry out profitable farming enterprises. Subsistence farming involves manual labour provided by family members, which places significant importance on family sizes and composition. Families with members within a productive active group are likely to have more labour access than smaller families with members in relatively younger or old age groups. Kebede et al. (2017) asserted that farmers within the active productive age group were more likely to adopt improved agricultural technologies and complement their practical experience for improved productivity. Adoption of new technologies is also related to the level of education possessed by the farmers. Technology transfer is relatively more straightforward to build upon farmers who are

Table 11. Wheat stem rust occurrence and knowledge of the respondents to the source of the disease and its dissemination in the study areas.

		Zone							
		EH		WH					
Variable	Category	Frequency	%	Frequency	%	% mean	χ^2	*df*	*P* value
Occurrence of rusts	No	2	2.8	3	4.2	3.5	.207	1	0.649
	Yes	70	97.2	69	95.8	96.5			
First onset of rusts	August	1	1.4	4	5.6	3.5	2.491	3	0.477
	September	50	69.4	42	58.3	63.9			
	October	21	29.2	23	31.9	30.6			
	Not known	2	2.8	3	4.2	3.5			
Onset of rusts at different grow stage	Stem elongation	4	5.6	6	8.3	7.0	5.487	5	0.359
	Booting	2	2.8	5	6.9	4.9			
	Flowering	34	45.8	30	43.1	44.5			
	Milk	21	27.8	11	15.3	21.6			
	Dough	11	15.3	16	22.2	18.8			
	Did not know	2	2.8	3	4.2	3.5			
Familiarity on sources the disease	Wind born	–	–	–	–	–			
	Alternate host	11	15.3	4	5.6	10.5	3.696	2	0.158
	High rainfall	52	72.2	57	79.2	75.7			
	Not known	9	12.5	11	15.3	13.9			
Knowledge of rust dissemination	Wind	25	34.7	10	13.9	24.3	8.500	2	0.014
	Wind and man	43	59.7	57	79.2	69.5			
	Not known	4	5.6	5	6.9	6.3			

EH, East-Hararghe; WH, West-Hararghe; *df*, degrees of freedom; -, no response.

more educated. Relatively less educated farmers are more likely to be less enthusiastic about adopting new technologies than educated farmers (Tefera et al. 2020). Nearly half of the participant farmers in the West-Hararghe zone (Table 3) had no formal education. In contrast, most farmers in East-Hararghe attained elementary and secondary education, indicating that more effort would be required to achieve technology transfer in West-Hararghe than East-Hararghe zone. About 53 and 40.3% of the respondent farmers in East- and West-Hararghe zones had access to farmer training centres in less than 30 minutes. The farmers′ proximity to farmer training centres was essential to ensure frequent contact with extension agents for information, inputs, and other extension services. Respondent Farmers in East and West-Hararghe had 17 and 15 times contact with extension agents in a year, in that order (Table 4). Previous studies found that frequent technical advice increased access to information and inputs for higher crop productivity (Adam et al. 2010; Tefera et al. 2020). In the study areas, most of the respondent farmers (60.4%) had limited access to input suppliers and markets (>3:30 hours), which are critical components for access to inputs and for farmers to sell their surplus. Access to inputs is important for acquiring appropriate seed, fertilisers and information for crop production. At the same time, the markets provide farmers with opportunities to generate income, especially considering that smallholder farmers have minimal surplus that must be sold at lucrative prices to generate a meaningful contribution to the household income. Farmers located furthest from the suppliers and markets incur high costs of production and marketing, which both reduce potential income (Ademe et al.

Table 12. Wheat rust diseases management options practiced by the respondent farmers in the study areas.

		Zone							
		EH		WH					
Variable	Category	Freq	%	Freq	%	% mean	χ^2	*df*	*P value*
Management applied	Yes	52	72.2	42	58.3	65.3	3.064	1	0.080
	No	20	27.8	30	41.7	34.8			
Management options	Cultural practices (C)	15	20.8	12	16.7	18.8	8.119	7	0.322
	Resistant cultivar (R)	10	13.9	9	12.5	13.2			
	Fungicides (F)	8	11.1	4	5.6	8.4			
	C + F	4	5.6	4	5.6	5.6			
	R + F	2	2.8	6	8.3	5.6			
	C + R	9	12.5	6	8.3	10.4			
	C + R+F (IDM)	4	5.6	1	1.4	3.5			
	None	20	27.8	30	41.7	34.8			

EH, East-Hararghe; WH, West-Hararghe; *df*, degrees of freedom; Freq, frequency; IDM, Integrated Disease Management.

2017). Access to basic infrastructures such as all-weather roads, markets and extension centres remains a challenge for rural communities.

More than 80 bread wheat varieties have been released in Ethiopia (Tadesse et al. 2018). In the present study areas, about 97.2% and 86.1% of respondent farmers had access to information on the existing improved varieties and received seeds from different sources, respectively (Table 5). Nevertheless, only a few (9) varieties have been thus far released and cultivated in the study areas (Table 6) due to a lack of new and improved varieties and quality seed supply. Some reported varieties are obsolete, low yielding and susceptible to wheat rusts.

In Ethiopia, there is no vibrant private seed sector. Variety release, seed production and supply are predominantly undertaken by the public sector and a few non-governmental organisations. Furthermore, in the country, there is a long-time gap between variety release and availability of the seed to farmers. This is attributed to the limited capacity of the seed sector for timely multiplication of a large quantity of seed and poor infrastructure for seed processing, transportation, storage and marketing (Tadesse et al. 2018, Semahegn et al. 2021). In the present study areas, Kingbird, the only stem rust-resistant variety, was adopted by few respondent farmers (4.2%) in East-Hararghe and none in West-Hararghe zone. The results indicate that farmers have poor access to seeds of improved and rust-resistant wheat varieties. The majority of the respond farmers opted for cluster farming, characterised by growing a few cultivars in larger plots of land for crop security against rust diseases and other production challenges (Table 7). Continuous wheat production using rust susceptible and few genetically related varieties in large areas escalate the chance of emerging and mutant stem rust races that can overcome the resistance genes present in the newly released cultivars. For example, resistant wheat cultivar, Digalu has become susceptible to a new stem rust pathotype (TKTTF) soon after being released (Olivera et al. 2015). The wide genetic diversity among wheat stem rust strains causes a shift in virulence patterns leading to the loss of resistance in many wheat varieties (Admassu et al. 2009). Hence, multiline wheat production, including genetically diverse landraces with modern disease-resistant cultivars, would confer adequate genetic variation and boost wheat production and productivity.

In their varietal choices, farmers preferred multiple traits in a single wheat variety (Table 8). An ideal variety was evaluated from different agronomic and quality perspectives. However, different traits had different levels of importance that influenced their ranking by the farmers during varietal selection. The farmers preferred a variety based on yield potential, disease resistance, and bread-making quality, the top traits. These agree with the findings by Jaleta et al. (2019) and Semahegn et al. (2021), who reported that grain yield and disease resistance were the most preferred traits for bread wheat verities in major wheat-growing areas in Ethiopia. Early maturity and drought tolerance were among farmer preferred traits during the survey, which is important considering that terminal drought stress was identified among the production constraints. There is an urgent need for early maturing and high yielding varieties whose critical and most sensitive developmental stages such as anthesis and grain filling do not coincide with the onset of drought stress. Daudi et al. (2018) found that farmers in Tanzania preferred early maturing varieties as a strategy to escape disease and drought stresses. Seed size and seed colour were the least preferred traits because these traits are mostly associated with market values. Wheat production in the study areas is primarily for household consumption. Only about 5.2% and 4.6% of the produce were sold in East-Hararghe and West-Hararghe in 2008, respectively (CSA 2009). High levels of food insecurity were noted in the study areas, possibly due to high population density, small and fragmented land and low wheat technology adoption (Haile et al. 2021).

Rust diseases were ranked as the most important yield-limiting factor (Table 9). Respondent farmers reported about 67 and 65% yield loss in the East-Hararghe and West-Hararghe zones, respectively (Table 10). This concurs with other studies that have found that yield loss due to wheat rusts can reach up to 70% (Yami et al. 2013). There are no rust-resistant wheat varieties available in Ethiopia; hence the farmers rely on chemical fungicides and cultural control to manage the disease. However, smallholder farmers usually cannot afford chemical control. Also, these farmers have small landholdings to practices cultural practices such as crop rotation and fallowing for adequate control. The farmers can benefit from accessing and cultivating slow rusting and diverse cultivars to manage the spread of wheat rust and avoid a rapid breakdown in rust resistance in newly released varieties. The breakdown of rust resistance soon after release has been widely reported. This indicates the need to identify and deploy diverse sources of resistance as breeding priorities in resource-poor farmers and to avail slow rusting varieties to farmers (Olivera et al. 2015). However, slow rusting cultivars were almost non-existent among the farmers in the study areas, with a negligible proportion of the farmers cultivating 'Kingbird' cultivar. The cultivar 'Kingbird' was introduced in Ethiopia in 2014 from Kenya after a new stem rust race (TKTTF) was identified in 2012 and raged through so many Ethiopian farmers' fields in 2013 and 2014. The TKTTF race was virulent against nearly all of the currently deployed resistance genes in Ethiopia. Kingbird carries adult plant resistance (APR) to the Ug99 group of races, the new TKTTF race, and is expected to have broad-spectrum resistance to most new and evolving races (CIMMYT 2015). However, it would be important to assess the Kingbird variety against the farmers preferred traits. Alternatively, this variety can be used in breeding programmes to introgress the disease resistance genes into a suitable genetic background that carries most of the farmer's preferred traits.

A large germplasm collection (over 470,000) was screened for wheat rust resistance in Ethiopia and Kenya. The screening was conducted from 2005–2014 in Ethiopia and Kenya that delivered few diverse race-specific and adult plant resistance (Prasad et al. 2016). Even though numerous resistance genes and several quantitative trait loci (QTL) have been identified, most of these were not functional due to the emergence of new and virulent races (McIntosh et al. 2016; Juliana et al. 2017). In Ethiopia, a series of severe wheat rust epidemics have been documented; including the yellow rust on the variety Laketch in 1977 (Hulluka et al. 1991), yellow rust on the variety Dashen in 1988 (Badebo et al. 1990), stem rust on the variety Enkoy in 1993/1994 (Shank 1994), yellow rust on Kubsa and Galema in 2010 (Denbel 2014), and stem rust on Digalu in 2013/14 (Olivera et al. 2015). Most (96.5%) of the respondent farmers observed rust diseases on their farms during the study period, showing that rust diseases are widespread in the study areas (Table 11). This was further confirmed by the majority of farmers concurring that rust diseases were the main constraint to wheat production. Most of the farmers had detected the onset of the diseases at flowering stages, which indicates that the yield loss could be enormous due to the early onset of the disease and most of the farmers used rusts susceptible varieties during the growing season. This finding agreed with Eshete (2018) report, which pinpointed a yield loss due to wheat stem rust reaching 100%. Thus, continuous assessment of the production constraints, farmer preferred traits and identifying genes for the target traits are important activities to guide breeding programmes.

Wheat rust disease is primarily managed by cultural practices such as early planting to minimise yield losses. However, the use of cultural practices alone may not be effective if a large exogenous inoculum occurs. The rust spores can cause disease epidemics by extending over long distances from neighbouring fields, regions, countries and/or continents in a given season (Roelfs et al. 1992). Early planting, fungicide application, and host resistance would provide more effective control of wheat rust (Hei et al. 2017), but the farmers lack financial resources to procure pesticides. Farmers in the study areas were well aware of the benefit of fungicides for controlling rust diseases. However, only a few farmers applied fungicides due to high costs and less accessibility of chemicals in the areas (Table 12). Rust-resistant cultivars were used by a small proportion of the farmers, although most of the varieties grown in the study area had become susceptible, except the recently introduced variety Kingbird. Resistant cultivars are the most effective, economical, and environmentally friendly approach to controlling rusts (Oliver 2014). Hence, the multiplication and distribution of newly released cultivars in sufficient quantities and on time will help in mitigating against the impact of wheat rust disease and contribute to the household food security of smallholder farmers in Ethiopia.

The land shortage was one of the chronic production constraints in the study areas (Tables 4 and 9). This aggress with the findings of Tesfaye and Seifu (2016), who reported that the eastern regions of Ethiopia are characterised by high population pressure and small farm sizes. Small and fragmented landholding systems contribute to limited agricultural inputs and low productivity in the smallholder production systems (Gebreselassie et al. 2017). The cost of fertiliser and pesticide inputs were too high for the smallholder farmers, and the low productivity on their small landholdings could not offset the production costs, which discouraged investment in input procurement. Low and suboptimal application rates of fertilisers have been reported previously, suggesting that smallholder farmers in Ethiopia do not generally afford to buy inorganic fertilisers (Hei et al. 2017).

The study identified the following major wheat production constraints: wheat rust diseases followed by lack of arable land and limited access to improved varieties. Farmers in the study areas reported a high preference for high yielding wheat cultivars, rust resistance and bread-making quality as major preferred traits in wheat. The result suggests the need to breed for high yielding wheat cultivars with durable rust resistance. Durable resistance (race non-specific resistance) can provide broader and long-lasting resistance to fight against the wheat rust pathogen that evolves into new races in high-risk areas of Ethiopian highlands where wheat cultivation and pathogen evolution is continuous.

Acknowledgements

The African Centre for Crop Improvement (ACCI) is gratefully acknowledged for the financial support of the study. Thanks go to Haramaya University/Ethiopia for granting a study leave to the first author. The authors are grateful to farmers in the study areas for making this study possible. We acknowledge the Bureau of Agriculture staff at zone and district levels, development agents and graduate assistances of Haramaya University for data collection and research support.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The study was funded by the Alliance for the Green Revolution in Africa (AGRA) throught the African Centre for Crop Improvement of University of KwaZulu-Natal.

Notes on contributors

Mulu Nigus is a PhD candidate at the University of KwaZulu-Natal in South Africa.

Hussein Shimelis is a Professor of Plant Breeding at the University of KwaZulu-Natal in South Africa. He is a co-author for the current study.

IsacK. Mathew is a Post-Doctoral Research Fellow in Plant Breeding at the African Centre for Crop Improvement (ACCI), the University of KwaZulu-Natal in South Africa. He is a co-author for the current study.

Seltene Abady is an Assistant Professor of Plant Breeding at Haramaya University in Ethiopia.

ORCID

Mulu Nigus http://orcid.org/0000-0003-0069-8560
Hussein Shimelis http://orcid.org/0000-0003-2793-8392
IsacK. Mathew http://orcid.org/0000-0001-7358-4690
Seltene Abady http://orcid.org/0000-0002-9618-0741

References

Adam B, Kassa B, Belayineh L, Tesfaye L. 2010. Effects of crop commercial orientation on productivity of smallholder farmers in drought-prone areas of the central rift valley of Ethiopia. J Rural Dev. 33(4):105–128.

Ademe A. 2017. Crop productivity, efficiency and commercialization of smallholder farmers in the highlands of Eastern Ethiopia. PhD Dissertation, Haramaya University, Ethiopia.

Ademe A, Legesse B, Haji J, Goshu D. 2016. Crop productivity as influenced by commercial orientation of smallholder farmers in the highlands of eastern Ethiopia. East Afr J Sci. 10(2):145–150.

Admassu B, Lind V, Friedt W, Ordon F. 2009. Virulence analysis of *Puccinia graminis* f.sp. *tritici* populations in Ethiopia with special consideration of Ug99. Plant Pathol. 58(2):362–369.

Agidie A, Tanner DG, Liben M, Dessalegne T, Kebede B. 2000. Farmer participatory evaluation of promising bread wheat production technologies in northwestern Ethiopia, 380-390. In: Payne T, Tanner D, editors. Eleventh regional wheat workshop for eastern, Central and Southern Africa, 18-22 Sep 2000. Addis Ababa, Ethiopia: CIMMYT; p. 436.

Atlas W. 2016. Commercial wheat varieties released in Ethiopia. http://wheatatlas.org/country/varieties/ETH/. Accessed on September 2021.

Badebo A, Stubbs RW, Van Ginkel M, Gebeyehu G. 1990. Identification of resistance genes to puccinia striiformis in seedling of Ethiopian and CIIMMYT bread wheat varieties and lines. Neth J Plant Pathol. 96(4):199–210.

Belay T, Araya ALEMU. 2015. Grain and biomass yield reduction due to Russian wheat aphid on bread wheat in northern Ethiopia. Afr Crop Sci J. 23(2):197–202.

Berhane G, Paulos Z, Tafere K, Tamiru S. 2011. Food-grain consumption and calorie intake patterns in Ethiopia. ESSP II working paper 23. International food policy research institute. Ethiopia strategy support program II, Addis Ababa, Ethiopia.

Bishaw Z, Struik PC, Van-Gastel AJG. 2010. Wheat seed system in Ethiopia: farmers' varietal perception, seed sources, and seed management. J New Seeds. 11:281–327.

Chambers R. 1994. Participatory rural appraisal (PRA): challenges, potentials and paradigm. World Dev. 22:1437–1454.

CIMMYT. 2015. Kingbird released in Ethiopia to combat new stem rust threat. https://www.cimmyt.org/news/kingbird-released-in-ethiopia-to-combat-new-stem-rust-threat/. Accessed on 19 November 2021.

CSA. 2009. Agricultural sample survey report on area and production of crops 2008-2009. Volume I Statistical Bulletins 446, Addis Ababa, Ethiopia.

CSA. 2021. Agricultural sample survey: Report on area and production of major crops (Private peasant holdings, Meher Season). Volume I Statistical Bulletins 590, Addis Ababa, Ethiopia.

Daudi H, Shimelis H, Laing M, Okori P, Mponda O. 2018. Groundnut production constraints, farming systems, and farmer-preferred traits in Tanzania. J Crop Improv. 32(6):812–828.

Dawit A, Tekalign M. 2007. The role of farmers' perception to enhance the adoption of improved field pea variety. Ethiop J Agric Sci. 19:91–101.

Denbel W. 2014. Epidemics of *puccinia striiformis f. sp. tritici* in arsi and West arsi zones of Ethiopia in 2010 and identification of effective resistance genes. J Nat Sci Res. 4(7):2224–3186.

Eshete B. 2018. Status and challenges of wheat stem rust (puccinia graminis f.sp.tritici) and threats of new races in Ethiopia. Int J For Hortic. 4(4):22–31. http://doi.org/10.20431/2454-9487.0404003.

FAOSTAT. 2018. Agriculture Organization of the United nations. Rome: Statistical database.

Gebreselassie S, Haile MG, Kalkhul M. 2017. The wheat sector in Ethiopia: current status and key challenges for future value chain development. working paper No. 160. Centre for development research (ZEF), University of Bonn, Bonn, Germany. ISSN: 1864-6638.

Haile D, Nigussie D, Ayana A. 2021. Nitrogen use efficiency of bread wheat: effects of nitrogen rate and time of application. J Soil Sci Plant Nutr. 12(3):389–409.

Hei N, Shimelis H, Laing L. 2017. Appraisal of farmers' wheat production constraints and breeding priorities in rust-prone agro-ecologies of Ethiopia. Afr J Agric Res. 12:944–952.

Hulluka M, Woldeab G, Adnew Y, Desta R, Badebo A. 1991. Wheat pathology research in Ethiopia: wheat research in Ethiopia: A historical perspective. In: H. Gebre-Mariam, D. G. Tanner, M. Hulluka, editor. Addis Ababa, Ethiopia: IAR/CIMMYT; p. 173–217.

Hundie B, Verkuiji H, Mawangi W, Tanner DG. 2000. Adaptation of improved wheat technologies in adaba and dodola woredas of the Bale highlands of Ethiopia. Addis Ababa, Ethiopia: CIMMYT/EARO.

ICPAC. 2019. Report on historical climate baseline statistics for East- and West-Hararghe, Ethiopia Vol 2. The IGAD Climate Prediction & Applications Centre (ICPAC), Nairobi, Kenya.

Jaleta M, Hodson D, Abeyo B, Yirga C, Erenstein O. 2019. Smallholders' coping mechanisms with wheat rust epidemics: lessons from Ethiopia. PLoS ONE. 14(7):e0219327.

Juliana P, Singh RP, Singh PK, Crossa J, Huerta-Espino J, Lan C, Bhavani S, Rutkoski, JE, Poland JA, Bergstrom GC, Sorrells ME. 2017. Genomic and pedigree-based prediction for leaf, stem, and stripe rust resistance in wheat. Theor Appl Genet. 130(7):1415–1430.

Kassa H. 2008. Agricultural extension in Ethiopia: historical evolution, relevant policies and challenges. In: Assefa T., editor. Digest of Ethiopia's national policies, strategies and programs. Addis Ababa, Ethiopia: Forum for Social Studies (FSS); p. 153–175.

Kebede D, Ketema M, Dechassa N, Hundessa F. 2017. Determinants of adoption of wheat production technology package by smallholder farmers: evidences from eastern Ethiopia. Turk J Food Agric Sci. 5(3):267–274.

McIntosh RA, Dubcovsky J, Rogers WJ, Morris C, Appels R, Xia XC. 2016. Catalogue of gene symbols for wheat: 2015-2016 supplement. DOI: https://shigen.nig.ac.jp/wheat/komugi/genes/macgene/supplement 2015.

Minot N, Warner J, Lemma S, Kassa L, Gashaw A, Rashid S. 2015. The wheat supply chain in Ethiopia: patterns, trends, and policy options. Washington, DC: International Food Policy Research Institute (IFPRI).

Oliver RP. 2014. A reassessment of the risk of rust fungi developing resistance to fungicides. Pest Manag Sci. 70:1641–1645.

Olivera P, Newcomb M, Szabo LJ, Rouse M, Johnson J, Gale S. 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. J Phytopathol. 105:917–928.

Owere L, Tongoona P, Derera J, Wanyera N. 2014. Farmers' perceptions of finger millet production constraints, varietal preferences and their implications to finger millet breeding in Uganda. J Agric Sci. 6:126–138.

Prasad P, Bhardwaj SC, Khan H, Gangwar OP, Kumar S, Singh SB. 2016. Ug99: saga, reality and status. Curr Sci. 110 (9):1614–1616.

Roelfs AP, Singh RP, Saari EE. 1992. Rust diseases of wheat: concepts and methods of disease management. Mexico, DF: CIMMYT, El Batan.

Sabarathnam VE. 1988. Manual of field experience training for ARS scientists. Hyderabad: NAARM.

Semahegn Y, Shimelis H, Laing M, Mathew I. 2021. Farmers' preferred traits and perceived production constraints of bread wheat under drought-prone agro-ecologies of Ethiopia. Agric Food Secur. 10:18.

Shank R. 1994. Wheat stem rust and drought effects on Bale agricultural production and future prospects. Report on February 17-28 assessment, Addis Ababa, Ethiopia.

Shiferaw B, Kassie M, Jaleta M, Yirga C. 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. Food Policy. 44:272–284.

Statista. 2021. Top wheat-producing countries 2020/2021. Accessed in August 2021. https://www.statista.com/statistics/237912/global-top-wheat-producing-countries.

Statistical Product and Service Solutions (SPSS). 2011. SPSS for windows release 20.0. SPSS Inc. 1989-2011. IBM Company.

Sununtnasuk C. 2013, December. Calculating wheat flour consumption: Sources and methods vol.14:p.1-61. In smarter features cost and economic benefit training workshop, December 10-14, 2013. USAID SPRING, Dares Salaam, Tanzania.

Tadesse W, Bishaw Z, Assefa S. 2018. Wheat production and breeding in Sub-Saharan Africa: challenges and opportunities in the face of climate change. Int J Clim Chang Str. 11(5):696–715.

Tefera T, Elias E, Koomen I. 2020. Drivers of farm-level adoption of crop extension packages in Ethiopia. J Agric Environ Int Dev. 114(1):5–32.

Tesfaye W, Seifu L. 2016. Climate change perception and choice of adaptation strategies: empirical evidence from smallholder farmers in east Ethiopia. Int J Clim Chang Strateg Manag. 8(2):253–270.

USDA. 2019. USDA world markets and Trade Report. Accessed on December 15, 2019.

Weltzien E, Christinck A. 2009. Methodologies for priority setting in plant breeding programmes. In: Ceccarelli S, Guimaraes EP, Weltzien E, editor. Plant breeding and farmer participation. Rome: FAO; p. 75–105.

Yami M, Fufa F, Fita T, Usman S. 2012. Prospects and challenges of wheat production in Ethiopia: evidence from major wheat producing regions of the country. In: E. Quilligan, P. Kosina, A. Downes, D. Mullen, B. Nemcova, editor. Conference proceedings, wheat for food security in Africa Oct 8–12. Addis Ababa, Ethiopia: WRCoE, EAAPP. p. 49-51.

Yami M, Solomon T, Begna B, Fufa F, Alemu T, Alemu D. 2013. Source of technical inefficiency of smallholder wheat farmers in selected waterlogged areas of Ethiopia: A trans log production function approach. Afr J Agric Res. 8:3930–3940.

Zegeye F, Alamirew B, Tolossa D. 2020. Analysis of wheat yield gap and variability in Ethiopia. Int J Agric Econon. 5(4):89–98.