Proceedings of the Delivering Genetic Gain in Wheat (DGGW) Project Closing Workshop

19-20 March 2020

EIAR, Addis Ababa, Ethiopia

Edited by

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Bedada Girma

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Ethiopian Institute of Agricultural Research

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Foreword

As you are aware, we are in the Changing World. After globalization and the changing environment and climate, we are now also facing a food crisis and financial or economic crisis. These changes are affecting our lives in many different ways. Food security will continue to be a major challenge for the international community. The biggest losers in the recent increase in food prices are the dry areas, including Ethiopia, since they are the largest importers of major food crops particularly wheat.

An epidemic of stem rust on wheat caused by race TTKSK (e.g. isolate Ug99) is currently spreading across Africa, Asia, and the Middle East and is causing major concern due to the large numbers of people dependent on wheat for sustenance. The strain spread to Kenya, then Ethiopia, Sudan, and Yemen, and is becoming more virulent as it spreads. Scientists are working on breeding strains of wheat that are resistant to UG99. However, wheat is grown in a broad range of environments. This means that breeding programs would have extensive work remaining to get resistance into regionally adapted germplasm even after resistance is identified. Apart from stem rust, Leaf rust and stripe rust are also economically important diseases in Ethiopia.

To curb the wheat rust problem a sub-award agreement was signed between Cornell University and the Ethiopian Institute of Agricultural Research (EIAR) to study the spread and management of wheat rusts in the country. Cornell entered into this research and development sub-award to implement the Delivering Genetic Gain in Wheat (DGGW) project which practically started on January 1, 2017.

Currently the project has been completed and a closing workshop was conducted on March 19-20, 2020 in Addis Ababa. Following this, it was found necessary to prepare proceedings of the workshop report. The report, sponsored by EIAR and DGGW was national in scope and dispatched to the stakeholders beyond the Ethiopian Institute of Agricultural Research (EIAR), to recognize that experimental information necessary to understand and manage wheat rust diseases research lies in communities across the entire world.

This workshop summary report has been prepared by the DGGW project management as a factual summary of what occurred at the workshop and is the result of the efforts and collaboration among several individuals. The workshop's success would not have been possible without the invaluable contributions by the many speakers, moderators, and other participants who donated their time and expertise to inform these discussions.

We wish to thank all individuals who had taken part in the preparation of this report. However, responsibility for the final content of this report rests entirely with the editors.

Diriba Geleti (PhD)
Deputy Director General of EIAR

Preface

In an attempt to meet the ever increasing demand, decades of efforts are in progress to improve wheat production and productivity in Ethiopia. Currently, wheat in Ethiopia is identified by the government as one of the strategic crops. However, biotic and abiotic factors are currently causing tremendous amount of yield losses in the crop. The NARS has generated 100+ improved wheat varieties for both highland and lowland agro-ecologies. Consequently, productivity has also improved more than two folds since the last three decades. Even then, wheat rust diseases are becoming a menace to wheat production in Ethiopia. In this regard wheat rusts induce heaviest crop losses over years.

Wheat rusts are caused by fungi and are significant diseases affecting cereal crops. Crop species which are affected by the disease include bread wheat, durum wheat, barley and triticale. Wheat is affected by three different types of rust diseases; leaf rust (caused by *P. triticina Eriks*), stripe rust or yellow rust (caused by *P. striiformis Westend. f. sp. tritici Eriks*), and stem rust (caused by *P. graminis* Pers: Pers. f. sp. *tritici Eriksi*). All of the above wheat rust types are known to occur in Ethiopia and inflict tremendous yield losses.

To manage yield losses due to wheat rusts, a joint project Delivering Genetic Gain in Wheat (DGGW) was initiated in 2017 by Cornell University and Ethiopian Institute of Agricultural Research (EIAR). The project has been completed in March 2020 and a closing workshop was held in Addis Ababa.

The early warning and advisory system developed through DGGW project in Ethiopia is now reaching hundreds of thousands of smallholders with timely and actionable advice for rust control based on advanced risk forecasting and rapid disease detection. This system provides a model for other regions and other crop diseases.

Dear Authors and esteemed Readers,
It is with deep satisfaction that we write this Preface to the Proceedings of the Delivering Genetic Gain in Wheat project Closing Workshop held in EIAR, Addis Ababa, Ethiopia, March 19-20, 2020.

The Workshop was attended by more than 70 participants from 7 different research centers and Institutions, many attending the workshop for the first time. About 120 participants from local and International institutions were invited to attend the workshop. However, some of the invitees could not appear at the Workshop because of travel restrictions as a result of COVID-19.

The Workshop particularly encouraged the project findings in the specific objectives and interaction of researchers working on wheat rust diseases with project partners, and relevant EIAR center and sector directors in an informal setting to discuss the output of project objectives and activities of the project to be carried out in the future. Their contributions helped to make the workshop as outstanding as it has been. The presentations are believed to contribute the most recent scientific knowledge known in the field of wheat rust diseases, their impacts, distribution and management in Ethiopia.

This type of workshop looks particularly appropriate and useful because research concerned with wheat rust diseases is rapidly growing, and a platform for rapid and direct exchanges about the latest research findings in the area can provide a further burst in the development of novel ideas. This Proceedings will furnish readers with an excellent reference book. We trust also that this will be an impetus to stimulate further study and research in all areas of wheat rust diseases.
We thank all authors and participants for their contributions.

Editors

Delivering Genetic Gain in Wheat (DGGW) Project Overview

Eshetu Derso[1] , Netsanet Bacha[1], Bekele Kassa[1], Ashenafi Gemechu[1], Tamirat Negash[1], Tsegaab Tesfaye[1], Habtemariam Zegeye, and Mekuria Temtme[1],
[1]*Ethiopian Instituete of Agricultural Research (EIAR) P.O.Box 2003, Addis Abeba, Ethiopia*

Introduction

A Subaward agreement was signed between Cornell University and Ethiopian Institute of Agricultural Research (EIAR). Cornell entered into this research and development subaward to implement the Delivering Genetic Gain in Wheat (DGGW) project which practically started on January 1, 2017. The prime sponsors and donors of the project were Bill & Melinda Gates Foundation (BMGF) and Department for International Development (DFID-UK) through Cornell University, Office of Sponsored Programs (OSP). Memorandum of understanding between Cornell University and Ethiopian Institute of Agricultural Research was signed on December 31, 2016.

The total estimated cost of performing the work was USD 1,465,003 with additional USD 44,023.00 funds obligated to this contract covered the work performed through March 31, 2020.

Sub-recipients performance under this agreement was under the direction of Dr. Eshetu Derso who was assigned as Principal Investigator (PI) for this project and considered essential to the work.

Project Management

The Principal Investigator was Dr. Eshetu Derso and the Technical Coordinators were Dr. Bedada Girma who was responsible for Breeding and Dr. Getaneh Woldeab for Pathology and were stationed at Kulumsa and Ambo research centers respectively. To facilitate and enhance project implementation, DGGW project implementing centers were requested to select one researcher as a project focal person who will be responsible for the technical and financial issues of the project at their respective centers. The main responsibility of the five focal persons were reporting technical and financial accomplishments of their respective centers to the project national coordinator. The focal person for finance was assigned from EIAR head office.

Table 1 .Project focal persons at implementing centers

No.	Name	Implementing Research Centers
1	**Dr. Bekele Kassa**	Holleta
2	**Ashenafi Gemechu**	Debre Zeit
3	**Tamirat Negash**	Kulumsa
4	**Tsegaab Tesfaye**	Ambo
5	**Tamene Mideksa**	Sinana
6	**Ephrem Negash**	EIAR head office (Finance)

Project objectives

Global Objectives:

- Modernize breeding programs at CIMMYT and national programs (Ethiopia, Bangladesh, India) to increase the rate of genetic gain
- Systematically reduce the world’s vulnerability to wheat diseases and heat stress
- Modernize surveillance of the host and diseases
- Advocate for and facilitate global investment in wheat improvement

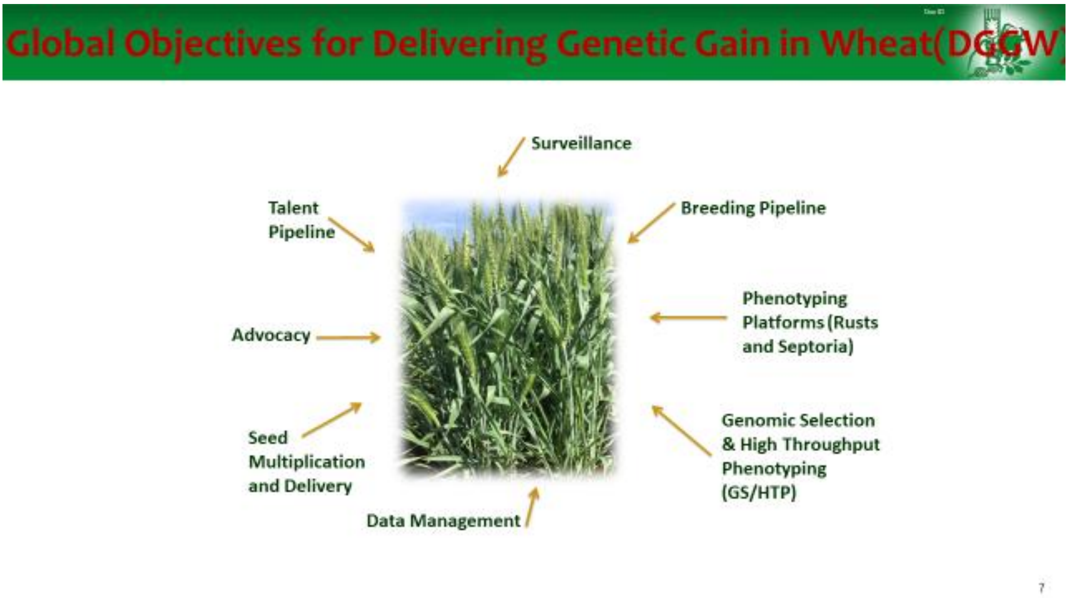

Figure 1. Global objectives for delivering genetic gain in Wheat (DGGW)

Ethiopia related objectives:

- **Surveillance-** Expand existing surveillance and monitoring systems of wheat diseases including rusts and septoria; stem rust race analysis and informing project partners and stakeholders;
- **Phenotyping Platform-** of international and national nurseries at hotspot locations and sharing of data;
- **Breeding Pipeline-** Support the National wheat breeding activities with the goal of providing improved and diverse BW and DW candidate varieties with improved genetic yield gain;
- **Maintenance of Critical facilities-** Repair and rehabilitation of research facilities and physical capacity building;
- **Talent Pipeline-** Support long and short term trainings. MSc and PhD

Green= Operational Red= Planned

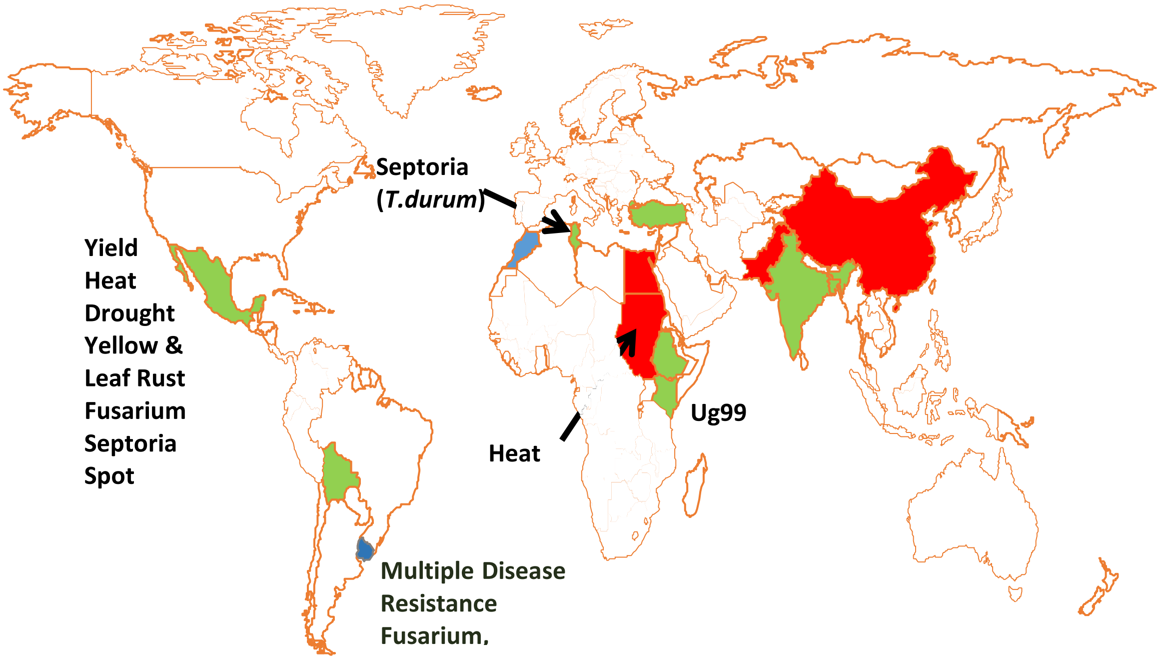

Figure 2. A global phenotyping network for wheat improvement

Some sites represent future climate analogues, others are hotspots for specific diseases.

Responsibility of implementing centers:

- Disease surveillance and race analysis- **Ambo research center**
- Stem rust and leaf rust phenotyping - **Debre-Zeit research center**
- Septoria phenotyping – **Holetta research center**
- Yellow rust and Leaf rust phenotyping **- Kulumsa research center**
- SR, YR and LR phenotyping - Sinana research center, support through OARI
- Partial budget support to BW and DW breeding programs;
- Support for local and external training;

- Maintenance and rehabilitation of physical research facilities; enhancement of internet connectivity at centers, surveillance, video conference – ICT EIAR head office

1. Surveillance

- Ethiopia Wheat Disease survey
- Three surveys (Belg, Early-Meher, and Meher seasons) conducted by DGGW project implementing research centers, partners from Regional research centers and Universities & summarized by Ambo and shared.
- Ethiopian Wheat Rust Trap Nursery
- Early warning system provided to stakeholders.

DGGW supported Pathology Activities

There were 16 wheat rust Pathology activities supported by the project

- Ethiopian Wheat Rust Trap Nursery
- Screening of Wheat Germplasms for combined Resistance to major Wheat diseases
- Characterization of *Puccinia striformis* f.sp.*tritici* (Race Phenotyping)
- Evaluation of wheat germplasm for adult resistance to stem rust (single race nursery)
- Survey of wheat diseases in major wheat growing areas
- Stem rust race analysis
- Survey of aeciospores from Barberry plant (*Berberris holstii*)
- Wheat stem rust race multiplication
- International wheat and barley genotypes screening nursery for stem rust
- Durum wheat elite lines and commercial cultivars screening for TKTTF and JRCQC
- Durum wheat elite lines and commercial cultivars screening for JRCQC
- Wheat early and late season survey
- Leaf rust race analysis
- Septoria phenotyping (Wheat germplasm screening for septoria leaf blotch)

Breeding Pipeline

Bread wheat breeding trials partially supported by DGGW project;

- Bread wheat preliminary variety trial for medium to late maturity (BWPL)
- Bread wheat preliminary variety trial for early maturity (BWPE)
- Bread wheat national variety trial for early maturity (BWNE)
- Bread wheat national variety trial for medium to late maturity (BWNL)
- Stress Adaptive Tolerance Yield Screening (SATYN)
- Harvest Plus bread wheat Yield trial (HPYT)
- Stem Rust Resistance Screening Nursery (SRRSN)
- Semi-Arid wheat Yield Trial (SAWYT)
- High Rainfall Wheat Screening Nursery (HRWSN)
- Semi-Arid Wheat Screening Nursery (SAWSN)
- Elite Spring Wheat Yield Trial (ESWYT)
- International Bread Wheat Screening Nursery (IBWSN)

Planned expected outputs

- Effective surveillance and monitoring of wheat diseases at the national level; race analysis at Ambo and feedback to key stakeholders nationally and globally delivered.
- Rust spore multiplication of prevalent and important races for single race screening nurseries at Debre-Zeit and Kulumsa performed.
- Phenotyping information from disease platforms generated.
- Improved candidate varieties of BW & DW with genetic yield gain higher than currently achieved; quality breeder seed generated.
- Enhanced research manpower through training, locally and externally, implemented.
- Better conditioned lab, green house and field research facilities; internet connectivity and usage maintained.

DGGW Project contribution on Impacts in Farmers Fields

- New, rust resistant varieties have been adopted at large scale
- >61% of the area planted to recent varieties
- Giving 12-17% yield advantage over old varieties
- Estimated 225,500 tones increased production

- Estimated US$50 million in benefit to farmers

Talent Pipe line

Human Capacity Building:

1. Long term training

   3 PhDs, namely,

1. **Shitaye Homa:** Debre Zeit research center, Field of study -Breeding at Cornell University
2. **Worku Dembel:** Debre Zeit research center, Field of study- pathology, at Minnesota University
3. **Endale Hailu:** Ambo research center, Field of study -pathology, at Minnesota University

DGGW supported MSc students trained in local Universities;

Table 2. Year 2017

No.	Name of Student	Center	University of study
1	Habtamu Tesfaye Ayehu	Debre Zeit	Haramaya University
2	Fikirte Yirga Belayneh	Kulumsa	Haramaya University
3	Belayneh Alamirew*	Adet	Bahir Dar University
4	Tsegaab Tesfaye	Ambo	Hawassa University
5	Lidya Tilahun Hadiss	Kulumsa	Jimma University

Table 3. Year 2018

No.	Name of Student	Center	University of study
1	Gizachew Hirpa	Mehoni	Jima
2	Workinesh Batu	D/Zeit	Haramaya
3	Tilahun Bayisa	Sinana	Haramaya
4	Yonatan Gedamu	Holeta	Hawassa
5	Gadisa Alemu	Kulumsa	Hawassa

Table 4. Year 2019

No.	Name of Student	Center	University of study
1	Ashagre Asnakew	Debre Zeit	Jima
2	Asheber Baye	Adet	Bahir Dar
3	Getnet Muche	Kulumsa	Bahir Dar
4	Kitesa Gutu	Ambo	Jimma
5	Mulatu Abera	Sinana	Haramaya

Table 5. Short Term Trainings abroad

Name	center	year	Place	Title	Prepared by (Joint collaboration)
Tsegaab Tesfaye	Ambo	Oct, 2015,	KALRO, NJORO, KENYA	"7th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Fikirte Yirga	KARC	Oct, 2015,	KALRO, NJORO, KENYA	"7th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Habtamu Tesfaye	DZARC	Oct, 2015,	KALRO, NJORO, KENYA	"7th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Kitesa Gutu	Ambo	Oct,2016	KALRO, NJORO, KEN A	"8th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Tamene Mideksa	Sinana	Oct, 2016	KALRO, NJORO, KENYA	"8th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Megersa Debela	Bako	Oct,2016	KALRO, NJORO, KENYA	"8th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Behaylu Tadesse	DZARC	Oct,2016	KALRO, NJORO, KENYA	"8th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Zerihun Tadesse	KARC	Oct,2016	KALRO, NJORO, KENYA	"8th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Woulita Wendewesen	Debre Birhan ARC	2018	KALRO, NJORO, KENYA	"10th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Ketema Mekonen	DZARC	2018	KALRO, NJORO, KENYA	"10th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Masresha ----	DZARC	2018	KALRO, NJORO, KENYA	"10th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Getinet Muche	KARC	2018	KALRO, NJORO, KENYA	"10th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.
Habtemariem Zegeye	KARC	2018	KALRO, NJORO, KENYA	"10th annual training course on stem rust note taking and evaluation of germ plasm"	CIMMYT, KALRO, BGRI, CORNELL UNIVERSITY.

Maintenance of Critical facilities

Physical Capacity

Vehicles: 2019

1. Three Toyota Pick up trucks: To:
    1. Septoria Phenotyping – Holleta
    2. Surveillance and race analysis - Ambo
    3. Surveillance and Phenotyping- Sinana
2. One Toyota SUV (Prado) - Project Management – EIAR head office

Publications:

1. Journal articles:

Pathology	=	11
Breeding	=	3
Protection (pesticide and yield loss)	=	2
Total	=	16

2. MSC Thesis produced = 15

Varieties Released (2016-2018)

Bread Wheat	**=**	**14**	**(4 Candidates)**
Durum Wheat	**=**	**6**	
Total	**=**	**20**	

Future Plan:

- **Objective 1:**
    - Continue with expanded surveillance monitoring of hosts and diseases.
    - Collaborative enhanced early warning and forecasting.
    - Continue race analysis of stem rust at Ambo;
    - Yellow rust race analysis at Kulumsa
    - Leaf rust at Debre-Zeit.

- **Objective 2:**
    - Continue phenotyping of national and international nurseries at Debre-Zeit, Kulumsa, Holetta and Sinana and provide information to national and global partners.

- **Objective 3:**
  - Continue support to BW and DW breeding with moderate supplementary budget
- **Objective 4:**
  - GH and other equipment maintenance is always a challenge and requires periodic repairs with contracted expertise.
- **Objective 5:**
  - Farmer level trainings will be enhanced;
  - Additional support to MSc students will continue (if budget available)
    - Long and short term trainings will continue to improve manpower capacity (if budget available).

Opportunities:

- Enabling government policies (commitment)
- Strong international support for wheat research
- Locally high demand for wheat
- Availability of high potential irrigable land
- Presence of large number of wheat farmers
- Extension system in place
- Strong collaboration with partners
- Accessibility of germplasm from CG centers and other organizations (CIMMYT.ICARDA, USDA, etc..,)

Lessons learned:

During the three years project implementation period, EIAR gathered that partnership, timeliness and transparency were very essential components to focus on, during project undertakings, in order to properly execute the project objectives and activities. These factors were observed to build trust among the partners (EIAR, Cornell University and DFID-(UK).

- **Partnership:** EIAR learned that, working in partnership with other stakeholders/partners locally or globally, for a common goal is the best way of leveraging project undertakings. Development of the **wheat rust Early Warning System (EWS)** in Ethiopia is the best example.
- **Timeliness:** The fact or quality of execution of each objective and sharing of the expected results and reporting being done or occurring at a favorable

or useful time as indicated in the activity plan for each objective was found to be very crucial.

- **Transparency**: The condition of being transparent on planned activities for the specific objectives were monitored in the research fields and openly discussing the existing problems and finding common solutions on how to proceed further was very essential.
- **Trust:** Firm belief in the reliability of the project outputs created convenience for the donors and project implementers. It also indicated convenience and satisfaction for both parties.

Challenges

- Limited varieties for diverse agro-ecological zones (AEZs)
- Continuous cultivation of susceptible varieties (high inoculum build up)
- Recurrent rust epidemic and gene break down of deployed cultivars
- Climate change (Erratic rainfall, drought etc. ..)
- Soil acidity and fertility degradation
- Limited lath house/green house facilities
- Wage and labor costs not compatible with gov. budgets
- Procurement associated issues
- Centers Poor budget utilization
- Delayed Reports submission
- Lack of commitment from few individuals

Way forward:

- Modeling and early warning system be strengthened and continued
- Adult plant resistance research should get more emphasis
- Breeding for tolerance of abiotic stresses (drought, heat, salinity,acidity) should get due consideration
- Periodic monitoring of races and virulence of wheat diseases in rust prone high land and lowland areas should be strengthened
- Local wheat crossing programs should be encouraged.
- Expanding wheat area coverage to lowland irrigated areas should be intensified
- Intensive wheat production in rain fed areas should be strengthened
- Enhancing rapid seed multiplication and distribution in main and off seasons to farmers should be enhanced.

- Varieties with known multiple effective genes be released (horizontal resistance)
- Fast track variety development and release mechanisms should be in place at a national level
- Enhancement of research capacity (facilities and manpower) should continue.
- Collaboration with regional, national & international institutions should be strengthened
- Genomic Selection & High Throughput Phenotyping (GS/HTP) research should be established.
- Data sharing with partners should be handled with care

Conclusion

Research contributions through DGGW in: Surveillance and race analysis, Phenotyping, Breeding pipeline, Maintenance of critical facilities and Talent pipeline, taken together, have yielded strongly positive impacts, and appear likely to continue doing so. The current conviction is that, wheat rust early warning system and race analysis researches stand out as having had the most profound documented positive impacts in the project and are the most advanced crop disease early warning and advisory systems in the African continent, if not in the world. The Ethiopian early warning and advisory system is now reaching hundreds of thousands of smallholders with timely and actionable advice for rust control. Currently, this system can represent a model for other regions and other crop diseases. Concerted efforts made by the DGGW implementing teams have resulted in the successeful completion of the above mentioned project objectives.

OBJECTIVE I. WHEAT RUST SURVEY AND SURVEILLANCE

Survey and Surveillance of Wheat Rusts in the Major Wheat Growing Areas of Ethiopia during 2017-2019

Netsanet Bacha[1], Getaneh Woldeab[1], Tsegab Tesfaye[1],
Berhanu Bekele[1], and Nigussie Hundessa[1]
[1]*Ambo Agricultural Research Center*

Introduction

Wheat is one of the major cereal crops grown in Ethiopia. It ranks fourth in total cultivated areas and production. Despite the significant area of wheat production in the country, the mean national wheat yield (2.1 t/ ha) is 24% below the mean yield for Africa and 48% below the global mean yield. This relatively low mean national yield may be partially attributed to diverse biotic and abiotic stresses, among which rust diseases are the most important. Wheat rust pathogens are known for their various races. New races of rust pathogens can occur during a single growing season due to mutation, recombination, and selection for virulence against rust resistance genes in wheat. Hence, each season it is crucial to carry out surveys to detect new and highly virulent pathogen phenotypes as they appear. The surveys also provide essential information to determine the gene combinations to be considered by breeding programs using major gene resistance. The improved wheat varieties and local landraces which are under production have to be evaluated for their status of resistance to wheat diseases.

Objectives:

- To determine the distribution of wheat diseases in major wheat growing areas of Ethiopia;
- To observe the shift in resistance of wheat cultivars to diseases

Summary of the research

The surveys were conducted from 2017-2019,two seasons Early main season (Mid July – late August) and Main season (September, October and early November) were covered during the project duration. Major areas in the country that are known to be wheat growing belts were covered during the three years. Oromia, Amhara, Tigray and SNNPR regions were assessed. A total of 3592 wheat growing farmers' fields, experimental plots and state farm fields were surveyed. Among the surveyed fields, 1214 and 2378 fields were assessed in the early and main seasons (Figure 3), respectively.

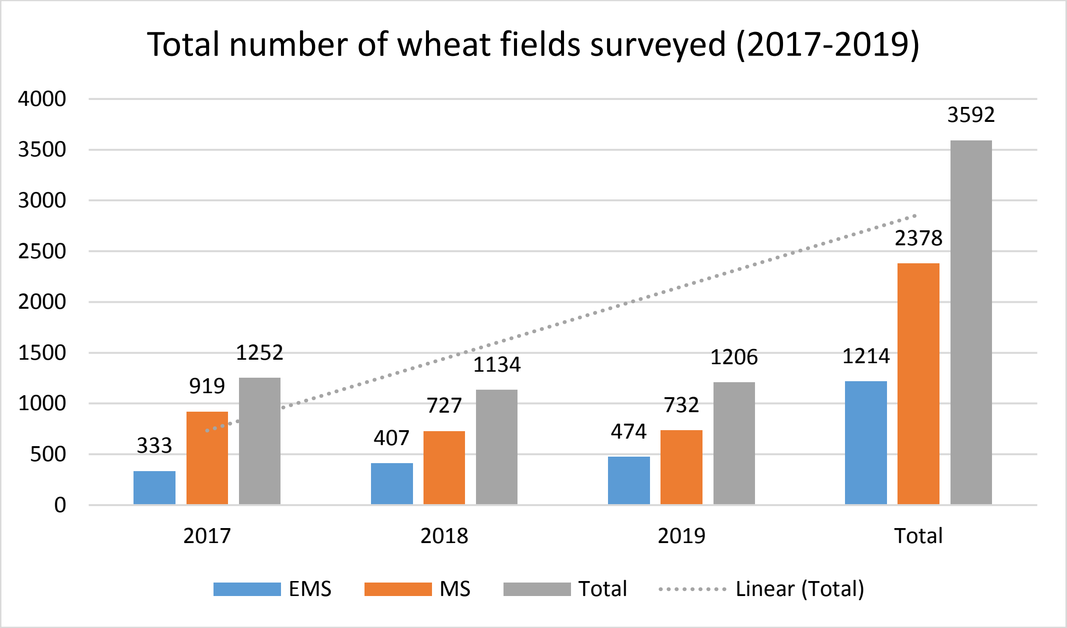

Figure.3 Number of fields observed during 2017-2019

The prevalence of wheat rust diseases in major wheat growing regions of the country (2017-2019)

The prevalence, incidence and severity of the wheat rust diseases were recorded from farmer's fields, experimental plots, and state farm fields in the surveyed regions. In 2017 cropping season, a total of 333 wheat fields were assessed for major wheat diseases. Yellow rust, Stem rust, leaf rust, Septoria, and Fusarium were among the most important ones. However, Stem rust (Sr), Yellow rust (Yr) and Leaf rust (Lr) were the most prevalent diseases of the season. Yellow rust disease was the most prevalent among the rusts with mean prevalence of 60.32 %. The maximum yr prevalence was scored at SNNPR (60.32%), followed by Oromia regional state with the mean prevalence of 30.12%. The disease was less prevalent in Tigray region (5.56%). A total of 919 wheat fields were assessed in the main cropping season of 2017, similarly, the yr disease was highly prevalent in SNNPR (68.81%), followed by Oromia (66.46%). In Tigray region the disease was less prevalent. The second most prevalent disease during both (EMS and MS) was stem rust. Stem rust disease in most cases is not highly expectable at early cropping stage, since it is a disease of mid – low land altitude and which requires warm temperature. In the Early Main Season (EMS), the maximum Sr disease prevalence was recorded at Tigray (19.44%), followed by Oromia (8.43%). The disease was least prevalent in Amhara regional state, (1.32%), followed by SNNPR (6.35%). Similar disease prevalence patterns were observed in the main season of the same year. The maximum Sr disease prevalence was attained at Tigray (50%), followed by Oromia (28.88%). The disease was least prevalent in Amhara and SNNPR with 4.75 and 8.6% mean prevalence, respectively. In the EMS of 2017 leaf rust was prevalent in SNNPR (36.51), followed by Tigray (16.67%). The disease was not observed in Amhara region, however, very few fields were infected with the disease, with mean prevalence of 2.41% in Oromia. In the main season of the year, leaf rust was highly prevalent in Tigray with mean prevalence of 16.35%, followed by Amhara regional state (13.75%) . However, the disease was least prevalent in Oromia with 8.7%.

In 2018 cropping season, a total of 407 wheat fields were assessed during the EMS of the year. The maximum Yellow rust prevalence was scored in Oromia (75.5%), followed by SNNPR (55.5%), whereas the disease was least prevalent in Amhara (32.4%). There was no Yellow rust disease during the EMS in Tigray. During the main season of the year, the disease was highly prevalent in Amhara and SNNPR with the mean prevalence of 79.6% and 76.6%, respectively. However, the Tigray region attained lower prevalence with 22%. The stem rust in the EMS of the year is highly prevalent in Oromia (29.4%), followed by SNNPR (17%).The disease was least prevalent in Amhara (2.1%) and not observed in Tigray in the season. However, the SNNPR has encountered maximum prevalence (66%) in the main season followed by Oromia (49.8%). The disease was least prevalent in Tigray and Amhara regions with 17.4% and 21.2%, respectively. The leaf rust in the EMS of the 2018 was not as such significantly prevalent as previous years. It was prevalent in all surveyed regions except Tigray. The disease was relatively less prevalent in the EMS of 2018 across the surveyed regions. For instance, the mean prevalence of a disease was 7.1%, 4.9% for SNNPR and Oromia regional states, respectively considered as maximum values, where as it was least prevalent in Amhara (1.1%), with no disease appearance in Tigray. However, in the main season of the year, the Lr disease was highly prevalent in SNNPR (38.3%) followed by Amhara (18.6%) and it was least prevalent in Oromia and Tigray with 16% and 4.3%, respectively.

In 2019 EMS, the Yr was prevalent across all the surveyed regions of the country. It was highly prevalent in Oromia , Amhara, and SNNPR with the mean prevalence of 28.42% , 27.39% and 24.75 %, respectively, but the disease was least prevalent in Tigray with 2.7%, however, in the main season (MS) of the year, it was highly prevalent in SNNPR (76.23%) followed by Amhara (73.41% and Oromia (57.62%) , but it was least prevalent in Tigray (29.62%). The stem rust disease in the EMS of 2019 is prevalent in SNNPR (10.81%) followed by Oromia (9.47%) ,with least prevalence in Tigray (1.89%) and not seen in Amhara , But in the main season of the year, it was highly prevalent in Tigray (62.96%) ,SNNPR (55.44%) and Oromia (47.45%) with least prevalence in Amhara (22.83%). The leaf rust was less prevalent in the EMS of 2019 compared with the previous years. It was only found in Tigray with 7.92% mean prevalence, but absent in the remaining surveyed regions (Oromia, Amhara, and SNNPR). However, it has become an important disease in the main season even though the mean prevalence value was lower. For instance, maximum disease prevalence was about 10.89 %, followed by SNNPR (9.24%), but it was least prevalent in Oromia and absent in Tigray.

The incidence and severity of the wheat rust disease in the major wheat growing regions of the country (2017-2019)

In the early main season, the maximum yellow rust mean incidence (22.44%) was recorded from SNNPR region in 2018 and Oromia in 2018 with 13.33% and 12.57% mean incidence severity respectively. However, the mean incidence of the disease was low at Tigray in 2017, Oromia in 2017 and Amhara in 2019. The mean severity of yellow rust disease was high at Tigray in 2019, followed by SNNPR with mean severity of 6.12% in 2018. However, the mean severity of the disease was not much higher in Oromia, Amhara and SNNPR in 2017, 2018. The observed decreasing trend of the yellow rust disease was due to concerted efforts made by researchers other stakeholders and partners, After the Bale epidemics which had caused 100% loss in some farms. The higher stem rust incidence was recorded in SNNPR (8.53%) in 2018, followed by Tigray (4.02%) in 2017. However, there was no Sr disease in the EMS of 2019. However, few fields were reported with trace amount Sr in Oromia and SNNPR in 2017, 2018 and 2019. The stem rust disease was severe in Tigray (2.59%) at 2017 compared with the remaining regions and years, followed by 2.45% in 2018 at SNNPR. The least Sr severity was recorded in Amhara in 2017,Tigray in 2018 and SNNPR in 2019 in the early warming season. The leaf rust incidence was higher in 2017 at SNNPR with mean incidence of 9.84% ,followed by same region in 2018 which was about 5.68%. However, lower leaf rust (2.41%) was recorded in Oromia in 2017, Amhara in 2017,2018 , the leaf rust severity however was sever in SNNPR in 2017 with mean severity of 1.84%. In general, leaf rust was not severe in wheat fields of all surveyed regions in the early main season of the year especially, leaf rust was not observed in Tigray in 2019, however, trace amount of Lr was observed in Amhara in 2017and SNNPR in 2019.

In the main season survey of the years , yellow rust incidence was higher in 2018 in SNNPR and Amhara with mean incidence value of 56% and 53.7 %, respectively, followed by Amhara in 2019 and Oromia in 2017, but the leaf rust incidence was recorded from Tigray in 2018 with mean incidence value of 2.4% and in 2017 (7.64%) of same region . The maximum yellow rust severity was scored in 2018 in SNNPR with 20.6% mean value, followed by Amhara in same year, 2018, with the mean value of 19.6%. The disease was severe in 2019 at SNNPR and Amhara with mean severity value of 17.6% and 17.57%. However, the least mean severity was recorded in Tigray at 2018 with 0.04 %, followed by Tigray in 2017 (3.5%) and 2019 in Oromia with 6.1 %. The mean Sr incidence was higher in 2018 in SNNPR and Oromia with mean value of 49% and 30.4 % respectively, followed by Tigray in 2019 (28.98%). The leaf rust Sr incidence was recorded from Amhara in 2017 (2.16%), followed by SNNPR of same year with the mean incidence value of 2.16% and in Amhara at 2019 (4.34%). The mean severity for stem rust disease was higher in SNNPR in 2018 with mean severity value of 21.5%, followed by Oromia in 2018 with 12% mean value and Tigray in 2019, However, the least mean severity was recorded in Amhara in 2017 (0.46%) ,2.4% and 1.16% in 2018 and 2019, respectively.

Leaf rust mean incidence in the main season was higher in SNNPR in 2018 (11.6%), followed by Tigray in 2017 (7.21%) . The least mean incidence of the Lr disease was recorded from Tigray in 2019 , followed by Oromia (0.48%) and SNNPR in 2019 (1.48%) whereas the maximum Lr severity was recorded in Tigray in 2017 with mean severity value of 4.18% ,followed by SNNPR in 2018 (2.8%).The least mean severity for the leaf rust was recorded in Tigray in 2019, followed by Oromia in 2018 (1.1%)and SNNPR (0.5%) in 2019.

Table 6. Wheat rust disease prevalence (2017-2019)

Region	Stem rust (%)						Yellow rust (%)						Leaf rust (%)					
	2017		2018		2019		2017		2018		2019		2017		2018		2019	
	EMS	MS	EMS	MS	EMS	MS	EMS	MS	EMS	MS	EMS	MS	EMS	MS	EMS	MS	EMS	MS
Oromia	8.43	28.88	29.4	49.8	9.47	47.45	30.12	66.46	75.5	49.5	28.42	57.62	2.41	8.7	4.9	16	0	2.96
Amhara	1.32	4.75	2.1	21.2	0	22.83	19.21	49.5	32.4	79.6	27.39	73.41	0	13.75	1.1	18.6	0	9.24
SNNPR	6.35	8.6	17	66	10.81	55.44	60.32	68.8	55.5	76.6	24.75	76.23	36.51	11.83	7.1	38.3	0	10.89
Tigray	19.44	50	0	17.4	1.89	62.96	5.56	29.81	0	22	2.7	29.62	16.67	16.35	0	4.3	7.92	0

Table 7. A. Incidence and severity of wheat rust diseases in the major wheat growing regions of Ethiopia (2017- 2019) in early **main season**

Region	Stem rust (%)						Yellow rust (%)						Leaf rust (%)					
	Incidence			Severity			Incidence			Severity			Incidence			Severity		
	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
Oromia	0.56	3.53	2.89	0.28	2.03	1.74	4.95	12.57	2.52	2.07	4.87	1.76	0.02	0.87	0	0.05	0.56	0
Amhara	0.1	3.53	0	0.19	2.03	0	7.56	10.27	1.48	2.74	4.87	1.18	0	0.11	0	0	0.02	0
SNNPR	1.03	8.53	3.48	0.35	2.45	1.01	13.33	22.44	5.96	2.91	6.12	2.29	9.84	5.68	2.64	1.84	0.95	0.6
Tigray	4.02	0	2.03	2.59	0	0.31	0.28	0	10.81	0.01	0	6.78	4.31	0	0	0.47	0	0

Table 7. B. Incidence and severity of wheat rust diseases in the major wheat growing regions of Ethiopia (2017-2019) in the **Main season**

Region	Stem rust (%)						Yellow rust (%)						Leaf rust (%)					
	incidence			Severity			Incidence			Severity			Incidence			Severity		
	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
Oromia	6.72	30.4	15.81	4.07	12	5.98	32.92	23.6	23.77	16.32	13	6.1	1.88	2.1	0.48	**1.08**	**1.1**	**0.15**
Amhara	1.02	6.3	4.34	0.46	2.4	1.16	30.86	53.7	43.01	9.98	19.6	17.57	4.77	2.4	3.25	**2.05**	**0.9**	**0.57**
SNNPR	2.16	49	17.02	0.92	21.5	6.47	35.08	56	32.72	5.04	20.6	17.6	2.43	11.6	1.48	**0.79**	**2.8**	**0.5**
Tigray	17.45	18	28.98	6.4	1.6	7.52	7.64	2.4	14.16	3.5	0.04	4.54	7.21	2.1	0	**4.18**	**0.6**	**0**

Wheat Stem Rust Races Analysis in the Major Wheat Growing Areas of Ethiopia during Project Implementation Period (2017-2019)

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Summary of results

The main objectives of this study was to identify stem rust races prevalent in major wheat growing areas. A total of 1384 stem rust samples were collected from different major wheat growing regions of the country. 294, 623 and 467stem rust samples were collected in 2017, 2018 and 2019 main cropping season from Oromia, Tigray, SNNPR and Amhara regions. In 2017 main cropping season, a total of 294 stem rust samples were collected from three main wheat growing regions of Ethiopia . Of these, 57 samples were not viable at the time of inoculation in the laboratory. The race analysis was carried out on 222 isolates, following the North American Nomenclature system. Seven races namely TKTTF, TTTTF, TKPTF, TRTTF, TKKTF, RRTTF, and TTRTF were identified. In general, TKTTF (Digelu race) was the most dominant race identified from 139 analyzed samples with the frequency of 62.6%, followed by TTTTF race from 67 samples with a frequency of 30.2%. TTRTF and RRTTF races were identified from 7 (3.15%) and 4 (1.8%) samples, respectively, whereas, TKPTF & TTRTF were less frequent race with 1.4% and 0.45%, respectively.

Table 8. Virulence spectrum of the Pgt races identified in Ethiopia in 2018 main cropping season

Races	Virulence	A virulence
TKTTF	*5, 21, 9e, 7b, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*11, 24, 31*
TTTTF	*5, 21, 7b, 11, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 9e, 38, McN*	*24, 31,*
TKPTF	*5, 21, 9e, 7b, 6, 8a, 9g, 36, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*11, 9b, 24, 31*
TRTTF	*5, 21, 9e, 7b,11,6, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*8a, 24, 31,*
TKKTF	*5, 21, 7b, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, Tmp, 9e, 38, McN*	*11, 36, 24, 31*
RRTTF	*5, 21, 7b, 11, 6, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*9e,8a, 24, 31*
TTRTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 36, 9b, 17, 9a, 9d, 10, Tmp, 38, McN*	*30, 24, 31*

Table 8 shows the virulence spectrum of the seven races identified in the season. The virulence of the races varied from 16 to 18 monogenic lines not to be effective to the races. Races RRTTF, TKKTF and TKPTF were less virulent as only 16 pgt lines were not effective to the races, while race TTTTF was virulent to the 18 pgt lines of the differentials. Out of 20 lines only gene Sr 24 and 31 were effective to all isolates tested during the season. A number of varieties were infected with these races , among which few are shown in table 9.

Table 9. Races isolated from varieties in 2017

Varieties	**TKTTF**	**TTTTF**	**TKPTF**	**TRTTF**	**TKKTF**	**RRTTF**	**TTRTF**
Kakaba	+			+		+	
Digelu	+						
Danda’a	+	+				+	
Hidasse	+	+		+	+		+
Huluka	+						
Dashen	+	+	+	+			
Tussie	+						
Shorima	+						
MedaWolabu	+						
Shahen	+	+					
Mekele II	+		+				
Kingbird		+					
Gambo		+					
Pavon 76	+	+					
Gassay	+						
Triticale	+						
Barley		+					

Table 10. Virulence spectrum of the *Pgt* races identified in Ethiopia in 2018 main cropping season

Races	**Virulence**	**A virulence**
TKTTF	*5, 21, 9e, 7b, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*11, 24, 31*
TTTTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*24, 31,*
TKKTF	*5, 21, 7b, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, Tmp, 9e, 38, McN*	*11, 36, 24, 31*
TKPTF	*5, 21, 9e, 7b, 6, 8a, 9g, 36, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*11, 9b, 24, 31*
TTRTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 36, 9b, 17, 9a, 9d, 10, Tmp, 38, McN*	*30, 24, 31*
TTKTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g,9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*36, 24, 31*

Five hundred thirty six stem rust samples were collected and received from Oromia, Amhara, SNNP and Tigray regions during 2018 main season. Of these, 179 samples were analyzed and six stem rust races namely TKTTF, TTTTF, TKKTF, TTRTF, TKPTF and TTKTF were identified (Table 10). Race TKTTF was identified from 61 (34%) stem rust isolates, while TTTTF was detected from 59 samples analyzed. In addition, TKKTF was isolated from 48 samples; however, TKPTF, TTRTF, and TTKTF were recorded from five, four , and two samples, respectively. One or more of these races infected wheat cultivars, Hidase, Hetosa, Danda'a, Kakaba, Kubsa, Kingbird, Ogolcho, Digelu, Dashen, Alidoro, Messeba, Limu, Durum and Emer wheats(Table 11). Race TKTTF is the dominant race and is virulent to all of differential lines except, *Sr11*, *Sr24* and *Sr31*. Race TTTTF was the second dominant race in the season and has wide virulence spectrum. It is virulent to all resistant genes, with the exception of two genes *Sr24* and *Sr3*. Race TTTTF thus poses a serious threat to the country's wheat production.

Table 11. Varieties from which the races were detected

Race	Variety
TKTTF	Kakaba, Kubsa, Kingbird, Ogolcho, Hidase, Digelu, Limu, Danda'a, Alidoro, Durum
TTTTF	Hetosa, Kakaba, Kubsa, Kingbird, Danda'a, Ogolcho, Hidase, Dashen, Messeba, LMPG, Durum and unknown
TKKTF	Kubsa, Danda'a, Hidase, Emmer, Ogolcho, Kingbird, Alidoro, LMPG, unknown
TKPTF	Kakaba, Kubsa, Digelu, LMPG, Unknown
TTRTF	Lines in nurseries
TTKTF	Lines in nurseries

A total of 467 stem rust samples were collected and received from Oromia, Amhara, SNNP and Tigray regions during 2019 early and main seasons. Of these, 146 samples were analyzed so far using the International Nomenclature System. Six stem rust races namely TKKTF, TKTTF, TTTTF, TKKTK, TTKTT and TTKTF were identified from samples analyzed; TKTTF is the most dominant one with the frequency of 47.9%, followed by TKKTF and TTTTF each with a frequency of 28.77% and 12.33 %, respectively. The race TTKTT, which now looks trace, will be a great threat in the future because of its virulence on Sr 24 gene, in which most Ethiopian varieties possessed. It is a race with low frequency (5.47%). The race TTKTF and TKKTK were the least frequent races obtained from the analyzed races with a frequency of 4.10% and 1.36 % respectively. Varieties from which the races were detected are indicated in table 12.

Table 12.Varieties from which the races were detected

Races	Variety
TKKTF	Unknown, Kekeba, Kingbird, Digelu, Denda'a, Hidase and Ogolcho,
TKTTF	Unknown , ETBW 9553, Denda'a, Kekeba, Kubsa and Digelu
TTTTF	Denda'a, Kekeba, Digelu and Unknown varieties
TTKTF	Denda'a, Wane and ETBW 9553
TTKTT	ETBW 9553, Honqoltu, Lakech and Ogolcho
TTKTF	Denda'a, Wane and ETBW 9553
TKKTK	Lemu

Survey of Barberry Plant (*Berberris holstii*) in 2017-2019

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Introduction

Berberis is a genus of many species of deciduous and evergreen shrubs. Two species of *Berberis* are present in Africa, *Berberis vulgaris* in northwest Africa and *B. holstii* in the mountains of eastern and southern Africa. The presence of *B. holstii* in Ethiopia is reported in a book of Ethiopian and Eritrean flora; however, there is no information indicating that the plant serves as an alternate host of wheat stem rust (*Puccinia graminis*). Since 2009, Ambo Agricultural Research Center has initiated studies on distribution of Barberry shrubs in Ethiopia and collection of aeciospores from the shrub and inoculation of different small cereal crops to confirm whether the aeciospores are functional stem rust or not.

Objectives:

- To survey the distribution of *Berberris holstii* plant in Ethiopia
- To detect aeciospore derived wheat stem rust from barberry plant *(Berberris holstii).*

Summary of the Research Progress

Survey of aeciospores from Barberry Plant (*Barberries holstii*), 2017-2019

Aeciospore survey was made in November 2017 in North Shewa zone of Amhara region, and adequate number of aeciospores were observed in North Shewa. Samples were collected and sent to CDL, Minnesota, USA. Duplicate samples were retained for analysis at Ambo research center. In June 2018, aeciospore surveys from Barberry plants were carried out in North Shewa, Wello and South Tigray zones and no aeciospores were found in the surveyed areas. In July 2018 the forest areas of central Ethiopia (Arsi) and south eastern highlands (Bale) were assessed to know the presence of Barberry plants in the areas. According to these preliminary studies, the plant was not found along the routes surveyed. Other uncovered zones of central, south eastern and southern highlands of Ethiopia will be assessed in the future. In October, 2018 similar surveys were carried out in N. Shewa and Wello zones and enough amount of aeciospore samples were collected from N. Shewa while trace aeciospore samples were collected from Wello. These samples were sent to Cereal disease laboratory, University of Minnesota for analysis. South Tigray was not assessed in October due to security problems in the area. Besides, in December 2018 and February 2019 aeciospore surveys were carried out in North Shewa, Wello and S. Tigray zones. Thirteen localities were covered in the surveys. In December aeciospores were observed only at three localities; Aderejersa, Kebele six and Faji/Kulebado of North Shewa zone and the samples were sent to Cereal Disease Laboratory, Minnesota while in February aeciospore samples were collected from Fali/Kulebdo, Faji/Afaf and Abogeda localities of Basona district of North Shewa for greenhouse analysis at Ambo.

In 2019, Surveys were made three times in the season (July, August and October) around North Shewa, Wolo, and S.Tigray . Trace amount of aeciospores were observed in North Shewa Dessie and in S. Tigray (Alamata area). Aeciospores samples collected from N.Shewa and Desse were sent to cereal disease laboratory (CDL), Minisota, USA for further study.

The collected aecia are waiting to be done on separate green house to avoid contamination with stem rust race analysis work.

Wheat Stem Rust Race Multiplication at Ambo Research Center

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Summary

In 2017, for screening four independent single race nurseries at Kulumsa, one at DebreZeit and many international wheat nurseries, the supply of virulent stem rust races was made from APPRC. The races multiplied and supplied for screening were TKTTF, TTKSK, TRTTF and JRCQC. Using these races hundreds and thousands of different kinds of wheat germplasms were screened every year. In 2018, eleven races TKTTF, TTKSK, JRCQC, TTTTF, TKPTF, TRTTF, TKKTF, RRTTF, TTRTF, TTKTF and TTKTT have been multiplied for screening and gene postulation experiments. Of these, six races namely TTKSK, TKTTF, JRCQC, TRTTF, TTTTF and TTRTF have been multiplied for single race nurseries conducted at Kulumsa and Debre Zeit ARCs. Races TKKTF, TTRTF and TTKTF were detected for the first time in the country during 2018 cropping season. Besides, to keep them in stock for future use in research all the races are multiplied, dried and stored in - 80ºC deep freezer. In 2019, Ten races TKTTF, TTKSK, JRCQC, TTTTF, TKPTF, TRTTF, TKKTF, RRTTF, TTRTF and TTKTF have been multiplied for screening and gene postulation experiments, TTKSK, TKTTF, JRCQC, TRTTF, TTTTF and TTRTF have been multiplied for single race nurseries conducted at Kulumsa and Debre Zeit ARCs.

Objectives:

- To multiply and preserve the stem rust pathotypes for future research use
- To supply important races to breeders and other researchers for experimental use

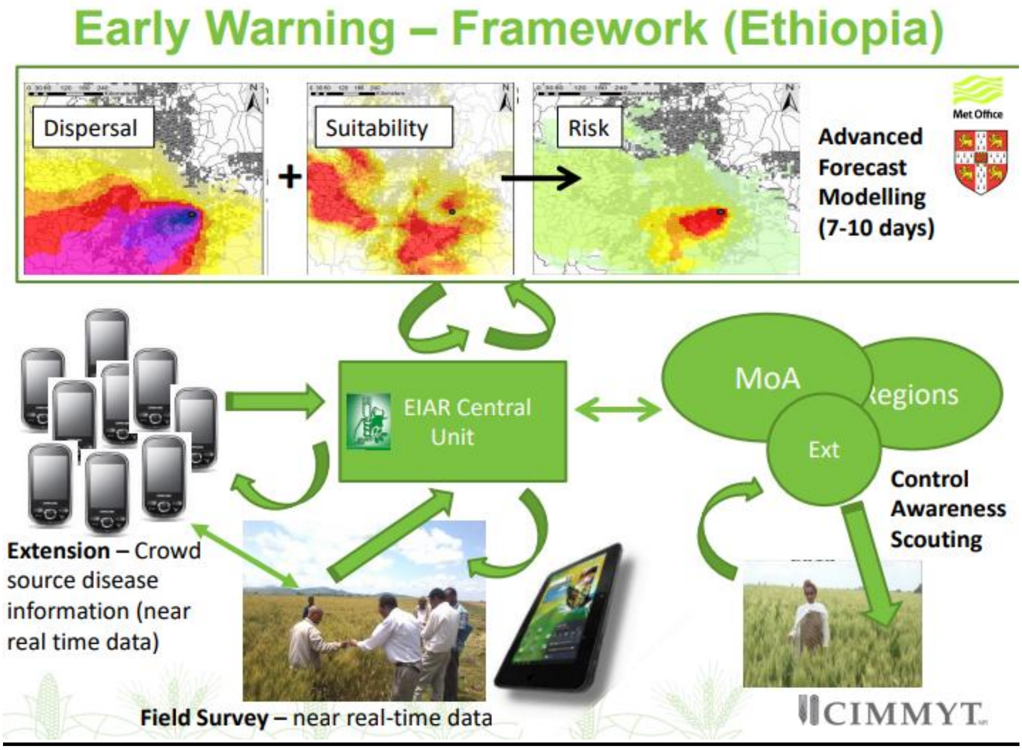
Table 13. Sr races multiplied and provided for international single race nurseries

Race	Virulence	Avirulence
TKTTF	5, 21, 9e, 7b, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN	11, 24, 31
TTTTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*24, 31,*
TKPTF	*5, 21, 9e, 7b, 6, 8a, 9g,36,30,9g, 9a, 9d, 10, Tmp, 38, McN*	*11, 9b, 24, 31,*
TRTTF	*5, 21, 9e, 7b,11,6, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*8a, 24, 31,*
TKKTF	*5, 21, 9e, 7b, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*11, 36, 24, 31,*
RRTTF	*5, 21, 7b, 11, 6, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*9e,8a, 24, 31*
TTRTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g,36, 9b, 17, 9a, 9d, 10, Tmp, 38, McN*	*30, 24, 31,*
JRCQC	*21, 9e, 11, 6, 9g, 17, 9a, 9d, McN*	*5, 7b, 8a, 36, 9b, 30, 10, Tmp, 24, 31, 38*
TTKSK	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, 31, 38, McN*	*36, Tmp, 24*
TTKTF	*5, 21, 9e, 7b, 11, 6, 8a, 9g,9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN*	*36, 24, 31*
TTKSK	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, 31, 38, McN*	*36, Tmp, 24,*
TTKTT	*5, 21, 9e, 7b, 11, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, Tmp, 24, 31, 38, McN*	*36*

In general, the DGGW project played a very vital role in supporting the wheat pathology works at Ambo research center , mainly in strengthening the wheat rust distribution and severity, early warning system and tracking national wheat disease survey in collaboration with global and national partners. The project has also enhanced Ambo's capacity to conduct research through capacity building, field, greenhouse and laboratory capacities upgraded. Knowledge and scientific skills of wheat researchers improved through training and internatonal workshops. Valuable rust data shared with national and international partners through surveys and race analysis.

Publications

Publications https://globalrust.org/race-manual/Ambo
https://apsjournals.apsnet.org/doi/10.1094/PDIS-07-19-1390-PDN
https://apsjournals.apsnet.org/doi/10.1094/PDIS-09-19-1825-PDN
Early warning frame work , Ethiopia as a role model for the world



Early Warning – Framework (Ethiopia)

Dispersal + Suitability → Risk

Advanced Forecast Modelling (7-10 days)

Met Office

EIAR Central Unit

MoA

egions

Ext

Control Awareness Scouting

Extension – Crowd source disease information (near real time data)

Field Survey – near real-time data

CIMMYT

Challenge

- Lack of knowledge and skill in advanced research tools such as molecular techniques.

Survey and Surveillance of Wheat Rusts in Central and West Arsi Wheat Growing Areas of Ethiopia during 2017-2019

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Getnet Muche[1] and Banchi Sime[1],
[1]*Kulumsa research center*

Introduction

Ethiopia is the second largest wheat producing country in sub-Saharan Africa. The crop is grown in two seasons, locally called *"Meher"* and *"Belg"* seasons. At Kulumsa and the surroundings *"Belg"* season wheat is planted in April and harvested in July- August whereas in the "*Meher"* season wheat is planted between June and August, and harvested in November/December (Hailu 1991). Ethiopia produces 4.8 million tons of wheat grain from 1.7 million ha in Meher season (CSA, 2018/19). Though the country is the second largest wheat producer in sub Saharan Africa, the productivity remained low, 2.7t/ha as compared to the world average,3t/ha. The low wheat productivity might be ascribed to diverse biotic and abiotic factors . Among the biotic factors plant diseases are considered the most important biotic constraint to wheat productivity and production in Ethiopia. Wheat rusts are the main challenges to wheat producing farmers from time to time at different parts of the country.

Table 14. Rust disease epidemics in Ethiopia and their challenges

Year	Variety	Defeated gene	Disease	Loss (%)
1974	Lakech	Sr?	Stem rust	?
1988	Dashen	Yr9	Yellow rust	58
1994	Enkoy	Sr36	Stem rust	67-100
2010	Kubsa/Galema	Yr27	Yellow rust	Up to 100
2014	Loga- Shibo/Gondare	Yr?	Yellow rust	Up to 100
2014	Digalu	SrTmp	Stem rust	Up to 100

As indicated in table 14 above, wheat rust epidemics have occurred at different times and different parts of the country both in large scale and in localized forms. After the launch of the DGGW project no wheat rust diseases were encountered at large scale farms due to proper implementation of the early warning and forecasting systems developed and practiced in most wheat producing areas of the country through rapid information dissemination systems.

Objectives:

- To provide information on the varietal response of the specific time against different rusts
- To quantify prevailing wheat diseases during the season
- To collect wheat rust disease samples and send them to the appropriate platform centers

In Ethiopia the surveillance work is very critical in wheat producing areas of Arsi and West Arsi. Kulumsa Research center is mandated to undertake research activities for these areas. Starting from the project launch, farmers' fields have been assessed for three consecutive years, during *"Belg"* season, early *"Meher"* season and late/normal *"Meher"* season. The *"Belg"* season survey is an indicative of the existence or presence of wheat rust disease, which fluxes ?? to the main *"Meher"* season. The early *"Meher"* season surveys are critical disease management practices for the wheat producing areas of Arsi and West Arsi through delivering information of rusts presence and the recommendation for wheat rusts management. Finally, the year round activities done every year during normal meher season provide information on the varietal response of the specific time against different rusts, used to quantify prevailing wheat diseases during the season and also used to collect wheat rust disease samples and send them to the appropriate platform centers (stem rust goes to Ambo, leaf rust goes to Debre Zeit and yellow rust goes to Kulumsa for race analysis). As indicated below in figure 2 a total of 474 wheat farmer fields have been assessed at different surveys during *"Belg"*, early *"Meher"* and normal meher seasons.

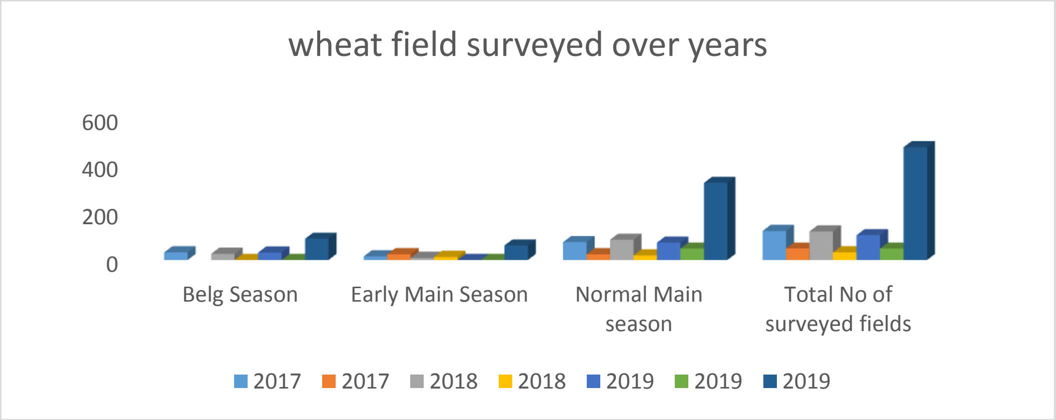


Figure 4. Summary of 2017-2019/20 field assessed for wheat disease in Arsi and West Arsi

The survey results , especially those starting from early meher season every year, were compiled and recommendations submitted to the two zones of agriculture office for management interventions. The wheat disease early warning system, based on collected data starting from the early main season survey mid July until the end of harvesting, is issued and provided every 15 days interval to all concerned stakeholders (Zonal, woreda experts and also DAs delivered) to develop their own mitigation strategies to manage wheat rust diseases.

Ethiopian wheat rust trap nursery (EWRTN):

About 210 wheat genotypes (wheat varieties both released and under pip-line, wheat differential lines) were planted every year for detection of the disease shift and check the response of mega cultivars and also to check the response of differential lines to yellow rust, stem rust and leaf rust at different hot spot areas of Arsi and West Arsi. The following activities have also been conducted;

- Detection of virulence of stem rust on Hidasse and Ogolcho at field condition
- Samples of recently detected stem rust virulence to sr24 have been sent to the concerned laboratories
- Yellow rust disease pressure from both commercial and differential lines have been recorded at field conditions based on the data from established field trial
- Rust samples have been collected from different wheat genotypes

Yellow rust race analysis

Under yellow rust platform, where Kulumsa research center is mandated, yellow rust race analysis is in progress at KARC. The capacity both in human and physical is currently in a better condition than it was during the previous years, with the exception of few facilities. Within the duration of the DGGW project Kulumsa agricultural research center conducted yellow rust race analysis on five yellow rust races (PstS 11, PstS 11 (V25), PstS 11 (V1), PstS 11(-), PstS2, PstS2 (v32). Currently, more than 18 isolates were isolated and characterized on ten selected bread wheat varieties and ready for race analysis.

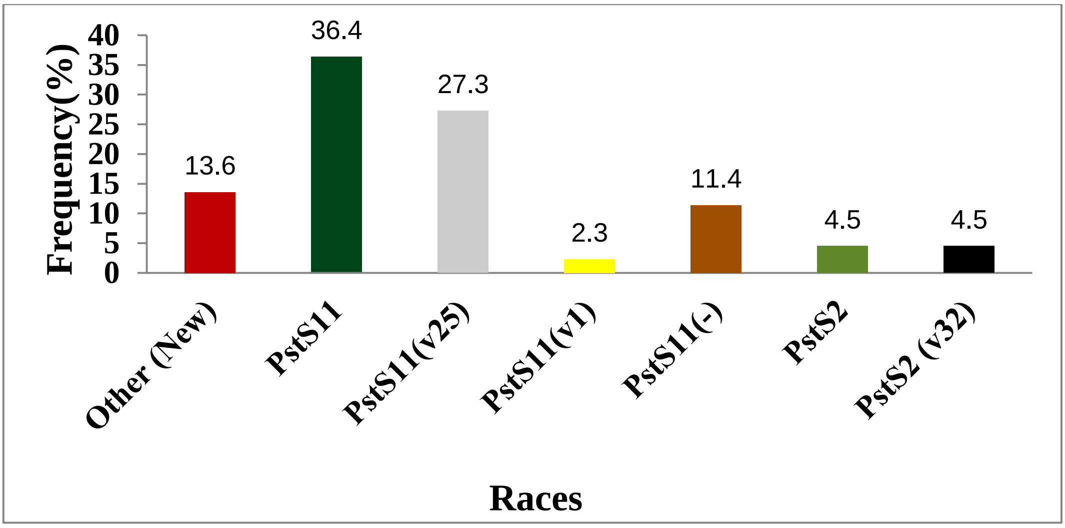
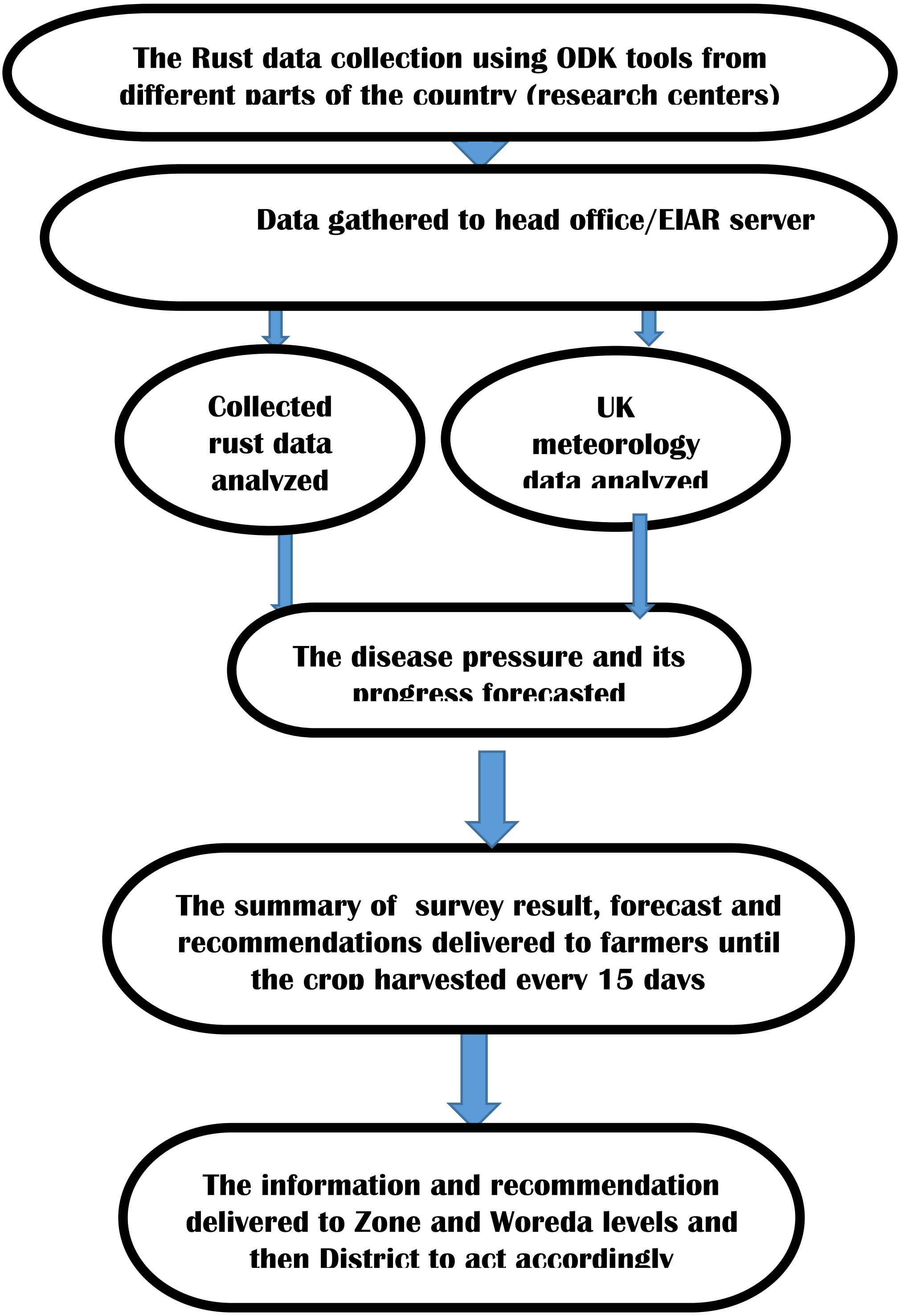
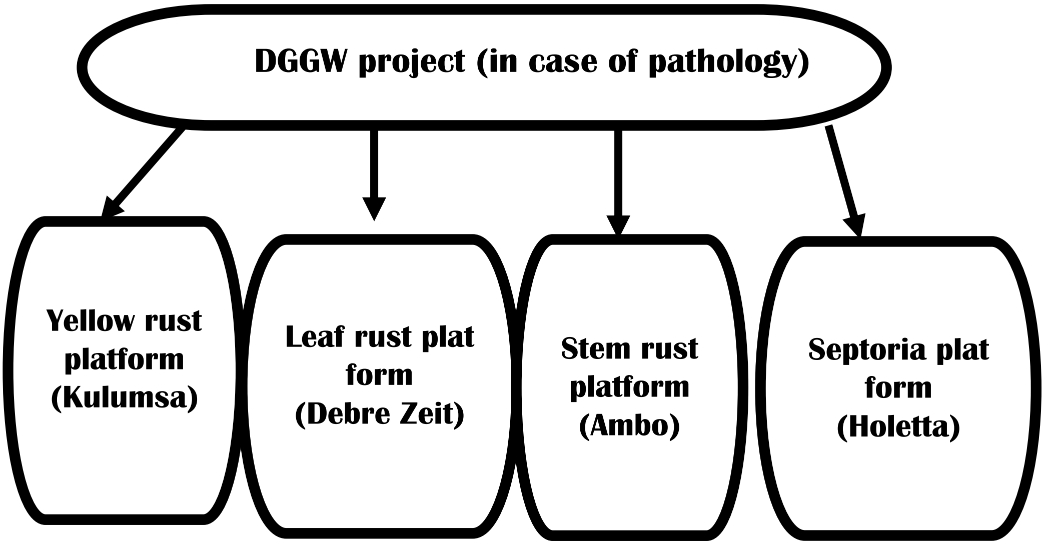


Figure 5. Summary of yellow rust race analysis


The Rust data collection using ODK tools from different parts of the country (research centers)
Data gathered to head office/EIAR server
Collected rust data analyzed
UK meteorology data analyzed
The disease pressure and its progress forecasted
The summary of survey result, forecast and recommendations delivered to farmers until the crop harvested every 15 days
The information and recommendation delivered to Zone and Woreda levels and then District to act accordingly


DGGW project (in case of pathology)
Yellow rust platform (Kulumsa)
Leaf rust plat form (Debre Zeit)
Stem rust platform (Ambo)
Septoria plat form (Holetta)

OBJECTIVE II: PHENOTYPING PLATFORM

Phenotyping of Wheat Lines at Kulumsa Agricultural Research Center (KLDN and Single Race Nurseries)

Tamirat Negash[1], Lidia Tilahun[1],Fikirte Yirga[1], Hawila Tesfaye[1],
Getnet Muche[1] and Banchi Sime[1],
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Key location disease nurseries (KLDN):

These trials have been conducted every year based on materials imported from different collaborators (CGIAR institutions and different universities), and materials from crossing blocks. The trials were designed and evaluated at different hot spot locations for target wheat diseases. About 220,361 and 375 wheat lines along with checks were evaluated at hot spot areas of Meraro,Bekoji and Arsi robe for stem rust and yellow rust diseases during 2017,2018 and 2019 cropping season respectively. From the evaluated materials 113,101 and 83 wheat lines were advanced to the next breeding stem jointly during the aforementioned cropping seasons.

Figure 6. Key location disease nursery disease pressure at Meraro field condition during 2019

Stem Rust Single Race Nurseries (SRN)

Stem rust new races are evolving every year at different parts of the country especially in wheat producing areas. The stem rust single race nurseries were designed to identify resistant wheat lines to specific stem rust races and also to identify the materials which showed combined resistance to different single races at field and green house conditions. A total of 250 wheat lines were evaluated during 2017 for TTKSK, TKTTF, TTTTF, JRCQC and TRTTF at separate sets. On the other hand, during 2018 main cropping season a total of 214 wheat lines were evaluated for TTKSK, TKTTF, TTTTF, TTRTF and TRTTF. Additionally the aforementioned wheat lines were evaluated during offseason for the race TTRTF in two replications. During 2019 cropping season a total of 220 wheat lines were evaluated for TKTTF, TTTTF, and TTRTF. In addition to the field experiment, test materials were evaluated for their seedling reaction against aforementioned stem rust races. The response of test materials, checks and differential lines of different cropping seasons were identified and shared to the concerned partners. The selected and resistant wheat lines for tested stem rust races were communicated to breeders and other concerned bodies.

Phenotyping of Wheat Lines at Debre Zeit Research Center (KLDN and Single Race Nurseries)

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EIAR, Debre Zeit Research Center, P.O.Box 32, Debre Zeit, Ethiopia

Introduction

The Borlaug Global Rust Initiative (BGRI) identified the Ethiopian Institute of Agricultural Research, EIAR as a partner to fight against the wheat stem rust Ug99 (TTKSK) in 2005. The center is located at 47 km Southeast of Addis Ababa, Ethiopia's federal capital city, with an altitude of 1900 m.a.s.l. The center has two major soil types (Alfisol/Mollisol and Vertisols) while the latter is the dominant type and receives about 851 mm annual rainfall; with maximum and minimum temperatures of 24.30 and 8.9 C0, respectively.

Annually quite a large number of bread wheat, durum wheat, barley and triticales were introduced from different countries, Universities and non-governmental institutions. Countries like USA, Australia, Kenya, Lebanon, CIMMYT, ICARDA,India, Cornell University, North Dakota State University and also from national like Kulumsa, Holeta, Ambo and Sinana.

Objectives:-

- To produce reliable phenotypic data for reaction to stem rust races disease.
- To enhance physical and human capacity.

Materials and Methods

Screening of wheat germplasm to stem rust is launched twice a year, from November to May under irrigation (off-season nurseries), and rain-fed, from July to November (main season). The offseason is warmer than the main season; as a result, stem rust disease pressure is often higher in the off-season than in the main season. However, wheat rust diseases pressure depends on availability of moisture and well established inoculum. Stem rust development could also be lower on varieties sown in black (Vertisol), if excess water is not drained and fertilized. The nurseries were planted one meter of two rows depending on the number of materials to be planted and the availability of land. The spreader rows were planted with the mixture of universally susceptible bread wheat (Digalu. PBW343, Morocco) and durum wheat (Local red, Arendato and Leeds). The initial pure stem rust races of TTKSK, TRTTF, JRCQC, TKTTF, TTTTF and TTRTF were received from Ambo Agricultural Research Center. Every week for two months at least 2- 3 plastic trays (10-12 pots/per tray) of seedlings of each variety was planted on a weekly basis in a clean greenhouse (no spores allowed) to ensure fresh tissue available for increase (Fig 1) Maleic hydrazide solution (3g/L) were applied to seedlings 4-5 days after planting to promote disease development.

Bulk inoculum is composed of spores from each isolate/race mixed in 1:1:1:1 (v/v/v/v) or adjusted ratio based on the viability of individual isolates (Table 15). The compositions of isolates were adjusted depending on the virulence and prevalence of races on bread and durum wheat genotypes.

Table 15. Pgt races and susceptible varieties for spore multiplication

No.	Stem Rust Races Since 2005-2019	Susceptible Varieties	Year of Detection
1	TTKSK	PBW343	2003
2	TKTTF	Digalu	2013
3	JRCQC	Local Red/st sr13	2013
4	TTTTF	Local red/Digalu	2017/18
5	TTRTF	Laketch or Morocco	2017/18

Summary of Results

Debre Zeit Agricultural Research Center (DZARC) was identified as International Durum Wheat Screening Site against stem rust. Screening of wheat germplasm to stem rust is launched twice a year, from November to May under irrigation (off-season nurseries), and rain-fed, from July to November (main season). The initial pure stem rust races of TTKSK, TKTTF, JRCQC, TTTTF and TTRTF shown in Table 16 were used for screening. During the past six seasons a total of 37,434 accessions, advanced and segregating populations, bi parental mapping populations were screened in international screening nurseries in Ethiopia in off-season and main-seasons 2017, 2018 and 2019. A total of 3273 advanced and segregating populations from CIMMYT and ICARDA were evaluated in Ethiopia. Over six seasons, 37434 lines from eight countries were evaluated at Debre Zeit and reliable phenotypic yield data were generated.

During the last three years of the evaluated genotypes, about 2244 were selected, of these 1560 were selected during the past three irrigated seasons and 684 genotypes were selected during the last three years main seasons.

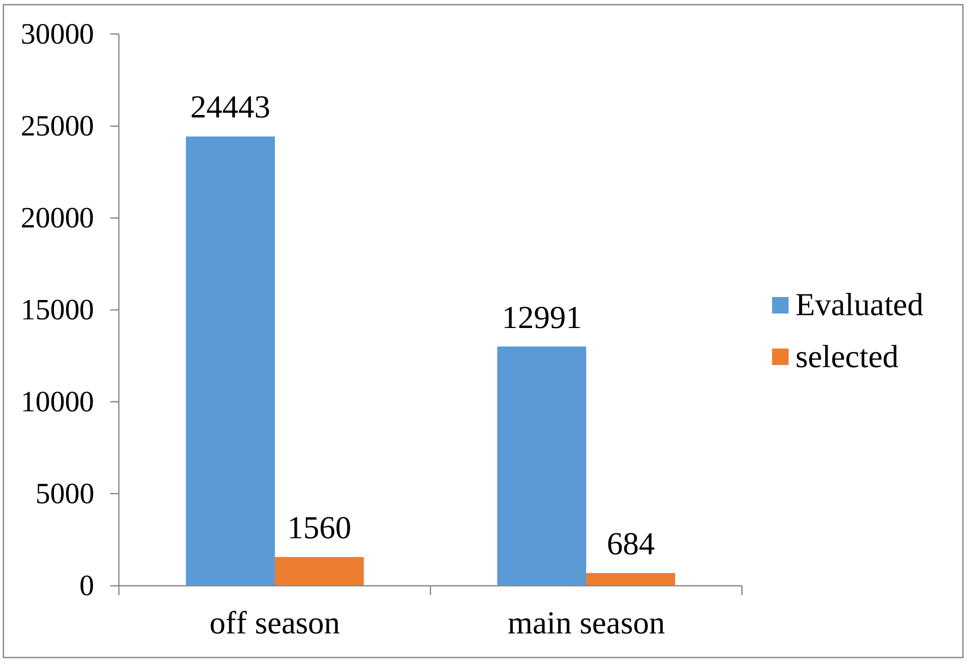

Fig 8. Charts showing the total genotypes evaluated and selected lines during the past three years

To identify stem rust resistant wheat lines for international and national wheat breeding programs:

Races Used in the Screening were TTKSK, TKTTF, JRCQC, TRTTF and TTRTF

A total of 12,892 genotypes from international and national breeding program were screened during off and main seasons in 2018 at Debre Zeit

- A total of 304 genotypes were selected based on their response to stem rust
- These selected genotypes showed severity level ranging from 0-30MS

Table 16. Number of genotypes introduced from International Nurseries Off-season 2017 main season at Debre Zeit

No.	Trial/Nursery name	**Origin**	# of entry	Remark
1	Tetraploids-Durum (Pablo)	USDA-ARS-CDL	1044	
2	Tetraploids-Durum (Maricellis)	NDSU	477	
3	Bread (Matt)	USDA-ARS-CDL	1468	
4	Double Haploid (Matt)	USDA-ARS-CDL	2394	
5	10th SRRSN(BW)	CIMMYT	208	Repeated
6	Elite bread wheat	CIMMYT	100	Repeated
	Total		5691	

Table 17. Number of genotypes introduced from International Nurseries during 2017 main season at Debre Zeit

No.	Trial/Nursery name	**Origin**	No. entries	Selected Entries	Remark
1	8th HLBSN	CIMMYT	52	**0**	**BW**
2	11th STEMRRSN	CIMMYT	171	**118**	**BW**
3	49th IDYN	CIMMYT	50	**4**	**DW**
4	49th IDSN	CIMMYT	124	**6**	**DW**
5	CD17th DZMS	CIMMYT	321	19	DW
6	Elite Lines	CIMMYT	100	23	BW
7	INDIA	India	145	0	BW
8	DW Land Races	Ethiopia (Debre Zeit)	596	**56**	**DWLR**
9	KLDWDN	Debre Zeit	185	**10**	**DW**
10	EWRTN	Kulumsa	208	**0**	**BW**
11	KLBWDN	Kulumsa	220	**71**	**BW**
12	DW land race accessions	EBI	1643	**0**	**DW**
13	Bread Wheat	Holeta (NABRC)	56	**0**	**BW**
	Total		3871	307	

Table 18. International Wheat Stem rust Screening Nursery Off-Season 2018

Name of Trials	Origin	Varieties/Genotypes			Selected lines	Remarks
		BW	DW	Barley		
Elite	CIMMYT	123	0	0	24	
Elite	ICARDA	138	0	0	0	
IDON	ICARDA	0	96	0	30	
IDYN	ICARDA	0	48	0	20	
Landrace	EBI	0	1650	0	0	
Screening against SR races	USDA	2751	1022	471	20	
18th HTSBWON	ICARDA	200	0	0	30	
18th DSBWON	ICARDA	200	0	0	19	
CD18_SRAMDzOS	CIMMYT	0	606	0	0	
CD18_SRDzOS	ICARDA	0	978	0	98	
VVT	Ethiopia	30	2	0	0	
Total		3422	4401	471	**241**	

KARC= Kulumsa Agricultural Research Center, DZARC= DebreZeit Agricultural Research Center

Table 19. International Wheat Stem Rust Screening Nursery Main Season 2018

No.	Name of Trials	Origin	Crops		Selected lines
			BW	DW	
1	Landrace	EBI	0	1650	**0**
2	Screening against SR	Australia	250	0	**12**
3	Screening against SR	Australia	300	0	
4	CD18_SRAM	CIMMYT	0	303	**15**
5	12th Stem RRSN	CIMMYT	0	136	**22**
6	KLDWSN	DZARC	205	0	**14**
7	EWRTN	KARC	208	0	**0**
8	41th IDYT	ICARDA	0	48	**5**
9	41th IDON	ICARDA	0	96	**8**
10	18th DSBWYT	ICARDA	100	0	**0**
11	CD18_SRDZOS	CIMMYT	0	102	**25**
12	Elite	CIMMYT	123	0	**15**
Total			**1186**	**2335**	**104**

Table 20. Wheat, Triticale and barley screening off-season nurseries in 2019

No	Trial /nursery name	Origin	Number of Entry	Selected lines
1	Land Race	EBI/ Ethiopia	1650	700
2	Bread (Matt)	USDA	1890	0
3	CD19 Eth SR	CIMMYT	1644	403
4	Iumillo	CIMMYT	3	0
5	Elite lines	CIMMYT	120	77
6	13th SRRN	CIMMYT	168	0
7	Filial generation two(F2)	CIMMYT	200	0
8	CD_19SR AM DzOS	CIMMYT	602	0
9	Ethiopian Crosses(F2)	Kulumsa	584	31
10	Screening against stem rust	Australia	480	0
11	CD19 BMP –A	CIMMYT	636	0
12	CD19 BMP-B	CIMMYT	620	
13	CD19 BMP-C	CIMMYT	736	
14	VVT	Sinana and Alamata	7	0
15	42th IDYT	ICARDA	48	9
16	42th IDON	ICARDA	96	5
17	Filial generation two (F2)	ICARDA	762	17
18	Filial generation two (F2)	ICARDA	212	0
	Total		10,458	1242

Table 21. Evaluation of wheat, triticale and barley in 2019 main season

No	Trial Name	Country	Number of entry	Selected lines
1	CD19BMP-A	CIMMYT	636	0
2	CD19BMP-B	CIMMYT	620	0
3	CD19BMP-C	CIMMYT	736	0
4	CD19DZMS	CIMMYT	403	182
5	KLDWDN	ETHIOPIA	167	32
6	EBI LAND RACE	USA	700	0
7	42IDON-19	CIMMYT	96	5
8	51IDON	ICARDA	159	16
9	42IDON	ICARDA	48	6
10	AMBO	ETHIOPIA	101	0
11	HOLOTA	ETHIOPIA	55	0
12	LAND RACE DZ	ETHIOPIA	312	38
13	15thSTEM RRSN	CIMMYT	168	0
14	HRWSN	CIMMYT	80	0
15	KENEYA(NAKURU)	KENEYA	275	0
16	EWRTN	ETHIOPIA	208	0
17	ZEREHUN	ETHIOPIA	500	0
18	YELLOW RUST	ETHIOPIA	250	0
20	AUSTRALIA	Aust	18	0
21	F3 KULUMSA	ETHIOPIA	31	-
22	FUNGICIDE	ETHIOPIA	36	0
23			5,599	273

Phenotyping of Bread and Durum Wheat Accessions, Lines and Varieties for Septoria Leaf Blotch (SLB) and Fusarium Head Blight at Holetta Research Center

Bekle Kassa[1] **and Yitagesu Kuma**[1]
[1]*Holetta Agricultural Research Center; E- mail bkassa74@yahoo.com*

Summary

Phenotyping of bread and durum wheat accessions, lines and varieties for Septoria leaf blotch (SLB) and Fusarium head blight were done under field conditions at Holetta agricultural research center for three seasons (2017-2019). In the study period a total of 2742 durum and Bread wheat materials were screened. The result indicated that during 2017, from the screened 1195 materials, population 1.3 %, 3.34%, 73.2% and 22.1 % were resistant, moderately resistant, susceptible and highly susceptible to SLB respectively. In the year 2018, 817 materials were screened of which 35 %, 10%, 43% and 11% of them had resistant , moderately resistant , susceptible and highly susceptible reaction, respectively. In 2019 season the trial was composed of 730 materials and as compared to the previous batches, the materials differed in response to the diseases. Of the tested materials, 9 %, 15%, 38% and 41% of them had resistant, moderately resistant, moderately susceptible and highly susceptible reaction to SLB, respectively. However, when the materials were evaluated for Fusarium head blight (FHB) which occurred at epidemic level, the materials have shown differences in response to the disease. Of the 261 Durum wheat lines screened, most of them (60%) scored 2 (in 0-5 scale) and 26 % of them, and 14 % scored 0-1 and 3-4 .Most of the materials which had resistant and moderately resistant responses with reasonable performance were selected and the information shared with international and national partners.

Introduction

Septoria leaf blotch (SLB) caused by *Zymoseptoria tritici* (Desm.) Quaedvlieg & Crous, 2011 (teleomorph –*Mycosphaerella graminicola* (Fuckel) J. Schrot.)

(Quaedvlieg et al., 2011), is an important wheat disease in several regions of the world. In Ethiopia, when local varieties were dominating in wheat cropping systems than improved varieties, the severity of SLB was not an economically important disease compared to rusts and during this period the yield loss due to the disease was estimated at 25 % (Eshetu,1986). However, substitution of mainly the landraces, which have been grown by farmers with high yielding varieties resulted in cropping limited numbers of varieties caused greater incidence of SLB over the last three decades and the loss increased to 41 % (Alemar and Temam. 2016). Concomitantly, the change in cropping system such as continuous wheat cropping, high seeding rates and excessive use of N fertilizers, which is practiced often by farmers, might have enhanced SLB proliferation as it was indicated by different researchers (Fernandez et al., 1998; Simon *et al.*, 2003; Ansar et al., 2010). Nowadays, the disease is widely distributed through out wheat growing areas and affects the crop severely. According to survey reports of Eshetu (1986) the yield loss of wheat as a result of this disease reaches 80 % on the susceptible bread wheat varieties at hotspot areas.

Though fungicide applications and the deployment of resistant wheat cultivars are among the most practices aiming to alleviate SLB (Goodwin, 2007; Lehoczki-Krsjak et al., 2010) and their benefits have been long acknowledged worldwide. However, genetic resistance by far is the most economical and environmentally friendly tool to manage diseases. In Ethiopia, the disease was not considered as one of the major threats to wheat production since there were no as such convincing research results that justify the importance of the disease. Hence, wheat researchers did not put forward their efforts to develop management strategy to the disease as they are doing to rusts. Hence, The purpose of this study was therefore, to produce reliable phenotypic data on the reaction of various wheat germ plasm for their reaction to SLB which may be useful in the national wheat improvement program and share the findings to researchers at international level.

Materials and Methods

The trial was conducted at septoria leaf blotch (SLB) hot spot area at Holetta Agricltural Research Center at quarantine field in 2017, 2018 and 2019 main seasons. In the nurseries a total of 2742 accessions, lines and/or varieties which were obtained from ICARDA, CIMMYT, Kulumsa Agricultural Research center (KARC) and Debre Zeit Agricultural Research (DZARC) centers were included.

In addition to the materials to be screened, susceptible varieties were planted after every 10 entries as spreader row to SLB. The design was two rows none replicated plots. The plot size depended on the quantity of seed obtained from the source and was 2.5 m X 0.2 m and/or two rows of 1 m length,. Fertilizer was applied at the rate of 50 / 100 N / PKS ha $^{-1}$.

Disease assessment was realized on five plants according to double digit scale (00-99) described by Eyel et al. (1983). The first digits represent the vertical progress of the disease. The second digit indicates the severity of the disease according to the scale 0-9 which every digit corresponds to a percentage of foliar surface covered by the disease (Sarii, and Prescott, 1975). To ensure the level of resistance available in the host to SLB, the relationship of the percent coverage of the disease (PCD) or coverage of the disease on the four uppermost leaves and the vertical disease placement or Septoria progress coefficient (SPC) in to four distinct cultivar response classes were used to categorize into classes. Where class A (Resistant) - PCD ≤ 15%/SPC ≤ 0.4, B (moderately resistant) - PCD ≤ 15% / SPC - 0.40-0.65, C (Susceptible) - PCD-15-40% / SPC-0.40-0.70 and D (Highly susceptible) - PCD - ≥ 40% / SPC ≥ 0.70.

Disease severity was recorded using double digit score (00-99) and average coefficient of infection (ACI) was calculated whereas, the incidence of the disease was recorded in percent. Fusarium head blight which is the most important disease to bread and durum wheat in the area was recorded using 0-5 score scale, other parameters such as growth stage (GS) at the time of disease reading, spike length and seed / spike and thousand seed weight (TSW) of each entry were counted and, measured and overall field performance of each entry was used as a selection criteria. All agronomic practices recommended for wheat production to the area were employed.

Result and Discussion

There were variations among bread wheat materials to the disease. However, the majority (53.2 %) of the population tested had moderately susceptible response (ACI in the range of 0.3087- 0.3946) and 7.0% of the materials had susceptible reaction (ACI in the range of 0.4316-0.4932). 11.0 % had highly susceptible reaction (ACI in the range of 0.5914-0.7885).Very limited proportion of the lines were in the range of 0.0369-0.1959 and 0.2178 - 0.2958 respectively. Lines categorized as moderately resistant, moderately susceptible and susceptible had a share of 14.9 % 20.7 % and 13.4 % and had ACI in the range of 0.308-0.3696,0.4312-0.49320 and 5554-0.8879, respectively (3.4 %) were categorized as resistant and 30 % as moderately resistant (Figure 9). The second batch of the materials consist of 500 advanced lines and varieties. Almost equal proportion of the materials (20.7-28.6 %) indicated all type of responses (Figure 10). However, 6.7 % of them had moderately susceptible reaction (ACI in the range of 0.308-0.3946). Materials selected and categorized as resistant and moderately resistant were 20.7 % and 21.2 % of the total population subjected to screening for SLB and had lower severity score (ACI in the range of 0.0 -0.1974 and 0.2178-0.2959 respectively). The rest materials, 22.6 and 28.8 %, were categorized as susceptible and highly susceptible, (ACI in the range of 0.4037-0.4937 and 0.5914-0.8906) respectively.

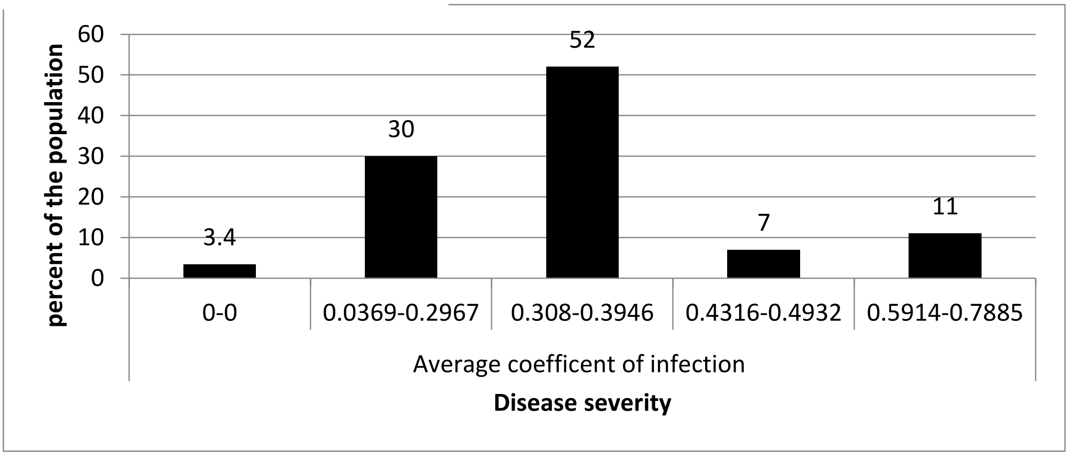

Figure 9. Response of bread wheat materials to SLB which were received from KARC in 2017 main season (1st batch)

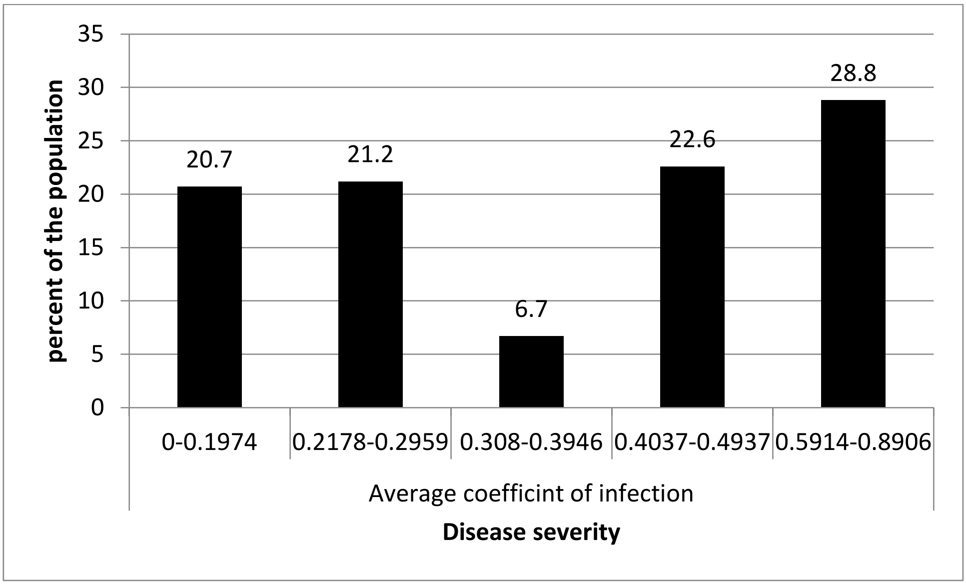

Figure 10. Response of bread wheat materials to SLB which were received from KARC in 2017 main season (2nd batch).

ICARDA was the other source of bread wheat materials for SLB phenotyping and contributed 261 lines. Though most of the lines had poor field performance and low thousand seed weight (TSW) they had low disease intensity (Figure 11.) Of the total lines screened, 38.3 % and 12.6 % of them had resistant responses with ACI

Based on their response to the disease, field performance together with TSW, materials received from KARC relatively fulfill the selection criteria and 59 lines were selected. Materials from ICARDA had poor field performance and susceptible to the disease as the result only four lines were selected. All data collected during the season were shared with international and national partners.

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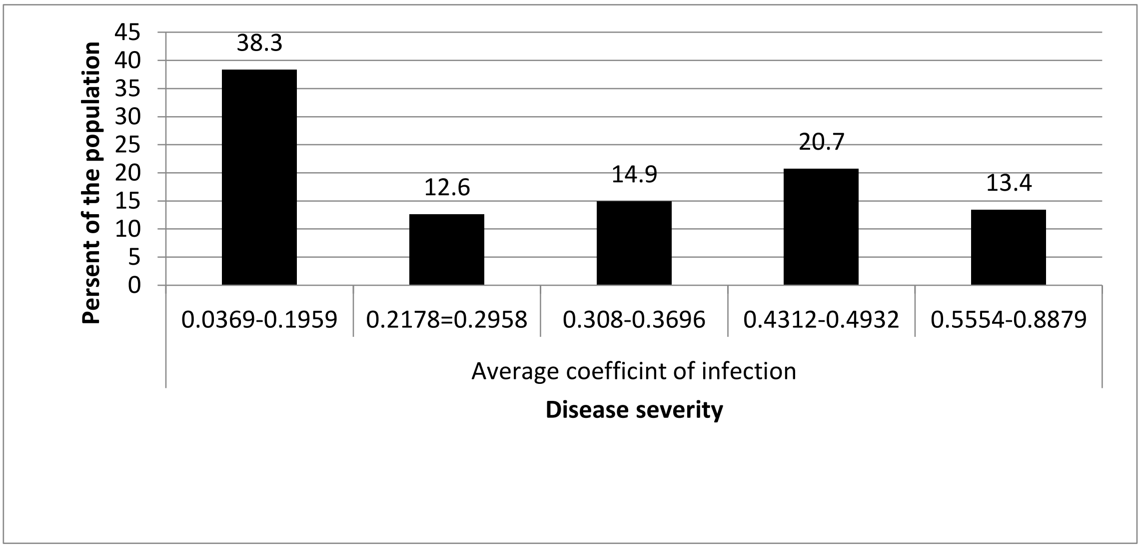

Figure 11. Response of bread wheat materials to SLB which were received from ICARDA in 2017 main season.

In 2018 the study consist of 539 materials of which 178 durum wheat lines obtained from DZARC,248 bread wheat accessions obtained from ICARDA, 65 accessions which were selected and retained from 2017 nursery and 361 obtained from KARC. Reaction of the durum wheat lines to SLB is presented in Figure 12. In the season the pressure of the disease under question was milled. However, the lines have shown variation in the level disease severity. The result showed that 39.5 % , 22..9 %, 13.7 % , 23.9 % of the screened materials had resistant, moderately resistant, moderately susceptible and susceptible response and the severity of each category as expressed in ACI was in the range of 0, 0.0243-0.0741, 01108-0.2962 and 039945-0.5519, respectively. This result might not be due to the presence of reasonable number of resistant lines in the population but, probably it happened because of the amount of inoculum in the air which might have created sufficient infection to discernment lines. This speculated statement could be supported by the degree of severity recoded (ACI- 0.5519) on most susceptible varieties which were used as susceptible check and as spreader rows.

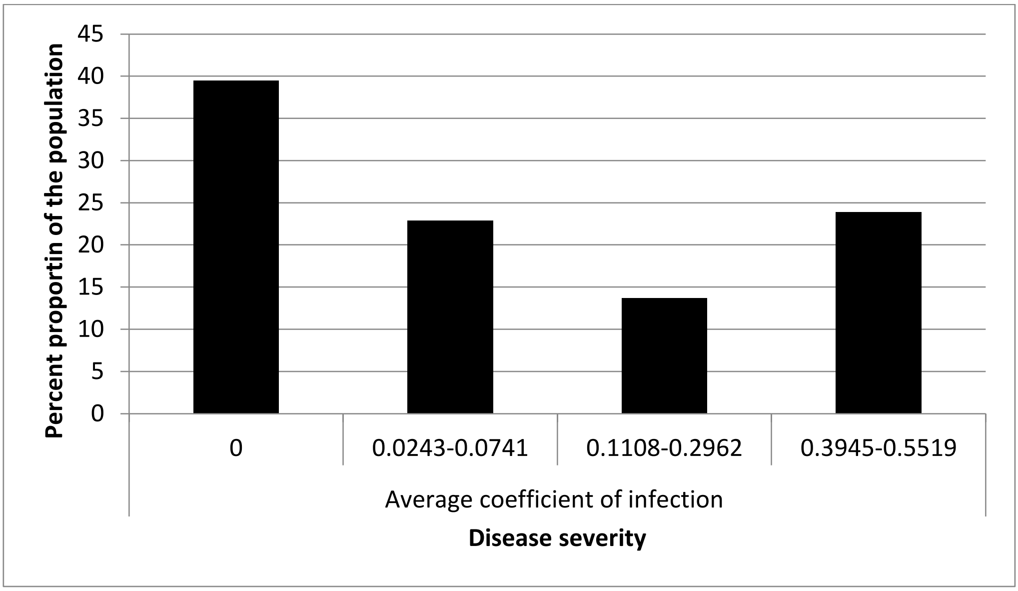

Figure 12. Response of Durum wheat accessions to SLB, 2018

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Materials obtained from ICARDA and included in the screening nursery had all categories of disease reaction except highly resistant ones (Figure 13). Though, limited, 0.55 % of the population had highly resistant response (scored 0). The share of resistant, moderately resistant, moderately susceptible and highly susceptible were 17.7, 15.2, 19.7, 19.1 and 27.7 % and the severity range as expressed in ACI was 0.0985 - 0.1976, 0.2219-0.29523, 0.3332-0.3949, 0.4225-0.5925 and 0.6048 -0.8882 respectively

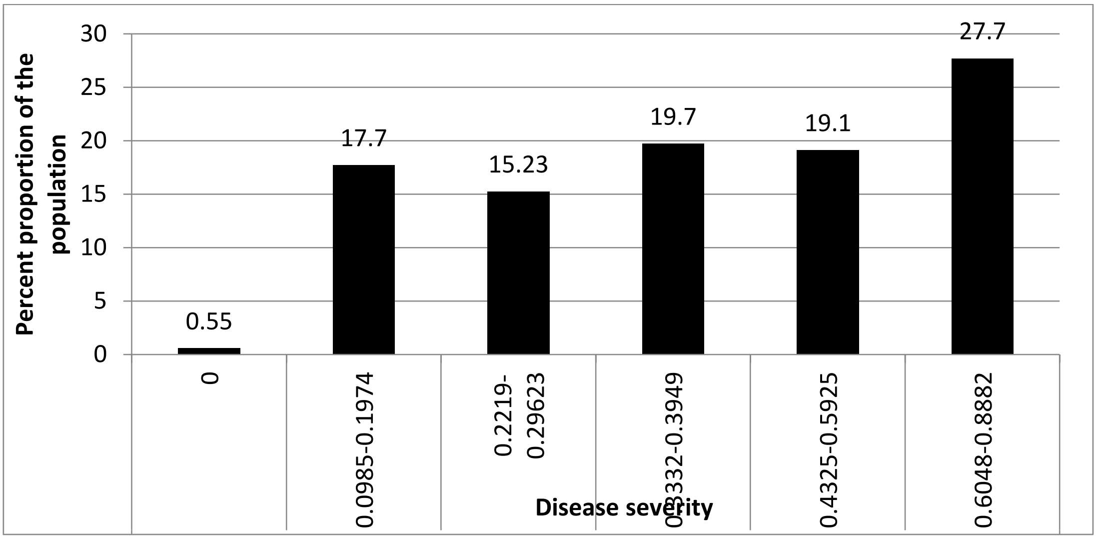

Figure 13. Response of bread wheat accessions, lines and varieties obtained from Kulumsa Agricultural Research Center to SLB, 2018

Unlike the previous seasons, In 2019 main season, wheat were also infected by FHB in addition to SLB. Fusarium head blight occurred and threatens wheat production throughout wheat production areas. However, durum wheat had more infection compared to bread wheat. Reaction of durum wheat lines to FHB is presented in figure 14. The result indicated that, 60 % of the lines had moderately resistant reaction and 14 % of the lines had susceptible to highly susceptible reaction. However, 26% had resistant reaction.

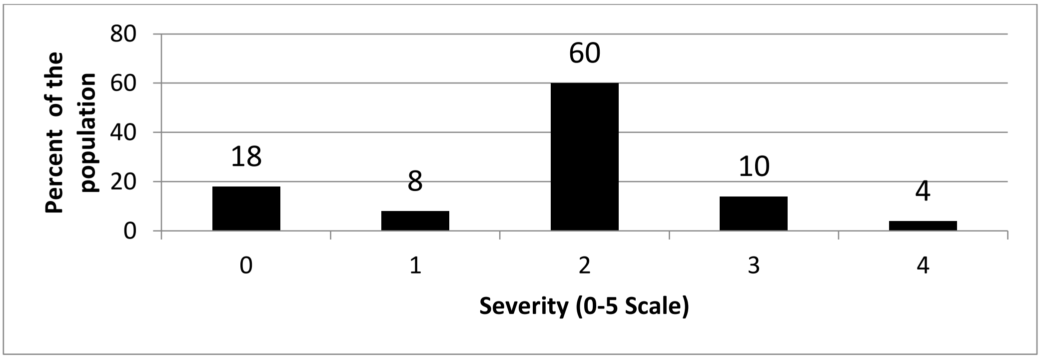

Figure 14. Reaction of Durum wheat varieties and lines to Fusarium head blight (FHB)

Reaction of bread wheat lines and/ or accessions and varieties to FHB is presented in Figure 15. Of the lines and /or accessions and varieties, there were no materials, which scored 0. However, 8.0 % of the materials scored two and were categorized as resistant. Those lines (31%, 42% and 18 % of the population) which scored

3,4,and 5 were categorized as moderately susceptible, susceptible and highly susceptible.

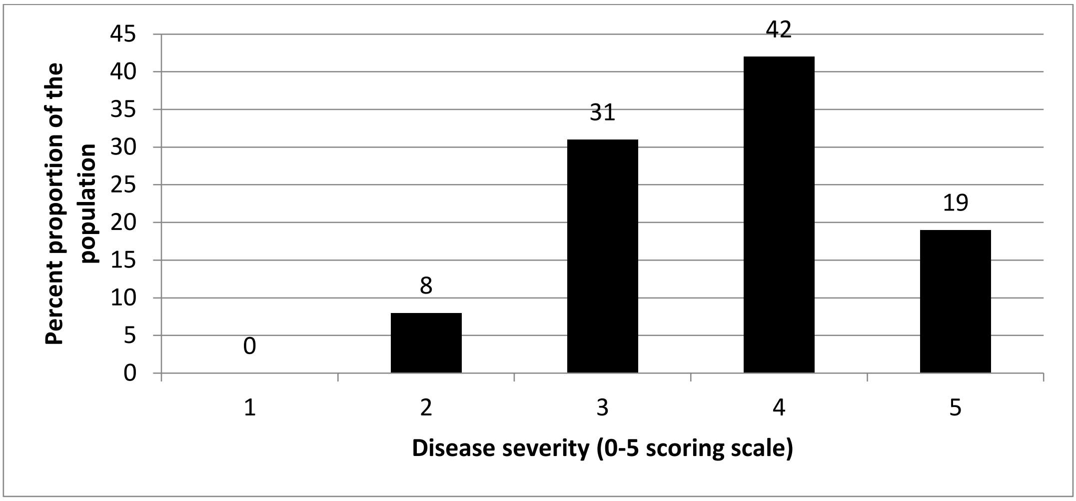

Figure 15. Reaction of bread wheat lines and /or accessions and varieties to Fusarium head blight (FHB)

Results of those bread wheat lines which were tested for three consecutive years (2017 2019) are presented in Figure 16. The verdict made to reevaluate further was because of their field performance and resistance to SLB as well as to their resistance reaction to major wheat diseases. However, in 2019 season majority (24 % and 35 %) of the materials have shifted from resistant category to moderately susceptible and susceptible group, respectively. However, still 17 % and 22.8 % of them had resistant and moderately resistant reaction. Generally, the result showed that wheat lines had in consistent reaction to the disease. Those lines which were categorized as resistant in the first and second seasons, appeared as moderately susceptible and susceptible in the last 2019 season. Those which had 0 score in 2017 did not show the same reaction in 2019 and had severity range of 0.0741-0.2934 ACI. In the same manner the maximum severity recorded in the previous years were less than 0.0365 ACI but, in 2019 the ACI increased to 0.7901 (Figure 16). Probably resistance to SLB in wheat may not sustain because of the change in race composition among seasons. Under such conditions, getting wheat lines with absolute resistance to the disease may not be a reality; however, resistance remain one of the main component of IDM for SLB.

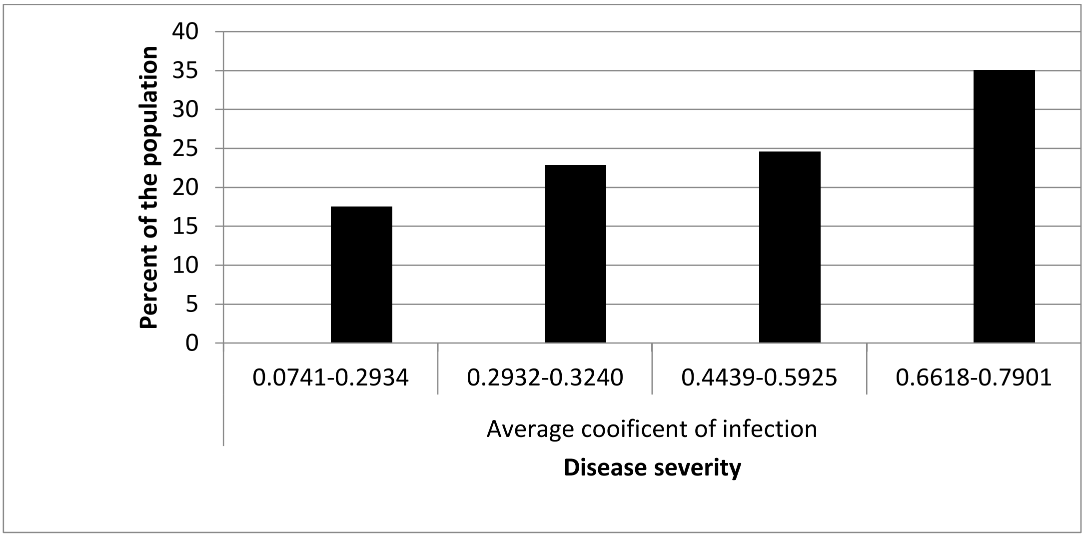

Figure 16. Reaction of bread wheat lines to septoria leaf blotch (SLB) which were tested for three years (2017-2019)

Regarding to the lines received from CIMMYT , 33.3 % of the lines had resistant to moderately resistant reaction (ACI in the range of 0.0732-0.2971) and had good field performance. But as to any population, the materials comprise of moderately susceptible, susceptible and highly susceptible category of lines (Figure 17). The result indicated that 10.53, 28% and 29 % of the lines were categorized as moderately susceptible, susceptible and highly susceptible and had AIC in the range of 0,3332-0.3722, 0.444-0.6899 and 0.7769-0.998 respectively**.** Phenotyping platform data generated during the research period have been shared with international and national partners.

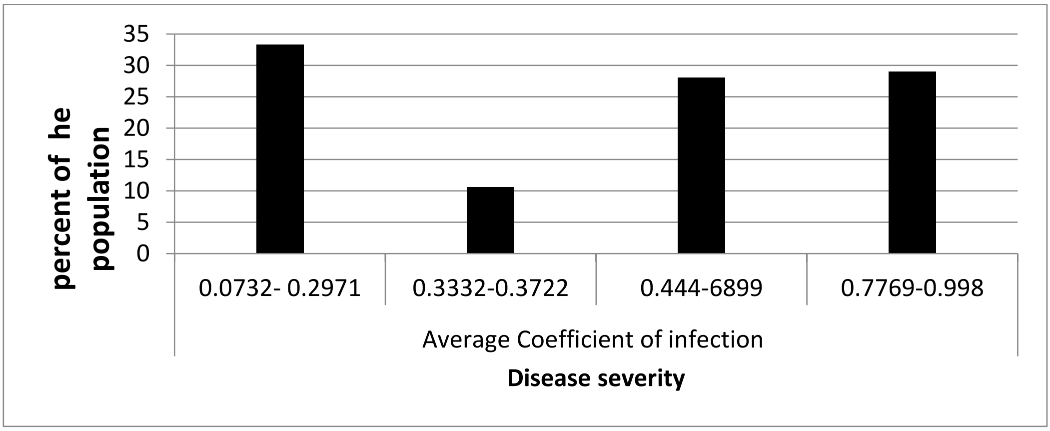

Figure 17. Reaction of CIMMYT materials bread wheat lines to SLB, 2019

Acknowledgements

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OBJECTIVE 3. BREEDING PIPELINE

International Nurseries at Kulumsa Research Center: Opportunities for Ethiopian Wheat Program

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Introduction

Ethiopia's agriculture system constitutes 46% of the gross national production, employs 85% of its population, and creates 75% of export commodity value (FDRE, 2013). Despite its large scale, the agricultural sector is largely formed by smallholder subsistence farms burdened by dependence on erratic rain-fed systems. All in all smallholder farms account for 96% of total area cultivated. Ethiopia's rain dependent agricultural system is particularly vulnerable to shifts in climate and weather, with less than 3% of households having access to irrigation or less than 1% of cereal acreage (Mann and Warner, 2015). These vulnerabilities are further exacerbated by extensive land use, land degradation, and household poverty. There has been substantial growth in cereals, in terms of area cultivated, yields and production since 2000, but yields are low by international standards and overall production is highly susceptible to weather shocks, particularly droughts. Thus, both raising production levels and reducing its variability are essential aspects of improving food security in Ethiopia, both to help ensure adequate food availability, as well as to increase household incomes.

Wheat is one of the most important staple food crops grown throughout the world. The current world production is 733 million metric tons (FAO, 2016). Wheat production must continue to increase more, particularly in developing countries at least by 2% in 2020 to meet the demands imposed by a rapidly growing population. Global average productivity is around 3 t ha^{-1} with high variability among countries and regions. It is the most important food grain source for humans supplying 40% of the world's food and 25% of calories consumed in developing countries. In Ethiopia, wheat is one of the most important cereal crops in terms of production and consumption. Annually about 4.6 million farmers produce close to 4.65 million tons of wheat on 1.6 million hectares of land. The current average productivity of wheat is about 2.73 t/ha (CSA, 2018/19) which has been consistently increasing for the last 20 years. The total production of wheat has also been increasing over the past five years, although somewhat slowly since 2009, mainly because of rust epidemics. Wheat production has lagged behind consumption resulting in increased annual imports close to one million tons since 2008. Despite enormous economic and dietary values of the crop in Ethiopia, the average yield has remained extremely low. This has been attributed to multifaceted biotic and abiotic factors including insufficient and erratic rainfall, poor agronomic practices, poor soil fertility, diseases and insect pests, and also shortage of appropriate varieties for some agro-ecologies.

Increasing the production of foodstuffs in developing countries against the background of rapid population growth, widespread food shortage, malnutrition and the destruction of the natural resource base still remains important for the future. Therefore, there is a need to intensify crop production through application of relevant innovations including better crop varieties adapted to varying agro-ecological conditions and socioeconomic set-ups. The development of cultivars or varieties, which can be adapted to a wide range of diversified environments, is the ultimate goal of plant breeders in a crop improvement program. The adaptability of a variety over diverse environments is usually tested by the degree of its interaction with different environments under which it is planted. A variety or genotype is considered to be more adaptive or stable one if it has a high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments. Hence, the genotype-by-environment interaction is probably the main cause of why traditional plant breeding failed to develop wide adaptable varieties (Ceccarelli *et al.,* 2006).

Over the last four decades as part of the international wheat improvement network, the International Maize and Wheat Improvement Center (CIMMYT) annually distributes germplasm to collaborators worldwide. Most important yield trials and nurseries distributed are the Elite Spring Wheat Yield Trial (ESWYT), Semi-Arid Wheat Yield Trial (SAWYT) and International Bread Wheat Screening nursery (IBWSN). The national wheat research program in Ethiopia has been working closely with CIMMYT for over half a century; as a result of germplasm introduction, screening and multi-location testing several CIMMYT lines have been released for commercial production, where 90% of released varieties currently grown by smallholder farmers are from CIMMYT source.

Developing high yielding and stable genotypes for wide and specific adaptation are important in wheat variety development strategy and evaluation across locations would form a basis for breeding. Therefore, this study was aimed to evaluate and identify bread wheat genotypes selected from CIMMYT international nurseries for their yield performance and to assess the nature and magnitude of genotype by environment interaction across different wheat agro-ecologies of Ethiopia.

Materials and Methods

Twenty eight bread wheat advanced lines selected from CIMMYT nurseries (Table 22) along with two check varieties (Ogolcho and Hawii) were evaluated for two years across eight locations of Ethiopia (Table 22) during 2015 and 2016 main cropping seasons. The locations are different in altitude, mean annual rainfall and soil types and represented the mid to lowland wheat growing agro-ecologies. Genotypes were planted in alpha lattice (5x6) with three replications in all experimental sites. Each plot had six rows of 2.5m length spaced 0.2m apart. Planting date for each location was on the onset of the main rainy season. Application of fertilizers and other agronomic practices were carried out as per the recommendation of each location. Grain yield data were recorded on plot basis and converted to t ha^{-1} for analysis.

Table 22. Description of testing locations, their climatic and soil conditions, 2015 & 2016 seasons.

Location	**Altitude**	**Longitude**	**Latitude**	**Rainfall, mm**	**Soil type**	**District**
ARSINEGELE	1960	38.42E	7.21N	933	Cambisols	Arsi-Negele
ASASSA	2340	39.10E	7.06N	620	Gleysols	Gedeb-Asasa
ALEMTENA	1575	38.95E	8.30N	728	Light-sandy	Bora
DHERA	1650	39.19E	8.20N	680	Andosols	Dodota-Sire
KULUMSA	2200	39.16E	8.02N	820	Luvisols	Tiyo
MELKASA	1567	39.21E	8.24N	801	Mollic/Andosols	Boset
SIRINKA	1850	39.36E	11.45N	876	Vertsols/Cambisols	Habru
MEKELLE	2254	39.47E	13.49N	714	Vertisols/Luvisols	Mekele

Note: **E-1=ArsiNegele**-2015; **E-2=**Asasa-2015; **E-3=**-Alemtena-2015; **E-4=**Dhera-2015; **E-5=**Kulumsa-2015; **E-6=**Melkasa-2015; **E-7=**Sirinka-2015**; E-8=** Mekele-2015**; E-9=ArsiNegele**-2016; **E-10=**Asasa-2016; **E-11=**-Alemtena-2016; **E-12=**Dhera-2016; **E-13=**Kulumsa-2016; **E-14=**Melkasa-2016; **E-15=**Sirinka-2016**; E-16=** Mekele-2016**;**

Statistical Analysis: Separate analysis of variance for grain yield for each location was performed prior to combined analysis. However, due to high heterogeneity result of error variance of individual locations for combined analysis, two years' data were treated as individual environment for each location. Hence, a total of sixty environments is used to analyze this data set. The mean square of genotype by environment interaction (GEI) for grain yield was used to test the effects of genotypes. The genotypes (G) and environments (E) were subjected to AMMI method of analysis (Gauch and Zobel, 1997). The AMMI model combines the analysis of variance for main effects of G and E with principal components analysis of GEI. The bi-plot constructed from main effect of means vs the first Interaction Principal Component Analysis Axis (IPCA) from AMMI analysis was used to study the pattern of response of G, E, and GEI. The bi-plot was also used to identify genotypes with broad or specific adaptation to target environments for grain yield. AMMI-II biplot was constructed in the dimension of first two IPCA, using a singular-value decomposition procedure (Yan *et al.,* 2000). The genotypes were represented on the bi-plots as the points derived from their scores and the environments as the vectors from the biplot origin to their points.

Table 23. Bread wheat genotypes evaluated across eight locations in 2015 and 2016 cropping season.

Code	Designation	Pedigree
G1	OGOLCHO	
G2	ETBW 7638	ATTILA/3*BCN*2//BAV92/3/KIRITATI/WBLL1/4/DANPHE
G3	ETBW 8506	AGUILAL/FLAG-3
G4	ETBW 8507	DURRA-4
G5	ETBW 7120	QAFZAH-23/SOMAMA-3
G6	ETBW 8508	REYNA-8
G7	ETBW 7213	CHAM-4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB
G8	ETBW 8509	REYNA-29
G9	ETBW 7038	ATTILA/3*BCN//BAV92/3/TILHI/5/BAV92/3/PRL/SARA//TSI/VEE#5/4/CROC_1/AE.SQUARROSA (224)//2*OPATA
G10	ETBW 8510	HIJLEEJ-1
G11	ETBW 7058	ROLF07//TAM200/TUI/6/WBLL1/4/HD2281/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/TACUPETO F2001
G12	ETBW 8511	BOW #1/FENGKANG 15/3/HYS//DRC*2/7C
G13	ETBW 7147	CROC-1/AE.SQUARROSA(224)// OPATA/3/QAFZAH-21/4/SOMAMA-3
G14	ETBW 8512	BABAX/LR42//BABAX*2/3/KURUKU/4/KINGBIRD #1
G15	ETBW 7871	PAURAQ/4/PFAU/SERI.1B//AMAD/3/WAXWING
G16	ETBW 8513	MUTUS//WBLL1*2/BRAMBLING/3/WBLL1*2/BRAMBLING
G17	ETBW 6940	UTIQUE 96/FLAG-1
G18	ETBW 8514	TUKURU//BAV92/RAYON/3/WBLL1*2/BRAMBLING/4/WBLL1*2/BRAMBLING
G19	ETBW 7368	D. 56455
G20	ETBW 8515	BECARD/3/PASTOR//MUNIA/ALTAR 84
G21	ETBW 7364	ACSAD1115
G22	ETBW 8516	KACHU/KIRITATI
G23	ETBW 7194	VAN'S'/3/CNDR'S'/ANA//CNDR'S'/MUS'S'/4/TEVEE-5
G24	ETBW 8517	FRNCLN*2/TECUE #1
G25	ETBW 7101	KAMB2/PANDION
G26	ETBW 8518	SUP152/AKURI//SUP152
G27	ETBW 7872	QUAIU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
G28	ETBW 8519	ATTILA/3*BCN*2//BAV92/3/KIRITATI/WBLL1/4/DANPHE
G29	ETBW 6937	AGUILAL/FLAG-3
G30	HAWI	

ETBW = Ethiopian Bread Wheat.

The equation for AMMI model (Zobel *et al.*, 1998) is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{n=1}^{N} \lambda_n \alpha_{in} \gamma_{jn} + e_{ij}$$

Where, Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; G_i and E_j are the genotype and environment deviations from the grand mean, respectively; λn is the eigen value of the PCA axis n; αin and γjn are the genotype and environment principal component scores for axis n, respectively; N is the number of principal components retained in the model and eij is the error term.

AMMI model does not make provision for a specific stability measure to be determined, such a measure is essential in order to quantify and rank genotypes according to their yield stability. Since the IPCA-1 score contributes more to GEI sum of squares, it has to be weighted by the proportional difference between IPCA-1 and IPCA-2 scores to compensate for the relative contribution of IPCA-1 and IPCA-2 in to the total GEI sum of squares called AMMI stability values (ASV). The following measure was proposed by Purchase (1997):

$$ASV = \sqrt{\left[\frac{IPCA\ 1\ sum\ \ of\ \ squares\ \ (IPCA\ 1\ score)}{IPCA\ 2\ sum\ \ of\ \ squares}\right]^2 + (IPCA\ 2\ score)^2}$$

Result and Discussions

The result of analysis of variance for grain yield revealed highly significant ($P \leq 0.001$) differences between genotypes (G), environment (E) and genotype by environment interaction (GEI) (Table 23). Highly significant differences between G and E for grain yield might indicate the presence of genetic variability among the genotypes as well as the environments. This is indicated by the mean yield of genotypes across environment range from 3.48 t ha^{-1} (G12) to 5.47 t ha^{-1} (G9) and environmental index ranged from 2.54 t ha^{-1} (E-12) to 6.92 t ha^{-1} (E-11) (Table 24). Significant GEI suggested the linier function of the additive environment effects and was reflected by the change in the ranking order of genotypes under varying environments. Similar results have been reported by different authors (Zerihun *et al.* (2016), Cotes *et al.* (2006), Ali (2006), Amin *et al.* (2005)). However, overall performance of genotypes depends upon the magnitude of GEI.

The highest grain yield across environments recorded from E-11 (G17=8.60 t ha^{-1}) and E-6 (G9=8.17 and G3=8.13 t ha^{-1}) (Table 4). The standard check variety G1 (Ogolcho) remained the third highest yielding 5.18 t ha^{-1} over all locations next to G9 (5.47 t ha^{-1}) and G3 (5.37 t ha^{-1}). This revealed that at least two promising genotypes were better than the standard check based on grain yield potential across locations. Whereas, the other check G30 (Hawii) ranked 21st with a grain yield of 4.62 t ha^{-1}.

Table 24. AMMI analysis of variance for grain yield (t ha^{-1}) of 30 genotypes tested across eight locations in 2015 and 2016

Source of Variation	df	SS	MS	Sum of Square Explained (%)		
				Total variation	G x E Explained	G x E Cumulative
Environments	15	2473.28	164.89***	64.70		
Reps within Env.	32	51.51	1.61	1.30		
Genotype	29	275.62	9.50***	7.20		
Genotype x Env.	435	655.08	1.51***	17.10		
IPCA 1	43	198.95	4.63***		32.51	32.51
IPCA 2	41	131.42	3.21***		21.48	53.99
IPCA 3	39	82.62	2.12***		13.5	67.49
IPCA 4	37	66.16	1.79***		10.81	78.3
IPCA 5	35	43.24	1.24***		7.07	85.36
IPCA 6	33	31.09	0.94***		5.08	90.45
IPCA 7	31	24.94	0.81***		4.08	94.52
IPCA 8	29	19.93	0.69*		3.26	97.78
IPCA 9	27	13.60	0.50ns		2.22	100
IPCA Residual	120	43.13	0.36			
Residual	928	369.77	0.40	9.70		
Total	1439	3825.25				

Grand Mean = 4.78 t/ha **R-squared = 0.90** **C.V = 13.2 %** **LSD (5%) = 0.25**

***= significant at P ≤ 0.001 and ns= non-significant;, *and ** Indicate significance at the 0.05 and 0.01 levels, respectively; ns = non-significant, IPCA = Interaction principal component axis.

The highest grain yield across environments recorded from E-11 (G17=8.60 t ha^{-1}) and E-6 (G9=8.17 and G3=8.13 t ha^{-1}) (Table 24). The standard check variety G1 (Ogolcho) remained the third highest yielding (5.18 t ha^{-1}) over all locations next to G9 (5.47 t ha^{-1}) and G3 (5.37 t ha^{-1}). This revealed identification of at least two promising genotypes better than the standard check based on grain yield potential across locations. The other check, G30 (Hawii), ranked 21st with a grain yield of 4.62 t ha^{-1}.

From the total treatment sum of square of the model, 64.7% was attributed to environmental effects and the rest to genotypic (7.2%) and GEI (17.1%) effects. The larger sum of square and highly significant mean squares of environment indicated that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. This shows the overpowering influence that environments have on the yield performance of wheat genotypes.

GEI component of variation was partitioned into nine possible interaction principal component axes (IPCA). The F-test indicates that except the ninth IPCA, all the first eight IPCA were highly significant ($P \leq 0.01$) and they explained the interaction effects of genotype by environment (Table 23). The first eight significant IPCA explained 97.78% of the total GEI sum of square while the 9th IPCA explained only 2.22% and was non-significant. Therefore, the first eight significant IPCA can be taken as adequate dimensions for this data set. However, the prediction assessment indicated that AMMI model with only two IPCA was the best predictive model (Yan *et al*., 2000). The first two IPCA explain 53.99% of the total GEI sum of square.

AMMI-1 biplot for grain yield of 30 wheat genotypes and eight locations for two years is plotted from the main effect against IPCA1 scores of the genotypes and environment (Figure 18). Accordingly, the IPCA-1 scores ranged from 1.70 down to -0.99 and grain yield means from 2.54 up to 6.92 t ha^{-1}, which is explained by 95.7% of the total sum of square. Both locations and genotypes are dispersed widely in all quadrants in the biplot (Figure 18). The AMMI biplot on the relative magnitude of the position and direction of genotypes on the plane of stability parameters (i.e., interaction principal component axis) regressed on environmental mean yields (main effect) is considered an important measure of not only the pattern of adaptation (wide *vis-à-vis* specific adaptation) but also that of performance stability (Zobel *et al.,* 1988). Accordingly, genotypes with IPCA-1 scores close to zero showed better general adaptation than specific adaptation and *vice versa* (Ebdon and Gauch 2002). For instance, G16 (0.00), G6 (0.01) and G23 (0.02), with IPCA-1 scores closer to zero, showed less differential response to the changes in the growing environments as compared to the other genotypes. However, except G16, these genotypes scored lower grain yield below the mean across tested locations. On the other hand, G17 (1.41), G2 (1.09) and G12 (0.75) scored the highest IPCA-1 and they are considered as non-stable, but except G12 the other genotypes showed better grain yield performance across locations (Table 24).

Table 25. AMMI adjusted mean grain yield (t ha^{-1}) of 30 genotypes tested across eight locations in 2015 and 2016.

	Genotype	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	E-10	E-11	E-12	E-13	E-14	E-15	E-16	Genotype mean	Rank	IPCA-1	IPCA-2	ASV
1	**G1**	5.13	6.14	4.72	4.26	3.69	7.60	6.80	5.32	4.85	3.93	7.00	3.01	3.88	7.12	3.89	5.56	**5.18**	**3**	**-0.16**	**-0.30**	**0.39**
2	**G2**	4.53	5.26	6.67	2.95	4.37	7.14	6.03	6.02	4.01	3.10	7.99	2.43	3.55	6.31	4.95	6.00	**5.08**	**9**	**1.09**	**-0.16**	**1.66**
3	**G3**	5.01	6.30	6.51	3.53	4.82	8.13	7.41	5.31	4.41	3.53	7.40	2.94	3.40	6.90	4.33	5.99	**5.37**	**2**	**0.55**	**-0.86**	**1.20**
4	**G4**	4.13	4.85	2.57	3.64	1.87	6.08	5.16	4.47	4.08	3.14	5.85	1.98	3.23	6.16	2.72	4.29	**4.01**	**29**	**-0.54**	**0.21**	**0.84**
5	**G5**	4.36	5.18	4.56	3.34	3.16	6.73	5.78	5.09	4.06	3.14	6.79	2.24	3.32	6.28	3.70	5.10	**4.55**	**23**	**0.20**	**-0.09**	**0.31**
6	**G6**	3.98	4.67	3.63	3.14	2.39	6.11	5.11	4.76	3.79	2.86	6.32	1.85	3.10	5.93	3.22	4.59	**4.09**	**28**	**0.01**	**0.14**	**0.14**
7	**G7**	4.46	4.99	4.45	3.54	2.97	6.48	5.36	5.61	4.27	3.33	7.17	2.32	3.74	6.36	4.08	5.26	**4.65**	**20**	**0.23**	**0.31**	**0.47**
8	**G8**	4.55	4.90	4.35	3.72	2.84	6.33	5.11	5.97	4.44	3.49	7.42	2.40	4.04	6.45	4.33	5.37	**4.73**	**18**	**0.23**	**0.58**	**0.68**
9	**G9**	5.19	6.43	6.22	3.85	4.71	8.17	7.45	5.42	4.66	3.77	7.41	3.10	3.64	7.10	4.33	6.02	**5.47**	**1**	**0.36**	**-0.75**	**0.93**
10	**G10**	4.66	5.03	3.09	4.22	2.18	6.22	5.09	5.60	4.71	3.75	6.85	2.48	4.15	6.65	3.72	4.98	**4.59**	**22**	**-0.39**	**0.68**	**0.90**
11	**G11**	5.12	6.48	4.98	4.11	4.05	8.04	7.45	4.77	4.71	3.81	6.63	3.02	3.46	7.13	3.51	5.48	**5.17**	**4**	**-0.21**	**-0.81**	**0.87**
12	**G12**	3.11	3.21	3.82	2.04	1.77	4.77	3.36	5.24	2.94	1.99	6.74	0.95	2.85	4.91	3.68	4.36	**3.48**	**30**	**0.75**	**0.82**	**1.40**
13	**G13**	3.94	4.36	4.35	2.91	2.62	5.91	4.70	5.42	3.72	2.78	7.00	1.80	3.33	5.80	3.92	4.94	**4.22**	**27**	**0.47**	**0.42**	**0.82**
14	**G14**	4.39	5.17	3.03	3.84	2.28	6.45	5.56	4.68	4.30	3.36	6.12	2.25	3.42	6.42	2.99	4.60	**4.30**	**26**	**-0.48**	**0.10**	**0.74**
15	**G15**	4.94	5.77	3.88	4.29	3.02	7.10	6.22	5.25	4.80	3.87	6.75	2.80	3.92	6.95	3.63	5.23	**4.90**	**15**	**-0.37**	**0.02**	**0.56**
16	**G16**	4.96	6.21	5.18	3.87	4.02	7.81	7.13	4.93	4.54	3.64	6.80	2.87	3.43	6.94	3.70	5.51	**5.10**	**8**	**0.00**	**-0.68**	**0.68**
17	**G17**	4.49	4.86	6.95	2.87	4.30	6.75	5.40	6.72	4.03	3.11	8.60	2.38	3.91	6.20	5.58	6.24	**5.15**	**6**	**1.41**	**0.30**	**2.15**
18	**G18**	5.02	5.87	3.20	4.59	2.69	7.07	6.25	5.04	4.96	4.03	6.44	2.87	3.98	7.09	3.29	5.03	**4.84**	**17**	**-0.72**	**0.05**	**1.09**
19	**G19**	5.15	5.89	3.74	4.61	2.98	7.15	6.24	5.50	5.07	4.13	6.91	3.00	4.22	7.17	3.78	5.35	**5.06**	**12**	**-0.48**	**0.16**	**0.75**
20	**G20**	5.05	5.99	4.03	4.37	3.22	7.34	6.53	5.17	4.87	3.94	6.72	2.91	3.89	7.07	3.59	5.30	**5.00**	**14**	**-0.41**	**-0.14**	**0.63**
21	**G21**	4.48	5.02	3.80	3.76	2.61	6.39	5.31	5.41	4.37	3.43	6.86	2.33	3.76	6.43	3.76	5.04	**4.55**	**24**	**-0.07**	**0.36**	**0.38**
22	**G22**	4.56	5.58	4.42	3.61	3.28	7.09	6.28	4.82	4.25	3.33	6.54	2.45	3.30	6.53	3.44	5.08	**4.66**	**19**	**-0.05**	**-0.33**	**0.34**
23	**G23**	4.31	4.45	3.43	3.70	2.09	5.74	4.43	5.86	4.33	3.37	7.13	2.13	4.04	6.22	4.03	4.98	**4.39**	**25**	**0.02**	**0.92**	**0.92**
24	**G24**	5.11	6.22	4.18	4.38	3.44	7.60	6.90	4.96	4.87	3.95	6.60	2.99	3.76	7.15	3.47	5.31	**5.06**	**11**	**-0.44**	**-0.38**	**0.77**
25	**G25**	5.09	6.35	5.00	4.08	3.99	7.90	7.24	4.94	4.70	3.80	6.76	2.99	3.55	7.09	3.65	5.52	**5.16**	**5**	**-0.14**	**-0.67**	**0.70**
26	**G26**	5.00	5.98	3.49	4.47	2.92	7.25	6.49	4.90	4.88	3.95	6.39	2.87	3.81	7.07	3.25	5.06	**4.86**	**16**	**-0.64**	**-0.15**	**0.98**
27	**G27**	5.23	5.85	3.19	4.91	2.64	6.99	6.04	5.59	5.28	4.32	6.86	3.07	4.46	7.29	3.72	5.27	**5.04**	**13**	**-0.71**	**0.39**	**1.14**
28	**G28**	4.93	5.91	5.17	3.87	3.84	7.48	6.63	5.37	4.58	3.66	7.14	2.82	3.70	6.87	4.05	5.60	**5.10**	**7**	**0.14**	**-0.32**	**0.38**
29	**G29**	4.67	5.47	6.06	3.30	4.13	7.23	6.21	5.79	4.22	3.31	7.67	2.57	3.62	6.51	4.61	5.84	**5.07**	**10**	**0.73**	**-0.19**	**1.12**

30	**G30**	4.66	5.23	3.38	4.12	2.47	6.50	5.48	5.35	4.62	3.68	6.72	2.51	3.93	6.66	3.59	4.99	**4.62**	**21**	**-0.35**	**0.38**	**0.66**
	ENV Mean (t ha^{-1})	**4.67**	**5.45**	**4.40**	**3.80**	**3.18**	**6.92**	**5.97**	**5.31**	**4.44**	**3.52**	**6.92**	**2.54**	**3.68**	**6.62**	**3.82**	**5.26**	**4.78**				
	CV (%)	**7.75**	**13.30**	**11.63**	**18.20**	**15.18**	**11.76**	**14.31**	**14.02**	**8.49**	**12.59**	**8.30**	**18.44**	**10.84**	**12.17**	**20.19**	**13.54**					
	LSD (5%)	**0.60**	**2.05**	**0.84**	**1.14**	**1.37**	**1.34**	**1.41**	**1.23**	**0.62**	**0.73**	**0.95**	**0.77**	**0.66**	**2.28**	**1.27**	**1.18**					
	R-squared	**0.89**	**0.74**	**0.93**	**0.77**	**0.87**	**0.75**	**0.84**	**0.69**	**0.89**	**0.74**	**0.85**	**0.83**	**0.84**	**0.65**	**0.75**	**0.79**					
	IPCA1	**-0.40**	**-0.55**	**1.70**	**-1.00**	**0.70**	**-0.20**	**-0.40**	**0.53**	**-0.62**	**-0.61**	**0.80**	**-0.38**	**-0.27**	**-0.56**	**0.86**	**0.41**					
	IPCA2	**0.04**	**-0.65**	**-0.68**	**0.35**	**-0.78**	**-0.85**	**-1.24**	**1.02**	**0.32**	**0.28**	**0.64**	**-0.02**	**0.83**	**0.00**	**0.64**	**0.10**					

All location and genotypes having the same sign of IPCA1 score interacts each other positively and different IPCA-1 score sign interacts negatively (Yan *et al.,* 2000).

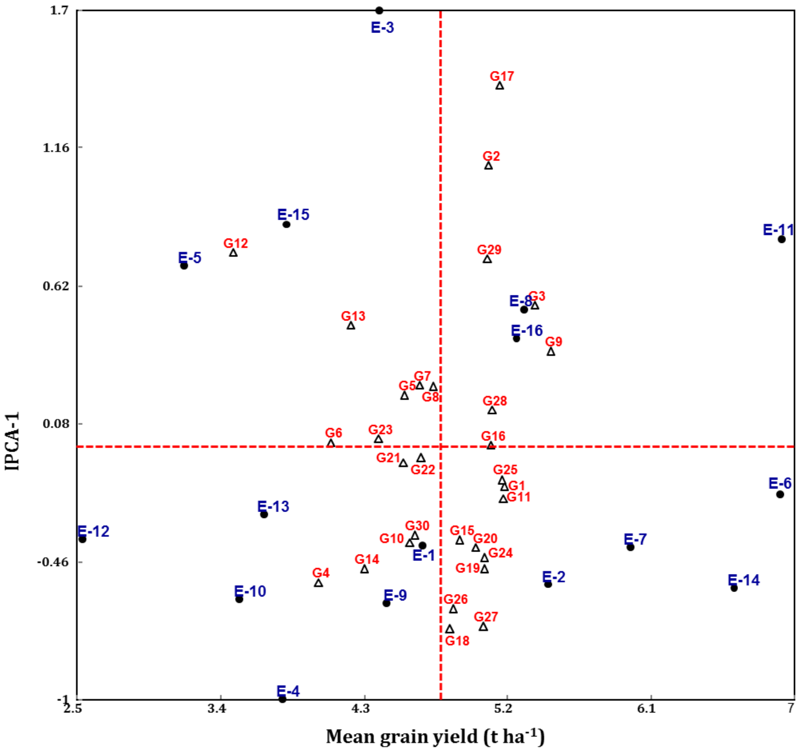

Figure 18. AMMI-1 biplot for grain yield of 30 wheat genotypes evaluated in 2015 and 2016.

In addition, AMMI-2 biplot generated by using the first two interaction principal component axes (IPCA1 and IPCA2) used to visual interpretation of the GEI patterns and identify genotypes or locations that exhibit low, medium or high levels of interaction effects (Yan, 2002). AMMI-2 interaction bi-plots for grain yield of 30 bread wheat genotypes tested in 2015 and 2016 are shown in Figure 19. Generally, most of the environment having longer vectors projected from the origin indicated the ability of the environment to discriminate the tested genotypes and they provided good information among genotypes.

Genotypes near the origin are non-sensitive to environmental interactive forces and those distant from the origin are sensitive and have large interactions (Samonte *et al.*, 2005). Accordingly, genotypes G6, G5 and G15 are non-sensitive to environmental interactive forces; and hence, these genotypes are considered as stable genotypes based on AMMI-2 biplot. Whereas; G17, G12, G23 and G3 were highly influenced by the interactive force of environment and sensitive to environmental changes, so these varieties were considered as unstable genotypes due to the long projections from the origin (Figure 15).

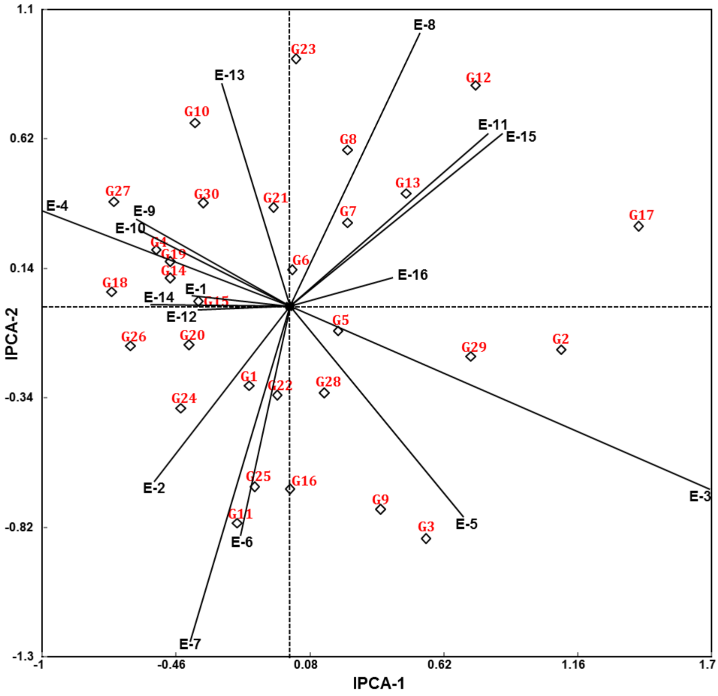

Figure 19. AMMI-2 interaction biplot for grain yield of 30 bread wheat genotypes tested in 2015 and 2016 seasons.

AMMI stability value (ASV): In ASV method, genotypes with least ASV scores are the most stable than genotypes with higher ASV (Purchase *et al.*, 2000). Accordingly, genotypes with small ASV values were G6, G5 and G22 found stable in the current study but except G26, all the genotypes had low grain yield performance across locations (Table 4). The most unstable genotypes according to the ASV approach are G17, G2, G12 and G3 having high ASV values. However, except G12, these genotypes had above average grain yield potentials. Not true!

Generally, based on the grain yield performance of the genotypes, relative adaptability and other agronomic performance of the genotypes including disease resistance (mainly rust), G2 and G3 are selected for further verification. G3 (5.37 t ha^{-1}) was the 2nd high yielding genotypes next to G9 (5.47 t ha^{-1}); and G2 (5.08 t ha^{-1}) is the 9th in terms of mean grain yield rank. However, there is no significant difference in terms of mean grain yield between G2 and the standard check G1

(Ogolcho) as shown in Table 24; and unfortunately, G9 was susceptible for stem and yellow rusts. Hence, from the point of disease resistance and other agronomic parameters, G2 outperformed G9 and the standard check G1. Based on this results, after one year of variety verification trials in 2017, G2 was released as a new variety for commercial production and was given a local name "DEKA" in 2018.

Summary and Conclusion

The present study revealed that bread wheat yield were subject to significant fluctuations with changes in the growing environments. Significant differences among the G and E for grain yield indicated the presence of genetic variability among the genotypes as well as the variability of environments under the study. Two years data showed different responses of the same location and this showed high seasonal variations within the same location. Hence, environment's contribution to the total variation was high, and its contribution to the GEI effect was almost nine times higher than that of the genotype effect. AMMI-I bi-plot clearly displayed the main and interaction effects of genotypes and the environment. Based on AMMI-II biplot, most of the environments have longer vectors projected from the origin and that indicated the ability of the environments to discriminate the tested genotypes, and hence provided good information about the genotypes.

Even though no genotypes showed superior performance across all the test environments, some genotypes with consistently better mean performance were identified. Based on the grain yield performance of the genotypes and stability parameters, it is very difficult to identify ideal genotypes with good performance across locations. Such complications from G x E interactions made it difficult to develop high yielding and stable varieties across locations. In fact, it is not recommended to develop and release a single genetic background of varieties across all locations since Ethiopia is historically vulnerable to rust epidemic due to mega variety deployment. However, there is a possibility to use a single variety across different wheat growing agroecology of Ethiopia by designing systematic variety deployment strategy.

This study demonstrated the importance of multi-location variety trials in Ethiopia to select best genotypes adapted to wide range of environments as well as to specific locations. The present study identified G2 (ETBW7638) and G3

(ETBW8506) having high grain yield and other good agronomic performance. These two candidate genotypes were submitted to the National Variety Release Committee (NVRC) for variety verification trials at multi-locations, and G2 (ETBW 7638) was released as a commercial variety with a designated local name of "**DEKA**". Based on its performance, this variety is recommended for mid to lowland wheat growing agro-ecologies of the country.

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Durum Wheat Breeding and Achievements with the Support of Delivering Genetic Gain in Wheat (DGGW) Project

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Introduction

Durum wheat is an economically important crop and widely grown in most parts of the world and Ethiopia. Wheat improvement research started in Ethiopia in 1949 (Hailu, 1991). Since then, the durum wheat breeding program has concentrated on improving grain yield potential, adaptation, disease resistance and stress tolerance (Getinet, 1988; Tesfaye and Jamal, 1982). In Ethiopia, durum wheat is cultivated in several parts of the country particularly in the central highlands, traditionally planted on heavy black clay soils (Vertisols) at altitudes between 1800-2800 meters above sea level (Tesemma and Belay, 1991). The national and regional agricultural research systems in Ethiopia have been striving to improve durum wheat production in Ethiopia since the late 1960's. As a result, 41 improved durum wheat varieties have been released for commercial production from 1966 to 2018.

Durum wheat grain is used for manufacturing pasta products viz. macaroni, spaghetti and noodles and for the preparation of traditional recipes including *injera, dabo, dabokolo, genfo, kinche, nifro* and other food types and beverages. The straw is mainly used as source of animal feed, but may be used for thatching roofs. Quality and yield of durum wheat are often affected by different biotic, abiotic, socio-economic and environmental factors; hence enhancing and sustaining its production and quality demands are quite a challenge. Concerted efforts on prioritized research areas are in progress to fulfill durum wheat development needs and to meet the country’s industrial raw material and food security demands. Therefore, durum wheat research project has mainly focused on three target environments: a) optimum moisture, b) lowland moisture stress and c) waterlogged areas with the following objectives.

I. To develop high yielding, disease resistant durum wheat varieties with acceptable industrial qualities.
II. To maintain true-to-type genotypes and to multiply high quality seeds of released durum varieties.
III. To identify and characterize durum wheat production and marketing constraints in Ethiopia.
IV. To promote improved durum wheat technologies through adaptation and pre-scaling activities.

Durum Wheat Germplasm Enhancement:

Hybridization

Targeted crosses are made at Debre-Zeit in the lath-house and on light soils in the field using parents identified from, durum landraces, improved varieties and introductions from ICARDA, CIMMYT, Australia, and Egypt. The aim is to develop high yielding, disease resistant and semi-dwarf genotypes with high grain protein content and other desirable agronomic traits for the different durum wheat growing agro-ecologies (environments).

The crossing combination include:

- Elite x elite
- Elite x released varieties
- Exotic pipeline x local varieties

Summary of hybridization results

- Durum wheat crossing has been in progress since 2013. With the inception of DGGW project in 2017, crossing activities continued with enhanced strength. Parental materials were selected based on the targeted traits (yield, quality, disease resistance, moisture stress and waterlogging tolerances, etc. Annually, at least 150 targeted crosses were made at Debre-Zeit in the lath-house and on light soils using parents identified from different sources.
- Parental lines were selected from introductions (ICARDA, CIMMYT), landraces and improved varieties based on targeted traits.

- During the last three years, 470 targeted crosses (single, double, top or backcrosses) were made.
- Pedigree selection method is employed at F_2 and F_5 generations.
- Selected bulk method usually employed for F3, F4 and F6 segregating population.
- Outstanding lines/families with desirable traits are selected and evaluated for agronomic and quality traits in preliminary observations and pre-national trials.
- Important traits observed included appropriate height (semi-dwarf), healthy and stay-green leaves, durable disease resistance, preferred spike type, lodging resistance, and desirable maturity date for different environments.

Figure 20. Durum wheat crossing activities in the lath-house at Debre-Zeit Research Center.

Durum wheat segregating populations

154, 119, 38, and 34 families of F_2, F_3, F_4 and F_5, respectively, were selected and tested during the 2019 main- and off-seasons. From each cross, 15 to 30 spikes were selected and bulked before planting. Selections were based on target traits such as yield, grain quality, disease resistance, moisture stress tolerance, agronomic features, etc. Promising and best lines were advanced to subsequent generations until they attained some degree of uniformity and homozygosity in the F6 and following generations.

Germplasm introduction and selection

Bi-annual screenings (off-season and main-season) of introduced germplasm are yearly carried out at Debre-Zeit Agricultural Research Centre (DZARC). The off-season begins in Jan/Feb and lasts until May, and the main-season starts during June/July and extends to Nov/December. Regarding wheat diseases, DZARC is a “hot-spot” area for economically important wheat diseases such as leaf rust (*Puccinia recondita*) and stem rust (*Puccinia graminis*). The evaluation and selection activities are jointly carried out by a team of pathologists and breeders usually in partnership with global scientists from CIMMYT, ICARDA, Cornell, USDA, Australia and other NARS who send their wheat materials to be screened at DZARC. About 15-20 nurseries are received and tested every season (off-season or main season). Entries of the nurseries are planted in two rows of 1m length with 20-30cm distance between rows. Appropriate universally susceptible checks are included and planted in every nursery and usually repeated after each 20 entries. Artificial inoculation with rust spores is applied with mixture of relevant races (Ethiopian prevailing races + Ug99). Materials with durable disease resistance and good agronomic features have been identified during the evaluation process. Outcome of germplasm introduction by entries, testing in nurseries and proportion of selection over 8 years is shown in Figure 21.

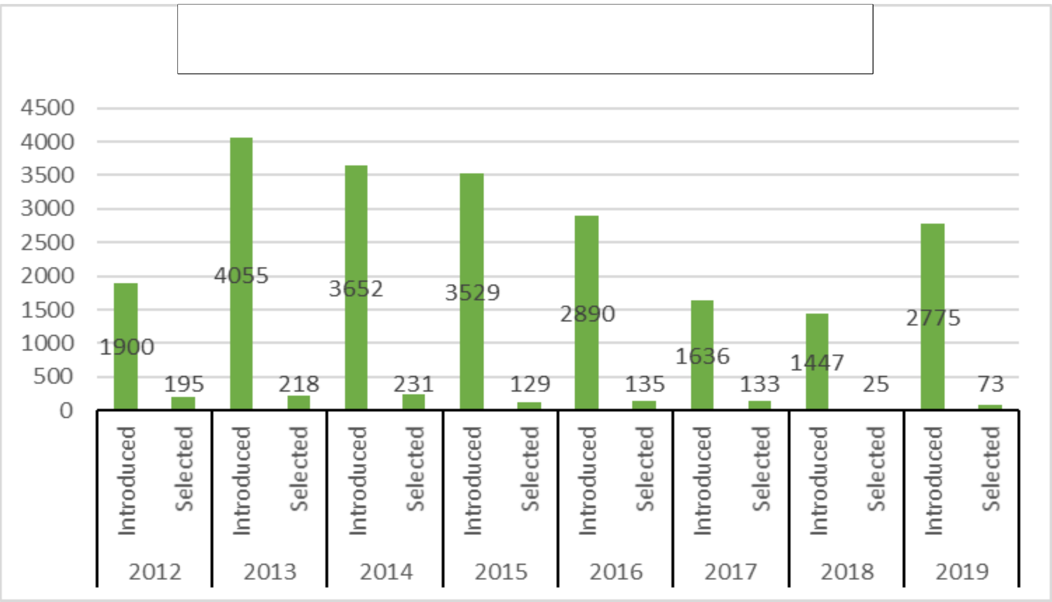

Fig 21. Durum wheat germplasm introduction and selection trend by entries from 2012 to 2019.

Durum Wheat Variety Development

Testing of advanced materials under different agro-ecological environments across the country has been the method for developing improved durum wheat varieties in Ethiopia. National Durum Wheat Research project has different stages of testing durum wheat materials. These include preliminary nursery observation, preliminary variety trials, national variety trials, and variety adaptation and variety verification trials (VVT). The target environments include optimum environments, moisture stressed lowlands and irrigated areas.

Preliminary observation nursery

Six hundred sixty eighty Ethiopian crosses and introduced genotypes with checks were evaluated at Debre-Zeit, Chefe Donsa and Alemtena testing sites. The nurseries were arranged in a partial replicated design across locations and were conducted during the 2017, 2018 and 2019 main seasons. The gross plot size was $1m^2$ and consisted of two rows of 2.5m length with 20cm between rows. Data on grain yield and yield components, reaction to major diseases and physical grain quality were measured from the whole two rows. Analysis of variance were conducted for yield using SASv9.1.3 and R 3.2 statistical software procedure.

One hundred forty five genotypes that out yielded standard checks, which had rust resistance and high industrial quality, were promoted to the next stages of variety trials under high stem and leaf rust disease pressure before including elite and advanced lines into next durum wheat national variety trials. It is not worthy that heritability of genotypes could be improved by analyzing a nursery or trial using modern experimental designs such as Spatial + MET. As demonstrated in Figure 22 below, analysis using the latest experimental design (Spatial + MET) was better than RCB or Spatial at all the three locations although Spatial is nearly equal to Spatial + MET at Chefe Donsa.

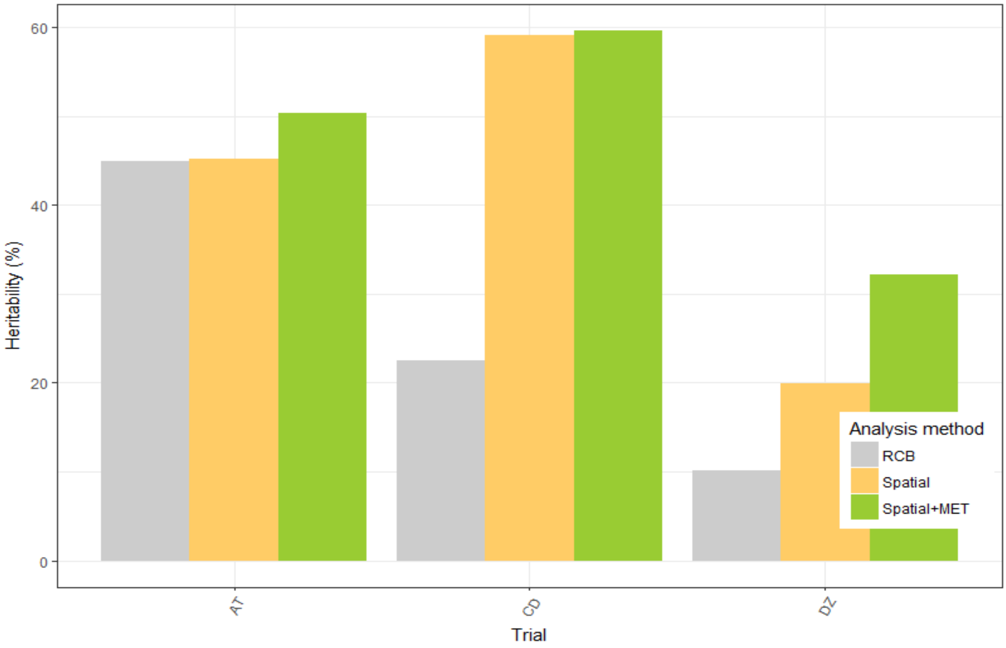

Figure 22. Comparison of experimental designs, data analysis methods and resulting heritability values for trials conducted at Alemtena (AT), Chefedonsa (CD) and Debre-Zeit (DZ) locations.

Preliminary (PVT) and national variety trials (NVT) for low moisture areas

One hundred thirty seven entries (76 from observation nursery and 61 from preliminary variety trial) and a common standard check across test locations and a local check specific to each location were evaluated in this study. The experiments were conducted during 2017 to 2019 main seasons at Alemtena, Asassa, Mekele and Minjar locations (Table 26). A Row-Column and RCB designs were used with two replications for PVTs and three replications for NVTs. The PVTs were conducted for one year while the NVTs were conducted for two years. Gross plot size consisted of six rows with 2.5m length and 20cm apart. Data were collected from the central four rows. Data on grain yield and yield components, reaction to major diseases and physical grain quality were also measured. Overall, genotypes with high mean yield are promoted to the next breeding stage for low moisture areas.

Table 26. Location mean seed yield (kg/ha) of durum wheat preliminary and national variety trials tested under low moisture areas (2017-19).

Trial name	Testing locations				
	Assasa	Alemtena	Minjar	Mekele	Grand Mean
PVTLMA 2017-19	2220.46	2906.95	3049.46	1654.84	**2711.78**
NVTLMA 2017-19	2447.85	2462.73	2890.17	2638.58	**2628.75**

Preliminary and national variety trials for high and optimum moisture areas

One hundred sixty four elite genotypes which were advanced from preliminary observation nurseries, and 83 elite genotypes from preliminary variety trials plus standard and local checks were planted in a Row Column and randomized complete block design with two replications for PVTs and three replications for NVTs. The PVT trials were conducted for one year while NVT trials were carried out for two years at representative locations (Table 27) across the country. The objectives of the trials were to identify elite genotypes from the PVTs to be included in the national variety trials and advanced genotypes from NVTs to be verified in the national variety verification trials (VVTs) for possible release to farmers and hence for commercialization. Gross plot size consisted of six rows, 2.5 meters length and separated by 20cm ($3m^2$).

Table 27. Location mean grain yield (kg/ha) of durum wheat preliminary and national variety trials tested under optimum and high moisture areas (2017-19).

Trial name	Location name								
	AK	CD	DZ	EN	GD	HL	KU	MN	Grand Mean
PVTOHMA	2357.80	3808.50	2738.64	-	-	-	5882.69	2696.79	**3026.41**
NVTOHMA	4222.97	4758.30	3315.38	2963.11	3591.91	3895.52	3399.07	3117.04	**3714.49**

Note: AK = Akaki, CD = Chefe Donsa, DZ = Debre-Zeit, GD = Gondar, EN = Enewary, HL = Holetta, KU = Kulumsa, and MN = Minjar.

Data were collected from the central four rows. Data on agronomic parameters, reaction to major diseases, grain yield and yield components, and physical and chemical grain/flour qualities were also measured. Based on the overall yield mean, agronomic features and quality analysis results, the best performers were promoted to national and variety verification trials.

To improve heritability of genotypes, all experiments were analyzed using recent experimental designs as seen in Figure 23 below.

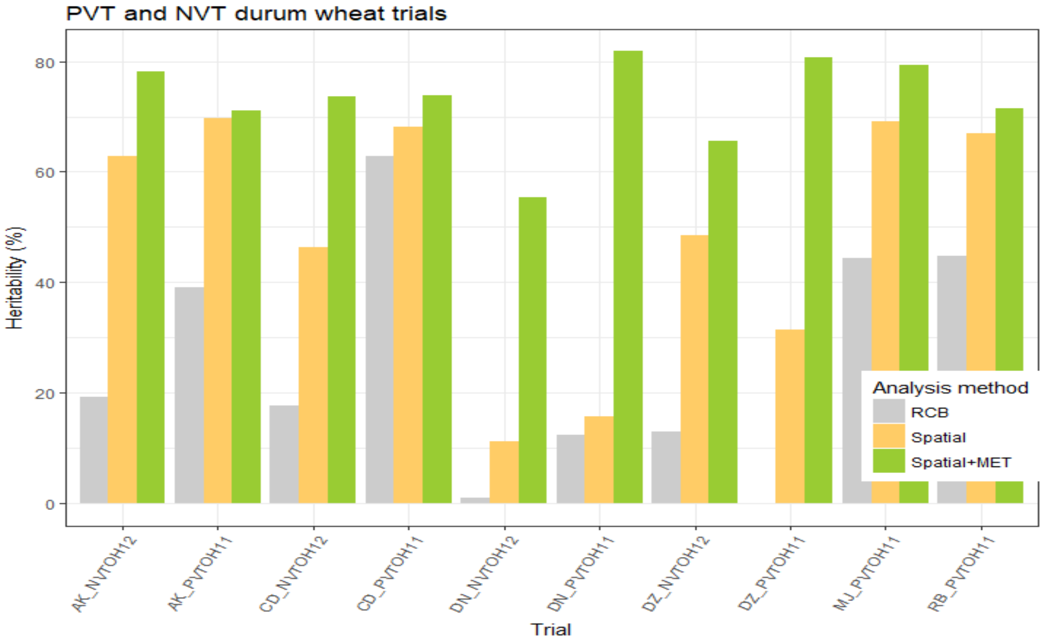

Figure 23. Comparison of heritability values (by locations) resulting from use of different designs.

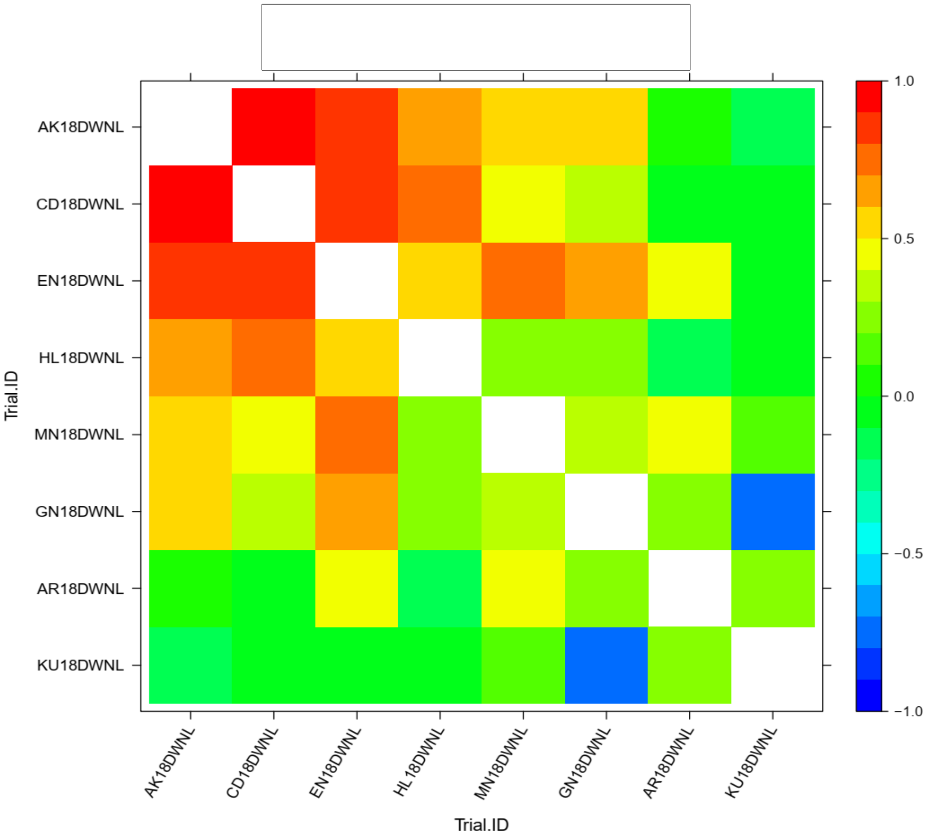

Figure 24. Correlation matrix for yield (DWNL18-19).
Note: Location acronyms are as defined in note below Table 28; AR here stands for Areka location.
DWNL = Durum wheat national variety trial for medium to late maturity.

According to correlations among locations, Akaki, Chefedonsa, Eneway and Holeta showed strong positive correlations with one another. Whereas Minjar, Areka and Kulumsa had no correlation with most of the testing locations (Fig.24). This is very useful for location optimization, by indicating which locations should be excluded from combined analysis because these locations could affect the final rank of genotypes if selection is operated based on yield and yield components. Gondar had negative correlation with Kulumsa.

Released durum wheat varieties during the DGGW project period (2017-2018)

The Durum Wheat National Research project released four commercial varieties, namely Tesfaye, Alemtena, Fetan and D2018, after testing them across different agro-ecologies in NVTs and VVTs in Ethiopia.

Durum Wheat Performance in Ethiopia

Variety: Tesfaye

Top cross of Tesfaye (CDSS04Y01186T-OTOPB-12Y-0M-06Y-1M-1Y-0B) was made at CIMMYT, Mexico. Debre-Zeit Agricultural Research Center received this genotype and it was included in variety trials across locations. The combined data analysis over locations and years using SAS 9.1 software (SAS Institute (2002) confirmed the adaptability of Tesfaye to the Ethiopian durum wheat growing environments.

Tesfaye was released as Ethiopian durum wheat variety in 2016. It is amber seeded with high protein content, has high yielding potential, and released as an alternative to Mangudo, Mukuye and Utuba varieties. The grain yield performance on research station ranged from 3.4 to 6.5 t ha^{-1} and on farmers' fields from 2.5 to 4.5 t ha^{-1}. Tesfaye, with 70 cm height, takes 68 days to head and 120 days to mature. It showed good level of stem rust resistance (10MS) and also was resistant to yellow rust.

Variety: Alemtena

Alemtena (CDSS02B00643S-0Y-0M-1Y-4M-04Y-0B-2Y) is one of the CIMMYT genotypes introduced in 2011. It was selected as an elite line after a series of yield tests in different major durum wheat-growing regions of Ethiopia.

Alemtena was released as an Ethiopian durum wheat variety in 2016. Alemtena is amber seeded, possesses good yielding potential, and has high protein content and bold grain appearance. This variety was released as an alternative variety to Quamy and Assasa varieties which were released in 1996 and 1997, respectively. Alemtena's grain yield performance on research station ranged from 3.4 to 5.0 t ha^{-1} and 2.5 to 4.0 t ha^{-1} on farmers' fields. With an average height of about 79cm, Alemtena variety takes 60 days to head and 94 days to mature.

Alemtena, as a climate smart variety, has several preferred advantages. It has drought tolerant genes, good tillering capacity and is early maturing. Alemtena's early heading allows it to escape the negative effect of the terminal drought and desiccating winds that occur with higher frequency toward the end of the season, especially in areas such as the Assasa Plain. The high level of resistance to rusts was one of the most visually compelling decision points for farmers to adopt the variety. Protein content in this variety tends to be high, the gluten is strong, and the color of the semolina is excellent amber yellow.

Variety: Fetan (ARMENT//2*SOOTY-9/RASCON-37/4/CNDO/PRIMADUR//HAI-OU-17/3/SNITAN)

The cross/top cross of Fetan was made at CIMMYT-Mexico with the purpose of developing stable, high yielding; and farmer/consumer preferred durum wheat varieties for low moisture agro-ecological wheat growing areas. In Ethiopia, it was targeted at developing a variety with high yielding potential and better quality than the improved contemporary standard check variety Assasa which is relatively tall. Fetan is comparatively shorter and fit for mechanization. Hence, Fetan was selected as a candidate through series of multi-environment yield tests in major durum wheat-growing areas of the country. Fetan was released as an Ethiopian durum wheat variety in 2018. Fetan is amber seeded, has high protein content and good yield potential and released as an alternative variety to Assasa and Alemtena varieties. The grain yield performance on research station ranged from 3.4 to 5.0 t/ha and on farmers' fields from 2.5 to 4.0 t/ha. Fetan, which is about 80.4cm tall on average, takes 62 days to head and 105 days to mature.

Fetan has several preferred advantages that make it attractive to farmers. The first is its great tillering capacity; another advantage is its earliness which helps to escape the negative effect of terminal drought and desiccating winds toward the end of the season. Moreover, resistance to rusts was one of the most visually compelling decision points for farmers to adopt the variety. Protein content (%) is within optimum range, while its gluten is strong, and the color of the flour is amber yellow.

Imported Durum Variety D2018, Performance in Ethiopia

Under technology shopping guideline, D2018 was introduced from Italy Private Durum Wheat Seed Producer Company for adaptation testing and registration. D2018 has a 55 to 65 q/ha yield potential as tested under rain fed conditions in 6 locations (Debre-Zeit, Chefe Donsa, Eneway, Kulumsa, Minjar and Alemtena) in 2016/17. It was partially resistant to stem and leaf rust diseases, and possessed desirable quality parameters for pasta making as described in Table 28. D2018 is suitable for areas with medium to late growing seasons and receiving mean annual rainfall of 700 to1000mm; it can be grown in agro-ecologies with altitudes ranging from 500 to 3000 masl.

Table 28. Major morphological and agronomic characteristics of D2018 variety.

No	Variety	Morphological, agronomic and quality characteristics	Measurement
1	D2018	Yield	5.5-6.5 t/ha
		Test weight	80-85kg/hl
		1000 kernel weight	42-54gm
		Days to heading	60-70
		Days to maturity	130-145
		Plant height	80-87cm
		Gluten index of semolina (0-100)	High >90
		Yellow index	Medium
		Grain color	Vitreous
		Protein content (on dry matter basis)	12.5-13%
		Disease resistance	Resistant to Septoria, yellow and leaf rusts

Demonstrations of Improved Durum Wheat Technologies

One of the planned activities at national level, Inclusive and Sustainable Value Chain Developments, are; demonstration and evaluation of rust tolerant, high yielding, and end use quality improved durum wheat varieties along with their updated agronomic practices. During the last four cropping seasons, six high yielding and quality durum wheat varieties (Mangudo, Utuba, Tesfaye, Alemtena, Fetan, and Yerer) were popularized and demonstrated in targeted districts of Oromia, Amhara and SNNP regional states of Ethiopia. The seeds were provided to farmers on a revolving seed basis. This was complemented by signing of a Memorandum of Understanding (MOU) between farmers, researchers, and district agricultural office representatives. About 1.2 tons of improved durum wheat seeds were distributed among 15 districts in the three regional states during the last four cropping seasons. The demonstrations were done with 74 household farmers on small plots ranging from 25m^2 to 2000m^2 and on FTC plots as shown in table 29 below.

Table 29. Farmers involved in durum wheat demonstrations in three regions, 2018-2019.

No.	Year	Male	Female	FTC	Total	Regions	Districts
1	2018-2019	64	6	4	74	Oromia, Amhara, Southern Nations Nationalities and Peoples (SNNP)	Ada-Lume, Ginbichu, Digelu-Tijo, Hitosa, Shashemene, Arsi-Negele, Ambo, Ziqala, Minjar, Eneway, Shebel Berenta, Bichena, Meskan and Mareko
	Total	**64**	**6**	**4**	**74**	**3**	**15**

Feed backs from producer farmers on demonstrated varieties showed that the farmers selected their best fit varieties to their respective environments as listed below.

- Utuba and Mangudo varieties have shown wide range adaptation and have high yield, good rust resistance and acceptable industrial quality.
- Alemtena and Tesfaye have shown specific adaptation; farmers liked these varieties because of their seed color (amber yellow), resistance to diseases and early maturity.

Durum Wheat Breeder Seed Production and Distribution (2018-19)

Ear to row and breeder seed production have been undertaken to maintain the distinctness, uniformity and stability (DUS) of the varieties. It is a good practice to rejuvenate, increase and maintain the true-to-type status of released varieties from time to time. Apart from producing nucleus and breeder seed by breeders, the Debre-Zeit Seed Multiplication Unit annually produces pre-basic and basic seeds of durum wheat varieties table 30, on about 13 hectares of land based on demands of seed producers and farmers in the Debre-Zeit Center mandate areas (Fig 25,26).

Table 30. Seven demand driven durum wheat varieties breeder seed multiplication at , 2018-19.

Item	Variety name	Seed produced (q)	Seed distributed (q)
1	Utuba	14.5	12
2	Mangudo	15	13
3	Alemtena	7.4	6
4	Fetan	8	6
5	D2018	16	
6	Tesfaye	8	6.3
7	Ude	7	5
Total		**75.9**	**48.3**

q = quintal = 100kg.

Fig. 25 Seed multiplication fields at Debre-Zeit, another view at early stage, 2019.

Fig.26 Seed multiplication fields at Debre-Zeit Research Center at later stage, 2019.

Field Days

To enhance improved durum wheat seed adoption through multiplier effects, at least one farmers' field day is organized every year. For instance:

- In 2018/19 cropping season, farmers' field day was held at Lume district of East Shewa Zone. Different stakeholders from agro-industries, public media, farmers, researchers, SMS, DAs, and other key partners *attended the field day*. There were a total of 130 participants. Public media (OBN) gave a wide coverage of the field day.

Fig.27. Durum wheat seed multiplication on farmer field being inspected by field day guests.

Fig.28. Farmers' field day attended by farmers, agricultural experts, officials and researchers.

Acknowledgements

We are very grateful to the management of Delivering Genetic Gain in Wheat (DGGW) Ethiopia project for the financial support to improve physical and human capacity building and for research support in generating new durum wheat varieties. Assistance from other collaborators in the execution of the multi-environment field experiments is greatly appreciated. Thanks also goes to Debre Zeit Agricultural Research Center (DZARC) management and administrative supports. The various researchers, technical and field assistants are hereby highly acknowledged for their hard work, kind cooperation and involvement in durum wheat research at all levels.

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OBJECTIVE IV. MAINTENANCE OF CRITICAL FACILITIES REPAIR AND REHABILITATION OF RESEARCH FACILITIES

I. Ambo Research Center

DGGW project has been supporting the wheat rust pathology work in Ambo by purchasing different lab items, maintaining green house and purchasing vehicle.

- **A. Greenhouse maintenance**
    - Old greenhouse fans have been replaced with new ones
    - Parts of the greenhouse wall cracks have been maintained
    - Footing of a fan/ventilator has been replaced
    - Pumps and pipes of the cooling pads were maintained
    - Electric lines of the greenhouse were fixed.
    - Silicone gel was filled in different cracked parts of the greenhouse.
    - Fourteen wheeled greenhouse benches were constructed to alleviate the shortage of benches.

Various items purchase were made by the DGGW project among which are;

- Vehicle
- Humidifier
- Spore collector
- Cryovials
- Desiccator
- Differential seed
- Mineral oil
- Growth chamber extension

Fig.29.List of items purchased for Ambo research center by DGGW project

Kulumsa Agricultural Research Center.

Physical capacity

- Construction of Bekoji substation office is underway
- Purchase of electric ABC cable for the greenhouse, cold room and growth chamber renovation is already secured
- About six laptops purchased and distributed to researchers
- Tables and chairs purchased and procured

✓ KARC resting rooms fully renovated

Fig.30. Growth chamber house furnished and finalized

Fig. 31. Green house facilities renovated

Fig.32. Aditional Lath-house constructed at KARC

Fig. 33. Greenhouse benches renovated

Fig.34. Greenhouse and growth chamber compound fenced, door and different parts of growth chamber houses constructed and furnished

Fig. 36. Moisture testers

Fig. 37. Different lab materials (consumables and others) procured

39. Lath-house partitioning established

Fig.40. HLW measuring tool purchased

Fig.41. Quarantine compound fenced both by barbed and mesh wire

L

Fig.42. New greenhouse fans purchased and the motors of old fans rewired

Fig.43. KARC irrigation facilities improved through purchase of sprinkler heads (> than 500)

Fig. 44 Greenhouse and growth chamber compound fenced,door and different parts of growth chamber houses constructed and furnished

Fig. 45 Greenhouse benches renovated

Fig. 46 New substation doors fixed and labels prepared and posted

Fig. 47 New substation doors fixed (A) and labels (B) prepared and posted

Debre Zeit Research Center

DZ Green house (three rooms) are currently working

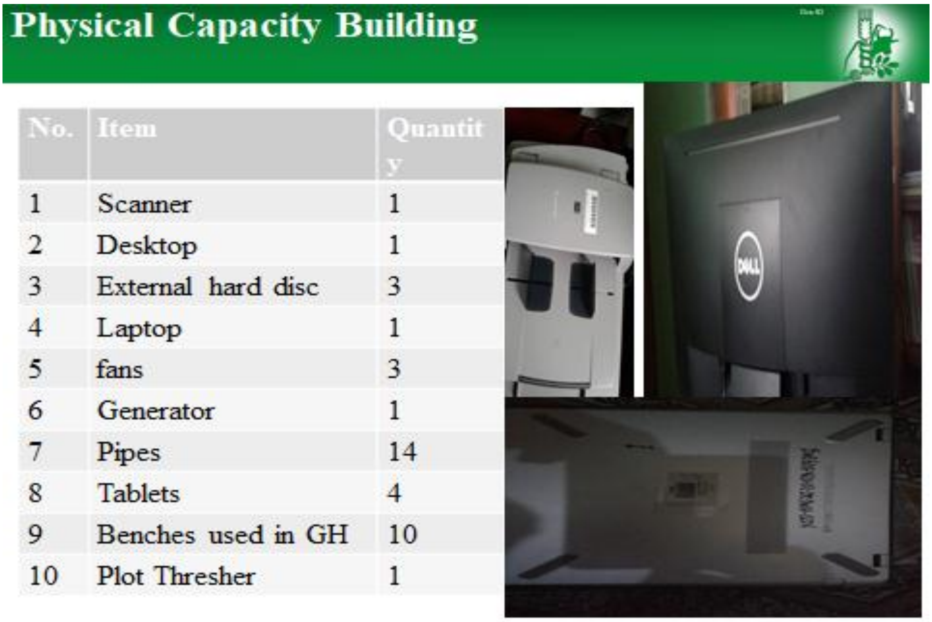
- Used for multiplication of races


Green house by DRRW


Maintained by DGGW

Bath room, Rest room and Generator already done

Fig. 48 Green houses and Generator room



Physical Capacity Building

No.	Item	Quantity
1	Scanner	1
2	Desktop	1
3	External hard disc	3
4	Laptop	1
5	fans	3
6	Generator	1
7	Pipes	14
8	Tablets	4
9	Benches used in GH	10
10	Plot Thresher	1

Cont...

Tables used in green house to to put seedling tray (10)

14 pipes were bought and each with 100m length

Generator for supplementing irrigation activity during off-season

7

Holetta Research Center

The project contributed in Capacity building such as maintenance of the old green house,, fencing of the quarantine field where the Phenotyping platform data were generated. The pathology laboratory and greenhouse facilities were also renovated The rest room was also renovated to the appropriate standard.

Fig. 50 Fencing of the International nurseries

A1&2

B1&2

Fig. 51. Pathology laboratory, green house (A1&A2) and rest room (B1&B2) renovated

OBJECTIVE V. TALENT PIPELINE

Ambo Research Center

A. Human Capacity

- Short term trainings (both local and abroad)

Locally, researchers from different regional and federal research centers were invited and participated in wheat rust field disease scoring, how to conduct survey and surveillance and race analysis of stem rust races. University post graduate students working on wheat rust disease, lecturers and Ethiopian biodiversity institute researchers were invited to attend the training on the wheat stem rust race analysis

- Training on '**Wheat rust surveillance, early warning and management system in Ethiopia'** was carried out at Ambo ARC and 27 wheat pathologists participated.

- ODK for real time rust forecast
  - **Wheat rust early warning refreshment trainings (**especially on use of IVR system) were carried out at Debre Zeit ARC, Kulumsa ARC, Kombolcha town, Adama and Butajira for DA's of Amhara, Oromia, Tigray and SNNP regions.

Table 31. Participants of the local trainings given during 2017-2019)

Participants				
	Male	Female	Total	Remark
Researchers	97	20	117	
TA's	20	9	29	
FA's	10	2	12	
Farmers	500	149	649	
Total	627	180	807	

Kulumsa Research Center

Fig. 53 Farmers trainings at various locations

Farmers training

- One hundred two male, Five female house hold head farmers have been given trainings on wheat diseases identification and variety selection
- One hundred twenty two male and 12 female house headed farmers also participated in new variety selection and evaluation training given to wheat producers of Assasa, Dhera and Arsi Negelle.

Fig. 54 Simulation modeling training for different researchers

Debre Zeit Research Center

Human Capacity

Table 32. Training given to farmers, Development Agents, Technicians and Researchers

	Woreda where the training was held		
		Male	Female
Farmers	MinjarShenkora, LumeAlemTena, Shashemene, ArsiNegelle,	85	35
Das	Shashemene, ArsiNegele, Minjar, Becho, Lume, ChefeDonsa	35	12
Technicians	At DZARC	16	7
Researchers	DZARC	20	4
Total		156	58

Generally, a total of 214 people were trained in different areas of discipline at different districts and the trainings are expected to improve awareness of the farmers. In 2010 there was the outbreak of rust in the country. Currently due to the awareness creation through this project farmers were aware of how and when to use pesticides. However, still there is variation among farmers who came from different areas, on scale of implementation of what they have been trained.

Table 33. Human capacity enhancing efforts through DGGW supported trainings

Title of Training	Trainees	Place	# of days	Male	Female	Total
Data management	TA and FAs	Debre-Zeit	1	13	14	27
Irrigated wheat production	Farmers, Cooperative unions	Metehara	1	25	5	30
Field, pest and data management	Zonal experts and Das	Modjo	1	39	6	45
Field, pest and data management	Zonal experts and Das	Arsi-Negele	1	40	15	55
Software	Researchers	Melkassa	5	2	1	3
Total			**9**	**119**	**41**	**160**

Fig.55. Training of zonal district agricultural experts and farmers from cooperative unions.

Field Days

To enhance improved durum wheat seed adoption through multiplier effects, at least one farmers' field day is organized every year. For instance:

- In 2018/19 cropping season, farmers' field day was held at Lume district of East Shewa Zone. Different stakeholders from agro-industries, public media, farmers, researchers, SMS, DAs, and other key partners *attended the field day.* There were a total of 130 participants. Public media (OBN) gave a wide coverage of the field day.

Fig.56. Durum wheat seed multiplication on farmer field being inspected by field day guests.

21

Fig. 57 Lecturing in class rooms for various stakeholders

Figure 58. Gears during lecturing…. Incorrect dressing

Table 34 . Human capacity enhancing efforts through DGGW supported trainings.

Title of Training	**Trainees**	**Place**	# of days	**Male**	**Female**	**Total**
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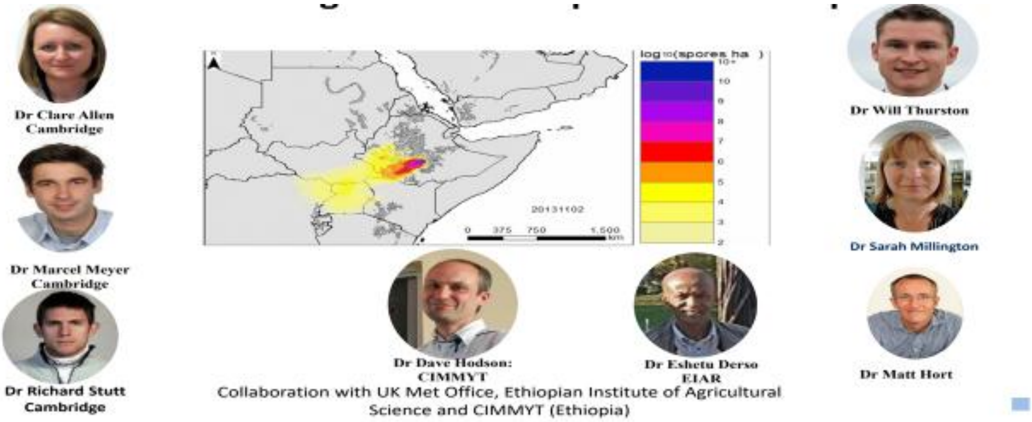
Software	Researchers	Melkassa	5	2	1	3
Total			**9**	**119**	**41**	**160**

Fig. 59 Training of zonal district agricultural experts and farmers from cooperative unions.

Figure 60. Third DGGW project team consultative meeting workshop participants



Collaboration with UK Met Office, Ethiopian Institute of Agricultural Science and CIMMYT (Ethiopia)

Figure 61. Real-time forecasting stem and stripe rust international team members

Septoria disease on wheat leaves and spike

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