



Achievements in fast-track variety testing, seed multiplication and scaling of rust resistant varieties:

Lessons from the wheat seed scaling project, Ethiopia

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Preface

The traditional staple crop; wheat is threatened in Ethiopia by recurrent epidemics of rust diseases. Rust pathogen races have evolved quickly in the country, overcoming the genetic resistance of widely sown wheat varieties, which is often based on major resistance genes. Seed of new resistant varieties adapted to important agro-ecologies is not easily accessible and most Ethiopian wheat farmers re-sow saved seed, contributing to low average yields for the crop. Building on past efforts to generate and spread seed of resistant wheat varieties and with generous funding from the U.S. Agency for International Development (USAID), the Ethiopian Institute of Agricultural Research and the International Maize and Wheat Improvement Center undertook in 2015 a three-year project to scale the use and value of high-yielding, rust-resistant bread and durum wheat varieties. The project was implemented in 54 major wheat growing woredas of Amhara (11), Oromia (28), SNNP (9) and Tigray (6) regions. Federal and regional research centers, private and public seed enterprises, farmers' cooperative unions, farmers' seed associations, regional bureau of agriculture were engaged in the project activities.

The eight chapters of this report document the project's vision and implementation, as well as components to strengthen rust surveillance, early warning and phenotyping, fast-track variety testing and pre-release seed multiplication, demonstration and field day activities, accelerated seed multiplication, the provision of "seed loans" to reach more farmers, efforts to link smallholder durum wheat farmers with the national value chain, and a formal external study to assess the achievements and impacts of these efforts. Each chapter covers activities, partners and implementation modalities, lessons learned and the way forward. I found this report to be quite interdisciplinary and inclusive.

In summary, more than 131,000 rural households directly benefited from the work. Wheat yields among participating farmers increased from an average 3.39 t/ha prior to the project to 4.09 t/ha by the end of the project, an improvement directly attributable to project efforts and measurably adding to farm household incomes and food security. The protocols applied to quickly scale quality seed of rust resistant wheat varieties among smallholder farmers are worthy of replication, and the project also points up the need to identify new resistance genes, develop wheat varieties of polygenic nature for durable resistance, promote farmers' use of a genetically diverse mix of varieties, and link farmers to better and profitable markets. I would like to acknowledge the USAID, the main donor, as well as implementing institutions, researchers, development agents and farmers who actively participated in this effort. I would also like to extend my appreciation to authors and editors of this report.

Dr. Mandefro Nigussie
Director General, EIAR

Acronyms and abbreviations

APR	Adult plant resistance
ARS	Agricultural Research Service
ASE	Amhara Seed Enterprise
ATA	Agricultural Transformation Agency
AUDPC	Area Under the Disease Progress Curve
BoANR/BoA	Bureau of Agriculture and Natural resources
C1	First generation of certified seed
C2	Second generation of certified seed
CDL	Cereal Disease Laboratory, USDA-ARS
CIMMYT	The International Maize and Wheat Improvement Center (Spanish acronym)
CSA	Central Statistical Agency
DAs	Development Agents
DGGW	Delivering Genetic Gain in Wheat
DRRW	Durable Rust Resistance in Wheat
DZARC	Debre Zeit Agricultural Research Center
EGS	Early-generation seed
EIAR	Ethiopian Institute of Agricultural Research
ESE	Ethiopian Seed Enterprise
ETB	Ethiopian Birr
FCU	Farmer Cooperative Union
FTC	Farmer training center
ha	Hectares
HH	Household
ICARDA	International Center for Agricultural Research in the Dry Areas
Lr	Leaf rust
IVR	Interchangeable video record
masl	meters above sea level
Met	Meteorology
MoANR/MoA	Ministry of Agriculture and Natural Resources
OSE	Oromia Seed Enterprise
PF	Private farm
PVS	Participatory varietal selection
Qt	Quintal
RARI	Regional Agricultural Research Institute
SNNPR	Southern Nations, Nationalities & Peoples' Region
Sr	Stem rust
SSE	South Seed Enterprise
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
Yr	Yellow rust

Chapter 1

Seed multiplication and delivery of high yielding rust resistant bread and durum wheat varieties to Ethiopian farmers

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1.1 Introduction

Ethiopia is the largest producer of wheat in sub-Saharan Africa. Wheat is a strategic food security crop grown by 4.2 million households on 1.7 million hectares (ha) under rain-fed conditions from 1,500 to 2,800 meters above sea level (masl; CSA, 2017). Wheat is fourth in area of cultivation and third in productivity among the cereal crops in the country. The major wheat growing regions are Oromia, Amhara, SNNP and Tigray, which provide about 99% of total production. Wheat production has steadily increased over the years, reaching 4.6 million metric tons in 2017. This is the highest production ever, though the country is still not self-sufficient in wheat because of shifts in food preferences and increasing incomes, urbanization and population. That same year the country imported 1.5 million tons at a cost of more than US \$600 million, with a significant impact on Ethiopia's economy. The national average yield stands at 2.74 t/ha, which is higher than for rain-fed wheat production in most other African countries but still far below the crop's potential, due to biotic and abiotic constraints, technical and socio-economic factors.

The major biotic constraints include diseases, insect pests and weeds. There are over 40 wheat diseases caused by fungi, bacteria, viruses and nematodes. The dominant fungal diseases are stem rust, yellow rust, leaf rust, septoria leaf blotch, fusarium head scab and leaf spots.

Recurrent stem and yellow rust epidemics have caused significant yield losses in Ethiopia. Many "mega" wheat cultivars, previously sown on large areas, such as *Laketch* (1977), *Dashen* (1988), *Enkoy* (1993), *Kubsa* and *Galema* (2010) and *Digalu* (2013/14) were severely hit by stem rust and/or yellow rust in the years in parentheses, creating havoc in wheat production and forcing the government to import wheat for local demands. New rust races either have evolved locally through mutation or recombination or migrated from abroad to overcome resistant genes and shorten wheat varieties' useful life spans. Because of their high sporulation capacity, airborne transmission and transboundary migration, stem and yellow rusts are the most feared wheat diseases, able quickly destroy a large wheat area.

Rusts can appear in any wheat field where there is an inoculum source, a conducive environment and a susceptible variety but their incidences and severities vary from environment to environment. Yield losses can reach 100%, depending on the variety grown, the onset of the disease in relation to wheat growth, the disease severity and the management practices employed (Badebo et al., 2008).

In 2010, yellow rust appeared in early August when the crop was tillering. Popular varieties such as *Kubsa* and *Galema* covering over 50% of the total wheat area at the time were severely hit by yellow rust and no one was ready to save the wheat fields. The government spent over \$3.2 million to import fungicides to contain the epidemic, though losses were inevitable because of the untimely responses.

In 2013-14, a new stem rust race appeared in southeastern Ethiopia, overcoming the resistance gene *SrTMP* in the variety *Digalu*, which had previously been resistant to both stem and yellow rust and was being grown on over 20,000 ha in the Arsi-Bale highlands (Olivera et al., 2015). Yield losses reached 100% on farms where fungicides were not applied.

Despite various efforts through diverse projects, rust continued to threaten wheat production. To address the situation, the U.S. Agency for International Development (USAID) funded CIMMYT and the Ethiopian Institute of Agricultural Research (EIAR) under the project “Emergency Seed Support and Demonstration of Rust Resistant Wheat Varieties in Stem Rust Affected Arsi, Bale and Shewa Areas of Ethiopia.” A memorandum of understanding was signed by CIMMYT, EIAR and Oromia Agricultural Research Institute (OARI) for early-generation seed multiplication, demonstration and popularization of rust resistant wheat varieties. The project produced 640 t of seed of 13 rust resistant wheat varieties at Debre Zeit, Kulumsa and Sinana research centers, as well as establishing a quarantine site at Sinana, training 132 development agents, subject matter specialists and model farmers, and organizing farmer field days. Another MoU between CIMMYT-Ethiopia and the Oromia Bureau of Agriculture provided for the distribution of rust resistant varieties to affected farmers in Arsi and Bale, with 165 t of seed purchased and shared with 2,194 farmers in 7 districts. Beneficiary farmers increased their yields by an average of 25%.

To further scale out new, rust resistant wheat, USAID funded the CIMMYT/EIAR project entitled “Seed multiplication and delivery of high-yielding rust resistant bread and durum wheat varieties to Ethiopian farmers” (referred to hereafter as the “Wheat Seed Scaling Project”) building on the preceding USAID-funded projects and the projects Durable Rust Resistance in Wheat (DRRW) and Delivering Genetic Gain in Wheat (DGGW), which were supported by the Bill & Melinda Gates Foundation and the UK Department for International Development (DFID). The overall goal was to ensure that seed of rust resistant wheat varieties reached small-scale farmers faster to reduce their vulnerability and increase productivity and food security.

The five interrelated project components were:

1. Enhancement of rust surveillance, early warning and phenotyping.
2. Fast-track variety testing and pre-release seed multiplication.
3. Accelerating seed multiplication.
4. Demonstration and scaling up of improved wheat varieties.
5. Improving market linkages between small scale durum wheat producers and agro-industries.

1.2 Implementation

As project awardee, CIMMYT designated the full-time project leader, coordinator and manager. The steering committee comprising seven members from the Ministry of Agriculture, EIAR, CIMMYT, the Ethiopian Agricultural Transformation Agency (ATA), the Millers Association and USAID met quarterly and provided overall technical guidance.

CIMMYT also signed a sub-grant agreement with the Cereal Disease Laboratory, University of Minnesota, USA, to implement rust surveillance, early warnings, phenotyping, and genotyping. Another MoU was signed with EIAR for work on fast-track variety testing and pre-release seed multiplication, accelerated seed multiplication of durable rust resistant varieties, demonstration and scaling of improved wheat varieties and improving the linkages of small-scale durum wheat producers with agro-industries.

1.3 Target districts

The project was carried out in 54 wheat-growing districts across 4 regions; 27 in Oromia, 11 in Amhara, 9 in Southern Nations and Nationalities and 6 in Tigray (Fig 1.1). Another district was added, based on losses from rust in a previous year.

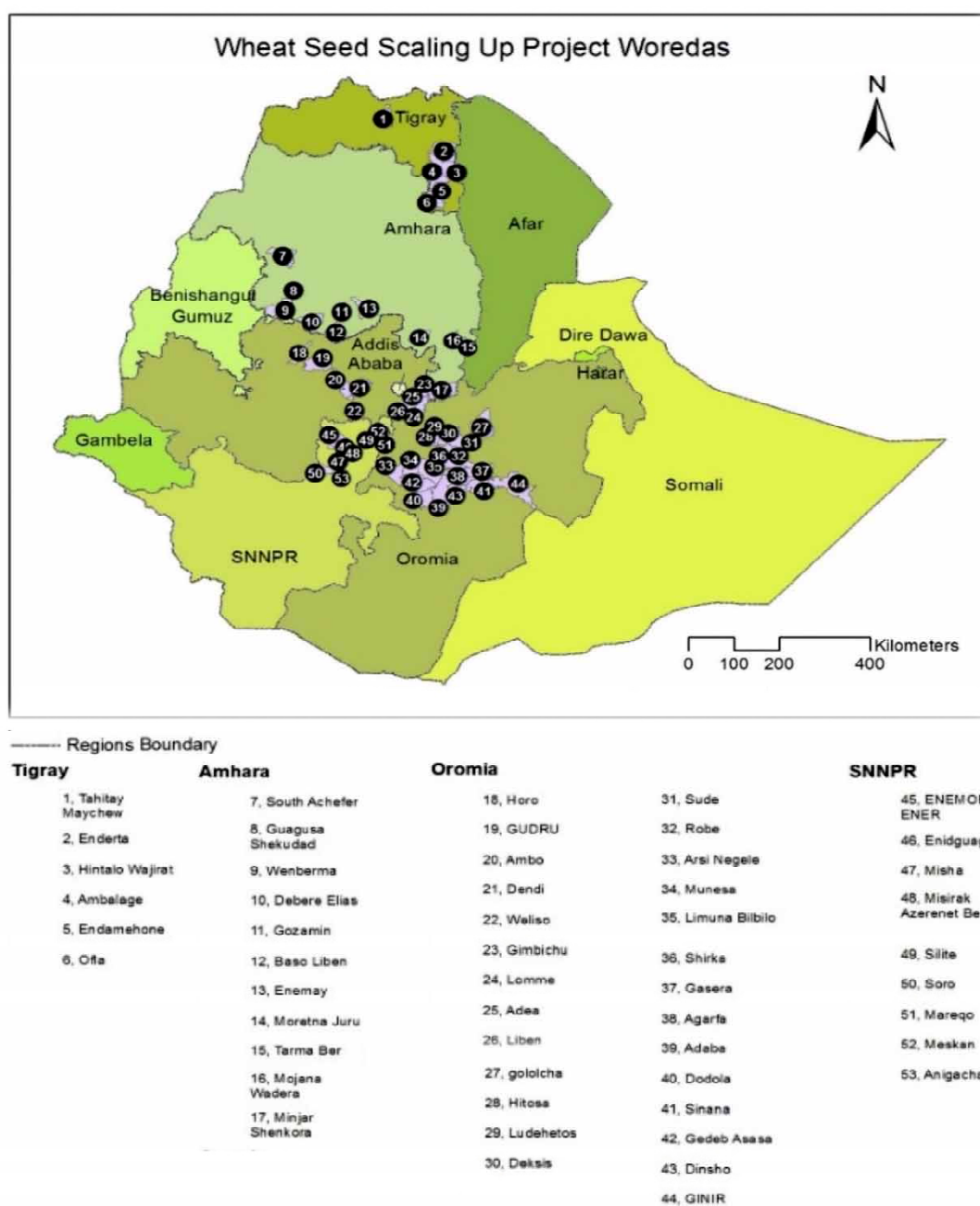


Figure 1.1. Project areas for demonstration and scaling of rust resistant wheat varieties.

1.4 Partners and stakeholders

Ten research centers were involved in fast-track variety testing, pre-release seed multiplication and technology generation, early-generation seed multiplication, demonstration, and training, and 27 public and private (including intermediate-scale) enterprises multiplied basic or foundation and certified seed of rust resistant wheat varieties. In addition, the Federal Ministry of Agriculture and Regional Bureaus of Agriculture of the four regions took part in planning and review workshops, implementation and supervision of the project and organizing farmer field days. The Cereal Disease Laboratory, University of Minnesota, USA, phenotyped and genotyped wheat through seedling tests, molecular studies, and race analyses, as well as contributing training and technical advice.

1.5 Summary of achievements

1.5.1 Enhancement of rust surveillance, early warning, and phenotyping

Participants conducted annual rust surveys during the *belg* and early main seasons. Early main season and phone surveys, as well as spore dispersal models, helped to monitor rust during the season, provide regular early warnings to stakeholders and served as content in rust planning workshops. Training was given to researchers; genotypic data was available for the germplasm evaluated and rust strains were identified from samples collected. The project shared genotypic and phenotypic data for some wheat varieties. The early warnings and broader awareness of threats and outbreaks, along with regional and federal training and supplies of seed of rust resistant wheat varieties, helped to reduce the incidence of rust disease. Both adult plant resistance (APR) and major stem rust resistance genes were identified in commercial cultivars and breeding lines through multi-pathotype seedling tests and molecular analyses in collaboration with the USDA Cereal Disease Laboratory (CDL-USDA-ARS). The information generated has been very useful for variety deployment and seed multiplication strategies.

1.5.2 Fast-track variety testing and pre-release seed multiplication

Introductions have been and continue to be the major source of germplasm for variety development. From 2015 to 2017, 46 international wheat nurseries consisting of 4,788 advanced lines were introduced from CIMMYT and tested at different quarantine sites of which 1,414 (29%) lines were selected and advanced to the next stage of variety development, based on their combined disease resistance and agronomic traits. In total, 2,772 advanced lines have been tested at multiple locations in different sets of advanced observation nurseries, preliminary yield trials, national variety trials, and variety verification trials under fast-track development, from which 12 varieties were released.

1.5.3 Pre-release seed multiplication

Under normal conditions, breeders multiply initial seeds of new varieties after the varieties are released, an approach that delays by a year or more farmers' access to the varieties and the genetic gains they offer. Accelerated main- and off-season multiplication of seed of elite lines prior to their release as varieties can result in farmers accessing seed the same year as the varieties are released.

A success story was the purchase and importation of five tons of seed of *Kingbird*, a wheat variety that is resistant to all three rusts and particularly to the TKTTF race of stem rust that infected wheat crops in Ethiopia in 2013 and 2014. Developed by CIMMYT in concert with

eastern African scientists as part of DRRW, Kingbird was multiplied on 38 hectares through the Wheat Seed Scaling Project at the same time as the variety underwent adaptation and verification trials. By its release in 2015, 80 tons of *Kingbird* seed was available for demonstration and distribution in target environments and the variety is grown in mid-altitude regions and lowlands, mainly in Amhara and Tigray regions.

In 2016, the project multiplied 10.3 tons of bread wheat seed and 6.6 tons of durum wheat seed, enough for demonstrations and early-generation seed multiplication when 3 bread and 4 durum wheat varieties were released. For instance, when *Wane* and *Lemu* were released, there were 885 demonstrations and breeders undertook early-generation seed multiplication on 60 hectares and produced 100 tons of seed.

1.5.4 Accelerated seed multiplication of rust resistant wheat varieties

Eight research centers produced 2,382 tons of early-generation seed and distributed it to 27 institutions, including private farms, farmer cooperative unions, farmer seed producer associations and model farmers in accelerated seed multiplication of rust resistant wheat varieties. These seed producers generated 1,728 tons of seed, most of which was sold.

1.5.5 Demonstration and scaling up of improved wheat varieties

The project held demonstrations at 6,635 farmer training centers and on model farmer plots in 54 woredas involving 18 bread wheat and 5 durum wheat varieties and with an average yield of 5.3 t/ha. Demonstration fields were supervised and field days organized by development agents and researchers. Farmers took part in selecting varieties adapted to their environments. A total of 10,984 (18% female) farmers attended field days organized by district/zonal development agents and research centers.

1.5.6 Scaling

A total of 2,098 tons of improved seed of rust resistant wheat varieties was purchased and distributed to 29,643 households as part of “seed loans” later repaid by farmers.

1.5.7 Improving market linkages

Durum wheat is a strategic commodity for agricultural commercialization and value addition in the agro-processing industry. Several durum wheat varieties that meet industrial quality standards were released in Ethiopia. However, the adoption of improved durum wheat production technologies and durum wheat marketing remained quite slow. A socio-economic survey of the durum wheat input and output value chains was conducted under the project, as well as a stakeholder consultation workshop and several planning and review workshops. The project also carried out “training of trainers” events focused on durum wheat production and quality control and attempts were made to facilitate contractual agreements between durum wheat producers and agro-industries. Despite the various market-related development interventions, smallholder durum wheat producers remained poorly linked to the market. The lack of business interest by the agro-processors remained the major challenge in most durum wheat value chain development efforts and past success stories in market linkage development were found to be short-lived. Durum wheat business development issues should be given due emphasis in future value chain development. Wheat import policy should be revisited by evaluating the competitiveness of local durum wheat production with the import market. The private sector should receive assistance in technology intervention, input credit and output financing.

1.5.8 Capacity development

The Wheat Seed Scaling Project supported the human and logistical capacity of researchers, development agents, seed producers, associations and key stakeholders. Eighty-three researchers (18% female) from 14 research centers were trained on quarantine pests of wheat and wheat breeding and pathology, disease management and quality seed production in Ethiopia.

Five trainees attended CIMMYT's basic wheat improvement course in Ciudad Obregón, Mexico. Additionally, diverse training was given in Ethiopia to development agents, subject matter specialists, trainers of the trainees and model farmers in four regions (see Chapter 6). A seed producing cooperative union in Zeretta, SNNP Region, that includes hundreds of farmers received a mobile seed cleaner that is being used for threshing or cleaning members' seed as well as being rented to other associations or unions. Four vehicles (three pickups and one land cruiser), two tractors and one grain protein analyzer were purchased and donated to EIAR for effective implementation of project activities in disease surveying, variety development, early-generation seed multiplication and analyzing grain samples for durum wheat farmers to obtain premium prices from agro-industries. Laboratory supplies were purchased for the Holetta, Kulumsa, Debre Zeit and EIAR HQ facilities to strengthen their delivery capacity and researchers' ability to evaluate wheat germplasm against major diseases.

1.5.9 Gender integration

Women comprise about 50% of the Ethiopian farming community and are also the most disadvantaged sector in Ethiopia, so the Wheat Seed Scaling Project gave due emphasis to women farmers. Among other things, women's participation in demonstrations of wheat technologies, seed production and scaling activities increased from 8% to 16% over the project, though the number of destitute farmers remains huge and beyond the project's reach. The project focused on women farmer associations with hundreds of members. Five such associations received initial seed and training on how to manage and produce quality seed, which fetches a higher market price than grain. Working as a team, members of the associations effectively prepared their land for sowing and controlled weeds. Traditional threshing, normally done either by walking oxen over the grain or hitting the wheat with a stick, is very tiresome and time consuming, so the project purchased five threshers and donated them to the women seed producer associations, along with training on their operation, maintenance, and rental for profit. The women seed producer associations are making good progress and benefiting their members, families and communities.

1.6 Vision of Success

Original project targets included providing 164,000 households with direct access to new technologies. The state of emergency during the 2017 crop season severely limited project travel and other activities, so in the end the project reached 131,320 households; 80% of the target. As wheat seed can be recycled and used for several years on average and direct beneficiaries shared their seed through exchanges or through sales, gifts, etc. with about 12 other people on average, we estimate that nearly 1.6 million individuals have benefitted from this project. Training was given to 4,877 agricultural development agents, subject matter specialists, seed producers and model farmers. In addition, 88 researchers received training locally in Ethiopia and in Mexico, and ultimately bringing the project to within 99% of its target of providing training for 5,000 individuals. The original plan was to cover at least 50% of the wheat area under cultivars with durable rust resistance, whereas the project achieved

62% as reported by a 2018 impact assessment (refer to Chapter 8), because of the continuous release of new high-yielding and existing rust resistant varieties, their accelerated seed multiplication and deployment of diversified wheat varieties to seed producers and farmers. To decentralize and diversify seed sources and ensure the supply of enough quality seed of the new, rust resistant varieties, 27 public, private seed producers, farmer unions and associations were engaged in seed production.

1.7 Impact assessment

The report of an independent consultant hired by CIMMYT to study the impact of the Wheat Seed Scaling Project was reviewed and finalized and shows that the average yield of rust resistant wheat varieties over the project period was 4.09 t/ha, 21% above the baseline of 3.39 t/ha (Setotaw, unpublished report). Farm income has also increased, particularly for farmer seed producers, who are able to sell their produce at a better price than mere grain. The higher yields of farmers who use the new rust resistant varieties for grain production have also improved farm incomes and food supplies (Chapter 8).

1.8 Challenges

Despite the project's multi-faceted efforts to contain rusts and boost wheat production and productivity, wheat rusts remain a threat and some farmers still grow susceptible varieties. The eastern African highlands represent a hot spot for rusts' spread and evolution. A high inoculum source will put pressure on current resistance genes, eventually causing them to break down. The problem will continue partly because wheat is grown throughout the year in Ethiopia or nearby countries, making a green bridge for the pathogen. Thus, protecting crops of wheat, a vital food in eastern Africa, requires the collaboration of farmers and governments, and long-term rust management will require the deployment of diverse crops, varieties, genotypes and resistance genes, in addition to the targeted and timely application of fungicides and agronomic practices.

Another challenge was the difficulty in linking small-scale durum wheat farmers with milling industries. A grain analyzer was purchased to determine quality and thereby facilitate the linkage for sustainable engagement of both parties, but several intermediaries confounded the efforts, pointing up the need for new policy directions and support.

1.9 Lessons learned

Harmonization of federal and regional breeding activities by setting up common adaptation trials and annual meetings for breeders and pathologists for rust control planning meetings were an excellent forum where breeders and pathologists interacted well and exchanged their views on the performance of wheat varieties under cultivation across the diverse environments.

Breeders and pathologists know clearly which wheat genotypes are performing well and which resistance genes are holding under the dynamic rust situation. Ethiopia is a big country with broad agro-ecological diversity for wheat production. Under such conditions, there are no "one size fits all" solutions, so research centers in different agro-ecologies must develop germplasm specifically adapted to their environments, while federal research centers can focus on broad-based germplasm that fits diverse agro-ecologies.

The project has decentralized the seed production and supply systems to provide improved seed of rust resistant varieties to farmers by furnishing initial seed, training, and material support to private farms, farmer cooperative unions, and seed producer associations.

The engagement of women's seed producer associations as a business model has created jobs and income for members. Teamwork, consultative planning and review workshops among stakeholders were key to understanding about the project and meeting its objectives.

Seed loans constituted a core approach that helped us reach many more farmers. Providing seed of rust resistant wheat varieties enhanced the adoption of new varieties.

Clustering of farmers' plots also favored quality seed production as farmers in a cluster decide on one or few varieties, avoiding mechanical mixtures during sowing. It also offers an entry point for mechanization by putting together the fragmented plots of small-scale farmers.

Through partnerships it was possible to get complete phenotypic and genotypic data that would not have been freely available otherwise and which helped breeders make decisions regarding variety releases.

Team building is the building block for success. The success we observed in this project is the sum contribution of all the partners involved.

1.10 Acknowledgements

We are sincerely grateful to the USAID for funding CIMMYT and partners to implement this project, particularly at a critical time when national food security was threatened by drought and emerging diseases. We also extend our thanks to research partners and those in ministries of agriculture, federal and regional, and at zone and district levels for active participation from project planning through implementation. The collaboration with the Cereal Disease Laboratory at the University of Minnesota in getting genotypic data for elite lines from Ethiopia is well acknowledged. We also extend our thanks to the DRRW/DGGW project coordinated by Cornell University and financially supported by Bill & Melinda Gates Foundation and DFID for their alignment of activities in achieving the goal.

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Chapter 2

Enhancement of rust surveillance, early warnings and phenotyping of wheat genotypes in Ethiopia

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2.1 Introduction

Wheat, an important staple crop in Ethiopia, is threatened by several diseases. More than 40 wheat pathogen species have been reported in Ethiopia. The three rust diseases (stripe rust, stem rust and leaf rust) are the most important (Badebo et al., 2008). Stem or black rust caused by the fungus *Puccinia graminis* f. sp. *tritici* (*Pgt*) is very important in warm and humid environments. The disease is more pronounced when late-maturing, susceptible wheat varieties are grown in vertisol or clay soil. The cool highlands of Ethiopia are a potential niche for the perpetuation of stripe (yellow) rust caused by *P. striiformis* West. f. sp. *tritici* Eriks. & E. Henn (*Pst*).

Damage from rust pathogens depends on the susceptibility of wheat varieties, the onset of epidemics, weather conditions, and the amount of rust spores. *Pgt* can cause up to 100% yield loss on susceptible varieties when it occurs in early stages of wheat growth. Stripe rust also causes severe yield loss on susceptible varieties, especially on crops at high altitudes (Badebo and Kebebe, 1996). A country-wide stripe rust epidemic in 2010 caused yield losses of up to 100% on susceptible bread wheat varieties in parts of Oromia and Amhara regions (Abeyo et al., 2014). The stem rust race known as Ug99 (TTKSK), virulent for the resistance gene *Sr31*, is considered a global threat for wheat (Pretorius et al., 2000). The Ug99 race was reported in Ethiopia during 2003 (Admasu et al., 2009). Since 2008, projects funded by USAID, the Bill & Melinda Gates Foundation and others have greatly helped to replace the widely grown, highly susceptible varieties, such as *Kubsa*, with resistant ones. In 2013-14, a new stem rust race TKTF (different from Ug99) severely infected the widely grown variety *Digalu* in Arsi and Bale (Olivera et al., 2015).

Repeated rust epidemics have triggered coordinated national and international efforts to strengthen early detection and response to evolving pathogen races and rust outbreaks in Ethiopia and, in the case of important pathogen changes, to guide wheat resistance breeding and deployment strategies. Effective rust surveillance and early warning systems are critical if the investments in seed multiplication and distribution are to be fruitful.

2.2 Activities, partners and implementation

For these purposes, the “enhancement of rust surveillance, early warning, phenotyping and genotyping” component was integrated in the USAID funded CIMMYT/EIAR Wheat Seed Scaling Project, with interrelated activities and outputs including rust surveys, race analyses, early warnings and better characterization (phenotyping and genotyping) of candidate wheat varieties and commercial cultivars, implemented in collaboration with diverse national and international partners (Fig. 2.1).

A joint planning and launch workshop were held in the Cereal Disease Laboratory of the University of Minnesota (CDL-UMN), USA, in 2015 with participants from CIMMYT, EIAR, Cornell University, Washington State University (WSU) and the UMN to expand on the rust monitoring, early-warning and phenotyping systems implemented by CIMMYT and EIAR under the DRRW project coordinated by Cornell. The CDL-USDA-ARS has contributed pathotyping and host plant resistance analyses and, in coordination with the EIAR Plant Protection Center at Ambo, has played a key role in characterizing stem rust races in Ethiopia. This has included the purification and multiplication of key races and their use to determine the nature and genetic bases of resistance in candidate wheat varieties.

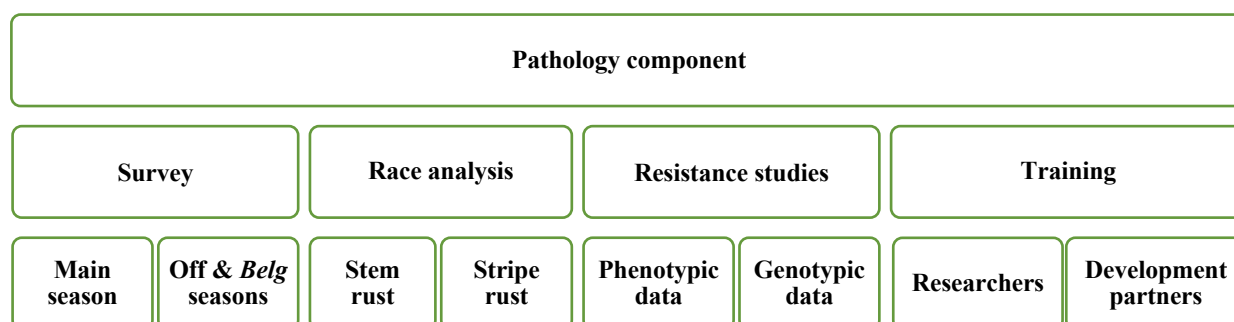


Figure 2.1. Activities of the pathology component of the Wheat Seed Scaling Project.

2.2.1 Formal and informal rust surveys and early warnings

The project conducted formal and informal disease surveys to rapidly detect rust outbreaks. Nationally coordinated wheat disease surveys were conducted in four major wheat growing regions (Oromia, Amara, SNNPR and Tigray) during 2015-17. Limited surveys were also conducted jointly with pathologists from Ambo and Werer RCs on irrigated wheat in Afar (Werer) and Oromia (Metahara) regions in March. Survey teams of plant pathologists based at 18 research centers in the aforementioned regions engaged in surveys during the main season (*Meher*) and *Belg* season. The *Belg* season surveys were conducted between July and August, while early *Meher* season surveys took place in August and main season surveys were conducted between October and November. The *Belg* season surveys took place only in Bale and Arsi. Stops were made at about every 5-10 km following pre-determined survey routes by each survey team. Rust incidence (percentage of plants infected) and rust severity (percentage of plant area infected) were recorded using the Modified Cobb’s scale (Peterson et al., 1948) and the average disease parameters of the four spots represented for each field assessed. Disease prevalence (number of infested fields/total fields assessed x 100) was calculated. Lat-Long coordinates were generated for each survey point.

Early warning: Early season rust surveys were integrated with spore dispersal models developed by Cambridge University and the UK Meteorological Office to provide early

warning alerts to stakeholders. All key stakeholders involved in rust surveillance and control—including federal and regional research centers, MoA, BoA, ATA and other development partners—were brought together in annual wheat rust planning meetings organized by CIMMYT. The awareness raising and regular early services helped development agents and farmers to better prepare and manage rust diseases in hot-spot areas. Government offices were also advised for contingency planning to source and make available fungicides.

Race analysis: Virulence surveys of wheat stem and stripe rust were carried out on samples collected from different wheat growing regions of Ethiopia during 2015-2017. Stem rust race analysis was conducted using internationally agreed norms and procedures in greenhouse facilities of the Plant Protection Center at Ambo (Fig. 2.2) according to Roelfs et al. (1992). Stripe rust race analysis was conducted as per Hovmøller et al. (2017) at the Global Rust Reference Center (GRRC) in Denmark.



Figure 2.2 Stem rust race analysis work at Ambo PPRC, EIAR.

2.2.2 Characterization of wheat genotypes for resistance

The project applied host plant resistance/pathology data in resistance breeding, variety selection and release, and to notify extension agronomists regarding changes in virulence to adopted cultivars. The integration of available seedling, field, and molecular marker data was used to make the most informed decisions. With these aims, elite wheat lines and commercial cultivars were exposed to different stem rust races at the seedling stage in greenhouse (overall resistance) at CDL-USDA and then in single race field nurseries at Kulumsa for APR. Important stem rust races were used in single race field screening nurseries and greenhouse seedling tests to determine the resistance bases in elite lines and commercial cultivars. The living culture collection, in combination with molecular marker assays, was used to determine variety resistance information and gene postulation. This work was accomplished in collaboration with the ongoing DRRW project and collaborating institutes in USA and USDA Cereal Disease Laboratory.

Seedling (overall) resistance test: Seed of bread wheat cultivars, breeding lines, near-isogenic lines (NILs), and check lines were assessed for seedling infection types (ITs) to stem rust at the USDA-ARS Cereal Disease Laboratory. The lines were assessed in two replications each for reactions to TTKSK, TRTTF, TKTTF, JRCQC and TTTTF in addition to three other races within the Ug99 race group (TTKST, TTKTT, TTTSK), according to previously described methods (Rouse et al. 2011).

Single-race stem rust nurseries: The objective of this screening was to identify candidate wheat varieties with APR to major stem rust races. By evaluating field resistance to multiple races in a single environment, researchers have sought to elucidate the potential race specificity of APR. Ethiopian bread and durum wheat cultivars and breeding lines were tested against 4-5 stem rust races (TTKSK, TRTTF, TKTTF, JRCQC and TTTTF) in single race nurseries at Kulumsa Research Center during 2014-17. Nurseries were established about 500 meters apart, surrounded with two rows each of rape seed and oats, and encircled with spreader rows of a susceptible variety. Disease severity and infection response were visually assessed four times starting at the onset of the disease using standard methods (Hundie et al., 2019).

Genotyping using molecular marker assays: Wheat germplasm from the national wheat research program was genotyped at the USDA-ARS Plant Science Research Unit in Raleigh, NC using molecular markers linked to *Sr2*, *Sr22*, *Sr24*, *Sr25*, *Sr26*, *Sr31*, *Sr35*, *Sr36*, *Sr38/Lr37/Yr17*, *Sr57/Lr34/Yr18*, and *Sr1RSamigo* (Hundie et al., 2019).

2.3. Achievements

2.3.1 Formal and informal surveys

Irrigated wheat survey: A wheat disease survey was conducted in irrigated wheat fields at Mecha Woreda of West Gojam zone, Amhara region, during May 2015. Stem rust was noted in all 24 fields of three kebeles surveyed with 30.6% mean incidence and 5.2% mean severity (range, 0-20%). Yellow rust was noted on 22 fields of two kebeles with a 17.5% mean incidence and 5.6% mean severity (range, 0-50%).

A wheat disease survey for irrigated wheat was carried out in Afar (Werer) and Oromia (Metahara) regions during March 2017. Of the three rust diseases, only trace levels of leaf rust were noted in one field at Amibara Kebele, near Werer RC. Fusarium head blight (FHB) was recorded on two and five fields at Werer and Metahara, respectively, with an incidence ranging from trace to 40%. FHB was most prevalent in this particular year in irrigated wheat areas which require close monitoring and supervision in Afar and Oromia regions and beyond.

Belg season surveys: The 2015 belg season was not conducive for rust development due to drought. The 2016 belg season wheat disease survey was conducted in the last week of July in seven districts of Oromia (Arsi zone) and SNNPR. Yellow rust occurred on three of the 23 farmers' fields assessed, with a severity ranging from trace to 30%. Stem rust was observed on only one field with trace levels of severity. Septoria was the most prevalent wheat disease (34.8%). Wheat rust diseases are not damaging in belg season, but rust inoculum present on belg crops can infect wheat grown during meher, the main rainy season, so information from belg surveys can help guide variety selection and fungicide sourcing and deployment.

Early main season survey (meher): Disease surveys were conducted by federal and regional research centers in Oromia, Amhara, SNNPR and Tigray regions from July to September, 2016. Yellow rust was noted on 90% of the fields surveyed in Arsi and West Arsi zones of Oromia in mid-July. Bread wheat varieties such as *Kubsa*, *Ogolcho*, *Kakaba*, *Huluka* showed susceptible-to-moderately susceptible reactions, whereas *Shorima* and *Hidasie* exhibited resistant-to-moderately resistant reactions. *Huluka* used to be resistant to yellow rust. Yellow rust was noted on 80-100% of farmers' fields in the West Shewa and Southwest Shewa zones of Oromia region during the last week of August. Similarly, yellow rust was reported at

tillering-to-booting growth stages in Bale zone in mid-September, 2016. About 75% of farmers' fields (24) surveyed in Wolayita, Hadiya and Kambata zones in SNNPR were infected with yellow rust. Of the 60 farmers' fields surveyed in North and South Wollo zones of Amhara region, only 5% and 3% had yellow and leaf rust, respectively. No rust was reported in Tigray during the early main season survey.

Main season survey (meher): A new, improved version of the wheat rust survey application has been developed using Open Data Kit (ODK) and features the use of barcodes for accurate tracking of samples collected. The new application was deployed to survey teams, along with training in its use, enabling near real-time data from the field to be used in forecast models. All survey data were compiled and uploaded into the wheat rust toolbox and made available through Rusttracker.org. More than 2000 individual sites were surveyed covering all the wheat growing regions of Ethiopia. Yellow rust was the most prevalent rust disease followed by stem rust, while leaf rust remained constantly low across seasons (Fig. 2.3). The prevalence of rust diseases varied across seasons. The highest prevalence of yellow rust was noted in 2016 followed by 2017. The highest prevalence of stem rust was observed in 2015 followed by 2016. Leaf rust incidence was relatively high in 2015. The incidence of wheat rust diseases varied across seasons and locations as well.

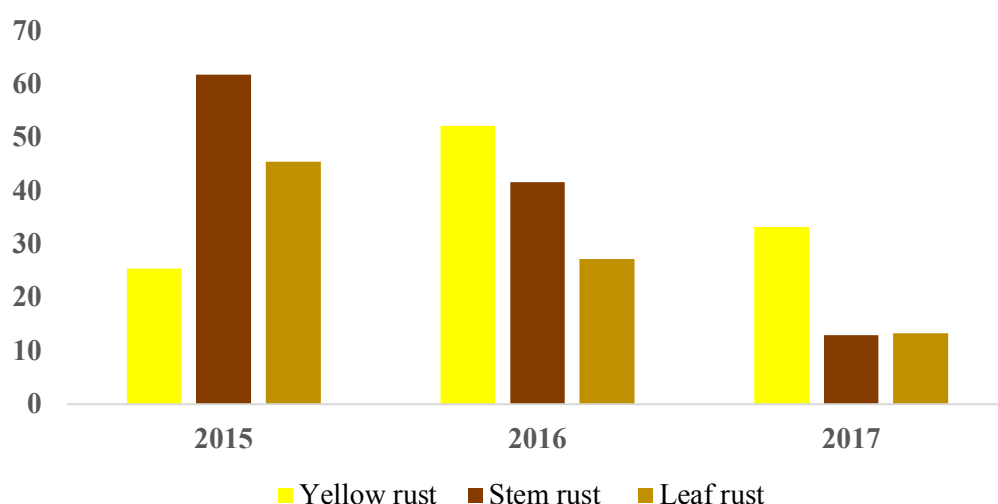


Figure 2.3. Prevalence of rust diseases.

The three-year survey results indicated that the central and southeastern highlands (N. Shewa, W. Arsi, Arsi and W. Shewa) are hot spots for yellow rust, followed by the southern (Hadya, Kambata), northwestern (S. Gonder) and northern (Southeast Tigray) regions. Hot-spot areas for stem rust are the Oromia region (W. Shewa, S.W. Shewa, Bale, E. Shewa) followed by SNNP (Siltie, Guraghe), Tigray (S.E. Tigray and Tigray) and Amhara (E. Gojam). The prevalence of leaf rust was low in general but relatively high in the northern (E. Tigray, S.E. Tigray, North Wolo), northwestern (N. Gonder, W. Gojam), Southern (Siltie), southeastern (W. Arsi) and Central (W. Shewa) parts of Ethiopia. Leaf rust was high on durum and emmer landraces while most of the modern wheat cultivars possess adequate resistance to leaf rust.

The widespread presence of yellow rust was partly due to the rapid spread of the new race AF2012, confirmed by the Global Rust Reference Center in Denmark and which is genetically and phenotypically identical to a race first detected in Afghanistan in 2012. The outbreak of this race in Ethiopia in 2015-16 overcame the longstanding yellow rust resistance of several commercial cultivars (*Digalu*, *Hulluka*, *Mada Walabu* and others). Despite the rapid spread of the new race, government authorities and research agencies believed that a good level of rust control had been obtained. The early warning information and awareness raising amongst farmers have improved management of the disease. There was anecdotal evidence that in some key areas forecast information from the early warning system had resulted in preparedness and successful control ahead of the disease.

2.3.2 Early warnings

CIMMYT has actively participated in the national rust technical committee established by the MoANR in collaboration with EIAR and ATA to implement the government program “Wheat rust surveillance, early warning and management systems in Ethiopia.” Weekly reports for the committee summarized surveys results, spore dispersal forecasts produced by Cambridge University and the UK Meteorological Office, and phone survey results.

An automated rust phone survey was developed by Ecomplc in partnership with ATA. The system was integrated with the Voice Recognition (IVR) 8028 system of ATA. The IVR system has over 1.5 million registered subscribers, permitting targeted surveys to be applied to specific groups (e.g., wheat farmers or DAs) and target districts. A simple automated phone survey consisting of five questions and requiring simple numeric responses was developed in three local languages (Amharic, Oromifa, and Tigrinya), piloted in 2016-17 and continuously refined. The aim was to crowd-source the reporting of the presence of stem and yellow rust by sending the survey every 4 days. Initially, all wheat farmers in 51 woredas were targeted, but over time the survey was refined and targeted only to DAs in key districts. The system is being modified so that respondents reporting the presence of rust will receive automated best control advice from the ATA IVR system (i.e. rust survey reports and control advice linked together).

Key locations (West Arsi, West Shewa and South Tigray) were incorporated into the spore dispersal forecast model pipeline with daily, 7-day forecasts produced from these locations to provide accurate early warning for wheat growing areas, thus enabling preparation and control activities. Modified, twice-weekly wheat rust phone surveys were implemented and targeted to some 5,000 DAs in 50 priority woredas with a high risk of rust, giving response rates of 30-40%. The survey format was modified based on user feedback and analysis of the data. Using the modified phone survey, promising results have been obtained with a signal of increasing rust pressure (yellow rust) over time obtained from woredas of Arsi, West Arsi and Bale zones and matching survey data from research center teams. This innovative data collection approach seems like a promising way to survey large areas at frequent intervals. Based on the emerging yellow rust outbreaks, especially in West Arsi and Arsi, and the data received from the early warning system, ATA sent out rust alerts using the IVR system and SMS to tens of thousands of farmers in high risk districts. The MoANR also used the early warning information to prioritize and target control activities.

2.3.3 Race analysis

A total of stem rust 11 races were detected out of 572 isolates collected in different wheat growing areas of Ethiopia (Fig. 2.4). Out of these, TKTTF (*Digalu* race) was the most dominant across locations and seasons.

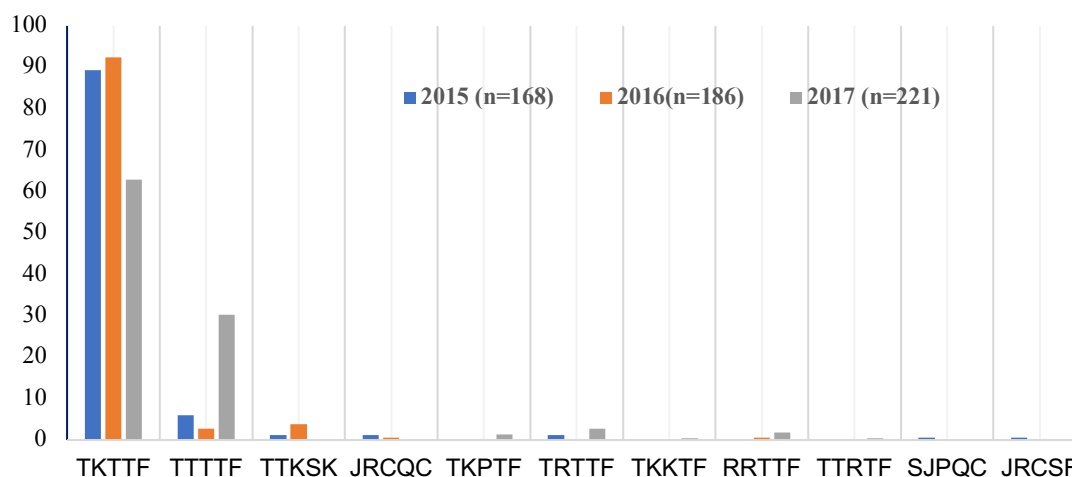


Figure 2.4. Frequency (%) of stem rust races detected in major wheat producing areas during 2015-2017.

TKTTF was first detected in Ethiopia at trace levels in 2012 and re-confirmed in 2013. In 2013, it caused localized stem rust epidemics on the popular bread wheat variety *Digalu* (carrying *SrTnp*) in Arsi and Bale (Olivera et al., 2015). Since then, it has remained the dominant stem rust race across Ethiopia's wheat-growing areas (Table 2.1). Studies indicated that TKTTF belongs to a genetic lineage that is different from Ug99 race group.

Race TTTTF also has wide virulence spectra and is the second most frequent (14%). It was detected at trace levels from samples collected in 2009 in eastern Shewa zone, Central Ethiopia (Lemma et al., 2014).

Stem rust race TTKSK (Ug99) was officially reported in 2005 (Admassu et al., 2009) and used to be the most threatening for wheat production in Ethiopia. Its frequency was more than 80% in the stem rust race population in 2013-14 but it now appears at less than 2%, with the population being dominated by TKTTF.

Stem rust race JRCQC (virulent on *Sr13* and *Sr9e*) was detected at a low frequency in Central Ethiopia. It is virulent mainly on durum wheat (Olivera et al., 2015).

Table 2.1. Distribution of stem rust races across different zones in the country during 2015-2017.

Race code	Zone											Totals
	Shewa	Arsi	Bale	Wollega	E.Haraghe	S.Wolo	Gonder	Gojam	S.Tigray	Gurage	KAT/ Hadiya	
TKTTF	174	62	34	38	19	17	29	20	43	14	8	458
TTTTF	9	7	6	1	3	3	19	14	19		8	89
TRTTF	1	2	1			1			4			9
TTKSK	2	4		2								8
SJPQC	1										1	2
JRCST	1	1									1	3
JRCQC	1											1
RRTTF							1		4			5
TKPTF				1					2			3
TKKTF		1										1
TTRTF									1			1
Totals	189	77	41	42	22	21	49	34	73	14	18	580

Most known stem rust resistance genes are no longer effective against most of the races identified, and *Sr21*, *Sr9e*, *Sr6*, *Sr17*, *Sr9a* and *Sr9d* are susceptible to all. On the other hand, *Sr31* was resistant to most of the races while *Sr24* was effective against all. *Sr31* virulent races used to be frequent among the race population before 2012-13. Stem rust races virulent for *Sr24* were reported in Kenya; our gene postulation and genotyping data indicate that a number of commercial cultivars in Ethiopia carry *Sr24* in (Hundie et al., 2019).

The preceding underlines the need to identify and use new sources of durable resistance or adult plant resistance to rust in wheat. This kind of resistance is especially important to reduce the evolution and survival of new virulent races where wheat is grown year-round (Singh et al., 2015). Most CIMMYT advanced lines now carry APR genes.

Yellow rust races: The *Dashen* race (*Yr9*) and later the *Kubsa* race (*Yr27*) used to be the dominant races among stripe rust populations before the incursion of AF2012 in Ethiopia in 2015-16, The new race PstS11 (*AF2012*) has virulence for *Yr 2*, *Yr4*, *Yr6*, *Yr7*, *Yr8*, *Yr17*, *Yr27*, *Yr32* and *YrAvs*. This race has severely affected previously resistant varieties *Digalu*, *Hulluka*, *Mada Walabu* and others.

2.3.4 Characterization of wheat genotypes for resistance (seedling evaluation)

Ninety-seven and 53 bread wheat genotypes were evaluated for seedling resistance against major stem rust races in 2015 and 2016, respectively. Of all 97 bread wheat lines including the check cultivars, 34, 65, 44, 95 lines were resistant to races TTKSK, TRTTF, TKTTF and JRCQC, respectively, whereas 52, 35, 42, 36, 38, 39, 18 and 5 showed sustained resistance to JRCQC, TTTTF, TKTTF, TRTTF, TTKSK, TTTSK, TTKST and TTKTT, respectively. All bread wheat breeding lines and cultivars were resistant to race JRCQC. The results also indicated that test and check genotypes differed in their responses to stem rust races.

None of the check cultivars were either susceptible or resistant to all races of *P. graminis* f. sp. *tritici*. Generally, the checks were susceptible to races TTKSK, TRTTF, and TKTTF, but resistant to race JRCQC. Exceptions included *Arendato*, which was resistant to race TRTTF but susceptible to race JRCQC, and *Digalu*, which was resistant to all races except TKTTF. *Danda'a* and *Kubsa* displayed intermediate responses to TKTTF and *Kingbird* displayed an intermediate response to race TRTTF. Four released bread wheat cultivars (*Hoggana*, *Honkolo*, *Hulluka*, *Ogolcho*) and 15 breeding lines (*CIMMYT14*, *ETBW6939*, *ETBW7258*, *ETBW6110*, *ETBW6086*, *6031*, *ETBW6022*, *ETBW6241*, *ETBW6057*, *ETBW6440*, *ETBW8481*, *ETBW7255*, *ETBW6937*, *ETBW7058*, *ETBW8508*) exhibited resistance to 7 races, including the major stem rust races in Ethiopia and TTKTT, a Ug99 variant not present in Ethiopia. *Hidasie* was also resistant to all the races except TKTTF and *Ga'ambo* was resistant to all to except TTKTT. Similarly, *ETBW8508* was resistant to all races except TTKST. Generally, 53 cultivars and lines were resistant at seedling stage to all four races prevailing in Ethiopia and none of the lines were susceptible at seedling stage to all four races. However, five CIMMYT lines and the cultivar *Gassay* were susceptible to TTKSK, TRTTF and TKTTF at seedling stage.

Molecular marker assays and gene postulation: Stem rust resistance genes were postulated and genotypic (DNA assay) data generated for 135 elite bread wheat breeding lines, in collaboration with CDL-USDA-ARS. Of the 135 bread wheat lines (including checks), 13, 20, 52, 13, 5, 2, and 30 lines possessed *Sr2*, *Sr57/Lr34*, *Sr24*, *Sr31*, *Sr1RSamigo*, *Sr25*, and *Sr38*, respectively, based on molecular marker assays (Fig. 2.5).

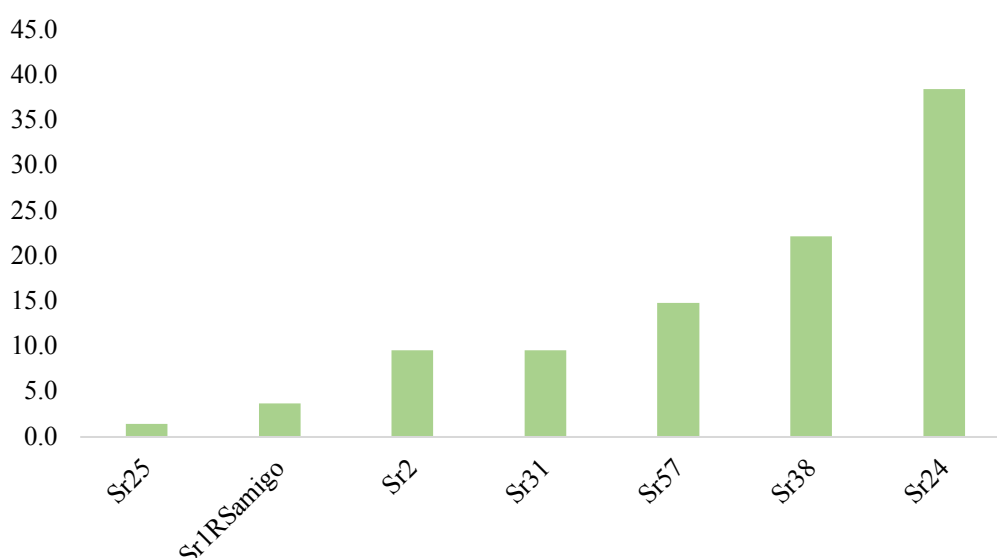


Figure 2.5. Frequency (%) of stem rust resistance genes in elite bread wheat cultivars and breeding lines.

The molecular assay test results indicated that 24.4% of wheat genotypes, including commercially grown bread wheat cultivars *Kingbird*, *Pavon-76*, *Kakaba*, *Danda'a*, *Sofumer* and *Tay*, had APR genes.

Sr22, *Sr26*, *Sr35*, *Sr36*, *Sr42*, and *Sr55/Lr67* were not detected at all in this set of wheat germplasm. Lines with *Sr24* were resistant as seedlings to all four races except for *CIMMYT 12*, *CIMMYT 43*, and *CIMMYT 44*, which gave susceptible responses to at least one *Sr24*-avirulent race in at least one replication, indicating that these lines are likely heterogeneous for *Sr24*.

Lines *ETBW8470* and *ETBW6875* possessed the resistant haplotype of the *Sr24* marker but were susceptible to race TKTTF and/or TTKSK, indicating that these are likely false positives for *Sr24*. *CIMMYT 40* and *CIMMYT 41* displayed an *Sr24*-characteristic seedling infection type pattern (resistant to all races except the *Sr24*-virulent TTKST and TTKTT) but lacked the resistant haplotype of the *Sr24* marker. These two lines were also more susceptible in the field than lines with both the *Sr24* resistant haplotype and infection type pattern. Only three lines possessed both APR genes *Sr2* and *Sr57/Lr34*: *Kingbird*, *Sofumar*, and *ETBW7364*, the latter being heterogeneous for *Sr57/Lr34*. Though *Sr38* was observed at the highest frequency following gene *Sr24*, it does not confer resistance to TTKSK, TKTTF, or TRTTF. Several breeding lines were identified with a combination of two or more effective seedling resistance genes: *ETBW6114* (*Sr24*, *Sr25*), *CIMMYT 19* (*Sr1RSamigo*, *Sr24*), *CIMMYT 43* (*Sr24*, *Sr1RSamigo*, *Sr31* heterogeneous), and *CIMMYT 44* (*Sr1RSamigo*, *Sr24* heterogeneous). Additional tests are needed to validate the genetic constitution of selections of *CIMMYT 43* and *CIMMYT 44*. Well adapted lines which pass rigorous field and laboratory/greenhouse tests are expected to be promoted for release and seed multiplication.

Resistance in 52 lines, including currently grown bread wheat cultivars such as *Biq'a'a*, *Alidoro*, *Hoggana*, *Honkolo*, *Hulluka*, *Menze*, *Millennium*, *Ogolcho*, *Qulqullu*, *Obora* and *Danbal*, is conferred by *Sr24*. Virulence for *Sr24* is common in the *P. graminis* f. sp. *tritici* population in Kenya (Jin et al., 2008). If *Sr24*-virulence were to predominate in Ethiopia, many, if not all, of these cultivars could become susceptible.

The marker and seedling data suggest there are effective stem rust resistance genes in Ethiopian germplasm. Genes such as *Sr22*, *Sr25*, and *Sr26* are effective against the races in this study and could be increased in frequency in Ethiopian germplasm to improve resistance. For adult plant resistance genes, increasing the frequency of lines with combinations of genes *Sr2* and *Sr57/Lr34* may improve resistance. However, the *Sr2* and *Sr57/Lr34* combination alone may not result in adequate resistance, given that variety *Sofumar* with this combination did not display significantly less AUDPC than *Danda'a* under infection by TTKSK. Our data revealed several examples of lines carrying *Sr2* but with a higher AUDPC to TTKSK than *Danda'a* (*ETBW6696*, *Sofumar*, and *Tay*). Results of stem rust response assessments for the limited number of durum cultivars and breeding lines tested in this study indicated that race JRCQC is much more virulent against durum wheat than the three other *Pgt* races tested. Testing of numerous additional durum wheat lines against race JRCQC, especially cultivars and advanced breeding lines, is warranted.

Stem rust single race nurseries: A total of 313 wheat genotypes were evaluated against 4-5 *Pgt* races (Fig. 2.6) in two sets of single race field nurseries at Kulumsa (Tables 2.2 and 2.3). Of the five checks included for comparison, bread wheat cultivar *Kingbird* had the highest resistance and *Danda'a* exhibited an intermediate resistance response between those of *Kingbird* and *Kubsa* for four races, TTKSK, TKTTF, TRTTF and TTTTF, as measured by AUDPC values. Genotypes with AUDPC values lower than that of *Danda'a* were considered to have adequate resistance. In general, bread wheat genotypes were resistant to JRCQC, the race most virulent against durum wheat. Among bread wheat test genotypes, lines and cultivars with *Sr24* were most frequent and showed the best resistance to the prevailing races.



Figure 2.6. A single-race stem rust nursery at Kulumsa research station.

Only three lines with APR but not possessing *Sr24* showed resistance as effective against the four races as that of varieties with *Sr24*. Wheat lines endowed with APR against TTKSK were identified, though they are relatively susceptible to TKTTF. This study demonstrated the importance of testing wheat lines against multiple stem rust races to determine if their resistance is non-race specific.

Table 2.2. Response of wheat genotypes and check varieties to major stem rust races, using average AUDPC, during 2014 and 2015.

Check varieties	Stem rust race							
	TKTTF		TRTTF		JRCQC		TTKSK	
	R	S	R	S	R	S	R	S
<i>Kingbird</i>	7	121	0	128	3	125	22	106
<i>Danda'a</i>	119	9	101	27	77	51	94	34
<i>Kubsa</i>	127	1	127	1	96	32	128	0
<i>Arendato</i>	127	1	119	9	128	0	116	12
<i>Digalu</i>	127	1	106	22	108	20	66	62

R = resistant, for genotypes with AUDPCs lower than those of respective checks.

S = susceptible, for genotypes with AUDPCs greater than those of respective checks.

The most immediate result of this study was the identification of wheat germplasm with resistance to multiple races of *Pgt* in Ethiopia. In particular, we identified bread wheat lines that possessed significantly greater resistance than *Danda 'a* to TTKSK and TKTTF. Only three lines with APR showed significantly greater resistance than *Danda 'a* (Hundie et al., 2019) and will be used to introgress all-stage and non-specific resistance genes into a single variety.

Table 2.3. Response variation of wheat genotypes to major stem rust races as compared to check varieties, using average AUDPC of 2016 and 2017.

Variety	Stem rust race									
	TKTTF		TRTTF		JRCQC		TTTTF		TTKSK	
	R	S	R	S	R	S	R	S	R	S
<i>Kingbird</i>	104	81	124	61	93	92	85	100	152	33
<i>Danda'a</i>	144	41	149	36	160	25	119	66	156	29
<i>Kubsa</i>	155	31	172	13	125	160	148	37	162	23
<i>Arendato</i>	178	7	183	2	184	1	174	11	185	0
<i>Digalu</i>	179	6	165	20	178	7	159	26	153	32

R = resistant, for genotypes with AUDPCs lower than those of respective checks.

S = susceptible, for genotypes with AUDPCs greater than those of respective checks.

The AUDPC of the 13 durum wheat lines assessed was lower than those of older durum cultivar *Arendato* in all 4 nurseries (Table 2.4). In general, the durum lines showed greater resistance than the bread wheat lines to TTKSK, TKTTF, and TRTTF but greater susceptibility to the *Sr13b*-virulent race JRCQC. Durum cultivars *Boohai* and *Kilinto* showed the greatest resistance to JRCQC and were intermediate in resistance to other races.

The single race nursery platform in Kulumsa was successful in identifying lines with resistance to *P. graminis* f. sp. *tritici* races in Ethiopia. As new virulent races emerge in the country, additional single race nurseries can be added or inoculations could be done using the new races. This study demonstrated that testing of advanced breeding lines against present *Pgt* races is possible and should be used to inform variety releases and deployment.

Table 2.4. The average AUDPC of durum wheat cultivars to five stem rust races tested in single stem rust nurseries at Kulumsa during 2016 and 2017.

Variety	Stem rust race				
	TKTTF	TTKSK	TRTTF	JRCQC	TTTTF
<i>Alem Tena</i>	193	1165	470	264	148
<i>Tesfaye</i>	180	126	335	143	50
<i>Utuba</i>	211	252	219	225	88
<i>Ambera</i>	890	1060	1183	1196	850
<i>Boohi</i>	70	215	19	531	20
<i>Fentale</i>	613	1553	4223	1110	538
<i>Lucy</i>	833	1050	1589	1014	1038
<i>Mangudo</i>	146	195	191	304	20
<i>Werer-1</i>	195	409.5	18.75	380	175
<i>Werer-2</i>	338.75	337	242.5	341.75	287.5

2.4 Training

Wheat rusts identification and scoring techniques: Training on wheat disease identification, surveillance, scoring techniques, nursery establishment and management was given to young pathologists and technicians in major wheat research centers (Figs. 2.7 and 2.8).



Figure 2.7. Rust surveillance training at Kulumsa for federal and regional center researchers aimed to refresh their knowledge and skills and to foster the generation and timely exchange of high-quality, consistent data.

Training of researchers and technicians: CIMMYT-Ethiopia organized training on quarantine pests of wheat at Holetta research center, where seed of most introduced germplasm is inspected, to raise awareness and strengthen the national quarantine system. Prior to the training, CIMMYT purchased and distributed laboratory equipment and supplies through the Wheat Seed Scaling Project. Twelve trainees from Holetta, Sinana, Kulumsa, Adet, Mekele, Werer and Ambo attended the three-day event, which was given by a senior pathologist and entomologists from EIAR and CIMMYT. The CIMMYT pathologist covered theory and practical skills including diagnosis, epidemiology and managing diseases caused by fungi, bacteria, viruses, and nematodes.



Figure 2.8. Researchers at a training event in Kulumsa enhanced their knowledge of disease detection methods and management, as well as practical skills for dealing with fungal, bacterial, and viral diseases of wheat in quarantine fields.

Training of trainers: Training was provided through annual events to at least 600 regional, zonal and district development partners, including subject matter specialists, experts and development agents. Among the topics covered were disease identification and management and updates on the resistance of commercial cultivars and new releases, based on surveillance data and phenotyping and genotypic results from partners.

2.5 Challenges and gaps

The concept of APR is not well understood among development agents, farmers or even researchers. The expression/effectiveness of minor genes depends on the number of genes and on the environment. Thresholds and expected losses for different varieties exhibiting APR need to be investigated in different environments.

Stem rust was once limited to warm, humid areas, but has recently moved into highland cropping zones, due either to climate change and/or pathogen races adapting to cooler environments and indicating the need to revise variety deployment strategies.

Stripe rust head infection is increasing in the high altitudes. Several morphological, genetic and environmental factors, among other considerations, are contributing to head infections but the issue requires further investigation.

2.6 Lessons learned

Early warning information, awareness raising, regional- and federal-level training and the supply of rust resistant wheat varieties have helped to lower the incidence of rust diseases.

Rust monitoring and phenotyping and genotyping in wheat germplasm by local and international partners have been quite useful for variety development and deployment.

Phenotypic and genotypic data are useful before varieties are released and multiplied. The outputs of this component have ensured that varieties demonstrated adequate levels of rust resistance under farmers' conditions before their advancement, release or seed multiplication.

2.7 Conclusions

Partnerships were strengthened among institutions and projects and the capacity of researchers enhanced for seedling tests, stem rust race analyses and phenotyping wheat for APR. Rust surveillance and monitoring were improved through new tools (tablets, mobile phones, etc.) and the on-line posting of information and molecular data for commercial bread wheat cultivars and elite lines. Local capacity for resistance gene identification in durum wheat needs to be developed.

Racial analyses for yellow rust have begun but should be strengthened through additional facilities and infrastructure at Kulumsa, as well as short-term training for researchers in gene identification and patho-genomics.

In general, the project has responded to the immediate threat of virulent stem rust races and also built the capacity of researchers to respond better to stem rust threats. The early warning system was strengthened and expanded. Information on the early incidence and distribution of rust diseases and the identification of prevalent races was applied to alert policy makers, development agents and farmers on contingency fungicide planning. Information on the rust resistance genes in candidate varieties reached breeders prior to variety release, seed multiplication and dissemination. The early warning information together with the awareness raising and training, along with the timely scaling of seed of rust resistant wheat varieties, have helped to reduce the incidence of rust diseases and to raise wheat yields and incomes across the wheat value chain.

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Chapter 3

Achievements in fast-track germplasm testing and pre-release multiplication of seed of rust resistant wheat varieties in Ethiopia

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3.1. Introduction

Wheat diseases, mainly stem and stripe rusts, are the chief threats to wheat production in Ethiopia. Since the inception of wheat research, more than 100 bread wheat varieties have been released to the nation's farmers but most had to be abandoned due to their susceptibility to new races of yellow and/or stem rust pathogens. The release of wheat varieties with similar parentages and farmers' wheat-based monoculture using few improved varieties, along with the emergence or introduction of new pathogen races, have resulted in frequent and damaging rust epidemics. The rapidly growing demand for wheat and the short life-span of released wheat varieties raises significant concerns for the country.

The conventional breeding and varietal testing and release process is slow and, even after their release, seed of new varieties takes several years to reach farmers. Faster and more comprehensive breeding and seed multiplication approaches are required to minimize risks associated with rust epidemics and maximize national wheat productivity.

Table 3.1. Historical rust epidemics on popular wheat varieties in Ethiopia.

Year	Pathogen	Varieties	Gene	Yield loss (%)
1977	Yellow rust	<i>Laketch</i>	<i>Yr2+</i>	
1988	Yellow Rust	<i>Dashen</i>	<i>Yr9</i>	58 ¹
1993	Stem Rust	<i>Enkoy</i>	<i>Sr36</i>	65-100 ²
2010	Yellow Rust	<i>Kubsa</i>	<i>Yr27+</i>	>50%
2014	Stem Rust	<i>Digalu</i>	<i>SrTmp</i>	100 ³

¹Ayele and Wondimu, 1992; ²Temesgen et al., 1995; ³Olivera *et al.*, 2015

This report highlights the achievements in fast-track variety testing and pre-release seed multiplication of bread and durum wheat during the project.

3.2 Activities

The major activities included introductions of elite lines, variety trials, pre-release seed multiplication of candidate varieties, variety verification and release, and adaptation trials across locations.

3.3 Partners and implementation

Both federal and regional research centers were involved in project activities starting from planning and implementation (Table 3.2).

Table 3.2 Summary of research centers and their responsibilities.

Center	Institution	Responsibility
Kulumsa	Federal	Coordination and testing of bread wheat breeding
Debre Zeit	Federal	Coordination and testing of durum wheat breeding
Holetta	Federal	Screening for Septoria resistance
Mekasa	Federal	Testing for drought tolerance
Werer	Federal	Coordination and testing wheat under irrigation
Ambo PPRC	Federal	Stem rust race analysis and seedling tests
Adet	Regional	Testing site for northwestern Ethiopia
Debre Birhan	Regional	Testing site for northern Shewa
Sinana	Regional	Testing site for the Bale highlands
Bako	Regional	Testing site for western Ethiopia
Areka	Regional	Testing site for southern region
Mekele	Regional	Testing site for northern Ethiopia

Activities involved the introduction of wheat germplasm from abroad and fast-track variety testing and pre-release seed multiplication using two seasons per year (Fig. 3.1). The varieties released from regional research centers have been assembled and tested across regions through adaptation trials. Based on their adaptation and/or recommendation domains, new varieties were introduced to farms through demonstration and field days. Seed multiplication of farmers' preferred varieties was accelerated to twice a year using supplementary irrigation.

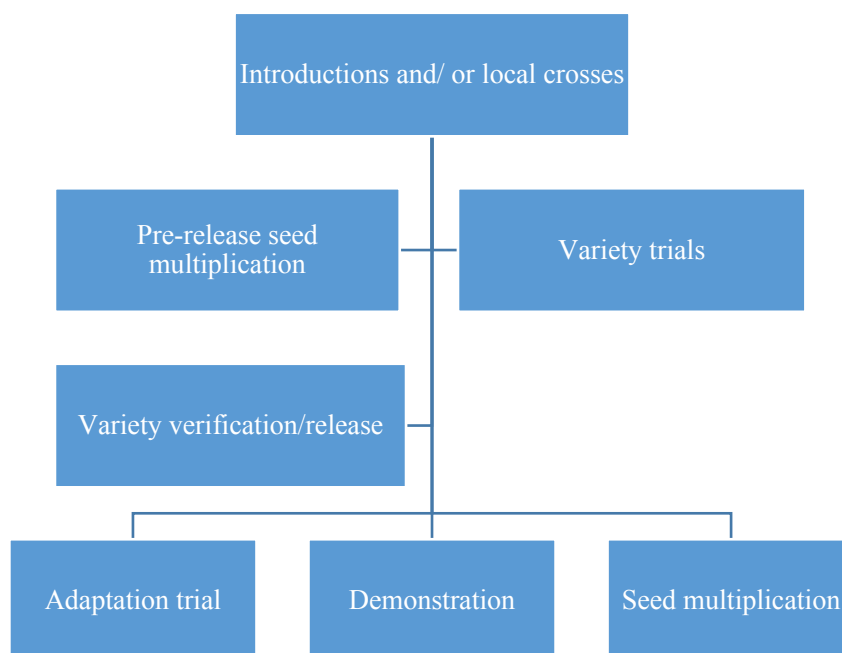


Figure. 3.1. Implementation approaches for variety testing and pre-release seed multiplication.

3.4 Achievements

3.4.1 Fast-track variety testing, release and registration

Fast-track variety testing is a path-breaking breeding procedure that makes wheat varieties with APR available to small-scale farmers and provides advanced wheat lines with novel resistance sources for the national breeding programs. The pillars of this strategy and major success stories are provided in the succeeding sections below and Fig. 3.2.

Ethiopian seed law allows the importation, evaluation, release and registration of varieties from foreign sources, along with their deployment in national seed systems in response to emergencies such as a severe rust outbreak. Cognizant of this, the wheat-breeding program has adopted fast, effective and durable varietal deployment strategy.

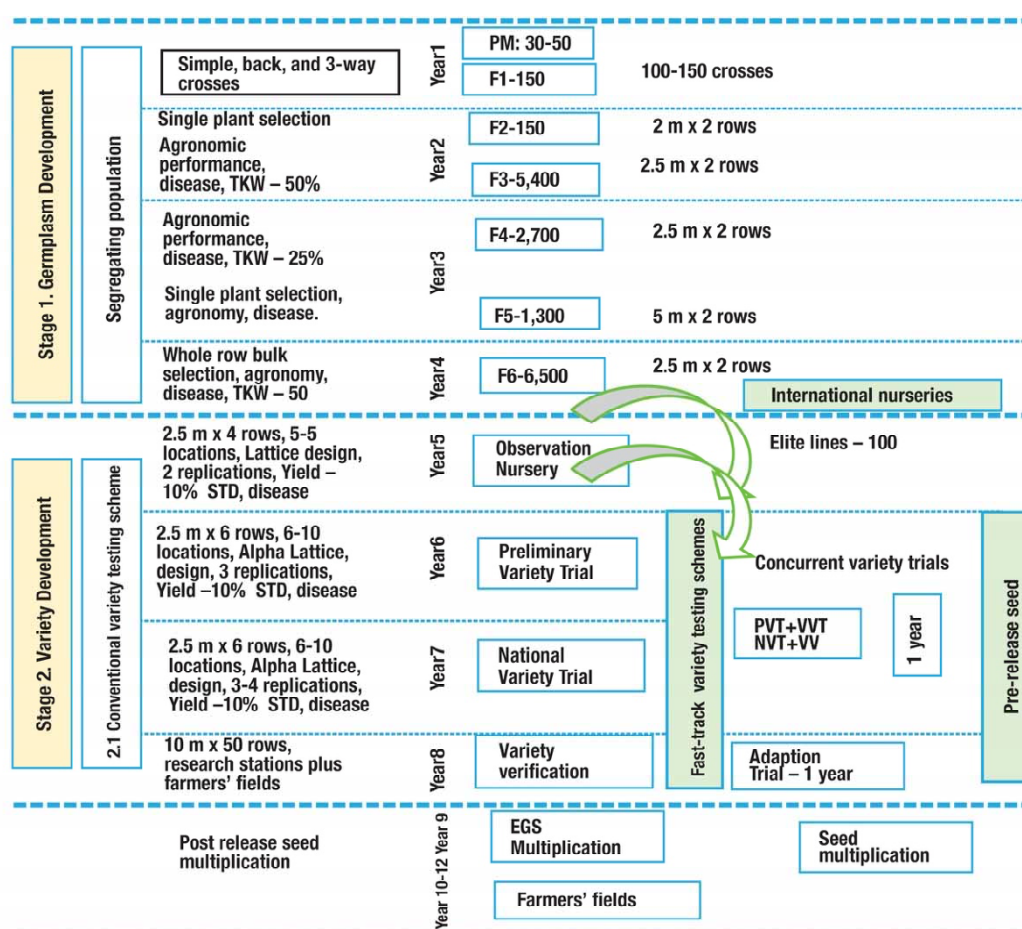


Figure 3.2. Comparison of the conventional vs fast-track variety testing and release schemes.

3.4.2 International nurseries

The total number of bread wheat genotypes (in the hundreds) screened, selected and the proportion of retained materials from international nurseries of CIMMYT during the three years' testing period are shown in Figs. 3.3 and 3.4.

Overall, 46 international nurseries containing 4,788 bread wheat genotypes were evaluated at Kulumsa and Debre Zeit Agricultural Research Centers during the main and off seasons. Through selections based on combined disease resistance and high yield potential, nearly 29% (1,414) of the tested genotypes were promoted to the next stages of variety trials (Fig. 3.3). Moreover, except in four nurseries (IBWSN, SAWSN, SAWYT and ESWYT), less than 30% of the tested lines in other nurseries were retained (Fig. 3.4).

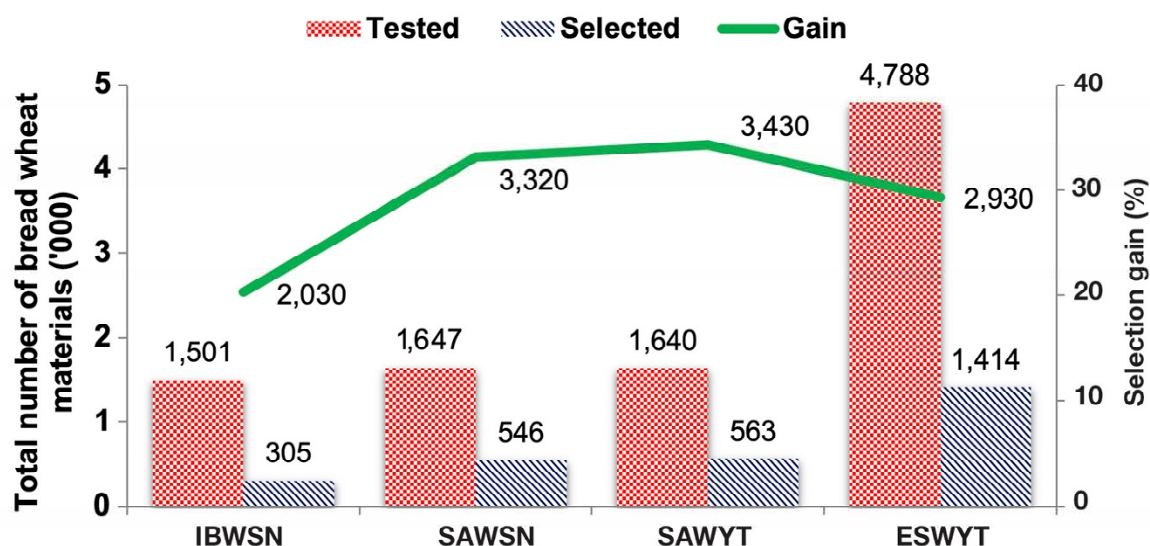


Figure 3.3. Bread wheat materials screened from CIMMYT international nurseries, 2015-2017.

During 2015-2017, the highest proportion of genotypes was retained in 2017 (34.3%) and 2016 (33.2%), while the lowest (20.3%) was in 2015. This could be due to the recurrence of the epidemic in the first year.

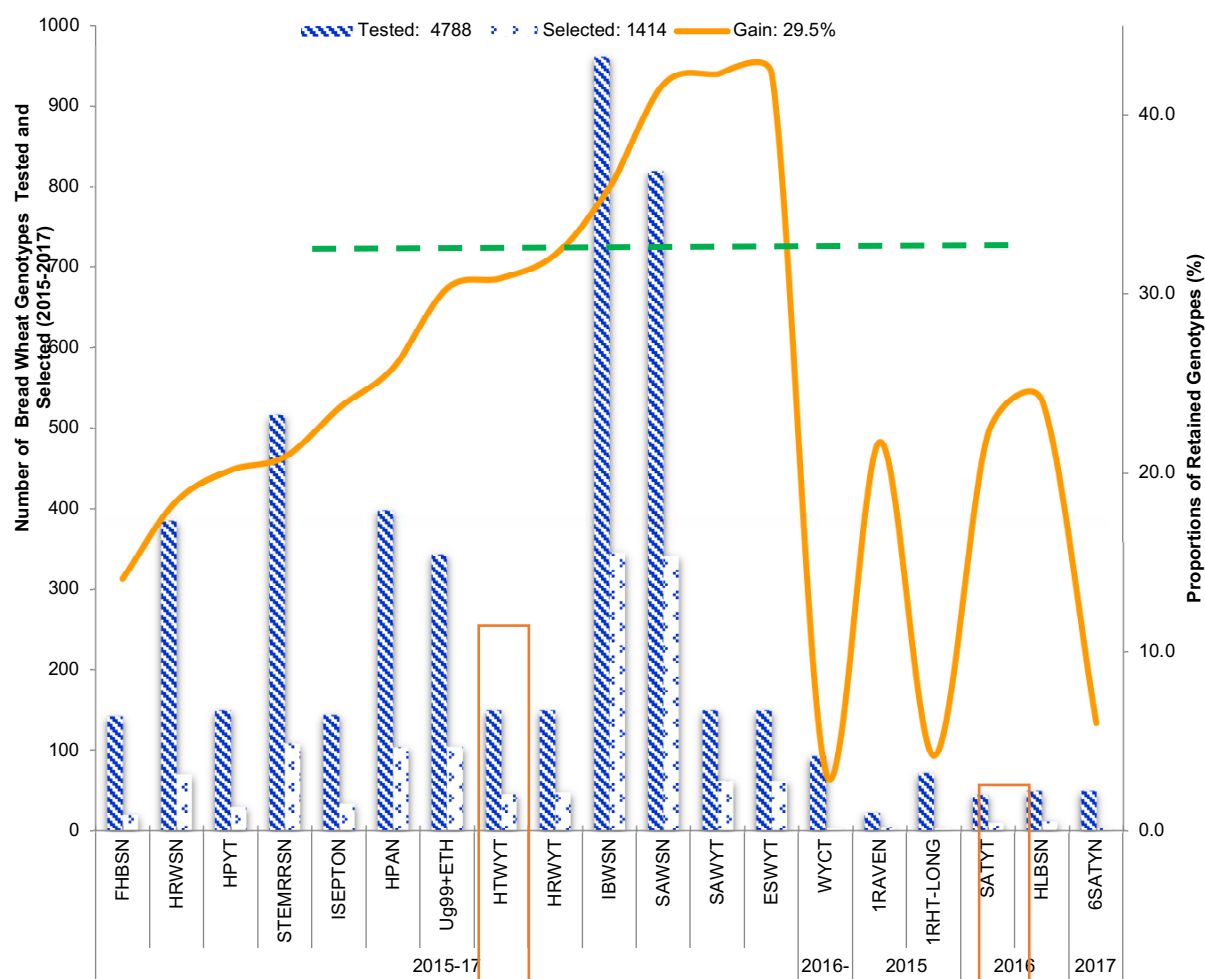


Figure 3.4. Number of tested, selected and proportion of retained genotypes from 46 CIMMYT international nurseries, 2015-17.

The number of genotypes selected does not relate to the number of entries tested under each nursery. For instance, more than 40% of lines were retained from ESWYT but less than 5% of tested materials from WYCT were selected for further testing. Hence, despite the opportunities of introducing and screening nurseries with large entry numbers, the details and genetic backgrounds should be considered to maximize genetic gains from selection.

3.4.2 Multi-location variety trials

Federal and regional research centers have also obtained grants to conduct wheat trials at different stages of variety development: observation nurseries (ONs), preliminary variety trials (PVTs), national variety trials (NVTs) and variety verification trials (VVTs). Wheat genotypes that have been selected and developed from regular international nurseries and fixed lines obtained from the national crossing program and those advanced from previous evaluation stages have been evaluated in their respective stages in target environments. Accordingly, genotypes with a 5-10% yield advantage over the standard checks and superior to the best existing check variety with respect to various economic traits have been identified and promoted to the subsequent breeding stage, for further performance testing in multi-location-year trials. The overall design, evaluation period, locations in target environments, and sequential procedure of various stages of variety development are shown in Fig. 3.2.

Overall, the number of bread wheat genotypes tested for the past three years (1,836) was almost twice as many as the durum wheat lines (933) and three times as many bread wheat genotypes (543) as durum genotypes (221) have been promoted. However, the proportions of retained genotypes in both species have showed insignificant variation. Despite the stripe rust epidemic in 2015, these figures show that stringent selection pressure was not employed during initial germplasm screening nurseries and yield trials, reducing efficiency and raising the costs and breeding time required in both programs.

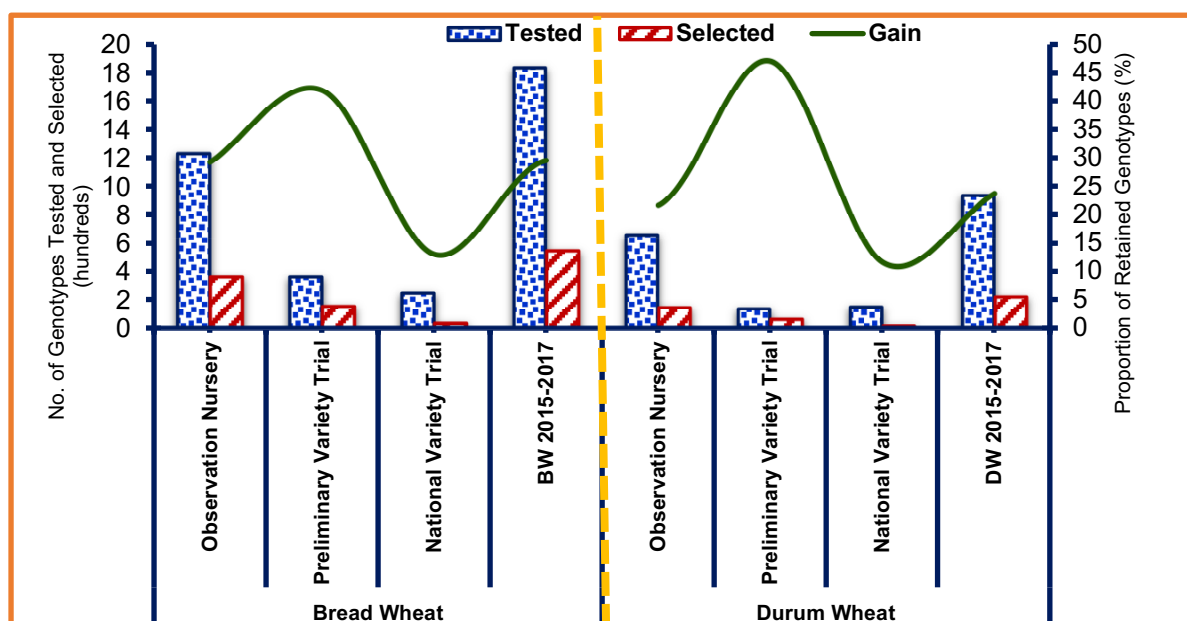


Figure 3.5. Number of bread and durum genotypes evaluated and selected, and proportion of retained genotypes during 2015-2017.

Elite Lines Screening Nursery: This third alternative involves evaluation of elite lines introduced from international agricultural research centers such as CIMMYT and ICARDA. Three CIMMYT nurseries were introduced during 2015-17 and evaluated during the main and off seasons.

The total number of tested entries and their retained proportion is shown in Fig. 3.3. Large numbers of elite germplasm and breeding lines from ICARDA, CIMMYT and national programs were grown at Kulumsa during 2015, 2016 and 2017; high-yielding lines from those with combined resistance to two or more diseases were selected and promoted for further evaluation and the best entered pre-release multiplication for variety evaluation and breeder and pre-basic seed.

3.4.3 Nomination of candidate genotypes

The variety release and registration system in Ethiopia does not urge breeders to provide genotypic data of their candidates revealing whether they possess adequate APR gene protection. This has resulted in the release of varieties that lack effective genes against prevailing pathogens.

In contrast, as part of the Wheat Seed Scaling Project breeders must provide phenotypic and genotypic data to get financial support for seed multiplication. Also, with project support, the national program has executed three phenotyping experiments on commercial varieties and breeding pipeline materials to gauge their response against prevalent diseases and their yield potential: single race nurseries (SRN), the key location disease nursery (KLDN) and multi-environmental trials (METs). In addition, conventional resistance gene postulation and genotyping analyses have identified wheat genotypes that feature major Sr or Lr resistance genes or *Sr2* for APR. The gene postulation information and molecular data for superior genotypes based on USDA-ARS genotyping lab data have guided nominations of genotypes for Variety Verification Trials (VVT) and supported parental line selections.

3.4.4 Multi-environment variety trials

During 2015 main cropping season three wheat field experiments were identified as core sources of promising lines for VVT and demonstrations: (i) concurrent variety trials, (ii) the elite lines nursery; and (iii) the adaptation trial (Fig. 3.2).

Concurrent variety trials (CVT): The national program executes preliminary and national wheat variety trials (PVT and NVT). Each trial with 15-35 superior entries is tested across 6-20 locations for 1-2 years, depending on the trials type (Fig. 3.2). In the fast-track testing scheme, trials of nominated candidates are executed concurrently with new variety verification trials on both farmers' and research station fields.

Out of the 12 promising lines nominated from 4 national variety trials, only candidates ETBW6861 (white-grained), ETBW6130 (white-grained) and ETBW8506 (red-grained) were chosen for fast-track testing and release. As a result, one national variety trial comprising 28 test entries including ETBW6861 and ETBW6130, along with two standard checks (*Danda'a* and *Hidasie*), were grown across 20 environments, while these top-ranking entries along with the best checks were concurrently evaluated in VVTs in the target environments.

Based on NVT data for 20 environments and the field level evaluation by TC, the National Variety Release Committee (NVRC) decided to release ETBW6861 for the highland environments and ETBW6130 for mid-highland growing environments, giving them the names *Lemu* and *Wane*.

3.4.5 Adaptation trial (AT)

This aimed to import at least 10 elite lines and, through multi-location adaptation testing, generating agronomic data for direct registration. Elite genotypes with desired traits were to be tested for one-year in multi-locations trial across major wheat agro-ecologies and released based on performance. However, this task was not delivered.

The performance of wheat varieties recently released from both federal and regional research centers was also to be tested to identify those with specific adaptation to target environments similar to the testing research centers. This task would have been the basis for selecting varieties for demonstration.

A trial of 15 genotypes/varieties released by both regional and federal research centers was conducted in the 2016 main cropping season (Figure 3.6). Breeders at respective research centers have identified varieties suited to their agro-ecologies. The trials were executed by 10 research centers supported by the project.

Since the inception of the project, a total of 12 varieties, 8 bread wheat and 4 durum wheat, have been released and reached farmers' fields (Table 3.3).

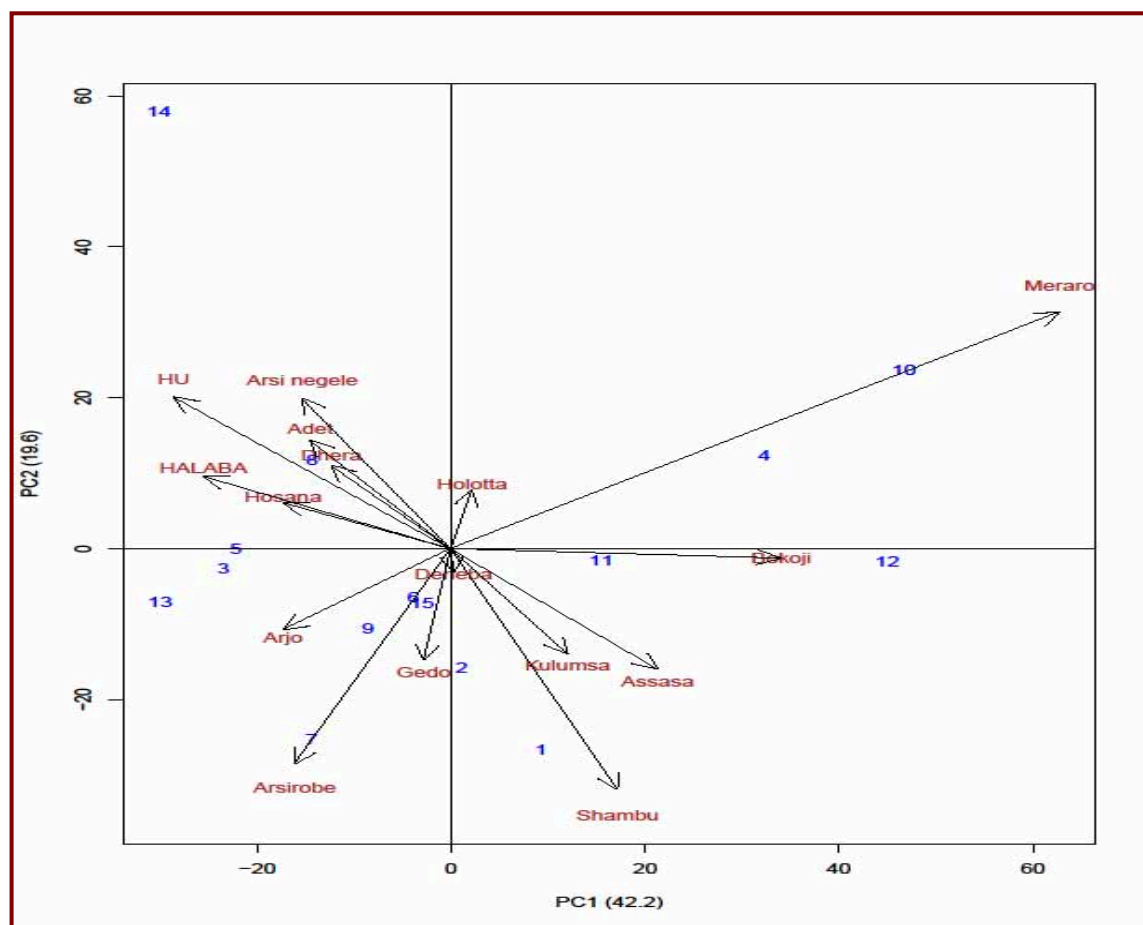


Figure 3.6. Genotype by environment interaction of bread wheat varieties in adaptation trials during 2016.

3.4.6 Pre-release seed multiplication

Wheat breeding programs normally undertake seed multiplication of new varieties soon after their official release and in fact from a very small initial seed source, causing a shortage of breeder seed at the time of release. With the drawn-out varietal development, testing and release system, the delivery of certified seeds to farmers can be delayed for 2-3 years (Turner and Bishaw, 2016). This project's fast-track variety testing and release scheme involved the pre-release multiplication of seed, considerably expediting the provision of enough early-generation seed at the time of release to commercial seed producers and thus certified seed to farmers. This was done simultaneously with advanced multi-environment variety trials.

Table 3.3. Characteristics and recommendation domains of recently released wheat varieties.

Variety	Year	Days to maturity	Rainfall (mm)	Altitude (masl)	Agro-ecology	Yield (t/ha)
Bread wheat varieties						
<i>Deka</i>	2018	75	700-1000	1500-2200	Midland	
<i>Wane</i>	2016	125	700-1000	2100-2700	Mid-highland	5.0-6.0
<i>Lemu</i>	2016	140	800-1100	>2200	Highland	5.5-6.5
<i>Kingbird</i>	2015	90-95	500 - 850	1500-2200	Low-Midland	4.0-4.5
<i>Buluk</i>	2015	85-88	>900	2300-2700	Highland	6.0-6.5
<i>Liben</i>	2015	122-125	>900	2300-2700	Highland	5.5-6.5
<i>Obora</i>	2015	144	750-1500	2000-2400	Highland	4.6-6.3
<i>Dembel</i>	2015	142	750-1500	2000-2400	Highland	5.6-6.3
Durum wheat varieties						
<i>Tesfaye</i>	2017	120-130	800-1200	1800-2800	Midland	5.5-6.0
<i>AlemTena</i>	2017	90-110	700-1000	1700-2000	Mid-highland	5.5-6.0
<i>Donmathew</i>	2018	NA	800-1200	1800-2800	Midland	5.5-6.0
<i>Fetan</i>	2018	105	700-1000	1700-2000	Mid-highland	3.4-5.0

Almost 170 quintals of source seed has been produced in both off-season and main-season multiplications, mainly of early-generation seed and seed for varietal demonstrations (Table 3.4). *Wane* and *Lemu*, for example, were demonstrated on 885 farmers' fields in 2016 and 2017 main seasons.

Table 3.4. Pre-release seed multiplication achievements, 2015-17.

Crop	Year	Number of candidates	Amount produced (qt)
Bread wheat	2015	5	74.6
	2016	14	16.0
	2017	27	12.1
Sub-total		46	102.7
Durum wheat	2017	4	66.4
Total		50	169.1

Pre-release seed multiplication has enabled breeders to speed up the diffusion of durable rust resistant varieties through formal and informal seed systems. Through this approach, the variety *Kingbird* was introduced from Kenya and within a year a large amount of seed was available for demonstrations and further seed multiplication (Fig. 3.7).

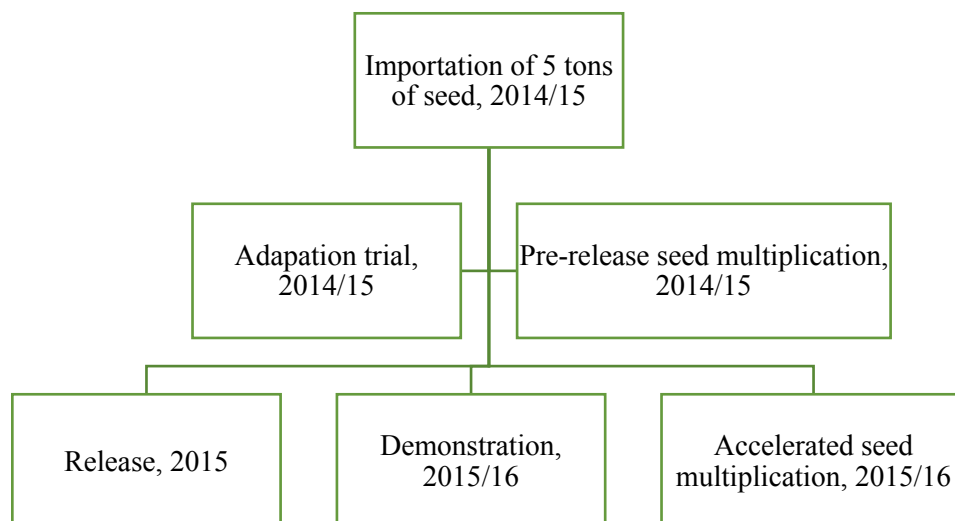


Figure 3.7. Importation and pre-release seed multiplication of Kingbird in Ethiopia.

Kingbird was bred in Mexico, and tested and released in Kenya in 2012 for its stem rust resistance. Breeders observed how this variety was performing under heavy stem rust pressure at Njoro, Kenya (Figure 3.8).



Figure 3.8. Stem rust screening facility at Njoro.

Five tons of *Kingbird* seed was purchased and introduced to Ethiopia through the DRRW project. CIMMYT-Ethiopia facilitated the transport and supported pre-release seed multiplication of the variety on 38 ha of land at Kulumsa research center. In 2015 when it was released 80 tons of clean seed was available for demonstrations and scaling. The Wheat Seed Scaling Project distributed seed of *Kingbird* for demonstration and popularization in many rust affected districts. *Kingbird* is resistant to Ug99 and TKTTF and gives hope for resource poor farmers in stem rust prone areas.

3.5 Challenges

There are considerable discrepancies among researchers, development agents and farmers regarding APR. Most farmers and development agents use fungicide even in the presence of APR in some wheat varieties. Awareness-raising campaigns are needed on the use of APR and researchers should come up with fungicide thresholds for different rust diseases, varieties and locations. During the project we saw limited use of genotypic data to inform varietal development and releases and there was reduced uptake of durum wheat varieties because of seed multiplication and market issues.

3.6 Lessons learned

Enhancing the efficiency of breeding program through multi-location testing of exotic germplasm: CIMMYT has helped establish quarantine testing sites at Kulumsa, Debre Zeit, Holeta, Melkassa, Adet and Sinana research centers. Data from the quarantine sites have been valuable to promote lines to the next stage of variety development. In the past, superior lines selected from most of these nurseries would have been entered into observation nurseries. Under the new approach, materials from international nurseries, particularly yield trials, are directly promoted to advanced yield trials, reducing operational costs and making fast-track variety testing and release more efficient.

Variety diversification through specific adaptation trials: Deploying several wheat varieties having different genetic backgrounds in specific agro-ecologies could help reduce crop loss from rusts. Prior to the direct demonstration and scaling of recently released varieties, adaptation tests are conducted at research centers to identify superior varieties, but it would be better to do such tests on-farm and involving farmers in the selection.

Decentralized early-generation seed multiplication at research centers: In Ethiopia early-generation seed multiplication of released varieties is centralized, which means the research centers that release a variety are mandated to maintain and multiply early-generation seed. In practice, it has been a challenge to avail enough seed of varieties in high demand. The Wheat Seed Scaling Project allowed seed of the resistant varieties *Sofumer* and *Tay*, which were developed at regional centers, to be multiplied by other centers. This decentralized approach enabled breeders to demonstrate and scale-up the varieties to new areas where they were not cultivated before.

Strengthening the capacity of the national breeding program: Over 2015-17 much germplasm was evaluated for various economic traits and targeting various wheat growing ecologies, but the proportion of successful lines retained was low considering the resources allocated, mainly because of the presence of virulent races of stripe and stem rusts, which resulted in the selection of fewer lines with combined rust resistance and superior agronomic traits. This suggests the need to establish core germplasm collections that offer greater diversity and a high-throughput molecular laboratory for the breeding program.

Targeted pre-release seed multiplication and demonstration: Pre-release seed multiplication successfully supported the achievement of project goals, ensuring enough seed. For instance, the early-generation seed multiplied during the 2015 off-season at Werer served as source seed during the 2016 main season. Consequently, 60 quintals of early-generation seed was available at the time of release and breeders were able to use the seed of the new varieties for demonstrations and seed multiplication through formal and informal channels.

3.7 Conclusion

Project has featured excellent coordination and collaboration among Ethiopian and CIMMYT researchers, as well as better integration among breeders and pathologists at federal and regional research centers.

Phenotypic and genotypic pathology data from collaborating institutes such as CDL-USDA have been quite useful for variety advancement, release and seed multiplication. Researchers and research centers' capacities need to be strengthened so that Ethiopian bread and durum wheat landraces can be exploited in breeding. Research facilities and modern tools are required to test and advance important traits.

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Chapter 4

Enhancing farmers' access to rust resistant wheat varieties through demonstrations and field days in Ethiopia

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4.1 Introduction

Wheat farmers in Ethiopia suffer from recurrent epidemics of rust diseases. Newly released, resistant wheat varieties take several years to reach farmers. Most farmers use either recycled seed or get access from the informal seed system (farmer-to-farmer seed exchange, local market etc.). In addition, the seed system is centralized and farmers take several years to be acquainted with the new varieties. Seed demand is based on previously known varieties produced by public seed enterprises. Participatory variety selection (PVS) can be used to identify farmer-preferred varieties and help overcome the constraints that cause farmers to grow old or obsolete varieties (Joshi & Witcombe, 1996; Witcombe et al., 1996). Through PVS, effective demonstrations can help farmers understand that using full recommended input packages will increase productivity and production and improve their livelihoods. Demonstration plots are a key tool for disseminating new technologies and also provide researchers with useful feedback regarding the on-farm performance of new varieties. Through the USAID-supported Wheat Seed Scaling Project, farmers and development agents were exposed to the new varieties through training events, demonstration trials at farmer training centers (FTCs), on farmers' fields and in field days, and the results directly informed seed multiplication and scaling activities.

4.2 Activities and implementation

Various interrelated activities and approaches were employed to demonstrate new varieties and agronomic practices on FTCs and model farmers' fields (Fig. 4.1).

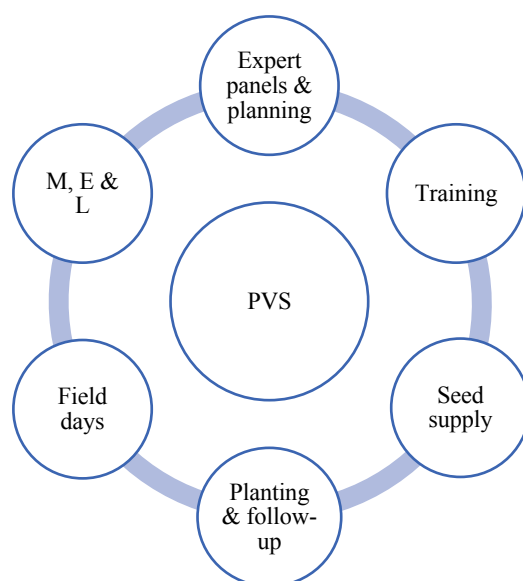


Figure 4.1. Activities and implementation approaches.

Identification of varieties for demonstration: Consultation meetings were held with wheat breeders and pathologists from different centers to choose candidate varieties for demonstrations, based on supporting phenotypic data obtained through KLDN and/or adaptation trials, together with genotypic data. Candidate varieties were classed as highland, mid-altitude or lowland.

Target woredas: Potential wheat growing woredas in Oromia, Amhara, SNNP and Tigray regions were selected for demonstrations of bread and durum wheat varieties (Table 4.1).

Table 4.1. Number of woredas involved in demonstration activities, 2015-2018.

Year	Region				Total
	Oromia	Amhara	SNNP	Tigray	
2015	24	11	9	6	50
2016	25	11	9	6	51
2017	28	11	9	6	54
2018	29	11	9	6	55

Awareness raising, training and joint planning: Through training-of-trainer events held in four regions annually, development agents (DAs), subject matter specialists and experts received instruction on pathology, agronomy and seed technology. Leaflets were distributed for each discipline.

Table 4.2. Wheat varieties used for demonstrations in four regions of Ethiopia, 2015-18.

Bread wheat	Year of release	Research center	Recommended agro-ecology
<i>Deka</i>	2017	Kulumsa	Lowland
<i>Lemu</i>	2016	Kulumsa	Highland
<i>Wane</i>	2016	Kulumsa	Mid to highland
<i>Kingbird</i>	2015	Kulumsa	Mid to lowland
<i>Obora</i>	2015	Sinana	Highland
<i>Bulluq</i>	2015	Bako	Highland
<i>Liben</i>	2015	Bako	Highland
<i>Biqa'a</i>	2014	Kulumsa	lowland
<i>Hidasse</i>	2012	Kulumsa	Mid to highland
<i>Hulluka</i>	2012	Kulumsa	Highland
<i>Ogolcho</i>	2012	Kulumsa	Mid to lowland
<i>Hoggana</i>	2011	Kulumsa	Highland
<i>Shorima</i>	2011	Kulumsa	Mid to highland
<i>Danda'a</i>	2010	Kulumsa	Highland
<i>Alidoro</i>	2007	Holetta	Highland
<i>Tay</i>	2005	Adet	Highland
Durum wheat			
<i>Bulalla</i>	2017	Sinana	Mid to high
<i>Tesfaye</i>	2017	Debre Zeit	Mid to high
<i>Alemtena</i>	2017	Debre Zeit	Low to mid
<i>Utuba</i>	2012	Debre Zeit	Mid to high
<i>Mangudo</i>	2012	Debre Zeit	Mid to high
<i>Obsa</i>	2006	Sinana	Mid to high
<i>Bakalcha</i>	2005	Sinana	Mid to high
<i>Ejersa</i>	2005	Sinana	Mid to high

Packaging and distribution seeds: A total of 16 bread and 8 durum wheat varieties were selected for demonstrations during 2015-18 (Table 4.1). The varieties were allocated to different -ecologies based on their recommendation domains in the registry book and/or adaptation trials by expert panels. In most cases, each variety was demonstrated on plots of 100 m² (10 m x 10 m) on FTCs and model farmers' plots; larger plots (20 m x 20 m) were used for relatively older varieties. The varieties were demonstrated using recommended agronomic practices along with locally adapted ones.

Planting, follow up and supervision: All farm operations were carried out by DAs (in FTCs) and model farmers (in farmers' fields) using recommended agronomic practices for each locality. Follow ups and supervision were carried out by DAs and researchers, depending on accessibility.

Participatory variety selection: Participatory assessment and evaluation of the new varieties were undertaken 2-3 times throughout crop growth. Mainly farmers and DAs were involved in participatory evaluation in the target districts; experts including researchers were engaged as well. Criteria used during PVS at early stages included rust resistance, uniformity in germination, tillering capacity and stand. For final selection, the criteria were earliness,

uniformity in heading, spike length, number of spikelets per spike, number of seeds per spike, height and lodging tolerance at mid-stages and shattering, threshability, seed size and seed color. The criteria were rated using a 1-5 scale: 1 = very poor, 2 = poor, 3 = good, 4 = very good and 5 = excellent.

Monitoring, evaluation and learning: Appropriate extension approaches and extension teaching methods (individual, group and mass contact) were employed alone or in combination during project implementation. Telephone calls, field visits and supervision, field days and group meeting and discussion sessions were used.

Farmer field-days: Field days were organized on selected woredas each year, experiences shared, and varieties selected by farmers for popularization next year. DAs also organized field days in their respective communities for participatory varietal evaluations.

4.3. Achievements

4.3.1 Awareness raising and training

A total of 3,032 experts and development agents, including 369 women, from Amhara, Oromia, SNNP and Tigray received training in the adaptation of new varieties, agronomic practices, seed technology, and rust disease identification and management, by experts from EIAR and CIMMYT. In addition, experts provided similar trainings to 1,845 model/progressive farmers (of whom 430, or 24%, were women). In total, 4,877 people (808 women, 16.6%) took part in training events on the performance of varieties, agronomy, seed technology and pest identification and management (Table 4.3).

Table 4.3. Training for trainers and model farmers during 2015-17.

Year	Experts and DAs		Model farmers		Total		Grand total
	Men	Women	Men	Women	Men	Women	
2015	2,335	333	361	93	2,696	426	3,122
2016	2,493	339	689	191	3,182	530	3,712
2017	2,663	369	1,406	439	4,069	808	4,877
Total	7,491	2,456	2,456	723	9,947	1,764	11,711

Training (durum wheat): A total of 626 (127 female) experts, seed producers, representatives from primary cooperatives and farmers' cooperative unions, as well as model farmers, were trained in field management, disease and post-harvest management and production of high-quality durum seed during 2015-17 (Table 4.4). Similar training was given to farmers at the grass root level by development agents and experts in their respective project districts.

Table 4.4. Participants in annual planning and review meetings.

Participants	2015/16		2016-17		2017-18		Total
	Men	Women	Men	Women	Men	Women	
Farmers	59	20	62	15	58	18	232
Development agents	88	10	91	21	84	24	318
Others	20	5	16	8	21	6	76
Total	167	35	169	44	163	48	626

4.3.2 Demonstrations

The project conducted demonstrations and field days to speed farmer adoption of rust resistant varieties, facilitating seed exchanges and the sharing of experiences among farmers. Seed distribution was based on -ecological suitability and feedback from stakeholders during regional review and planning workshops. Wheat varieties released from regional research institutes were demonstrated on selected farmers' fields. The FTCs and model farmers were instrumental in demonstrating and promoting new crop technologies. This was observed during a field visit to Bale, where model farmers and FTCs increased seed from 2016-17 demonstration plots.

Demonstration fields were supervised by DAs and farmers took part in varietal selection. Farmer feedback was also recorded, discussed during regional review and planning workshops, and helped to guide seed multiplication and scaling activities in each region, zone and district.

Table 4.5. Quantity of seed (kg) used for demonstrations across seasons, 2015-18.

Season	Amhara	Oromia	SNNP	Tigray	Total
2015	600	1,860	540	1,040	4,040
2016	605	470	90	115	1,280
2017	110	355	95	85	645
2018	44	150	110	30	334
Total	1,359	2,835	835	1,270	6,299

Seed use in demonstrations: A total of 6,299 kg of seed of different wheat varieties was distributed across locations and seasons (Table 4.5) for demonstrations. The greatest amount was used in Oromia (2,835 kg) followed by Amhara (1,359 kg) and seed distribution decreased after 2015.

Bread wheat varieties used for demonstrations: Sixteen bread wheat varieties were used for demonstrations in four regions (Fig. 4.2). The highest proportion (22.2%) was of *Wane*, followed by *Lemu* (18%) and *Alidoro* (10.6%). *Wane* and *Lemu* were released in 2016 by Kulumsa Research Center.

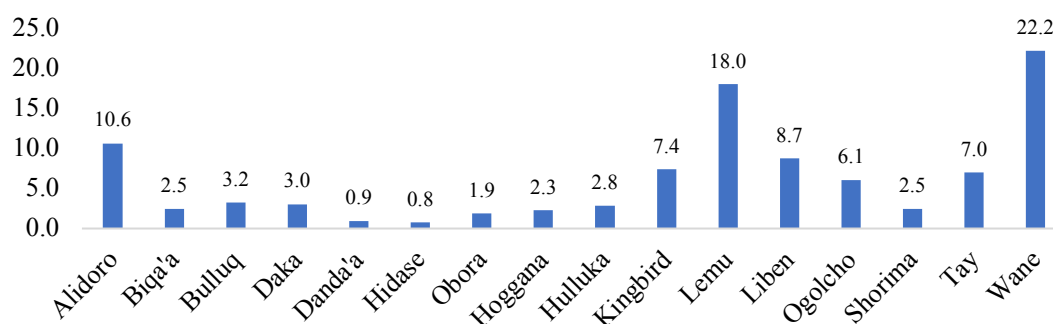


Figure 4.2. Frequency (%) of demonstration plots per bread wheat variety (N=526), 2015-18.

The distribution of these varieties varied across regions (Fig. 4.3) and was based on adaptation trial results and/or recommendation by the expert panels.

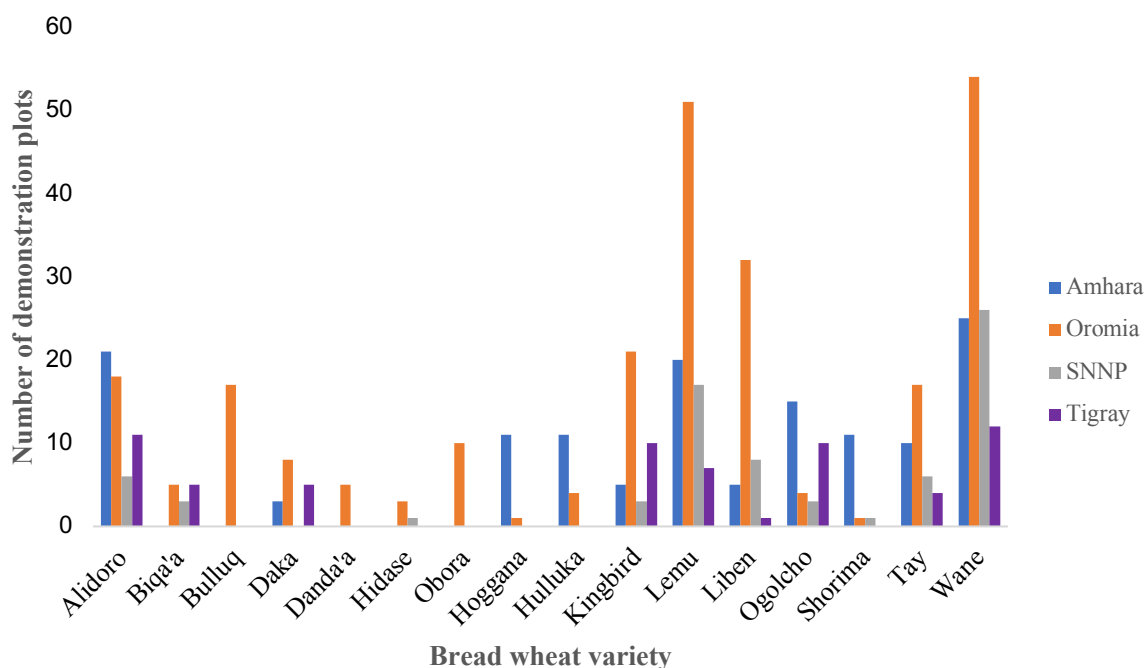


Figure. 4.3. Frequency of demonstration plots per variety x regions, 2015-2018 (n=526).

In 2015, four rust resistant bread wheat varieties released nationally and regionally were selected for demonstrations. *Kingbird* was planted at 10 demonstration sites in Oromia, Amhara and Tigray regions and was used in 33% of all demonstrations that year. *Alidoro* and *Tay* were used in 29% of demonstrations in selected wheat growing Woredas of Oromia, Amhara, Tigray and SNNPs. The bread wheat variety *Biqu'a* was used in Oromia and Tigray in 9% of demonstrations.

In 2016, there was strong involvement of breeders, pathologist and agricultural experts, among project focal persons and 10 bread wheat varieties were demonstrated (Figs. 4.4 and 4.5), with *Wane* and *Lemu* accounting for large areas in 51 woredas.

In 2017, six bread wheat varieties were demonstrated on selected districts previously not covered. *Wane* and *Lemu* were demonstrated in 45 and 27 woredas, respectively.

In 2018, the project demonstrated 9 bread wheat varieties. *Wane* and *Kingbird* were demonstrated in 21 woredas and *Lemu* and *Deka* in 17 and 16 woredas, respectively.



Figure 4.4. Wheat demonstration fields at one of Horo, Wollega during 2016; variety *Liben* (left) and *Alidoro* (right).

Demonstration of durum wheat varieties: Several improved durum wheat varieties were released by federal and regional research centers but farmers had little access to durum wheat seed or other technologies from research centers.

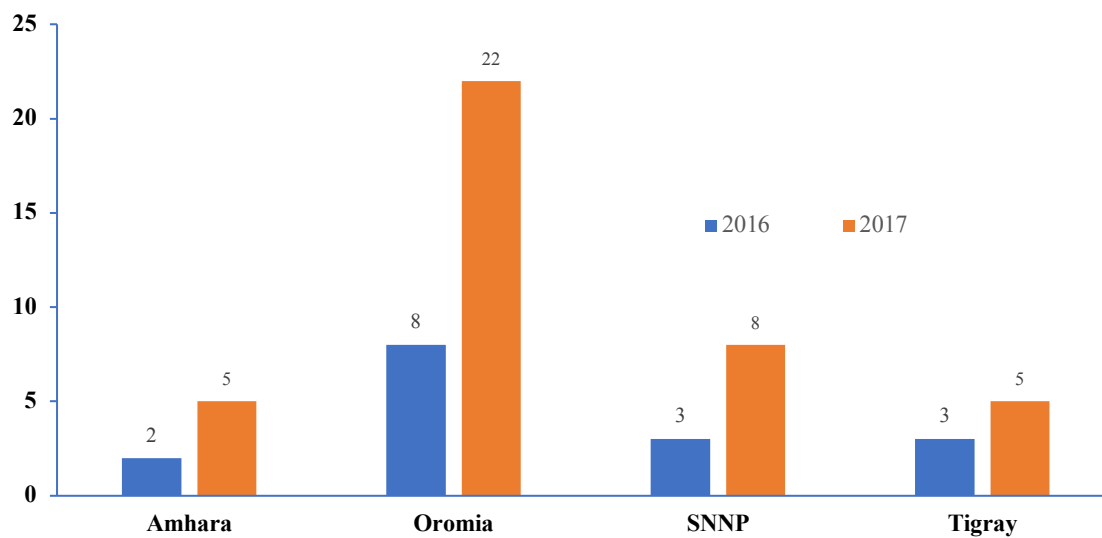


Figure. 4.5. Number of woredas for durum wheat demonstrations in 2016 and 2017.

Stakeholders helped select woredas for demonstrations during the planning workshops, and participation was enhanced at yearly, regional planning workshops. A total of 16 and 40 woredas were identified for demonstrations of durum wheat varieties during 2015 and 2016, respectively (Figure 4.5). Researchers and extension agents were involved in follow-ups on demonstration plots, with eight durum wheat varieties in all being grown (Fig. 4.6.).

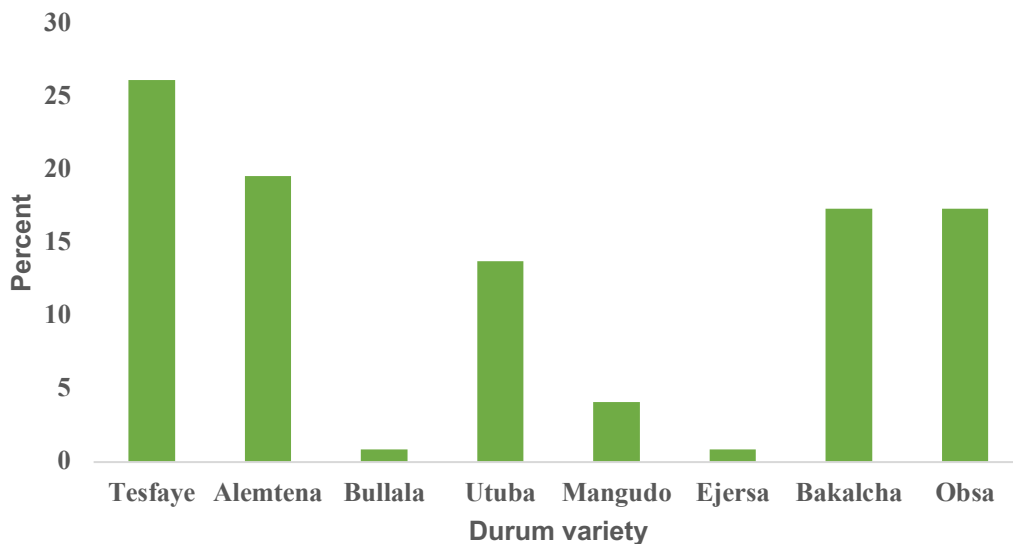


Figure 4.6. Frequency (%) of durum wheat varieties used in demonstrations, 2015-18 (n = 582).

4.3.3 Field days

Field days served to introduce newly released technologies, evaluate the new technologies, exchange experiences among visitors, popularize the accepted technologies with farmers, and expose experts and administrative officials to project activities (Fig. 4.7).



Figure 4.7. A durum wheat field day in Oromia.

A total of 10,984 people participated in field days conducted in the four implementation regions (Table 4.6).

Table 4.6. Number of participants in field days organized in different regions, 2015-18.

Region	Men	Women	Total	% women
Oromia	4,437	460	4,897	9.4
Amhara	3,003	412	3,415	12.1
SNNP	1,246	831	2,077	40.0
Tigray	338	257	595	43.2
Total	9,024	1,960	10,984	

For example, a field day organized in Mojanawodera Woreda, North Shewa Zone, Amhara, in November 2015 engaged 318 (28% female) participants including farmers, DAs, woreda experts and experts from the North Shewa Zone agricultural bureau, as well as researchers and delegates from Amhara seed enterprise. Farmers had sown *Danda'a* and *Hidasie* in clusters. The field day participants visited two of the clusters (78 farmers) with a total of 36 ha of land planted to *Danda'a* and another cluster (four farmers) of 3.5 ha planted to *Hidasie*, with an expected average grain yield as high as 6 t/ha.

A total of 195 participants (65% female) attended a field day at Endagegn Woreda, SNNPR, that same year. Varieties *Alidoro* and *Tay* were grown on selected FTCs and model farmers' fields and yielded very well, being preferred by many farmers despite their late maturity.

A field day at Gimbichu Woreda, Oromia, in November 2015 drew 200 people (5% female) and began at an FTC with demonstrations of improved wheat varieties. 36 farmers had grown *Danda'a*, and farmers shared experiences and feedback that was documented for further improvement within the Wheat Seed Scaling Project.

A field day at Misha Woreda, Hadiya Zone, SNNPR, in December 2016 was attended by 165 persons (20 female), including farmers, researchers, seed producers, development agents, regional experts, and representatives from zone and woreda offices, who visited seed production and demonstration plots and shared ideas and information. The number of field days at a national level was limited due to political unrest, but several regional- and woreda-level field days were held.

Supervision: Regular follow-ups and supervision of on-farm activities were performed by a team of researchers from the project in cooperation with project woreda and BoANR experts, as well as focal persons and development agents. A meeting at Debre Zeit Research Center in November 2016 drew 100 participants (20% female), including woreda focal persons, seed producers, 10 researchers and representative from zonal offices. Woreda focal persons presented the status of demonstration and scaling activities. Discussions covered achievements, constraints, lessons learned and improvements needed.

4.4 Performance of bread wheat varieties

Bread wheat varieties performed according to their adaptation across regions (Fig. 4.8). For example, in 2017 demonstrations, high-yielding and rust resistant releases *Lemu*, (9.2 t/ha), *Wane* (9.0 t/ha), *Liben* (8.2 t/ha), and *Hidasie* (8.2 t/ha) out-performed other entries. In general, the highest yields were obtained in Oromia followed by SNNPR.

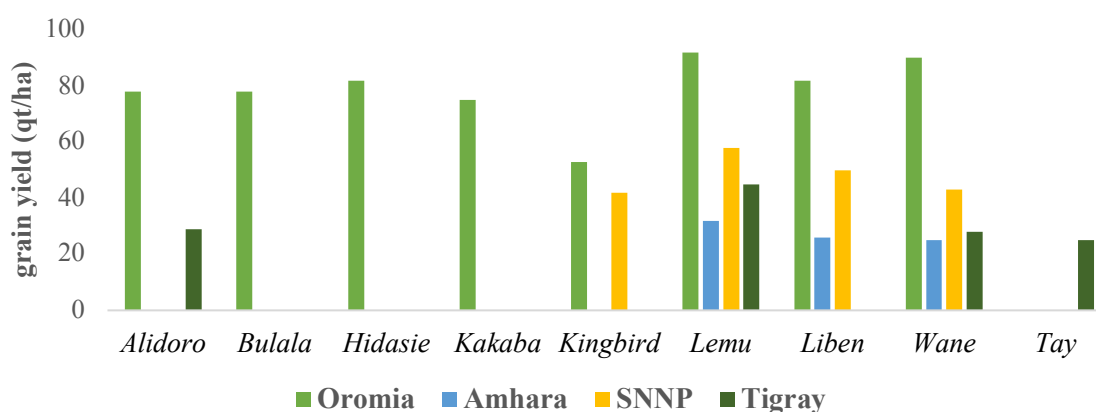


Figure 4.8. Performance of bread wheat varieties across the four regions in Ethiopia, 2017-18.

The performance of the durum wheat varieties varied across locations (Table 4.7). The highest durum wheat yield was obtained in Oromia while the lowest was in Tigray Region. According to these demonstrations, the potential durum wheat districts in Oromia are Sude, Agarafa, Horo, Gimbichu and Robe. In addition, durum wheat varieties performed well in Misha and Mareko (SNNP), Minjar Shenkora (Amhara), and Ofla (Tigray) districts.

Table 4.7. Performance of durum wheat varieties in demonstration plots planted on FTCs across regions, 2017-18.

Region	Variety	Yield (qt/ha)	
		Lowest	Highest
Amhara	<i>Alemtena</i>	20	25
	<i>Tesfaye</i>	18	31
SNNP	<i>Tesfaye</i>	21	55
	<i>Alemtena</i>	24.5	44.6
Tigray	<i>Alemtena</i>	12	51
	<i>Tesfaye</i>	9	47
Oromia	<i>Alemtena</i>	42	80
	<i>Tesfaye</i>	46	90

4.5 Challenges

- Some farmers were reluctant to take durum wheat seed because of durum wheat market issues. Linking durum wheat producers with agro-industries has been challenging.
- Poor data recovery and feedback from some woredas due to staff turnover; over-estimation and under-estimation of grain yield.
- Political instability hindered frequent supervision visits or follow up.

4.6 Lessons learned and conclusions

- The demonstration plots exposed farmers to the most recent wheat varieties, creating opportunities for farmers to request seed of the most well-adapted.

- Field days brought local farmers together to exchange skills, knowledge and seed.
- The demonstration plots of recently released bread and durum wheat varieties from federal and regional research centers promoted crop and varietal diversification.
- Farmer institutions in formal and informal seed systems had opportunities to select varieties for seed multiplication.
- Farmers had quick access to new varieties and agronomic practices.
- Researchers gained direct farmer feedback and farmers interacted directly with researchers.

4.7 References

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Chapter 5

Accelerated seed multiplication of rust resistant wheat varieties through the formal and informal seed sectors in Ethiopia

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5.1 Background

Wheat is a traditional staple crop cultivated by about 5 million households in Ethiopia and its productivity is challenged by several biotic, abiotic and socio-economic factors. The recurrent epidemics of rust diseases have been major challenges for wheat production in Ethiopia. The life span of newly-released varieties is short and seed supplies of rust resistant varieties are meagre. Most farmers do not have access to seed of high-yielding, rust resistant wheat varieties. According to the CSA (2017), the formal seed system accounts for less than 20% of the wheat area. The formal and the informal seed sectors have roles in wheat seed multiplication and delivery. In general, there is an inadequate supply of early-generation seed (breeder, and pre-basic seed) of wheat varieties for relevant agro-ecological zones, as well as few certified seed producers, lack of an efficient seed delivery system, and an overly-centralized production and distribution of seed.

The formal wheat seed system includes all institutions and individuals involved in variety development, release and registration, seed multiplication and processing, quality control and certification, and seed marketing and distribution. The formal seed system operates under rules and regulations governing the production, quality control, and distribution and marketing of certified seed. The major actors in the formal seed system are public seed enterprises such as the Ethiopian Seed Enterprise (ESE), Amhara Seed Enterprise (ASE), Oromia Seed Enterprise (OSE), Southern Nation, Nationalities and Peoples Seed Enterprise (SSE), along with private seed enterprises, federal research centers, regional agricultural research institutes (RARIs) and higher learning institutes.

The research centers supply early-generation seed to seed enterprises and private farms. Generally, the formal sector is characterized by inadequacy, inaccessibility and the supply of few varieties, offering few options for different agro-ecological zones. Crucial challenges in wheat production derive largely from limitations in quality seed production and capacity constraints (facilities, infrastructures) in both systems. There is a shortage of early-generation seed, a limited number of formal seed producers, and lack of an efficient seed delivery system.

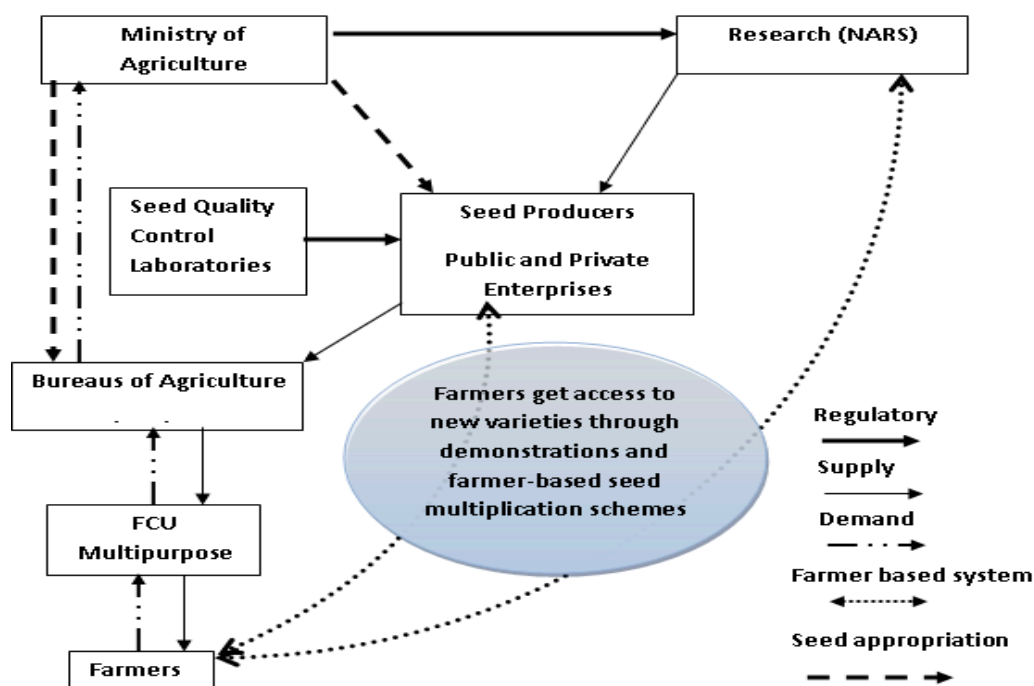


Figure 5.1. The seed system in Ethiopia (Gizaw and Kalsa, 2014).

Small-scale wheat farmers are threatened by the emerging races of rust pathogens in Ethiopia and their susceptible varieties need to be replaced quickly, requiring the engagement of the formal, intermediary and informal seed systems. The chief aim of the project “Seed multiplication and delivery of high-yielding rust resistant bread and durum wheat varieties to Ethiopian farmers” implemented by CIMMYT during 2014-18 in partnership with EIAR and with funding from USAID and described in this report, was to increase wheat production and achieve food security through accelerated seed multiplication.

The specific objectives have been to (i) strengthen the capacity of research centers to supply sufficient early-generation seed, (ii) increase the number of private seed growers, farmer seed producer associations, including women farmer groups, and farmer cooperative unions (FCUs) participating in accelerated seed multiplication of resistant wheat varieties, and (iii) improve the capacity of the formal seed and informal seed systems to multiply seed of rust resistant wheat varieties more quickly.

5.2 Activities

The project provided initial seed and technical and material support to seed producers. Specific activities included (i) increasing the supply of pre-basic and basic seed of rust resistant wheat varieties, (ii) enhancing stakeholders’ (public, private, smallholder seed producing farmers) capacity in accelerated seed multiplication, (iii) increasing the production of commercial seed of rust resistant wheat varieties, and (iv) boosting the supply of seed of improved wheat varieties through informal seed systems.

5.3 Partners and stakeholders

Partners and stakeholders included federal and regional research centers, public and private seed enterprises, cooperative unions, farmer seed associations and women’s groups

(Table 5.1). Ten research centers from EIAR and regional research institutes (RARIs) have been engaged in research-based, early-generation seed multiplication. These centers were linked both to formal and informal seed producers to supply initial seed. Four public seed enterprises (federal and regional) were engaged to produce certified seed and, in some cases, basic seed. A total of 10 farmer cooperative unions, 12 farmer seed producing associations and 4 private seed farms were engaged in accelerated seed production of rust resistant wheat varieties.

Table 5.1. List of partners and stakeholders engaged in accelerated seed multiplication.

Research centers	Public seed enterprises	Farmers' cooperative unions	Seed producer associations	Private farms
Adet Areka Bako Debre Birhan Debre Zeit Holetta Kulumsa Mekele Sinana Werer	ESE	Oromia (5) Lume Adama, Hettosa, Sekomendo, Chefe- Buluq Raya Wakene	Oromia (4) Biftu, Megertu Hawi Giche	Gadisa Amauri Ethio-veg
	OSE	SNNP (2) Ediget Zeretta	Amhara (3) Sebadar Limichin Memhir Hager	Zendetta
	ASE	Amhara (2) Tegulet (N.Shewa), Ediget (Gojam)	Tigray (1) Hashenge	
	SSE	Tigray (1) Andinet Raya	Women SPAs Megerisa (Oromia) Tiret (Amhara) Tembo Awtena & Akach (SNNPR)	
10	4	10	12 (8+4)	4

5.4 Implementation

Federal and regional research centers and public and private seed enterprises multiplied different classes of seed of high-yielding, rust resistant varieties (Fig. 5.2). Research centers produced early-generation seed (breeder, pre-basic and basic seed), while private and public seed enterprises produced certified seed and early-generation seed (basic seed). Farmer cooperatives, unions, seed associations and women's groups produced different classes of seed, depending on certification agencies' quality standards. Some seed producers were linked to the formal seed sector. The seed was also sold within the community, depending on the quality and market availability.

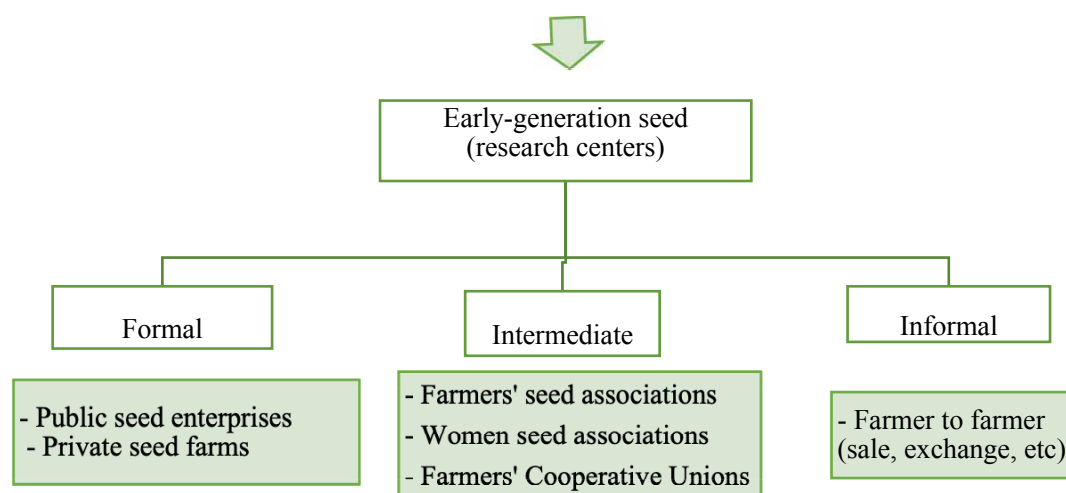


Figure 5.2. Different classes of seed produced by different institutions.

Procedures under the accelerated seed multiplication scheme included the identification of varieties, awareness raising and training, joint planning and review with stakeholders, technical backstopping and establishing and pursuing market linkages.

Identification of varieties for multiplication: Eight to 10 research centers multiplied early-generation seed yearly during the main and off seasons using supplementary irrigation. The varieties were selected based on adaptation and data from demonstration trials across project sites. In addition, data on resistance to major diseases from testing at Njoro, Kenya, disease data from Ethiopian locations, single race nursery data from Kulumsa, and seedling and genotypic resistance data from CDL-USDA were used by breeders and stakeholders in annual meetings to select varieties whose seed to multiply. Based on the breeders' recommendations using phenotypic and genotypic data, wheat varieties were identified for early seed multiplication in the main and off-seasons using supplementary irrigation. Those varietal selections were supplemented and refined during regional planning and review workshops with stakeholders.

To supply enough early-generation seed to seed multipliers, pre-release and post-release approaches of accelerated seed multiplication schemes were followed: i) two crop cycles per year; the main cropping season followed by off-season, irrigated production at Werer and Kulumsa research centers; ii) increased multiplication rates through intensive management, including a newly recommended seed rate, for fast-track seed increases; and iii) strengthening the capacity of seed producers and research center facilities.

Awareness raising and training: In-country training for stakeholders in the formal and informal seed sectors supported quality seed production and included the distribution of brochures and manuals and participation in field days to demonstrate improved seed production technologies.

Joint planning and review: Yearly joint planning and review meetings with researchers, seed producers, experts and development agents at the regional, zonal and district levels included the selection of varieties for multiplication, information exchange, and feedback on varietal performance.

Revolving seed loans: The project provided basic seed public and private seed producers, FCUs, primary cooperatives and seed growing farmers associations, which were encouraged and advised on seed multiplication. Private seed producers, FCUs and informal seed

producers received early-generation seed “loans” for repayment. Every year data on the distributed seed, area coverage, total production and repaid seeds were recorded and summarized.

Capacity building: The project gave a seed cleaner to a farmer cooperative union in SNNP. Five wheat seed threshers were donated to five women associations. Similarly, the project provided three seed cleaners to three FCUs in Amhara, Oromia and Tigray. The machines were installed and operational training given.

Technical backstopping and market linkages: Attempts were made to link wheat seed producers to markets. The regional seed regulatory authorities cooperated on the timely inspection and certification of seed on farm and in warehouses.

5.5 Results and outcomes

5.5.1 Seed produced by research centers: Eight research centers produced a total of 2,382 tons of early-generation seed during the project (Fig. 5.3). The early-generation seed include 233 tons of breeder seed, 1,147 tons of pre-basic seed and 1,002 tons of basic seed. Kulumsa research center produced 44% of the seed, Werer 23%, and Debre Zeit 12%; the remaining centers (Holetta, Bako, Sinana, Debre Birhan, Adet and Mekele) produced 522 tons of seed of different classes. The wheat seed was provided to commercial seed producers or used for on-farm seed multiplication, variety popularization and large-scale promotion. Seed of 17 bread wheat and 7 durum wheat varieties was multiplied, in both off-season (under irrigation) and main season seed plantings.

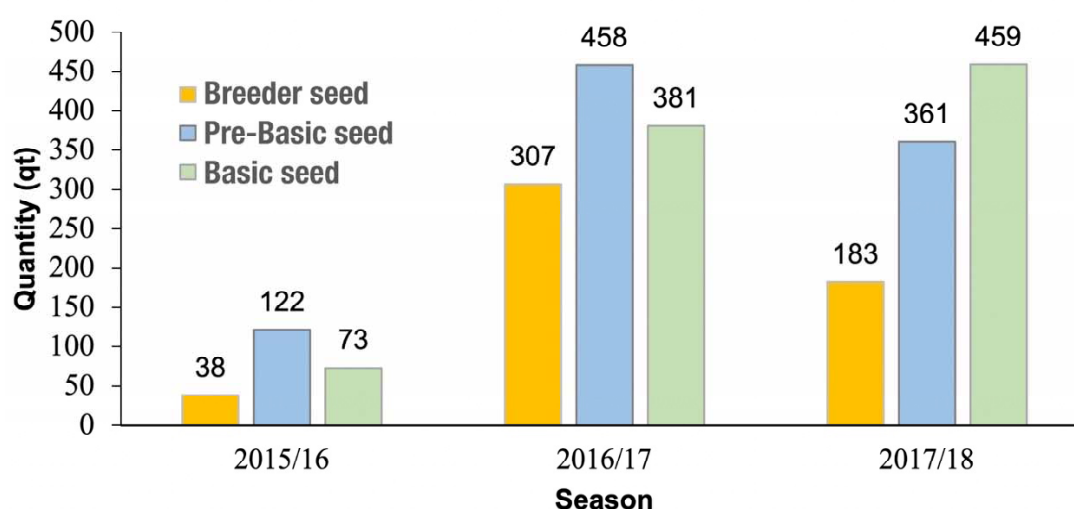


Figure 5.3. Quantities (qt) of seed produced by research centers under the project, 2015-18.

Accelerated early-generation seed multiplication by research centers using two seasons per year considerably improved the availability of initial seed for growers, as well as for demonstrations and promotion.

Awareness raising and training by research centers has greatly improved the quality and quantity of early-generation seed supplies. About 50 farm managers and seed experts from federal and regional research centers also benefited from in-country training on quality seed production of pre-basic and basic seed. Material support included the distribution of three double-cabin pick-ups, two tractors with accessories and diverse laboratory equipment,

including a durum wheat quality testing machine for Debre Zeit and equipment for the quarantine laboratory at Holetta, among others. In addition, a total of 156,000 polybags (ethylene bags) of different sizes and carrying the EIAR logo were delivered, for seed promotion and marketing.

5.5.2 Seed produced by private farms and farmer associations: Community-based seed multiplication supported by the project worked through local private seed producers and FCUs. Production and delivery were accompanied by physical and technical support and advice on improved crop management techniques. On-farm seed production plots were inspected by the external regional regulatory agencies that also formally certify the acceptability of the plots and protocols. A total of 4,629.2 tons of seed was produced by private farms and farmers' institutions during 2015-16 to 2017-18 (Table 5.2)

Table 5.2. Quantity (tons) and yields (t/ha) of seed production by different organizations under the project.

Organization	2015	2016	2017	Total	Yield (t/ha)
Private farms	31.5	172.0	188.0	391.5	4.1
Farmer cooperative unions	-	826.2	1,080.2	1,906.4	3.6
Women's seed producer associations	-	706.4	682.3	1,388.7	4.3
Seed producer associations	-	373.1	569.5	942.6	3.5
Total	31.5	2,077.7	2,520	4,629.2	3.7

Private seed farms (PFs): The project provided 21 tons of pre-basic and basic wheat seed on revolving basis to four private farms and these farms produced 392 tons of different types of seed (Fig. 5.4). Attempts were made to link private seed farms to markets. In addition, the project bought seed for redistribution to surroundings farmers.

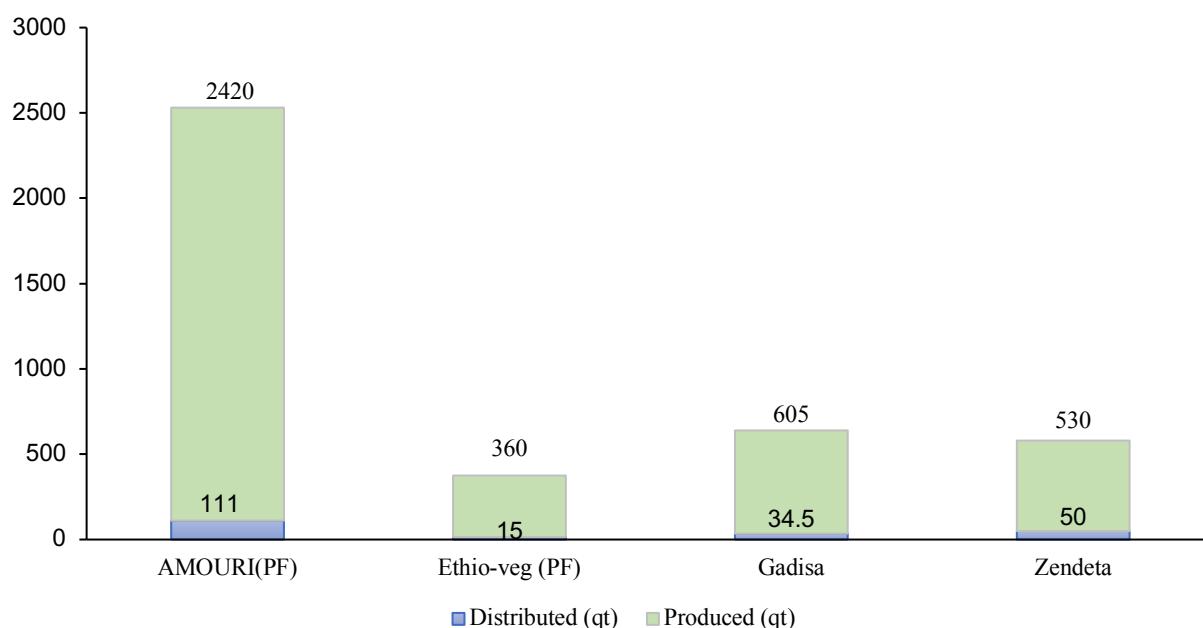


Figure. 5.4. Quantity (qt) of seed distributed and produced by four private farms, 2015-18.

Farmer cooperative unions: Farmer cooperative seed unions (FCUs) are legally registered enterprises to produce and sell seed (FCA 2016). They are well-organized and have experts in seed production, management and marketing. Seed unions often produce seed through primary seed cooperatives that are members of the seed union. In some regions, selected multipurpose unions can operate as seed businesses, as long as they fulfil the criteria set by the regional quality control agency.

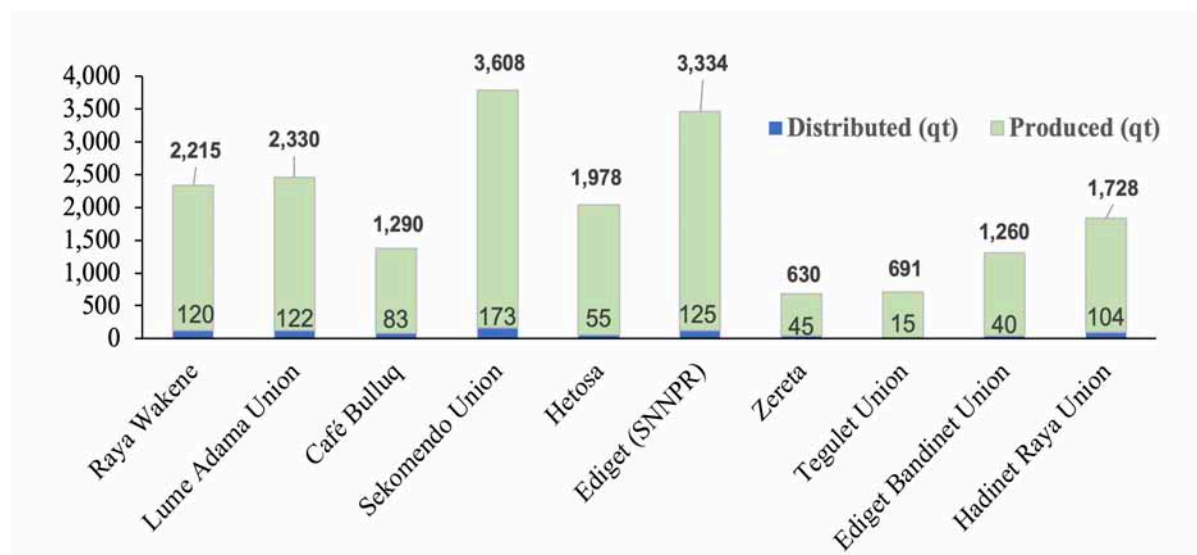


Figure 5.5. Quantity (qt) of seed produced and distributed by farmer cooperative unions, 2015-18.

In 2016-17 and 2017-18 cropping seasons, 88.2 tons of early-generation seed of improved wheat varieties was provided to 10 FCUs. Of these, 19,064 quintals of seed were produced (Fig. 5.5). The seed was sold either directly or through public seed enterprises to farmers in the vicinity. The Wheat Seed Scaling Project purchased certified seed and re-distributed it to different districts as part of scaling. Purchasing seed directly from FCUs reduces transport costs and helps give farmers access to seed of durum wheat and other varieties adapted to

their agro-ecological zones. Farmers also profited through seed production; for example, members of Zereta Kembata Seed Multiplication and Marketing Union in SNNP region collected more than \$90 each, on average, in payments from the union in 2018. According to Mr. Yosef Balewold, manager, the union collected certified seed of various wheat varieties grown by more than 1,100 farmers, several hundred of whom were women, belonging to eight cooperatives. Using a seed cleaning machine supplied by the project, the union was able to market cleaned and packed seed, which brought better prices to members.



Figure 5.6. Seed production of variety *Sofumer* by Raya Wakene FCU at Dodolla, Oromia, 2016.

Seed produced by farmers' seed associations (FSAs): The informal sector operates without license or certification with small-scale wheat farmers, farmers' seed producer associations, and women and youth groups as major actors. The proximity and lower prices of seed from such providers makes it more accessible to small-scale farmers than seed from the formal sector. During the Wheat Seed Scaling Project, more than 93 tons of early-generation seed of mainly three bread wheat varieties (*Kakaba*, *Kingbird*, and *Wane*) and two durum wheat varieties (*Mangudo* and *Ude*) were provided to 8 FSAs, which produced 943 tons of seed (Figs. 5.7 and 5.8).

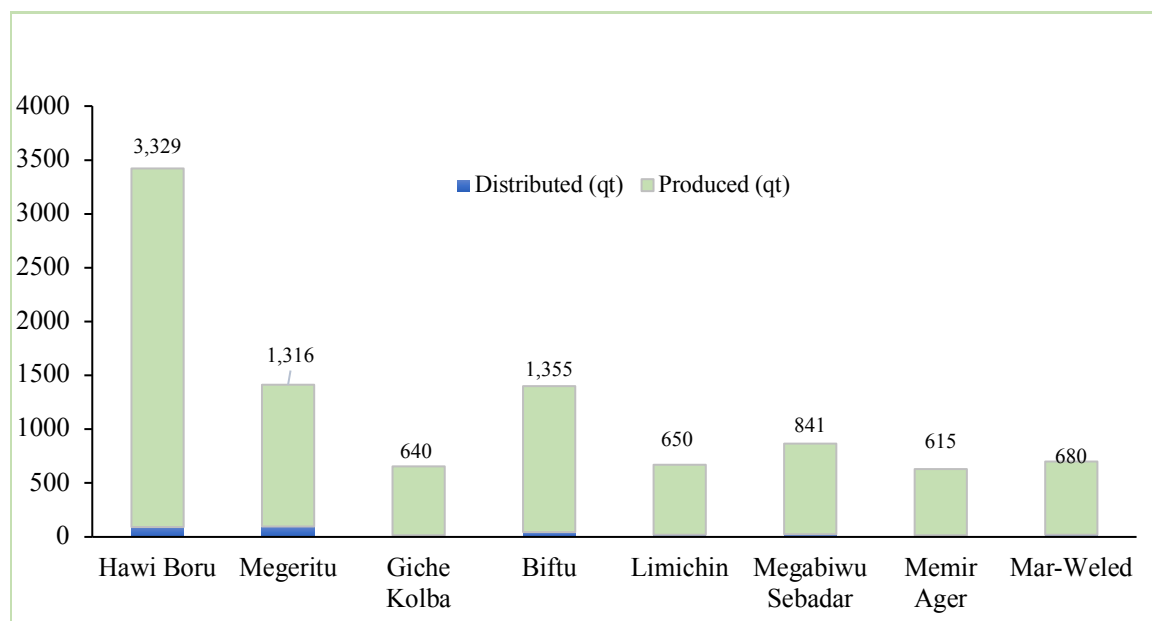


Figure 5.7. Quantity (qt) of seed distributed and produced by eight FSAs, 2015-18.

Large numbers of multipurpose cooperatives involved in seed production do not have a legal license to produce or sell seed but work with public and private seed companies on contract, mobilizing members to work as out-growers. The cooperatives provide services such as the supply of inputs (seed, fertilizer), sale of seed grown by farmers, negotiating prices with contracting parties (big seed companies), and supporting members' access to training and technical support in seed production and marketing.



Figure 5.8. Production of seed of durum wheat variety *Mangudo* by Biftu FSA, Lume Woreda.

Intervening in the informal seed sector for wheat was an important part of the Wheat Seed Scaling Project. Whereas the formal sector usually focuses on a few widely-adapted varieties, offering fewer options for small-scale, resource-poor farmers (Bishaw et al., 2015), the informal sector can handle a higher number of improved varieties, helping small-scale farmers in promoting new varieties and technologies and improving their access to quality seed at affordable prices. Informal seed multiplication activities were handled mainly through individual farmers and farmer seed producer associations.

The participation of farmer seed grower associations in intermediate, on-farm seed multiplication was the other aspect the project pursued to alleviate seed shortages. The establishment of such associations usually with about 25-30 members was encouraged and it is believed that they gradually transform into formal seed producers, depending on their capability. The associations were assisted through the provision of source seeds of improved varieties and technical backstopping.

Seed produced by women seed producer associations: In collaboration with district agricultural offices, the Wheat Seed Scaling Project mobilized women farmers to form seed producer groups in Angacha and Endegagn Woredas of SNNP (Figs. 5.9 and 5.10); Lode Hetosa District (Arsi Zone) of Oromia region and Moretna Jiru District (North Shewa) of Amhara region, viewing the group approach and ownership of enterprises as ways to empower women farmers.



Figure 5.9. Seed production by women's seed producer associations at Angacha and Endegagn Woredas, SNNPR.

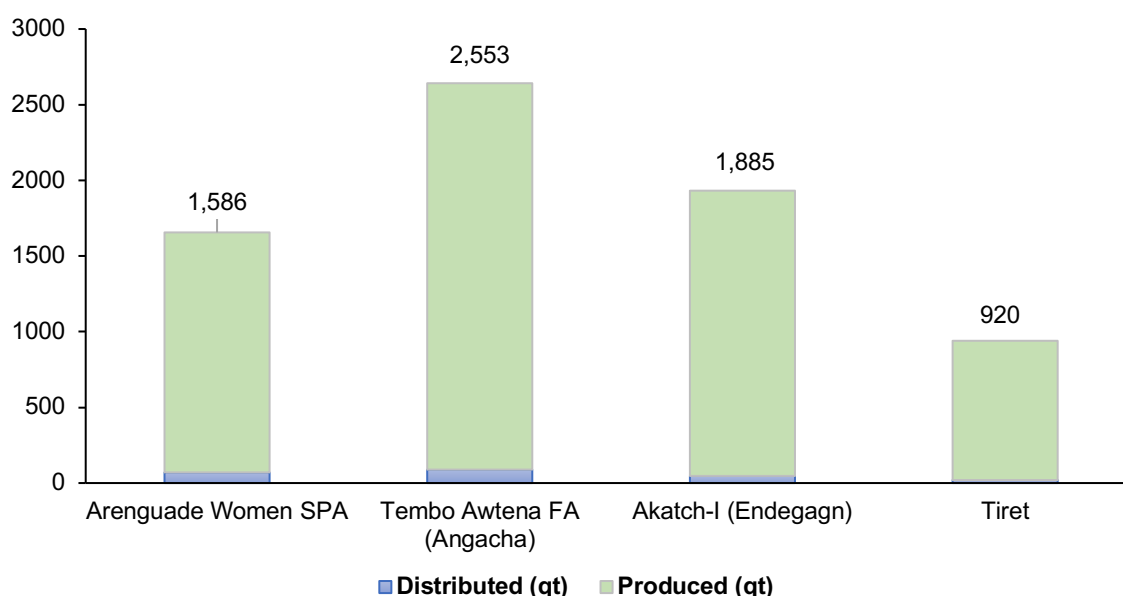


Figure 5.10. Seed produced and distributed by four women's seed producer associations, 2015-18.

The project provided nearly 17 tons of source wheat seed to women seed producer associations in 2016-17 and 2017-18 cropping seasons; enough to sow 163 hectares and produce 694 tons of seed of different types (Fig. 5.10). Some of this was sold to regional seed enterprises with a 15% premium price. It was found as well that women seed growers produced better quality wheat seed than men farmers and, with technical support and initial financing from the project, quickly became self-sufficient in seed production. For example, the Tembo Awtena WSPA in Angacha District, SNNP, began producing wheat seed for sale in 2015. A member of Zereta FCU, the association received early-generation seed from the project and a seed thresher from CIMMYT-Ethiopia. Said Tembo Awtena Chairwoman, Amarech Desta: "With the new machine, members could thresh in three hours what would have taken us three days by oxen or by hand. In 2016 we sold more than \$7,400 worth of seed. Our success attracted 30 additional women farmers in 2017, bringing the total membership to 133."

5.5.3 Seed produced by public seed enterprises: Meeting the increasing demand for seed of newly released rust resistant wheat varieties from federal and regional seed enterprises, private companies and farmer seed associations has been a challenge. Working through extensive partnerships, the Wheat Seed Scaling Project has helped to meet this demand, supplying varieties with superior yield potential, end-use quality and combined resistance to stem rust and yellow rust. The capacity of public seed enterprises to provide certified seed has increased significantly during the project period, owing to the engagement of a greater number of capable contract growers, including farmers and farmer seed producer associations, who have gained experience through the project's informal, on-farm seed multiplication scheme.

In the last three years, early-generation seed supplied to public enterprises comprised 41.9 tons of breeder seed, 242.8 tons of pre-basic seed and 49.9 tons of basic seed, a total of 334.7 tons. In 2017-18, four public seed enterprises produced 56,468 tons of certified seed of wheat varieties (Fig. 5.11), enough to sow 23-28% of the wheat area.

Despite the apparent demand, each year public enterprises were left with 15-20% of seed they produced but could not market. This could be due to discrepancies between demand and the supply of varieties targeted to specific agro-ecologies. For example, about 50% of the varieties produced in 2017-18 fit low-to-mid highlands, while the majority (>60%) of the wheat area is located in the highlands. The exact demand for wheat seed should be assessed based on results of adaptation and demonstration trials in farmers' fields and FTCs.

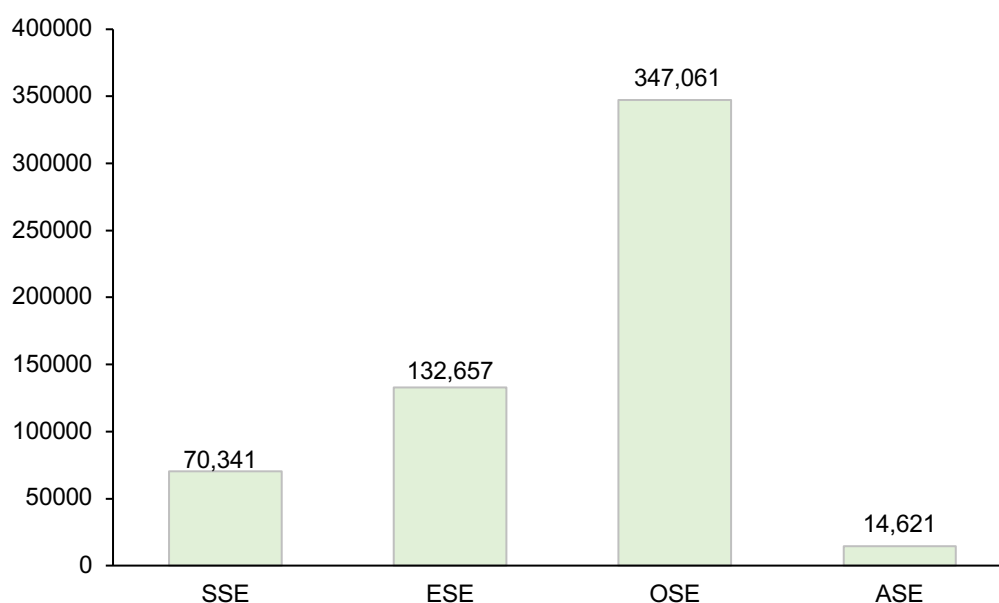


Figure 5.11. Quantity (qt) of certified seed produced by four public seed enterprises (PSEs) (2017/2018).

The public seed enterprises Ethiopian Seed Enterprise (ESE), Amhara Seed Enterprise (ASE), Oromia Seed Enterprise (OSE) and South Seed Enterprise (SSE) are the major actors in formal wheat seed production and marketing. They did not receive direct support from the Wheat Seed Scaling Project but benefit from project activities in various ways. They obtained larger amounts of early-generation seed of new and old rust resistant wheat varieties from research-based seed multiplication than was previously the case. Also, the early-generation seed and the training provided to farmers by the project have created better and broader options for the enterprises to source seed from farmer-based multiplication schemes through contractual agreements with farmers or associations that meet quality standards. Finally, thanks to the project, the demand for certified seed has risen, because farmers are now more aware of the need to replenish regularly their own saved or deteriorated seed of improved varieties.

5.6 Challenges

- The rate of recovery of seed loaned to farmers via the revolving scheme was low, due to the mixing of seed of different varieties during mechanical harvesting, especially in Arsi and Bale.
- Rust pathogen races frequently change.
- Farmers, development agents and even researchers do not properly understand APR.
- There were market problems, especially for durum wheat.

5.7 Lessons learned

- Joint planning and reviews meetings and field days proved to be excellent ways for exchanging information among stakeholders and getting feedback on varietal performance, as well as increasing demand for seed of new varieties.
- Use of lower seeding rates increased the seed multiplication factor.
- The cluster approach (combine plots of adjacent farmers) for seed multiplication was useful to introduce improved technologies and link production to market outlets.
- The decentralized wheat seed multiplication system gave farmers access to seed of bread and durum wheat varieties adapted to their agro-ecologies.
- Researchers, DAs and farmers' understanding of the meaning of APR increased.
- Seed production fields managed by women gave higher yields than those managed by men.
- Two seasons per year of seed multiplication increased the availability seed of resistant wheat varieties.

5.8 Conclusions and ways forward

- Rapid deployment of rust resistant varieties to cope up with fast-evolving rust strains requires efficient seed systems that considerably improve farmers' access to improved technologies and seed. Also crucial is farmers' use of a diversity of varieties to avoid total crop failure in case of serious disease outbreaks; this has to be backed with technology generation/adaptation from the research side. The formal sector might not be that efficient in maintaining diversity, but the opportunities in the informal sector have to be exploited. Wheat research programs in partnership with the Wheat Seed Scaling Project have strived to develop and spread improved production technologies, enhancing the availability of early-generation seed and increasing the food security and household income of farming communities.
- Future R4D should support wheat seed systems with business models and value chain development, especially for durum wheat. Organizing seed producer associations into big seed unions could improve their business performance, increase their market competitiveness, and improve their access to markets. The associations also need to be recognized in basic seed allocations, both national and regional. The government and development partners should support and strengthen wheat seed producer associations, as well as both the formal and informal seed sectors, to ensure wheat seed security in Ethiopia.

- For sustainable wheat seed production and supply it is essential to strength public-private partnerships within Ethiopia's national agricultural research system, as well as linkages with diverse stakeholders including international research centers and funding agencies. Future productivity in wheat will most likely increase through the integration of disciplines and institutions in technology generation, seed multiplication and promotion, and market and product creation. Moreover, only through concerted inter-institutional efforts can we bring about a technological breakthrough and better the livelihoods of resource-poor farmers in Ethiopia.

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Chapter 6

Scaling out rust resistant wheat varieties through “seed loans” in Ethiopia

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6.1. Introduction

Despite wheat’s primary importance as a food crop in Ethiopia and the country’s long history of wheat cultivation (CSA, 2014), the crop’s productivity has remained low due to several biotic, abiotic and socioeconomic factors, significantly wheat stem rust and yellow rust diseases and the failure of seed systems to respond to ever-changing rust pathogen races.

The USAID-supported Wheat Seed Scaling Project that operated during 2014-18 built on efforts described in earlier chapters of this document and chiefly aimed to increase farmers’ access to seed of rust resistant varieties. This chapter describes activities and achievements in varietal demonstrations, farmer field days, community-based seed production and a scheme of seed loans to foster increased seed production and availability.

6.2. Participating woredas

Fifty-four woredas (the number per region are in parentheses) were identified in consultation with stakeholders from Oromia (28), Amhara (11), SNNP (9) and Tigray (6) regions during the consultation and planning workshops and based on their potential for wheat production and the prevalence of rust diseases.

6.3. Activities and implementation

Diverse partners and stakeholders participated to implement the activities included in scaling seed of rust resistant wheat varieties to farmers, as follows (Fig. 6.1).

Workshops: At the inception workshop, representative from different research institutes, MoA, BoA, ATA, ICARDA, CIMMYT, seed suppliers, and model farmers provided comments and feedback that were incorporated in the work plan. In subsequent national and regional consultation, planning and review workshops, participants developed joint work plans, identified regional, zonal and district level project focal persons, selected prospective wheat varieties and seed sources, and detailed activities and responsibilities among stakeholders. Varieties were selected based on their performance in adaptation trials conducted by researchers and in demonstration plots on FTCs and model farmers’ fields.

Training of trainers: Each year at least four training events were held with development agents (DAs) on the new varieties, including crop management practices and seed production techniques.

Seed purchase and dissemination: Certified seed of selected varieties was purchased, packed in labeled 37.5 kg bags, and transported to participating woredas and kebeles. The seed was distributed to selected farmers through farmers' primary cooperative on a revolving basis—that is, as loans to be repaid by farmers. Development agents provided training to participating farmers in clusters. The woreda office was responsible for collecting the seed at the end of the year.

Training of farmers and monitoring activities: Development agents from each kebele were responsible for training farmers in clusters, as well as following and monitoring the activity from planting to harvesting, threshing and storage.

Field days: Field days were held for farmers, researchers, and development partners to share experiences.

Revolving seed collection and re-distribution: After threshing, the loaned seed was collected by woreda focal persons, checked for quality, and redistributed to another farmer in the vicinity. Special emphasis in re-distribution was given to resource-poor farmers and women-headed households.

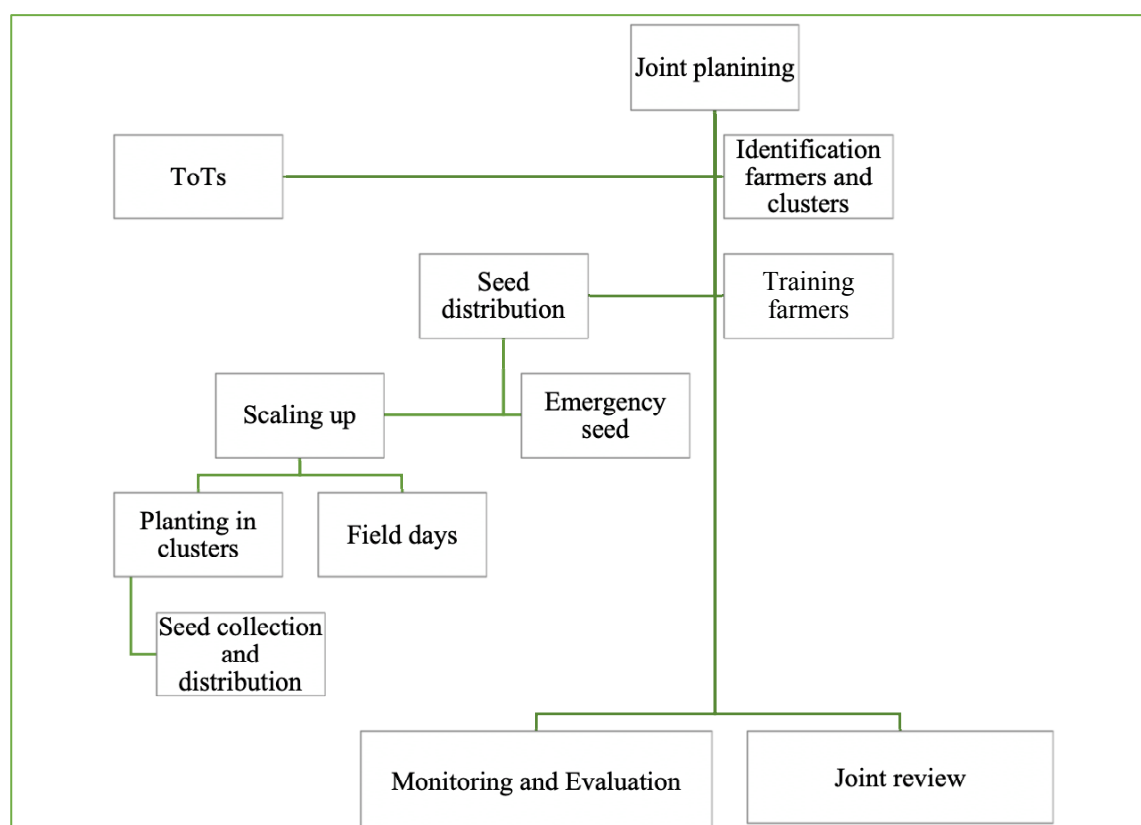


Figure. 6.1. Activities and implementation to scale seed of rust resistant varieties.

6.4 Partners and stakeholders

See Chapter 1 for a complete listing. In addition to CIMMYT (project leader) and EIAR (principle partner), key wheat sector actors included farmers, district agriculture offices, farmer cooperative unions (FCUs), seed producer associations (SPAs), private farms (PFs), and women's seed producer associations (WSPAs). Other stakeholders and partners included EIAR research centers and regional agricultural research institutes (RARIs), the Federal Ministry of Agriculture (MoA), regional bureaus of agriculture and natural resources (BoA) and public seed enterprises described in Chapter 5.

Seed scaling used certified seed procured from suppliers including seed enterprises, FCUs, private farms and seed producer associations. Seed was provided to farmers on a revolving basis (essentially, a seed loan) whereby farmers committed to pay back the same amount of seed they received. To expand scaling the following year, new and loaned seed was given to farmers who had not benefited the previous year.

6.5. Achievements

6.5.1 Training of farmers and field days

Training: Each year the project conducted training for regional experts, development agents and subject matter specialists on new varieties, disease identification and management, agronomy, seed and post-harvest technologies (see Chapter 4). District and kebele DAs in turn trained progressive farmers at different stages of crop development (Fig. 6.2)



Figure 6.2. Farmer training events.

Field days: Stakeholders from different institutions participated in regional, zonal and woreda level field days to evaluate the new technologies and exchange experiences among farmers, researchers and development agents. The field days drew over 10,900 participants (see also Chapter 4). Fields were also designated at each woreda and kebele close to FTCs to evaluate new technologies on FTCs and cluster plots in model farmers' fields (Fig. 6.3).



Figure 6.3. Field days on durum wheat clusters in Bale, 2017.

6.5.2 Provision of seed to farmers

A total of 2,097.5 tons of wheat seed (1,199 tons of certified seed and 898.5 tons of second-generation certified seed) of different bread and durum wheat varieties was directly supplied to farmers in four regions (Fig. 6.4).



Figure 6.4. Seed transportation and distribution in Bale.

Supply of first-generation certified seed (C1): Certified seed was provided to model farmers organized in clusters, allowing DAs to monitor seed multiplication using recommended production packages. A total of 1,199 tons of certified seed of rust resistant bread (13) and durum wheat (5) varieties identified based on demonstration plot performance was distributed to model farmers in 4 regions. The final variety deployment decisions were made jointly with stakeholders during annual planning meetings. The quantity of seeds distributed to each region was based on the number of districts participating in scaling activities (Fig. 6.5). Farmers in Oromia Region received the highest quantity (571.2 tons) of certified seed followed by Amhara and SNNP.

Seed distribution was based on regional wheat production statistics and conducted by woreda offices. Each district received about 8 tons of C1 wheat seed each year, on a revolving basis.

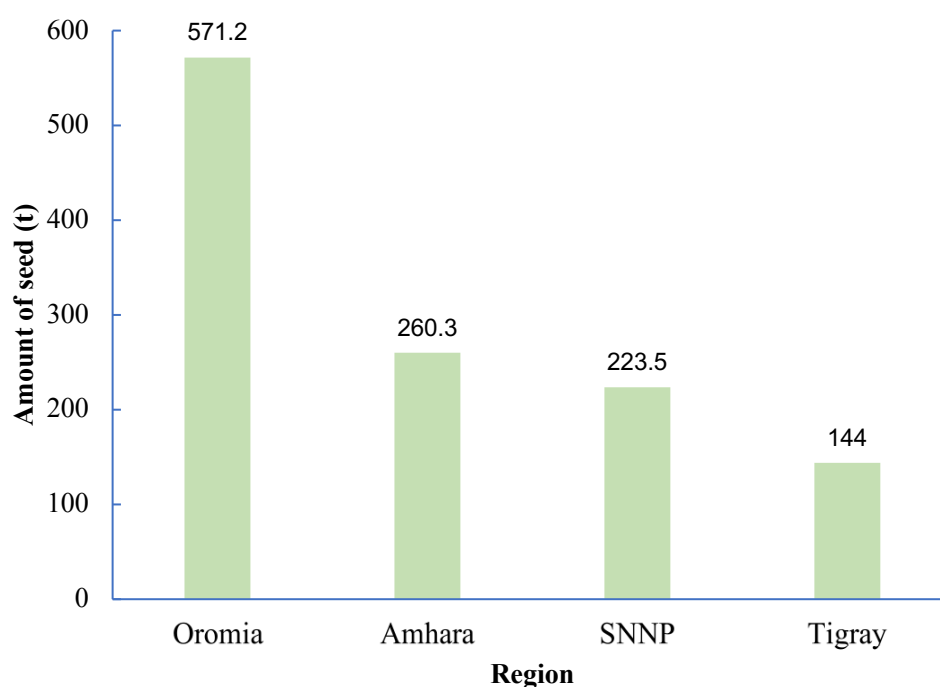


Figure 6.5. Certified seed of bread wheat and durum wheat varieties distributed to farmers in 54 districts of Oromia, Amhara, SNNP and Tigray regions.

Revolving seed scheme (C2): Participating farmers received certified (source) seed as a loan to pay back with an equivalent amount of seed after harvest, an approach that helped to scale farmers' access to seed of new varieties. Managed by districts and kebele- and village-level focal persons using official agreements and legal enforcement where needed, the scheme was generally effective but encountered occasional quality challenges due to seed getting mixed during combine harvesting, especially in Arsi and Bale. Drought also affected seed production in some areas.

Repayment in the form of C2 seed was collected from 48 of 54 districts (89%). The approach accelerated the introduction and promotion of newly released, rust resistant wheat varieties and strengthened community-based seed production and farmer seed exchanges.

Table 6.1. Quantity of C2 seed (tons) collected from farmers across regions and years.

Year	Oromia	Amhara	SNNP	Tigray	Total
2015	118.4	54.7	53.4	27.3	253.7
2016	166.0	73.6	62.1	25.5	324.2
2017	167.2	68.9	60.9	20.6	317.6
C2 seed collected	451.6	197.2	176.4	73.4	898.5
% seed recovery	79.1	75.7	78.2	50.9	74.9

C2 seed collected from farmers totaled 898.5 tons (75% of total C1 seed distributed) and was re-distributed to additional farmers. The highest recovery rate was in Oromia and the lowest in Tigray, due largely to drought.

6.5.3 Wheat area coverage

A total of 17,866 ha was sown using C1 and C2 seed provided directly to farmers (Table 6.2), who seeded at a rate of 1.17 qt/ha, on average. Farmers in Oromia seeded at the highest rate (1.3 qt/ha) and the lowest (1.1 qt/ha) was in Amhara. Also a lower seed rate (1.1 qt/ha) was associated with C1 than C2 seed (1.3 qt/ha), possibly due to differences in seed quality and the participation of DAs with model farmers in sowing C1 seed (C2 seed was distributed preferentially to non-model farmers).

Table 6.2. Area (ha) sown with certified seed (C1) and second-generation seed (C2) across regions, 2015-17.

Seed class	Region and area sown (ha)				Total
	Oromia	Amhara	SNNP	Tigray	
CI seed	5,017	2,481	2,177	1,126	10,801.0
C2 seed	3,134.4	1,797.5	1,321.4	812.1	7,065.4
Total area	8,151.4	4,278.5	3,498.4	1,938.1	17,866.4

6.5.4 Beneficiaries

Direct seed supply to farmers (C1 and C2): A total of 29,643 households (21.7% women headed) benefited from the provision of C1 and C2 seed during 2015-17.

C1 seed: A total of 13,953 households (16.6% women-headed) benefited from the direct provision of certified seed of bread and durum wheat varieties during 2015-17 seasons (Table 6.3). The highest percentage of women beneficiaries was in Tigray (26%).

Table 6.3. Number of households benefiting from direct provision of certified seed (C1) of bread wheat and durum wheat varieties across the regions, 2015-17.

Beneficiaries	Region				Total beneficiaries
	Oromia	Amhara	SNNP	Tigray	
Male	3,357	4,360	2,281	1,643	11,641
Female	504	454	775	579	2,312
Total	3,861	4,814	3,056	2,222	13,953
% female	13.1	9.4	25.4	26.1	16.6

Revolving seed (C2): A total of 15,690 households (26.2% women headed) benefited from the redistribution of C2 seed collected from model farmers (Table 6.4). Unlike the certified seed, more attention was given to women households and other resource-poor farmers. The highest frequency of women-headed household beneficiaries was in SNNP (53%) followed by Tigray (26.1%), while the lowest proportion of women beneficiaries was in Amhara.

Table 6.4 Number of households benefiting from direct supply of second-generation certified seed (C2) of bread wheat and durum wheat varieties in four regions, 2015-17.

Beneficiaries	Region				Total beneficiaries
	Oromia	Amhara	SNNP	Tigray	
Male	3,357	4,297	2,281	1,643	11,578
Female	504	454	2,575	579	4,112
Total	3,861	4,751	4,856	2,222	15,690
% female	13.1	9.6	53.0	26.1	26.2

6.5.5 Wheat production and productivity

A total of 65,673 tons of seed of improved wheat varieties was produced using C1 and C2 seed provided to farmers in four regions during 2015-17 (Tables 6.3 and 6.5). By seed class, farmers produced 39,748 and 26,001 tons of C2 and C3 seed, respectively. This production was used either as seed or grain, depending on the quality and demand from neighboring farmers. Given that most varieties were new in each area, they were expected to be exchanged, sold and/or given to friends.

Table 6.5. Wheat area, seed production and average productivity per region, 2015-17.

	Region				Total or average
	Oromia	Amhara	SNNP	Tigray	
Area (ha)	8,151.4	4,278.5	3,498.4	1,938.1	17,866.4
Production (t)	31,627.4	15,958.8	12,699.2	5,387.9	65,673.4
Yield (t/ha)	3.88	3.73	3.63	2.78	3.68

Average yields ranged from 2.78 to 3.88 t/ha, with the highest in Oromia and the lowest in Tigray, and some progressive farmers who grew resistant varieties using recommended practices achieved yields of from 4 to 6 t/ha. The Wheat Seed Scaling Project has not only improved access to seed of rust resistant varieties but also contributed to higher yields. The highest yields were in 2016 (4.23 t/ha average) and the lowest (3.0 t/ha average) in 2015, the latter due mainly to drought conditions, especially in the Rift Valley and parts of Tigray and Amhara regions. On average wheat productivity increased from 3.3 t/ha during the baseline year to 3.7 t/ha in 2017.

6.6 Challenges

- Revolving seed recovery did not go as expected in some districts due to drought, seed mixtures where combine harvesting occurred (particularly Arsi and Bale), frost and unexpected rain at harvest.
- Rust incidence affected some previously resistant bread wheat varieties in the highland areas of Oromia, Amhara and SNNPR.
- Political unrest and staff turnover at the woreda level affected field days and monitoring and evaluation.

6.7 Lessons learned

- Engagement of key stakeholders starting at the planning stage was useful. The direct involvement of stakeholders from different institutions enabled smooth implementation of activities.
- Mobilization of public/governmental resources minimized costs and increased efficiency in technology generation, demonstration, seed multiplication and popularization.
- Addressing farmers in clusters enhanced information exchange, efficient use of resources and quality seed production. The seed-cleaning machine provided to one FCU improved access to quality seed and income for members.
- Support for WSPAs in the form of threshers reduced drudgery, made threshing more efficient, and generated income via provision of threshing services for neighboring farmers.
- Efforts to link regional seed regulatory authorities with seed producers enabled FCUs and private farms access to certified seed, which they could sell at a better price and easier access for farmers.
- Communities diversified their wheat fields by having access to bread wheat and durum wheat varieties of different genetic backgrounds, thereby reducing the risk of catastrophic losses to rust diseases.

6.8 Conclusions

- Through training and field days, the project raised awareness among development agents and farmers regarding the monitoring and management of wheat rusts, crop management practices, the availability and value of seed of new varieties, and post-harvest technologies.
- Participating farmers benefited directly from access to seed of different varieties.
- The direct beneficiaries increased their yields by growing high-yielding and rust resistant varieties and, through this and community seed production, raised their incomes.
- Farmer-to-farmer training, field days and demonstration plots on FTCs and model farmers' fields were also key to raising awareness, and farmers in communities associated with those activities have benefited through seed exchanges or purchases from neighbors.
- In general, participating farmers (direct and indirect beneficiaries) diversified their wheat fields and minimized rust epidemics, lowered production costs, and increased their wheat yields and production.
- The regular engagement of researchers and development agents in awareness raising, planning and review workshops, demonstrations, field days and scaling activities strengthened research-extension linkages.

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Chapter 7

Integration of smallholder farmers into the durum wheat value chain: Achievements, challenges and lessons learned

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7.1 Introduction

Despite the growing demand for durum wheat by local agro-processing companies and the availability of suitable agro-ecologies in Ethiopia, durum wheat production has been declining over the last few decades, being replaced increasingly by bread wheat. A wheat baseline survey in 2015 showed that durum varieties covered merely 5% of the national wheat area (Setotaw, 2016). Conversely, most local pasta manufacturing depends mainly on imported wheat widely believed to be hard bread wheat, as well as local hard bread wheat, despite the fact that local durum wheat production has a comparative advantage over the import market (Senait et al., 2006).

Several concerted research and development efforts have sought to improve the performance of the durum wheat sector in Ethiopia. The national durum wheat research program in collaboration with CIMMYT and ICARDA have released high-yielding, rust resistant durum varieties with acceptable industrial quality. Since 2000, 24 improved durum wheat varieties – 8 of which are semi-dwarf varieties (CIMMYT, 2015) – have been made available to smallholder farmers, provide average yields of from 2.5 to 4.5 t/ha on farm, and overall meet the quality standards of agro-processing industries in Ethiopia (Setotaw, 2016). However, the adoption of improved durum wheat production technologies and durum wheat marketing by smallholder farmers depends on the development of viable and remunerative market linkages.

With this context and based on success stories from the Bale durum wheat value chain project (2011-15) led by Ethio-Italian Development Cooperation (Genene Gezu- project coordinator, personal communication), the Wheat Seed Scaling Project chose to include promoting enhanced market linkages between smallholder durum wheat producers and domestic pasta manufacturing industries as a strategic intervention and pursued this aim in 10 potential durum growing districts through innovative business models involving contractual arrangements based on group approaches, including work with farmers' cooperatives and unions. The project sought to play a facilitator and catalyst role through the provision of key enabling linkage facilities. This chapter examines the achievements and major challenges of that effort, while drawing key lessons from previous durum value chain interventions.

7.1.1 Local pasta processing industries

With its strong linkages to agriculture, the agro-processing industry has been identified as the third priority subsector in manufacturing, next to textiles and leather, in Ethiopia's industrial

development strategy (MoI, 2002). In terms of industrial value of production, it is the largest subsector of the manufacturing industry. There were about 621 medium- and large-scale agro-processing companies with a total value of production estimated at Birr 13.10 billion that accounted for 25% of the country's total value of manufacturing products in 2010-11 (CSA, 2012).

The pasta manufacturing industries are becoming an important sector of agro-processing in Ethiopia, although they have currently a limited industrial value share. According to a recent survey report on manufacturing industries, there are about 20 pasta making factories producing 50 thousand metric tons of different pasta products mainly for local markets (CSA, 2012) and accounting for 4.3% of the gross value of agro-processing products. Population growth and rapid urbanization offer a real market opportunity for pasta manufacturing, but the sector has major limitations including a poor use of capacity (only about 55.5%, on average), a strong reliance on imported wheat, which supplies as much as 50% of the wheat used by the industry, and a lack of competitiveness that constrains exports (CSA, 2016). The low capacity utilization primarily stems from a shortage of raw materials, along with a lack of market demand, frequent interruptions in power and water supplies, and working capital constraints (CSA, 2015 and 2016).

Based on the current production performance, the raw material consumption for pasta manufacturing industries in Ethiopia is estimated at about 71,085 tons per annum but could reach 110,538 tons, if it were to operate at full capacity.

Ethiopian pasta manufacturing industries mainly target local markets, but imported pasta products are increasingly competing with local products, offering higher quality associated with the use of better raw materials and modern processing technologies, and recently averaging more than 37,000 tons per year, or 40% of national supplies at an annual average cost of 584.5 million birr, according to trade data for 2010-17 (Fig. 7.1).

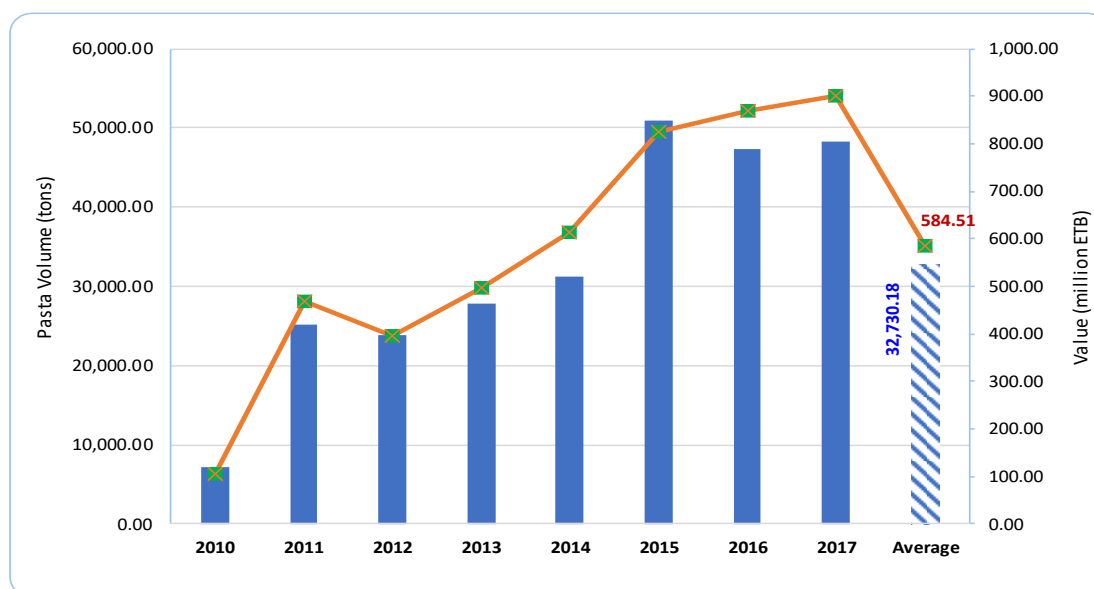


Figure 7.1. Imports of pasta products, Ethiopia, 2010-17. Source: Computed using ERCA data.

Supplying 65% of the total pasta import to Ethiopia, Turkey was the leading pasta exporter followed by Oman (24%), UAE (3%), and Saudi Arabia (3%) (Fig. 7.2).

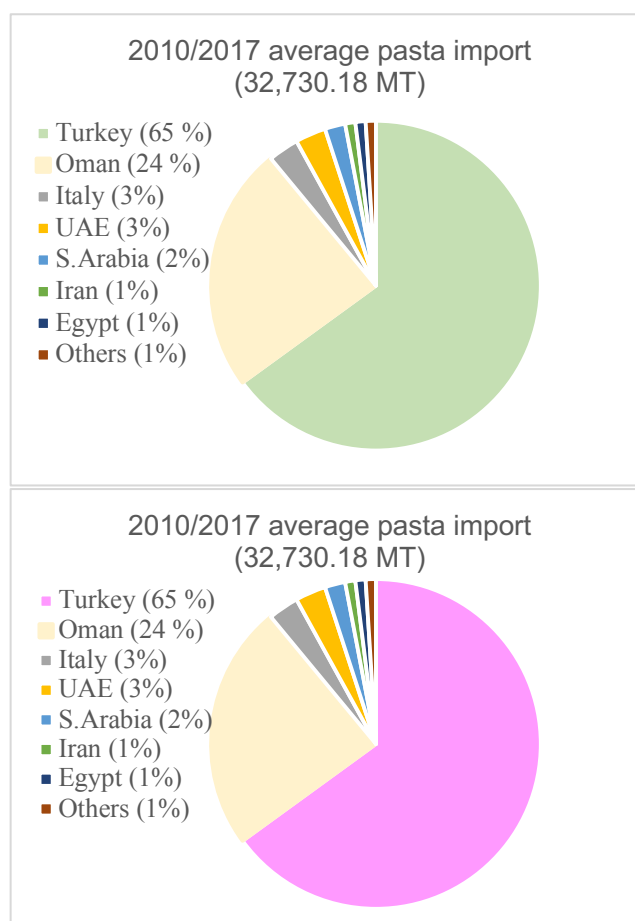


Figure 7.2. Sources (%) of pasta imports to Ethiopia, 2010-17. *Source: Computed using ERCA data.*

7.2 Local durum wheat production and supply

Wheat is an important raw material for wheat-based food agro-processing industries in Ethiopia. Reports show that 57% of the total wheat production in Ethiopia is consumed at the farm level, while 22% marketed (CSA, 2015b). Due to diverse constraints described in detail in other chapters, national wheat production falls short of domestic demand and Ethiopia imports 23% of the wheat it consumes (FAOSTAT, 2016).

Durum wheat was the dominant wheat crop during the 1980s, covering as much as 70% of the wheat area (Abdalla et al., 1992; Getachew et al., 1992). Durum wheat production has declined in recent decades due in part to the promotion of high-yielding, semi-dwarf bread wheat varieties and formidable competition from tef, the cereal used to make injera, in more traditional durum wheat growing areas (Tesafye and Demissie, 1992). Recent wheat baseline survey results and some conservative expert opinions estimate the current durum wheat area at below 10% of the total wheat area.

Urbanization, population growth, improved incomes and dietary diversification are driving rapid growth in wheat consumption and demand for wheat-based food products such as bread, flour, macaroni and spaghetti in Ethiopia and other African countries (Jayne et al., 2010). At the same time, local agro-processing industries handle only 53% of the total wheat supply in local markets (World Bank, 2012); the remainder is traded in the form of unprocessed whole grain.

A recent survey report showed that the local durum wheat supply is critically low, causing high demand from local agro-processing industries for hard wheat varieties (FBPIDI & TNS, 2017). Since local hard wheat production is also very limited, 94% of wheat processors mix hard wheat with soft wheat to improve the quality of their products. About 1.7% of wheat processing factories use hard and soft durum wheat types and only 1% used exclusively hard wheat.

The major raw material suppliers for local wheat processing industries include commission agents, cooperative unions, farmers, government, and traders (FBPIDI & TNS, 2017). Local pasta manufacturing industries in Ethiopia commonly obtain their raw materials from local and import markets.

Local markets: Hard bread wheat from major wheat growing areas is the predominant product, with a very limited supply of durum wheat. If durum wheat shares at local markets reached 15% of total wheat production with a marketable surplus of 21.5%, the national average for wheat, the local durum wheat supply would amount to 112,000 tons---almost equivalent to the potential demand for durum wheat by the pasta industry. There are Ethiopian durum wheat varieties that meet industrial quality standards (Senait et al., 2006).

Import markets: The main source of hard wheat types for pasta industries in Ethiopia, import trade supplied 1.4 million tons of wheat worth 9.4 billion Birr each year during 2014-17. Common wheat types accounted for 63% of import volumes, hard wheat 36%, and durum wheat only 1% (Fig. 7.3). This disproves local agro-industry claims that they produce pasta from high-quality durum wheat and, in fact, the price of imported durum would raise production costs to the point of making local pasta products uncompetitive.

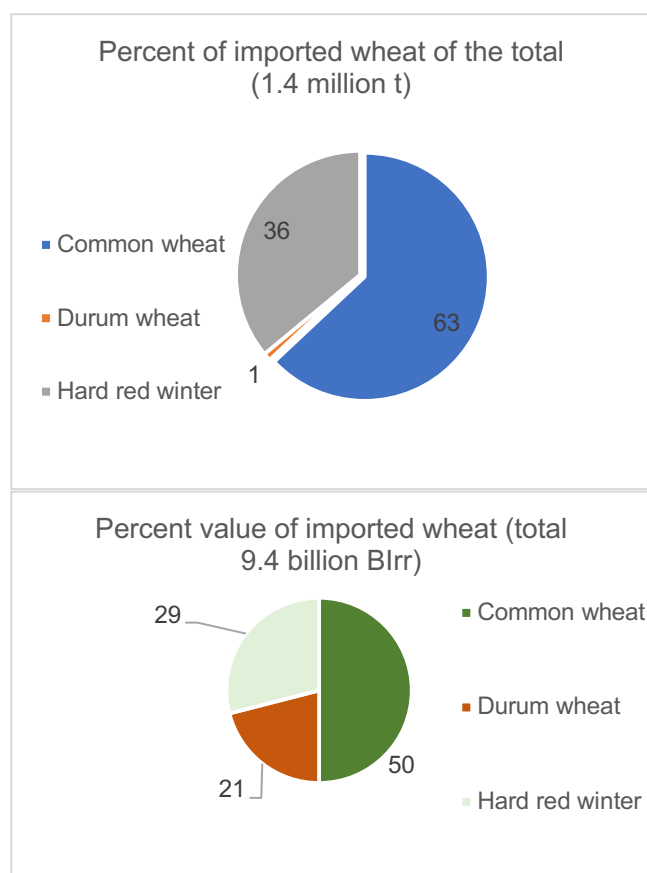


Figure 7.3. Wheat import in Ethiopia during the period 2014/2017 by wheat type Source: computed from ERCA data.

7.3 Previous durum wheat market linkage interventions

Several efforts over the last 15 years have sought to integrate smallholder durum wheat producers with local pasta agro-processing industries and promote the adoption of improved durum wheat farming technologies, primarily following intermediary-driven business models with research and development partners helping to facilitate business partnerships.

7.3.1 Research facilitated smallholder-processors market linkage

The first research-driven market linkage initiative was implemented by the national durum wheat research program at Debre Zeit Agricultural Research Center (DZARC) in 2000-01. It promoted adoption of market-preferred improved durum wheat varieties through a business model linking smallholders with local pasta industries and involved woreda bureaus of agriculture, woreda administrations, farmers research groups, farmer cooperatives and unions and processors. Kaliti Food Share Company (KFSC) took part pilot testing of the approach in selected durum wheat farming areas, including Ada, Akaki, Lume, Liben, Ziquala, Minjar-Shenkora, Sodo and Mareko. The Yerer and Lume-Adama cooperative unions as well as the Kesem primary cooperative participated.

The main argument for importing wheat by local pasta producers was a perceived lack of quality in local durum wheat, so the initiative identified improved durum wheat varieties with industrial standard quality. KFSC did lab tests on quality and nine durum wheat varieties were selected for promotion and commercialization (Table 7.1).

Table 7.1. DZARC-released durum wheat varieties and industrial quality standards.

Variety	Year of release	Properties			
		HLW (kg/hl)	Extra hard/soft	Wet gluten (%)	Protein (%)
Gerardo	1976	78.60	90/10	33.77	15.01
Boohai	1982	82.50	94/6	28.90	13.90
Foka	1993	81.50	95/5	30.27	13.04
Kilinto	1994	80.10	94/6	27.40	13.90
Tob 66	1996	82.85	97/3	35.80	15.47
Quami	1996	82.15	99/1	28.90	13.90
Asassa	1997	83.50	100/0	32.70	14.77
Ude	2002	82.40	96/4	31.03	14.39
Yerer	2002	83.50	99/1	32.12	14.63
Standard		>	90/10	27.36	13.15

Source: Durum Wheat Research Program at DZARC (unpublished).

A memorandum of understanding among DZARC, KFSC, and bureaus of agriculture (BoAs) from Ada'a, Lume and Akaki woredas formalized efforts to promote and grow quality durum wheat varieties for agro-processing. A contract between farmer research groups established by DZARC and KFSC stipulated that DZARC would provide source seed and technical

support to farmers. Participating farmers sowed seed of the varieties *Kilinto*, *Foka*, *Quamy*, *Tob 66*, and *Boohai* and KFSC was to pay a 20% premium over market prices for the grain, provided it met industry standards, with logistics managed by the company and field supervision and monitoring by the BoAs. It was expected that 50 tons of quality durum wheat would be supplied to the pasta factory in the first season, but only 7.5 tons were actually purchased due in part to lengthy quality testing and procurement procedures. The remaining grain was sold on local markets at a much lower price.

Despite this, the number of participating farmers increased in the second season and the total durum wheat supply reached 150 tons, but the factory breached its agreement, arguing that the supply was too small and not economical for its business operation, and farmers subsequently switched to growing bread wheat. The following major limitations were identified from this initiative:

- The approach was primarily research-driven technology promotion, with participating farmers engaged through FRGs, rather than farmer organizations such as cooperatives or unions.
- The scale of intervention was limited, failing to generate a viable bulking size for processing.
- The contracts were insufficiently structured or detailed, with clear commitments and mutual business interest between farmers and agro-processors.
- Quality testing was lengthy and payments to farmers by the company overly delayed.

DZARC tried to restart the initiative in 2005-06, establishing a durum wheat stakeholders' platform and applying lessons from the first attempt. The new platform brought together research (DZARC), KFSC, farmers and farmer unions/cooperatives (Kesem, Lume-Adama and Yerer), offices of agriculture and woreda administrations of eight districts (Ada'a, Akaki, Liben, Lume, Mareko, Minjar-Shenkora, Sodo and Ziquala) and was expected to foster market linkages and promote improved durum wheat technology, developing a structured MoU and establishing a technical oversight committee. DZARC in turn facilitated contractual arrangements between farmers and processors and provided quality seed, training, technical backstopping and platform moderation. The first year, 85 smallholder durum producers in Ada'a Woreda produced 236 tons of durum wheat but KFSC purchased only 25% of this (Table 7.2). The following season, 712 farmers from two woredas produced 1,384 tons of durum wheat grain, only 21% of which was purchased by the company. In the third year, production by 1,238 participating farmers in East Shewa Zone reached 4,768 tons and the factory bought only 1.25%.

Table 7.2. Contract durum wheat production, 2005-08.

Cropping season	Woreda	# of farmers	Production (t)	Amount purchased (t)	Amount purchased (%)
2005/06	Ada	85	23.6	60	25
2006/07	Ada and Akaki	712	13,840	300	21
2007/08	Minjar-Shenkora Ada, Ziquala and Lume	1238	4,768	60	1.25

Source: DZARC Research Extension (unpublished data)

In addition to the issues hindering the first phase of the initiative, concerns included contract breaches (side sales) by farmers and unions and a lack of company support for contract growers. While not taking part in further market linkage initiatives, DZARC has been actively engaged in durum wheat technology scaling, fostering production of 1,350 tons of durum wheat (Table 7.3).

Table 7.3. Durum wheat technology scaling up during 2008-2012.

Cropping Season	Woreda	# of farmers	Production (t)
2008/09	Ada'a, Ziquala, Sodo, Mareko, Meskan	250	250
2009/10	Minjar, Mareko, Meskan	193	156
2010/11	Minjar, Meskan, Mareko	242	234
2011/12	Minjar, Ziquala, Ada, Mareko, Meskan	632	711
Total	9	1317	1,350.4

Source: DZARC, Research Extension (unpublished data).

7.3.2. Development partner-facilitated market linkages

This initiative was implemented in Bale zone jointly by the Oromia Bureau of Finance and Economic Development (BoFED) and the Ethio-Italian Development Cooperation.

The initiative aimed to reach the production of 50,000 tons of quality durum wheat grain from 2011-12 to 2016-17, thus meeting industrial demand for that period. Stakeholders included 4 unions and 15 agricultural cooperatives, Sinana Agricultural Research Center (SARC), and local institutions in Agarfa, Ginir, Goro, Gololcha, and Sinana of Bale zone, with some 10,000 smallholder farmers as expected beneficiaries. In the first year, SARC supplied 46 tons of basic seed of improved durum wheat varieties *Bakalcha* and *Ejersa*. Its current sustainability is uncertain, but the project was successful at linking smallholder farmers with agro-processing industries using a contractual business model, with achievements including the following.

- Significant increases in quality durum wheat supplies to local pasta industries, reaching 4,500 tons by 2013-14.
- Introduction of grain supply contracts system between unions and local agro-processing industries.
- Awareness raised regarding grain quality and market linkages through events with cooperatives and processing industries.
- Introduction of grain quality-based price incentive mechanisms.
- Capacity building for cooperatives and unions in aggregation and bulking of durum wheat supplies, including investments in warehouse facilities.
- Joint promotion of new seed multiplication schemes for achieving both larger volume and high quality of durum wheat supplies and generally promoting sustainable high quality and homogeneous and consistent supplies.
- Empowering and engaging more farmers cooperatives.

- Support to cooperatives in the form of high-quality seed, training and technical assistance.
- Capacity building and equipment for local institutions.
- Continuous lobbying and awareness creation to engage local pasta industries.

Despite the above, fundamental market linkage issues remain unaddressed.

- Lack of trust between farmers and agro-processors due to opportunistic behavior by both.
- Farmers' high price expectations, which pose a challenge to competitiveness.
- Private sector unwillingness to provide embedded services (finance, inputs, technical support) for contract growers.
- Lack of grades and standards in Ethiopia's durum wheat marketing system.
- Limited capacity of farmer cooperatives.

7.4 Market linkage

Building on previous market linkage development experiences, the Wheat Seed Scaling Project included as a component the promotion and commercialization of improved rust resistant durum wheat varieties through enhanced market linkages between smallholder producers and local agro-processors in 10 potential durum wheat-growing districts of Amhara, Oromia, SNNP, and Tigray.

Market linkages in this effort included the provision of critical enabling services such as inputs, extension, finance, and business development to make linkages commercially viable for agro-processors while ensuring a better income for smallholder farmers. As part of this, the project also promoted contract farming as a business model and provided services such as inputs, technical support, and contract facilitation.

7.4.1 Seed input supply and implementation of seed revolving scheme

As described in detail in preceding chapters, the project adopted a revolving seed (seed loan) scheme to improve farmers' access to quality seed of improved varieties. In 2015-16, 273 farmers received about 70 tons of durum wheat seed, which they sowed on 683 hectares to produce 2,664 tons of grain, mainly for marketing.

Four additional districts were added to the initial 10 target districts to receive services and the number of participating farmers reached 2,792 with a total durum grain production of 10,890 tons, or 55% of the milestone of providing 20% of pasta producers' demand, by the end of the project (Table 7.4). A major challenge was to obtain enough durum wheat seed from formal seed systems.

Table 7.4. Durum wheat technology scaling in project target areas, 2015-18.

Season	Woredas	Seed distributed (t)	Seed loaned (t)	Total seed (t)	# of farmers	Area (ha)	Production (t)
2015/16	Ada'a, Agarfa, Gimbichu, Lume, Chiqualla, Asasa, Gasera, Gololcha, Arsi Robe, Minjar Shenkora, Moretina Jiru, Silti, Mareko, Meskan	70		70	273	683	2,663.90
2016-17	Mojana Wadera, Minjar Shekora, Moretina Jirru, Agarfa, Gasera, Gololcha, Lume, Gimbichu, Ada'a, Chiqualla, Ginir, Ofla	51	61	112	437	1091	4,256.83
2017-18	Agarfa, Arsi Robe, Sinana, Gololcha, Lume, Gimbichu, Ada'a, Chiqualla, Ginir, Meskan, Mareko, Silti, Mojana Wadera, Minjar Shenkora, Moretina Jiru	60	44	104	407	1018	3,970.38
Total	18	181	105	286	1,117	2,792	10,890

7.4.2 Training and technical support

Training and technical support were key features of the project and covered improved durum wheat production and quality management, durum wheat industrial quality parameters, approaches to promoting and scaling market-preferred, rust resistant durum wheat varieties, and contract farming and cooperatives as agribusiness models. Major stakeholders such as subject matter specialists, development agents, farmer cooperatives and unions, agro-processors, researchers, and representatives from regional and zonal agricultural offices took part. The first season there were 7 events (3 in Oromia, 2 each in Amhara and SNNP) involving 28 participants (3 women). In 2016-17, 35 farmers from East Shewa zone were trained in quality durum wheat production and visited the companies Alvima and Prima.

As part of annual project planning, “trainers” – including field technicians and frontline extension workers – were trained on setting up and managing demonstration and scaling

activities, covering issues such as wheat rust disease control and management, variety development and crop management practices, seed technology and systems, demonstration and scaling up of rust resistant wheat technologies, and contract farming. On average, 132 participants (10% women) from Oromia, SNNP, and Amhara region received training each year. Stakeholders including seed producer associations, farmer cooperatives and unions, and private enterprises, with researchers from federal (Debre Zeit, Kulumsa, Werer) and regional (Areka) centers and CIMMYT staff as resource persons.

7.4.3. Agro-processing linked community-based seed production

The project sought to link agro-processors with community-based producers of high-quality seed. In 2016-17 and with valuable support from DZARC, the company Alvima PLC was linked with community-based seed producers in Minjar-Shenkora Woreda, with an agreement that the company would buy the seed produced by the association at a 45% premium over local wheat grain prices. Farmers were trained in improved seed production management and there was continuous monitoring and technical backstopping at field level. The 52 tons of seed harvested was delivered to the company at the price specified in the contract.

Encouraged by the price premiums, more farmers from the same seed producer group and nearby villages signed on as contract growers in 2017-18. That year, some 34 tons of seed of *Utuba* was loaned to 482 smallholder farmers and sown on 343 ha, yielding 849 tons of durum wheat. Unfortunately, despite favorable outcomes of quality tests by DZARC, the company alleged that the grain quality was below industrial standards and refused to buy the grain, marring farmers' trust in contract farming of durum wheat.

7.4.4. Market linkage facilitation and formation

To facilitate viable market linkages between smallholder durum wheat farmers and local agro-processing industries through contractual arrangements, the project carried out continuous consultations with farmers, farmer cooperatives and unions, agro-processing companies, the Ethiopian Millers Association, MoI, MoA, BoANR-Oromia, and woreda offices of agriculture and local administrations, including the following activities.

7.4.4.1. Stakeholders consultation workshop: A durum wheat stakeholders consultation workshop held in November 2016 with the major objective of creating awareness on the current challenges and opportunities in the durum wheat value chain and reach a common vision among the stakeholders and get policy support. Here, a total of 82 participants (3 were women) consisting of major stakeholders in the durum value chain participated; i.e., farmers, development agents, SMS, farmers' cooperatives/unions, seed producers (associations, private and public enterprises), agro-processors, the Ethiopian Millers Association, Federal Ministries (Industry & Trade), regional/zonal agricultural offices, the Agricultural Transformation Agency (ATA), and researchers (Table 7.5).

Table 7.5. Participants in the durum wheat market linkage consultation workshop, Nov. 2016.

Stakeholder institution	Number of participants
Woreda Offices of Agriculture/Focal persons	10
Zone BoA (East Shewa, Bale, & Gurage)	3
Region BoA (Oromia)/ATA Clustering	6
Cooperatives (Yerer, Lume-Adama, Kesseme, Wedera, Kejiwa, Dire Gudo, Ediget)	7
Agro-Processors (Dire Dawa, Prima, KOJJ, ASTCO, ALVIMA, Universal Food Complex)	6
Ethiopian Millers' Association (EMA)	1
EIAR Management/Researchers from Federal Research Centers	20
Seed Producers (Private & Associations, ESE)	13
Federal Ministry (MoI/Agro-processing, MoT)	2
Farmers	14
Total	82

Outcomes and conclusions included the following:

- The durum wheat market linkage initiative needed to ensure sustainability after the project. Some project aspects market could be integrated with the "East Shewa Commercialization Cluster Platform" coordinated by Zone Bureau of Agriculture.
- In successful malt barley smallholders-market linkage experiences, success factors included the sustained provision of quality seed and enhanced multiplication of early-generation seed, access to credit from companies for key inputs (seed, fertilizer, agri-chemicals), and financing for cooperatives and unions to pay farmers immediately upon delivery of grain.

Participants also noted the need for agreed quality standards for both local and imported pasta and the marginalization of durum wheat in the formal seed system (the Ethiopian Seed Supply Enterprise confirmed that it had ceased to produce seed of improved durum wheat varieties since 2012 due to low demand).

7.4.4.2. Contract design, specification, and negotiation: Collective action through farmer cooperatives and unions was adopted for contract design and negotiations. Farmer organizations can help manage value chains activities such as collection, bulking, grading, and post-harvest treatment and storage, as well as negotiating contracts to increase farmers' bargaining power (Perret and Mercoiret 2003; Onumah et al. 2007; Kelly, 2012).

The major farmer cooperative unions located within the project durum wheat domain were Yerer, Lume-Adama, Kesseme, Wedera, Dire Gudo, Odda Roba, Kejiwa, and Ediget. Based on the consensus stakeholder workshop participants, the project's market linkage activities were integrated into the East Shewa Commercialization Cluster Platform coordinated by the Zone Bureau of Agriculture. The project initiated first contract arrangements and negotiations between two cooperative unions (Lume-Adama and Yerer) in East Shewa zone and three pasta factories. Also involved in contract design and negotiations were the Oromia Trade & Market Development Bureau (OTMDB), an Oromia ATA clustering, and the Ethiopian Millers Association (EMA).

Contract negotiations – particularly, to craft terms that satisfy often unrealistic expectations from contracting parties – can be challenging (Shepherd, 2007; Eaton & Shepherd, 2001) and farmers need sound background knowledge, including of their production costs and prevailing market prices, to negotiate.

For the project we developed a structured contract based on previous experiences and priority concerns for contracting parties, which were cooperative unions and agro-processors. The market specifications for transactions stipulated an agreement regarding specific products, their quality attributes, and the time and location of delivery. There were also clear terms for contract length, pricing arrangements, premiums for quality parameters, payment schedules, delivery, storage, and conflict resolution.

Based on the draft contract, at least five rounds of contract negotiations were held between agro-processors (Dire Dawa, Prima, and Kepron) and farmer unions (Yerer & Lume Adama) for durum wheat harvested in 2016-17 cropping season. A consensus was reached on the following contract terms:

- Production of quality durum wheat from *Mangudo* and *Ude* varieties, with the following grain quality parameters: moisture content not exceeding 12.5%, minimum protein content of 11%, minimum of 78 HLW, and foreign matter not exceeding 6%.
- Grain quality was to be tested by the national durum wheat research program at DZARC using a mobile quality tester lab machine purchased by the project. In this case, quality test results would be given to the contracting parties for their decision.
- Grain delivery would be completed by end of April with a maximum of three loads and a minimum truck load of 40 tons.
- Bagging and loading costs would be covered by the unions, while transport and other logistics were to be managed by the processors.
- Pricing was agreed to include a premium based on the level of protein content and using an average benchmark price determined by local wheat markets.

At the time of contract negotiations, surveys at Bishoftu, Mojo and Adama determined the average benchmark price in local spot markets. In addition, DZARC conducted grain quality tests on samples collected from 109 durum wheat growing farmers in Gimbichu, Ada'a, Lume and Minjar-Shenkora during February-March, 2017. Sample test results showed that the average protein content was 11.2%, enough to meet industrial quality standards, while moisture content was 11%. Based on expressions of interest, Yerer Union purchased some 600 tons of durum wheat grain mainly of *Mangudo* at Gimbichu and Ada'a with a price of Birr 850 per quintal during March and April 2017, prior to signing the contract.

Unfortunately, none of the pasta companies that participated in contract negotiations were willing to sign a deal or purchase the durum wheat grain from the union, which consequently cease to make further durum wheat purchases from local markets and sold the durum wheat it had on the normal grain markets.

Despite persistent consultation and lobbying by research and development third parties, durum wheat contract and marketing arrangements failed.

7.5 Key lessons

Despite the successive market linkage development interventions, smallholder durum wheat farmers remain poorly linked to markets. The interventions involved mainly intermediary-

driven business models, where research and development partners provided linkage support services such as inputs, technical support, capacity building, and financing, which are supposed to be provided by the private sector as embedded services. Past successes have been short-lived and fell apart as soon as subsidized support services ceased. Challenges hindering the development of viable and sustainable market linkages for smallholder durum wheat farmers include the following:

- Lack of trust or a common vision between farmers and agro-processors.
- Lack of quality-based price incentives.
- Lack of contract enforcement mechanisms.
- Highly opportunistic attitudes and behavior on the part of farmers, whose price expectations were unrealistic, and agro-processors, who used their market information advantages to source grain from spot markets.
- The significant import market, which is believed to suppress the price of local durum wheat grain. In fact, Ministry of Trade data show that government programs which since 2014 have supplied low price durum wheat to the local markets to benefit poor urban consumers creates disincentives for local wheat farmers.
- Farmer cooperatives and unions lack capital and storage and bulking facilities.

The following key lessons emerged:

- Relevant stakeholders in the durum wheat value chain need to be involved early on in project planning.
- Alternative incentive-based contract enforcement mechanisms are required.
- A group approach is critical for contract specification and negotiation to establish market linkages between small-scale farmers and agro-processors.
- Sustainable business relations depend on mutual trust between the contracting parties; linkage activities should focus on developing trust.
- Efforts should shift from an ad hoc, project-based approach to institutional policies that foster the development of viable and sustainable smallholder-market linkages, particularly in the absence of subsidized support services for farmers from time-bound projects (the latter approach is generally incompatible with commercially sustainable agribusiness).
- Smallholder market linkage activities should consider not only constraints to farmers' market participation but also linkage viability for companies given the current wheat market structure.
- It takes time and effort to establish viable and sustainable market linkages between smallholders and processors; all parties must be aware of this when initial business partnerships are formed.

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Chapter 8

Impact of rust resistant wheat varieties on the productivity, income and food security of small-scale farm households in Ethiopia

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8.1 Introduction

The national wheat research program of Ethiopia, together with research organizations such as CIMMYT and ICARDA, have responded to the persistent threat for wheat crops of devastating stem and yellow rust disease outbreaks by rapidly developing and supporting the seed of resistant wheat varieties to farmers. As a result, in recent years a number of widely-grown, highly-susceptible wheat varieties have been replaced with resistant, improved alternatives.

As described throughout this publication, the Wheat Seed Scaling Project fostered fast-track variety testing, seed multiplication and dissemination to improve farmer access to new, resistant varieties and thereby replace the susceptible ones in use, building on diverse prior initiatives that include the ICARDA/EIAR wheat seed project implemented from 2008-09 to 2014-15 and the Borlaug Global Rust Initiative (BGRI). To accomplish the above, the project sought to:

- Strengthen Ethiopia's ability to detect and respond to emerging rust threats through crop surveys, rust pathology diagnostics in Ethiopia, better characterization (phenotyping) of candidate wheat varieties, and early warning systems.
- Implement fast-track variety testing and release as well as accelerated seed multiplication for wheat lines from the Ethiopian Wheat Research Program, CIMMYT and ICARDA.
- Demonstrate new wheat technologies on farm and at FTCs, for scaling.
- Link small-scale durum wheat farmers to markets and agro-industries.
- Provide technical and financial support to wheat research centers for multiplication of pre-release, breeder, pre-basic (the progeny of breeder seed) and basic (the progeny of breeder or pre-basic seed) seed.
- Improve the formal seed system through assistance to private seed growers, seed associations, farmer cooperatives and unions, and public seed enterprises.
- Improve the informal seed system through assistance to small-scale wheat farmers, FCUs, and women and youth groups that produce and multiply seed.

8.1.1 Impact assessment

This chapter describes (i) the technical and financial feasibility of the rust resistant wheat varieties disseminated through the project, as measured by adoption rates and intensity and profitability, and (ii) the extent to which project activities and outputs improved household food security. The reported results come from an independent impact assessment and evaluation exercise using data from sample farmers in the target woredas, from key informants and, in some cases, from secondary sources. Major indicators considered were adoption rate, adoption intensity, seed replacement rate, wheat yield, farm income from wheat production, and household food security and nutrition security status. Reference is made to the project document (CIMMYT, 2014) and to the baseline assessment report (Setotaw, 2017) for comparison with circumstances following the project.

Table 8.1. Sample size and sampling techniques.

Sample units	Sample size	Total	Sampling technique
Project target woredas	13	13	Purposive
Project target kebeles (within sample woredas)	26	26	Random
Farmers who grow resistant wheat varieties	15	390	Random
Farmers who grow susceptible wheat varieties	16	416	Random

Two kebeles were selected randomly from each woreda and from among the kebeles in which the project worked. The beneficiary and non-beneficiary farmers were drawn equally from the 13 sample woredas, at a “rate” of 30 beneficiary and 32 non-beneficiary farmers per woreda. From the cluster of farmers who grew and didn’t grow rust resistant wheat varieties in the selected kebeles, 15 and 16 sample farmers, respectively, were randomly selected to conduct the survey (Table 8.1). The sampling frame for beneficiary farmers and non-beneficiary farmers is the list of farmers who grew rust resistant wheat varieties and those who grew rust susceptible wheat varieties. The lists were obtained from agricultural extension agents in the respective kebeles.

8.2 Methodology

8.2.1 Survey design and sampling

The quantitative impact analyses used data from primary sources (sample survey) and secondary sources (baseline reports, annual reports, and other records from respective Bureaus of Agriculture and Rural Development, CIMMYT, and EIAR). The survey was applied to 806 randomly selected beneficiary (390) and non-beneficiary (416) farm households in respective target kebeles.

The sample size minimizes the margin of error to about 5% (as a standard) at the 95% confidence level. The number of non-beneficiary farmers means that each beneficiary farmer can be matched to at least 1.5 non-beneficiary farmers, as a counterfactual. The sample

survey was conducted in 13 woredas, comprising about 20% of the 54 Wheat Seed Scaling Project woredas. A multistage, purposive, stratified random sampling procedure was used to select woredas, kebeles, and respondent farmers (Table 8.1).

The sample woredas were selected proportionately and purposively from the four regions (three from Amhara, six from Oromia, and two each from Tigray and SNNPR) taking into account issues related to coverage during the baseline survey, geographic coverage for representativeness, and accessibility for a cost-effective survey.

Table 8.1. Sample size and sampling techniques.

Sample units	Sample size	Total	Sampling technique
Project target woredas	13	13	Purposive
Project target kebeles (within sample woredas)	26	26	Random
Farmers who grew resistant wheat varieties	15	390	Random
Farmers who grew susceptible wheat varieties	16	416	Random

Two kebeles were selected randomly from each woreda and from among the kebeles in which the project worked. The beneficiary farmers and non-beneficiary farmers were drawn equally from the 13 sample woredas, at a “rate” of 30 beneficiary farmers and 32 non-beneficiary farmers per woreda. For the survey, the assessment drew randomly upon 31 wheat farmers per kebele, 15 of whom were growing rust resistant wheat varieties and 16 growing susceptible ones (Table 8.1).

Data collection: Data were collected from selected farmers in each kebele through face-to face interviews using a structured questionnaire. The questionnaire was pre-tested on selected farmers in Ada’a woreda for technical completeness and consistency. It was applied by 12 trained enumerators, with monitoring by trained survey supervisors among them, oversight by the lead consultant and a CIMMYT expert, and assistance from woreda focal persons and kebele level development agents. Data collection and aggregation used the Census and Survey Processing System (CSPRO) software on data collection tablets, for data monitoring and automatic transfer to ensure efficiency, quality, and timeliness. Data management and analysis used STATA software.

8.2.2 Data analysis

Analyses combined quantitative and qualitative techniques, in consideration of the issues discussed above and in compliance with the assessment ToR. This approach allowed analysts to triangulate quantitative results against qualitative observations from informed stakeholders.

Indicators and analysis techniques: The assessment was based on descriptive and rigorous quantitative analysis techniques to generate quantitative evidence on the selected adoption

and impact indicators: adoption rate, adoption intensity, variety replacement rate, yield, farm income, food security, and nutrition security. The descriptive analysis was based on both primary and secondary quantitative data and conducted mainly to assess adoption rate, adoption intensity, and seed replacement rate using chiefly averages and percentages. Descriptive techniques for yield and farm income analysis were complemented by Propensity Score Matching, to assess whether there was a significant difference in the outcome variable of interest (yield and farm income) from rust resistant wheat varieties vs susceptible ones (the counterfactual). Because the comparison was between farmers having similar characteristics (demography, resource ownership, farming system, and access to inputs and services, among other factors), except for growing either rust resistant vs susceptible wheat varieties, any positive differences in an outcome variable can easily be attributed to use of rust resistant wheat varieties.

In addition to yield impact assessment to determine the technical feasibility of adopting rust resistant wheat varieties, we assessed farm income to discover whether adoption was economically beneficial, taking into account the wheat market channels in which farmers participate, including: wheat grain sales through traditional markets, durum wheat grain sales to agro-processors, and seed sales to cooperatives, government seed enterprises, and other farmers (including farmer-to-farmer exchanges or other informal arrangements).

Variety adoption rate: Unlike its traditional definition as a behavior affecting choice and as a random variable, adoption in this study refers to sowing seed of rust resistant wheat varieties disseminated through the project. Calculated as the proportion of farmers who adopted a specific variety, this measure indicates the variety's popularity, use, or diffusion among farmers during a particular crop cycle in a particular place, in relation to all other rust resistant wheat varieties disseminated in the area.

Adoption rate of RRW_i = (Number of beneficiary farmers who planted a specific rust resistant wheat variety) / (Number of beneficiary farmers who planted rust resistant wheat varieties)

Variety adoption intensity: Adoption intensity indicates the area on which a particular rust resistant wheat variety is grown in a given season. Some project beneficiary farmers grew both rust resistant and rust susceptible wheat varieties on their land. The results were aggregated and discussed at regional and overall project site level. Adoption intensity is calculated as follows:

Adoption intensity RRW_i = Area under a specific rust resistant wheat variety / Total area under wheat

Variety replacement rate: This is the ratio of two proportions: *Proportion 1*, which shows the relative quantity of seed of a particular wheat variety used by a farmer (for example, variety A) during year 1 (for example, 2016-17) and *Proportion 2*, which shows the relative quantity of the same variety type (variety A) used by the same farmer during the next production year (2017-18). Under the assumption of a similar seed rate per unit of land, a ratio of *Proportion 2* to *Proportion 1* indicates whether there has been varietal replacement or not (seed A in this case). Wheat variety A is expected to have replaced some other variety during, say, the 2017-18 crop cycle if the ratio is greater than 1. A ratio of 1 indicates no variety replacement and less than 1, that variety A is being replaced by other varieties.

Variety replacement rate RRW_i = Relative quantity of seed of a particular rust resistant wheat variety used during a particular crop cycle / Relative quantity of seed of the same wheat variety used during the previous crop cycle.

Impact on wheat yield: Impact on wheat yield was assessed using the Propensity Score Matching (PSM) technique. Comparing mean yields of varieties grown by beneficiaries and non-beneficiary farmers without controlling for differences in basic farmer characteristics could be misleading. PSM helps to match individuals from both groups who share similar characteristics, using a propensity score that is a scalar value showing the probability of participating in a program given the set of all observed characteristics (Rosenbaum and Rubin, 1983).¹

Where there were too few non-beneficiary farmers in a kebele to survey, wheat yield of rust resistant varieties was directly assessed over time and in comparison with the yields of other wheat varieties.

Analyses also indicated the presence or not of statistically significant differences in the yields of rust resistant wheat varieties in 2017-18 vs the baseline.

Wheat yield = Weight of wheat harvested / Wheat cropping area

Impact on farm income: Gross margin income was calculated as the difference between expected revenue from sales of grain (both marketed and consumed) or seed vs costs to produce and market the grain and/or seed. This can help to compare the profitability of different marketing schemes and channels (conventional, agro-processors, cooperatives, government seed enterprises, and village or farmer-to-farmer levels). Further profitability analysis using gross farm income was made by assessing *rate of return* per unit operational cost.

Gross margin per hectare = [(Estimated revenue from grain or seed + - Operating costs) / Land area cultivated]

Impact on food and nutritional security: The food security and nutritional impact of rust resistant wheat variety adoption was assessed using descriptive techniques. Perceptions of respondent farmers regarding the *continuous* availability of *adequate* food for the family and the *diversity of food* consumed by family members, both over the last three years, served as proxy indicators for food security and nutrition. Follow up questions explored whether the availability of adequate and diverse food could be attributed to rust resistant wheat variety adoption. In addition, opinions were obtained from key informants about the food security of beneficiary farmers.

Qualitative analysis: Quantitative analyses were complemented (and checked) with qualitative assessments of adoption and impact from stakeholders (mainly woreda-level focal persons and kebele-level development agents) to understand the attributes of rust resistant wheat varieties that affect adoption, adoption rates and patterns of resistant wheat varieties among participating farmers, key challenges and constraints to promoting varietal adoption,

¹ Musa et al. (2017) applied the technique to assess the productivity and welfare impacts of improved wheat varieties; Chilot et al. (2016) assessed the yield and socioeconomic impact of the project “Deployment of Rust-resistant Varieties for Ensuring Food Security in Ethiopia; Tesfaye et al. (2016) applied PSM to assess the yield and socio-economic impact of improved wheat technology adoption; and Getnet et al. (2015) used it to assess the yield impact of physical soil and water conservation structures in western Ethiopia.

and best practices to be scaled and to expand varietal adoption. Key informant interviews were conducted face-to-face or by telephone.

8.3 Major findings

8.3.1 Adoption rate

Adoption rates depend on various factors, including the attributes of the particular variety, a farmer's socio-economic conditions (availability of land, labor, and cash), extension and other related services, agro-ecological conditions, time elapsed since the introduction of the variety, and the accessibility of the variety as affected mainly by adequacy and timeliness of supply, among others.

The variety *Kakaba* was the most highly adopted rust resistant wheat variety among the sample beneficiary farm households (31%) during the 2017-18 crop cycle, followed by *Ogolcho* (29%), *Hidase* (20%), and *Mangudo* (17%) (Fig. 8.1). The findings on adoption rates for sample farmers are similar to those from analyses of secondary data collected from sample kebeles and identified *Kakaba* as having the highest adoption rate (nearly 30%) for the three successive years starting during the 2015-16 crop cycle, followed by varieties *Danda'a*, *Ogolcho*, *Mangudo*, and *Hidase* (Fig. 8.2).

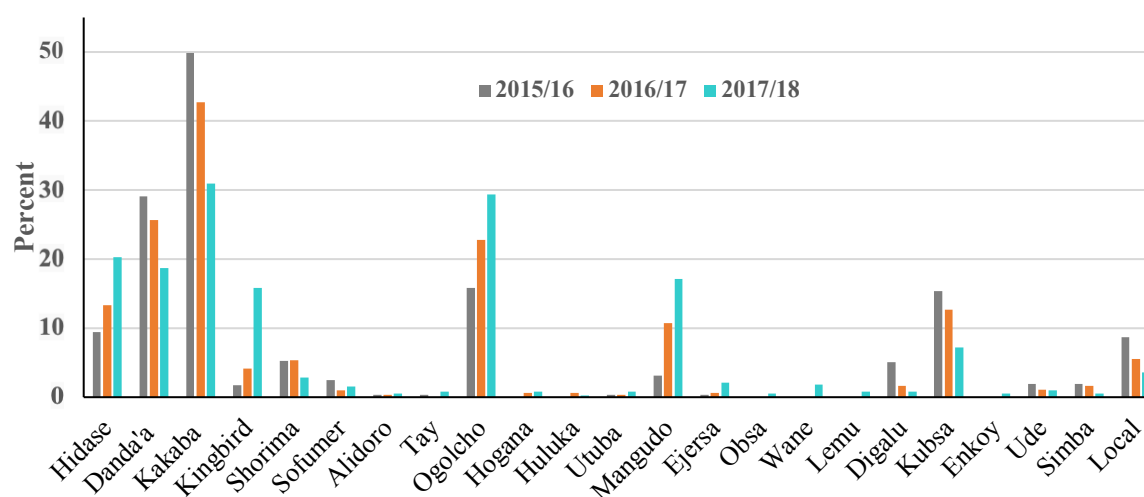


Figure 8.1. Adoption rates of rust resistant wheat varieties among sample farmers for the 2017-18 crop cycle (aggregate for all sample project sites).

Kakaba was also the most popular variety during the baseline cycle (2014-15), with an adoption rate of 40%. A visible change since the baseline period was the increasing importance of diversifying varieties such as *Ogolcho*, *Hidase*, and *Mangudo* by replacing *Danda'a*, *Digalu*, and *Kubsa*, which ranked third, and fourth, respectively, in terms of their adoption rate during the baseline period. The declining importance of *Digalu* and *Kubsa* was due to their susceptibility to rust disease

a) Annual adoption rates

b) Three-year average adoption rates

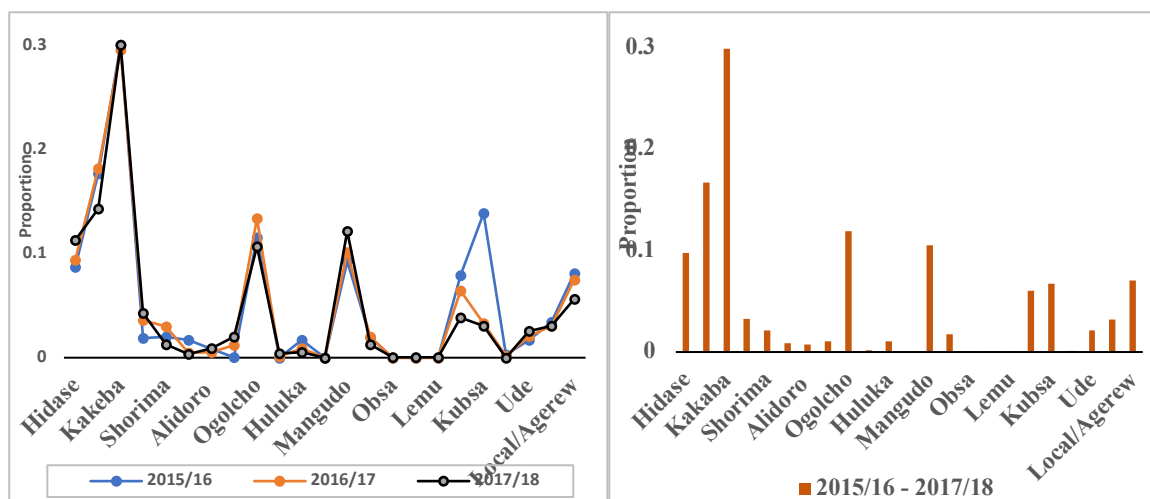


Figure 8.2. Adoption rates of wheat varieties, based on secondary data collected from woredas and kebeles.

Kakaba's adoption has been declining, going from 50% during 2015-16 to 43% during 2016-17 and 31% during 2017-18, while the adoption rates of *Hidase*, *Kingbird*, *Ogolcho*, and *Mangudo* increased since 2015-16. This is a result of efforts to convince farmers to grow a more diverse selection of wheat varieties, rather than relying on mega-varieties, as a way to lessen crop losses from recurrent yellow rust and stem rust outbreaks.

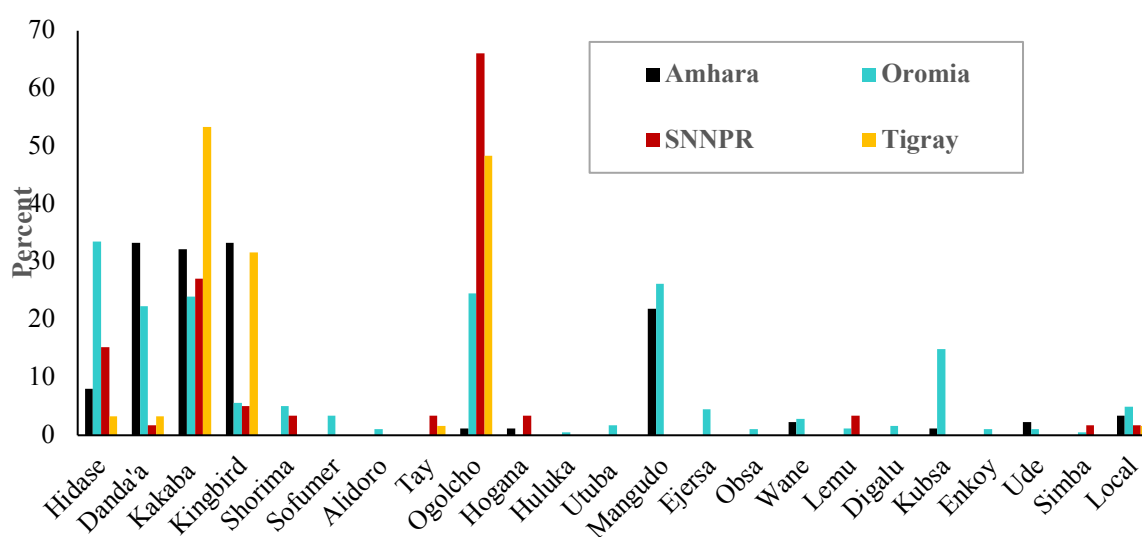


Figure 8.3. Rust resistant wheat variety adoption during the 2017-18 crop cycle, by region.

As expected, the adoption rate of rust susceptible wheat varieties declined over the three years of the project, though *Kubsa* is still grown by a considerable proportion of farmers (7%) during the 2017-18 crop cycle. The findings suggest the need to increase the supply of new, rust resistant wheat varieties, including *Hidase*, *Ogolcho*, *Mangudo*, *Kingbird* and *Wane*. Adoption of rust resistant wheat varieties has a regional (or geographic) dimension, perhaps attributable to agro-ecological conditions. The highly adopted rust resistant wheat varieties in Amhara region during the 2017-18 crop cycle were *Danda'a* (33%), *Kingbird*

(33%), and *Kakaba* (32 %) (Fig. 8.3). In Oromia, *Hidase* (34%), *Mangudo* (26%), and *Kakaba* (27%) were the most highly adopted varieties. Most farmers in SNNPR adopted *Ogolcho* (66%), followed by *Kakaba* (55%) and *Hidase* (15%). In Tigray *Kakaba* was most highly adopted (53%), followed by *Ogolcho* (45%). *Kakaba* was the most widely adopted variety in the four regions, perhaps showing the adaptability of the variety in different agro-ecologies.

8.3.2 Adoption intensity

Results from the analysis of the sample survey data show *Kakaba* also had the highest adoption intensity (22%) overall during 2017-18 (Fig. 8.4), which is in line with its adoption rate during the same period. Similarly, *Ogolcho* and *Hidase*, which had the second- and third-highest adoption rates, also showed high adoption intensities (20 and 12%, respectively). The finding shows a similar situation observed during the baseline period during which *Kakaba* had the highest adoption intensity at 31% (Setotaw, 2017).

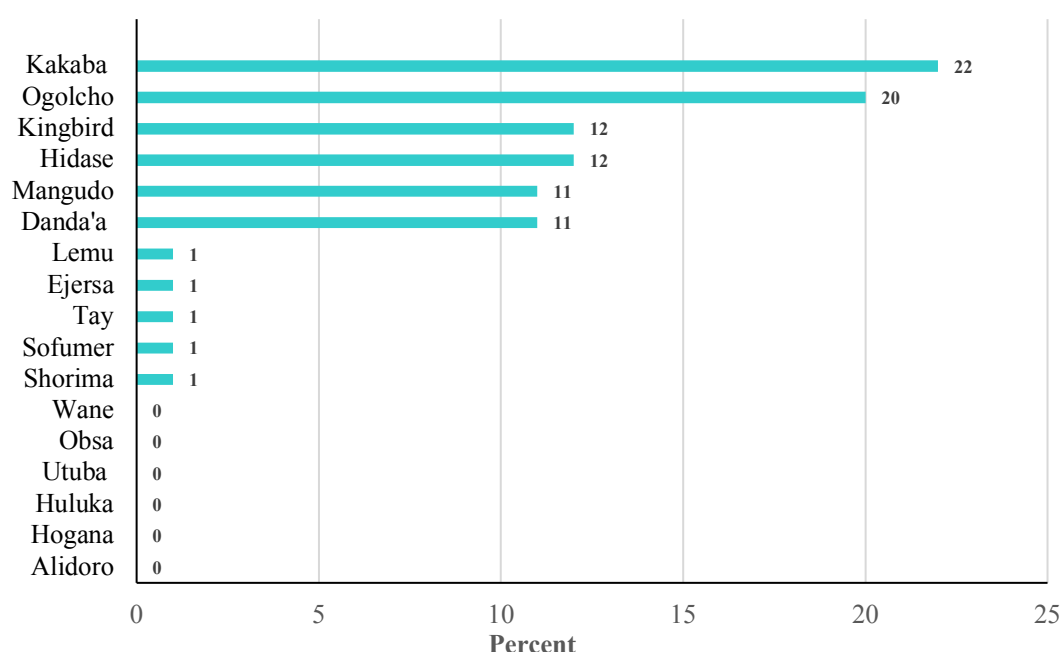


Figure 8.4. Adoption intensity of rust resistant wheat varieties (2017-18) (aggregate of all sample project sites).

As occurred in the case of adoption rates, adoption intensities varied by region. *Kakaba*, with the highest adoption rate and intensity overall, had the highest adoption intensity in Tigray (35%) (Fig. 8.5). The variety *Ogolcho* was grown on about 57% of the land allocated to rust resistant wheat varieties in SNNPR. About 20% of the land area under rust resistant wheat varieties in Oromia was sown to *Hidase*, followed by 19% for *Mangudo*. In Amhara, 29% of the land allocated to rust resistant wheat varieties during the same period was sown to *Kingbird*, followed by *Kakaba* (28%).

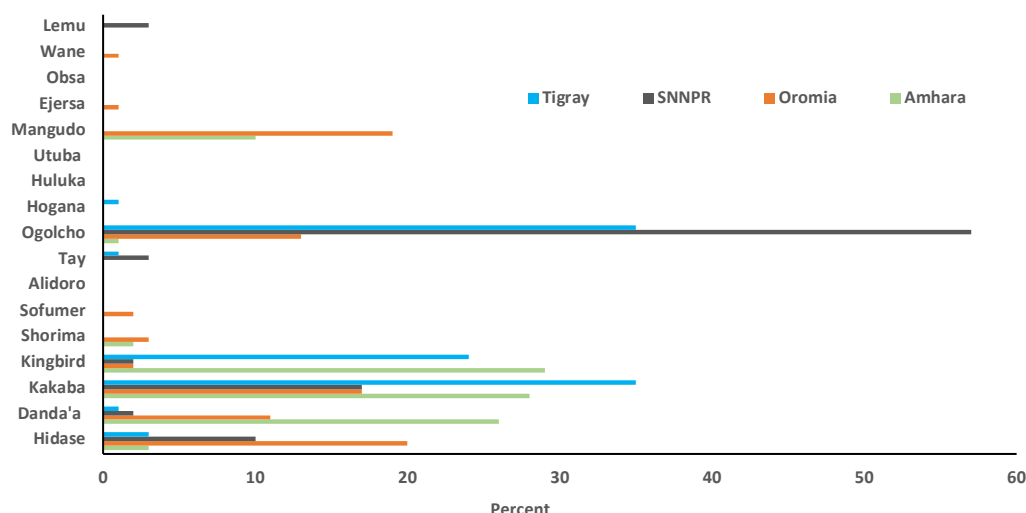


Figure 8.5. Adoption intensity for rust resistant wheat varieties in four regions, 2017-18.

The adoption intensity of rust resistant wheat varieties averaged 95% during the three years of the project in the areas studied (Fig. 8.6). However, together with that of the next production period (2018-19) for which sample farmers reported their anticipated wheat sowing plan, the trend shows a decline, perhaps due partly to declining yields from use of the third generation of saved seed of the varieties (farmers mentioned this repeatedly during informal discussions). This is a good reminder to develop and supply new rust resistant wheat varieties and to increase the supply of basic seed of existing ones.

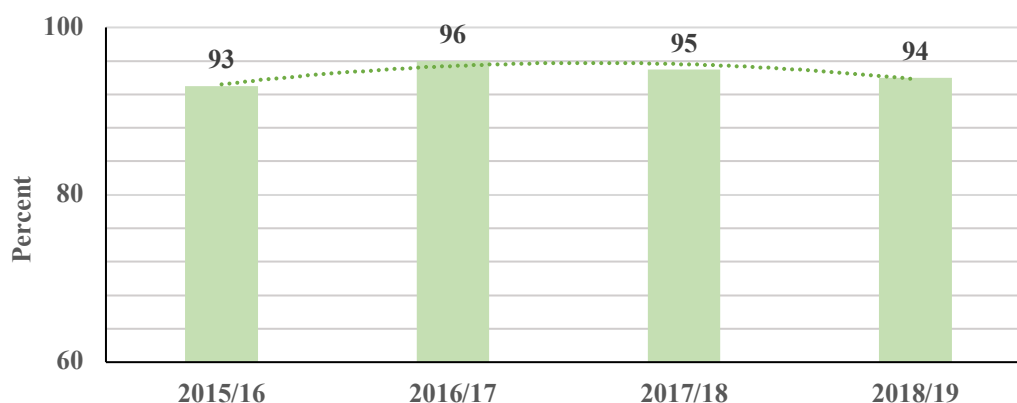


Figure 8.6. Trend in adoption intensity of all rust resistant wheat varieties together (2015-16 to 2018-19) (aggregate of all sample project sites).

8.3.3 Variety replacement rate

Farmers replace traditional or old wheat varieties with improved ones for diverse reasons, including better yield performance and rust resistance. Understanding observed variety replacement rates for each wheat variety helps to inform seed multiplication and scaling programs about the magnitude and pattern of variety replacement so that the program can effectively respond to observed changes and revealed demand.

Sowing more seed of a particular wheat variety, while the seed rate remains the same, can be an accurate indicator of a farmer's preference for a variety.

Relative to the 2016-17 crop cycle, the replacement rates of *Ogolcho*, *Kingbird*, and *Hidase* increased during 2017-18 (Fig. 8.7). For *Ogolcho*, the rate rose from 0.98 to 1.29, for *Kingbird* from 0.21 to 0.49, and for *Hidase*, from 0.59 to 0.74. This may show the importance of those varieties in replacing older rust resistant wheat varieties such as *Kakaba*, *Digalu*, and *Mangudo*, whose respective replacement rates for the same period declined. This finding agrees with the increasing adoption rates and intensities of *Ogolcho*, *Kingbird*, and *Hidase* and with the decreasing adoption rates and intensities of *Kakaba*, *Danda'a*, and *Digalu* during the same period. Anticipated replacement rates (Fig. 8.7) show potential increases for *Kingbird*, *Hidase*, and *Danda'a*, possibly an indication of increasing demand. Among rust susceptible wheat varieties, *Ude* (durum) and *Simba* increasingly replaced others.

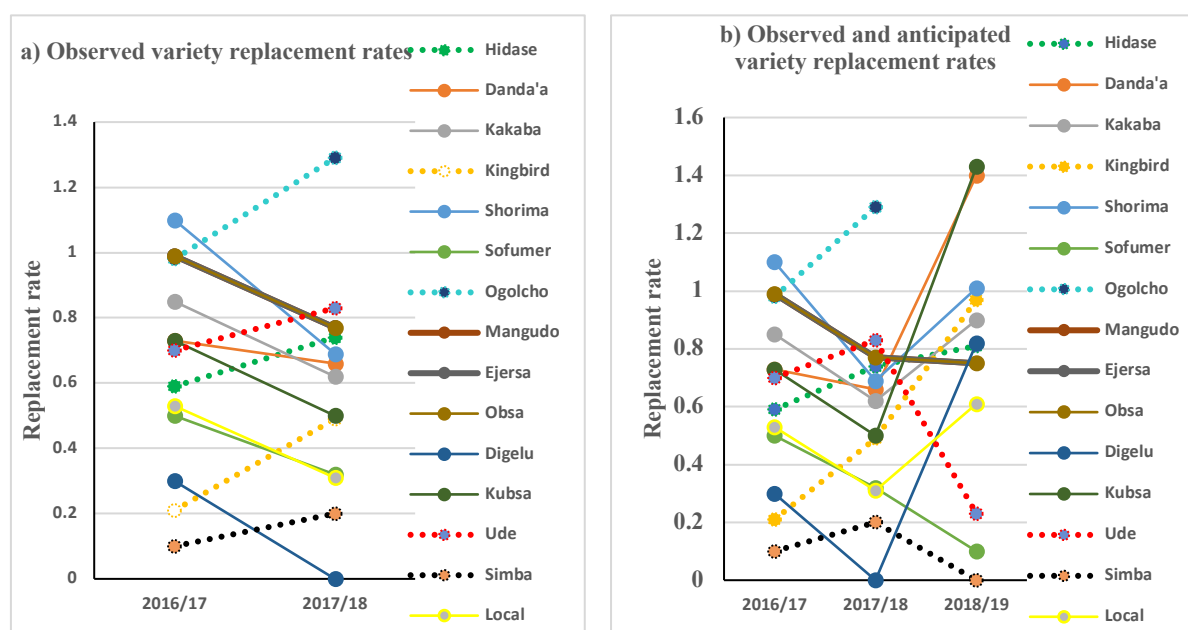


Figure 8.7. Wheat variety replacement rates (average of all sample project sites).

8.3.4 Impact on wheat yield

Adopting a rust resistant wheat variety and replacing others is not an end in itself; it is rather a means to increase yield and improve farm household income. There are two major yield impact related assessments presented in this report: whether wheat yield from rust resistant wheat varieties is improved when compared to the baseline situation and if any improvement can be attributed to using rust resistant wheat varieties, as a result of the Wheat Seed Scaling Project. The answer to the first question (which also helps to answer whether the Wheat Seed Scaling Project has achieved its target of increasing wheat yield by 25%) was based on temporal comparative assessments of wheat yield at two levels. First, yield of all rust resistant wheat varieties were considered together for each year of the project. This indicated the trend in overall yield performance and average yield levels of all rust resistant wheat varieties over the project. Regarding the second question, after controlling for differences in household characteristics, PSM was applied to determine whether or not the yields of rust resistant wheat varieties was significantly different from that of rust susceptible varieties. PSM was applied only for 2017-18 yields, because that is the only period for which data on the covariates for the analysis were available.

Yield comparison: The average yield of 5.2 t/ha obtained for rust resistant wheat varieties in Oromia during the 2015-16 crop cycle was the highest of the four regions. During 2016-17, the highest average yield of 4.2 t/ha was obtained by farmers who grew rust resistant wheat in Amhara (Fig. 8.8). During 2017-18, farmers in Oromia obtained average yields of 4.2 t/ha for the rust resistant wheat varieties they grew, the highest level of the four regions. Average yield for all rust resistant wheat varieties across project locations was 3.98 t/ha for 2017-18 (Fig. 8.8), compared with average yields of 4.98 t/ha for 2015-16 and 4.50 t/ha for 2016-17, the first two years of the Wheat Seed Scaling Project.

The discernible decline in average yields for rust resistant wheat varieties might result from use by farmers of second and third generation seed, either their own saved seed or seed supplied by cooperative unions from stocks collected as certified seed from seed producer farmers. The performance of varieties grown from such seed can decline over time, pointing up the importance of regularly supplying farmers with high-quality certified seed. This also came out in discussions with key informants and farmer responses regarding the technology interventions they value most, where some 37% of the farmers who grew rust resistant wheat varieties suggested the need for more seed. Finally, external factors such as extreme or erratic weather reduced yields.

Intervention activities of the project lasted over three years (from 2015-16 to 2017-18), so it is reasonable to consider the cumulative yield impact of the project by considering average wheat yield achieved over those years.

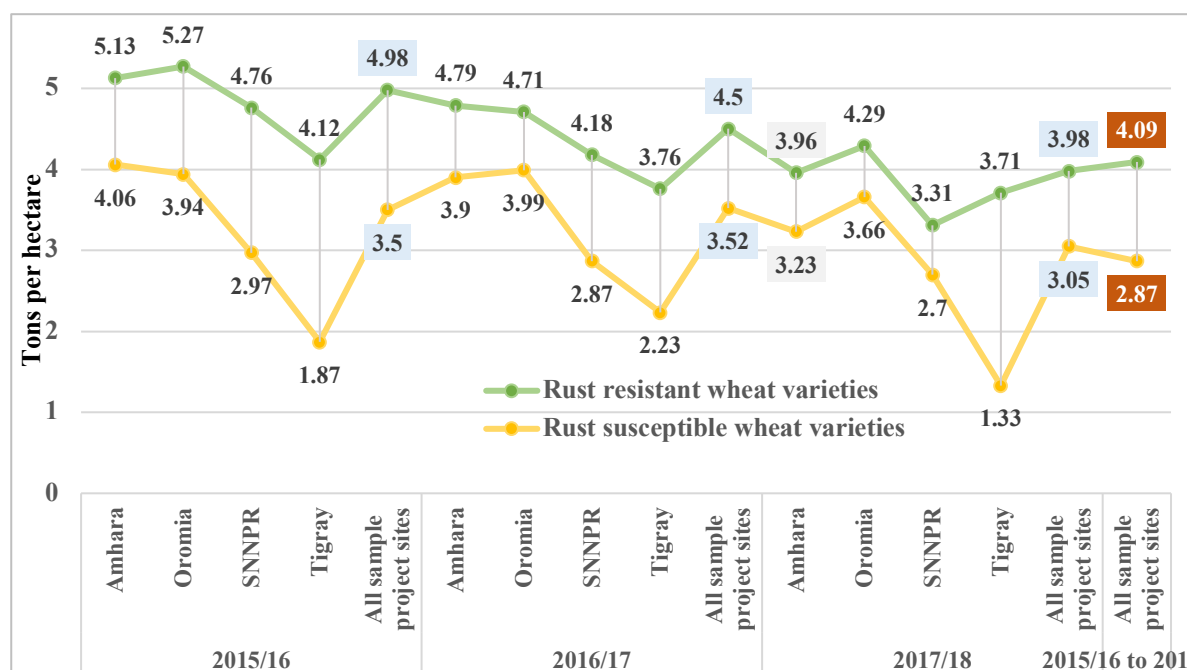


Figure 8.8. Yield of rust resistant wheat varieties and rust susceptible wheat varieties (t/ha).

Yield comparison (PSM on yield from rust resistant vs susceptible wheat varieties): The average yield (3.98 t/ha) from all rust resistant varieties during the final crop cycle of the project was 30% more than that from susceptible varieties (3.05 t/ha). To determine the extent to which the difference owed to use of rust resistant wheat varieties per se, rather than factors such as a bias in selecting the most productive and progressive farmers to grow rust resistant wheat under the project, we took estimates from the treatment effects model under

the nearest neighbor matching technique. This showed that growing rust resistant wheat resulted in a positive mean yield difference of about 0.61 t/ha, at a statistical significance level of 1% (Table 8.2). This is fairly similar to the difference in the average yields cited above. The yield effect is statistically significant also under a caliper matching algorithm in which only farm households having a difference of less than 0.1 in their propensity scores were matched. According to the result, the mean difference under the matching algorithm was 0.47 t/ha.

Table 8.2. Estimates of average wheat yield impact from participation in rust resistant wheat variety production (t/ha).

Treatment effect	Coefficient	Z-value	P> Z-value 	Matching technique
Average treatment effect on the treated (beneficiaries versus non-beneficiaries), ATET	0.61	2.58	0.01**	Nearest neighbor matching
	0.47	1.71	0.08*	Caliper matching
Average treatment effect on entire farmers (beneficiaries versus non-beneficiaries), ATE	0.44	2.14	0.03**	Nearest neighbor matching
	0.37	1.61	0.10*	Caliper matching

Note: **, * refer to respective statistical significance levels of 5% and 10%.

Further analysis showed that average wheat yield would be 0.44 t/ha more (the nearest neighbor matching technique) and 0.37 t/ha more (the caliper matching algorithm), if all Ethiopian wheat farmers grew rust resistant wheat varieties (Table 8.2). This finding gives insight about the potential yield impacts of scaling out project activities to reach many more wheat farmers. PSM identifies assumptions and conditions that hinder non-biased selection when using non-experimental data for causal impact analysis.

Non-beneficiary wheat farmers in this study are assumed as potential beneficiaries and represent a pool to find matching counterfactuals for each beneficiary farmer. However, comparisons between wheat yields obtained by members of the two opposing groups of farmers can be made only if they are likely to be growers or non-growers of rust resistant wheat varieties (Bryson et al., 2002; Heckman et al., 1999). Such a condition is referred to as “overlap of propensity scores.” The adequacy of the propensity score model can be checked by evaluating the balance of covariates (similarity in the distribution of covariates) across treatment groups. The validity of the assumption in this analysis is tested by assessing whether the propensity scores (i.e., probabilities of being participants observed for beneficiaries and probabilities of being non-participants observed for non-beneficiaries) overlap, thus making it possible to predict the counterfactual wheat yield of beneficiaries using that observed for matching non-beneficiaries. The most straightforward method to check whether the common support condition is satisfied is to make visual inspection of the density distribution of propensity scores (Garrido et al., 2014; Lechner, 2000).

The visual evidence supports the validity of PSM in this case and, consequently, the robustness of the Table 4.3 estimates. Moreover, there are 801 estimated propensity score observations in the common support region (out of the expected total 806 observations

included in the estimation (390 beneficiaries and 416 non-beneficiaries). Only one propensity score in the beneficiary groups is unsupported. Accordingly, the difference in wheat yield levels during 2017-18 is due to the use of rust resistant wheat varieties, which, in turn, can be attributed to the project.

8.3.5 Impact on farm income

Small-scale farmers, like any other economic agent, make rational production decisions (Bishaw et al., 2016) to generate adequate profits from their investments in wheat production, preferably with low or no financial risk. The structure of operating costs for wheat production and the market prices for wheat grain and by-products are discussed below.

Operating costs: Included in this analysis are the costs of labor (including family and hired labor for land preparation, sowing, fertilizer application, weeding, harvesting, and threshing), chemical fertilizers, organic fertilizers, herbicides, pesticides, machinery rentals, land rental, fuel, and marketing.

The highest cost for both types of farmer was labor (averages of ETB 11,406 and ETB 9,402, respectively, per hectare), followed by fertilizer (ETB 3,448) and seed (ETB 1,589), with no statistically significant cost differences for the latter two inputs between the farmer groups (data not shown), nor for costs lumped together as “other operating costs per hectare.” Mean labor costs were significantly different, though only at a 10% level of significance ($p = 0.1$) and farmers who grew rust susceptible wheat varieties also paid more for pesticides (ETB 843 per hectare, vs ETB 520 for farmers who grew rust resistant varieties).

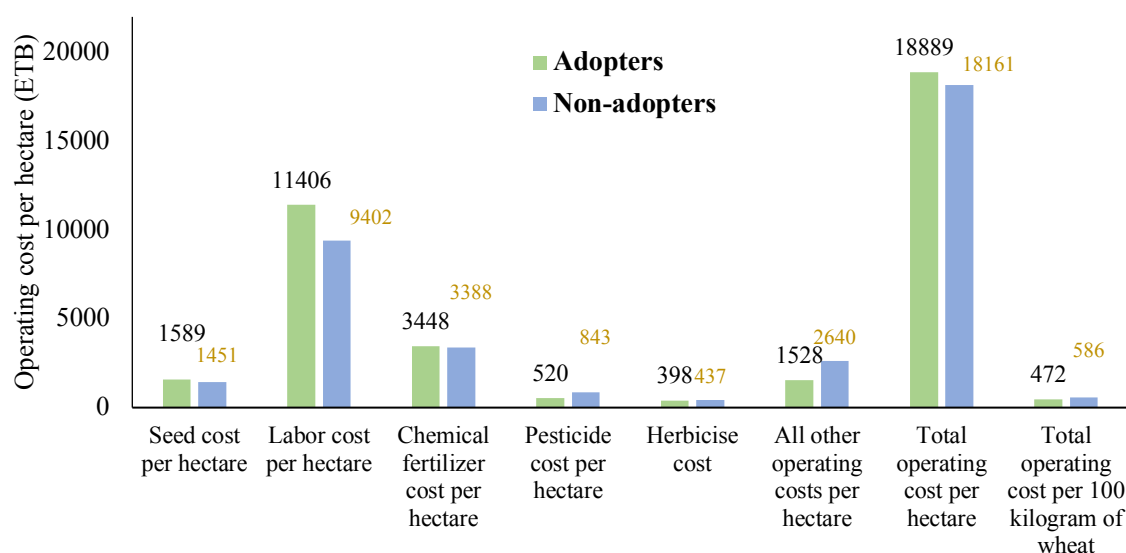


Figure 8.9. Operating cost incurred per hectare and per 100 kilograms of wheat produced, 2017-18.

Market outlets and prices: The price of wheat largely determines farmers’ income from wheat sales. Though small-scale wheat farmers are generally price takers in a competitive output market, whether they sell their products individually or collectively and through traditional market outlets or through contract farming schemes can make an important difference in the income generated.

Small-scale farmers targeted by the project fall under diverse institutional arrangements according to how and if they market grain, seed, or other products of rust resistant wheat varieties. Some farmers operate as individuals, selling their wheat produce in traditional markets. Some are organized under FCUs and others (durum wheat producers) may operate under contract farming schemes with wheat processors. Finally, some farmers market wheat seed to government seed enterprises and may also sell to (or exchange seed with) other farmers. Differing prices and transaction costs under particular marketing arrangements will affect farmer income. Understanding such differences can help wheat farmers and policy makers to better organize for farmers' profit and to foster their expanded and sustained use of quality seed of the latest rust resistant wheat varieties.

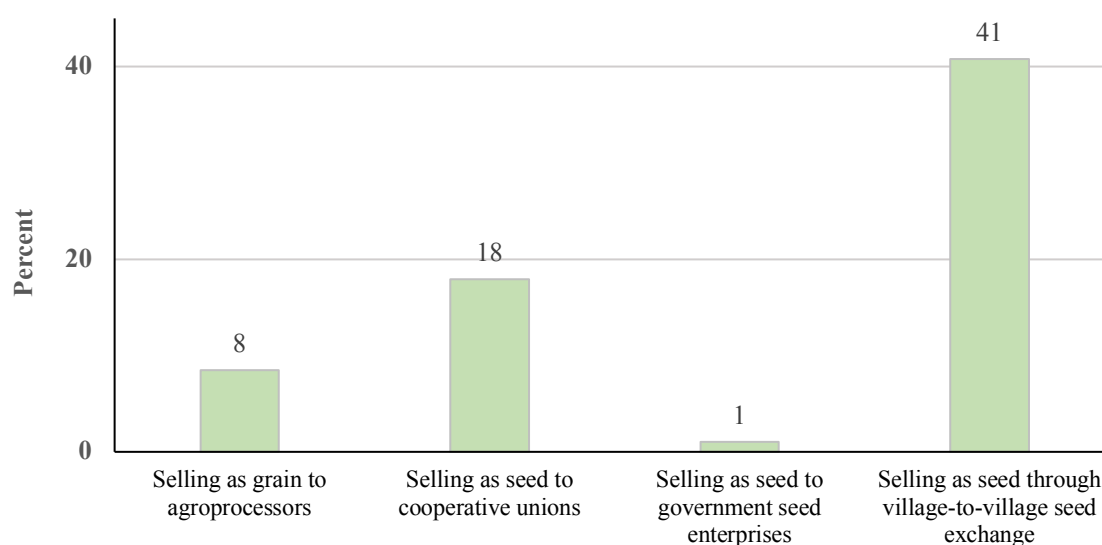


Figure 8.10. Marketing outlets (other than the traditional markets) for products of rust resistant wheat varieties grown under the project, 2017-18.

All farmers can sell wheat grain through the traditional market outlets, which generally provides relatively low income. Grain sales through non-traditional outlets such as agro-processors or marketing seed to cooperative unions or government seed enterprises can generate a better return on investment. The project attempted to promote such innovative marketing arrangements, especially for durum wheat farmers and farmer seed producers and cooperative unions.

A fairly large portion (41%) of farmers growing rust resistant wheat marketed their wheat as seed to other farmers at the village level (Fig. 8.10) and seed sales to cooperative unions was a popular outlet (18%). Sales of grain (particularly of durum wheat) to agro-processors or of wheat seed to government seed enterprises were more limited.

As envisaged by the Wheat Seed Scaling Project, non-traditional market outlets offered more profitable alternatives for durum wheat farmers, who received on average ETB 1,172 per quintal from grain sales to agro-processors and ETB 1,375 per quintal for wheat seed sold to cooperative unions (Fig. 8.11). The average price for wheat in traditional markets was ETB 1,122 per quintal.

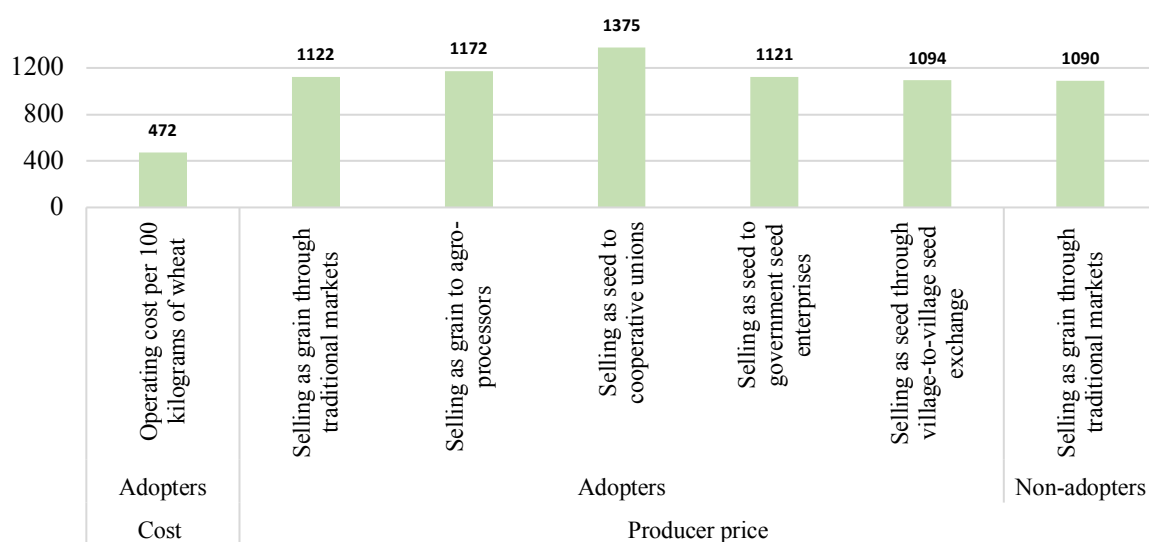


Figure 8.11. Average prices and operating costs (ETB per quintal) for products of rust resistant wheat via diverse market channels, Ethiopia.

Higher prices via non-traditional markets, coupled with higher average yields from rust resistant wheat varieties, improved farm incomes and household welfare, depending on operating costs. This study shows that wheat grain and seed prices through alternative market channel during 2017-18 exceeded average unit operating costs (Fig. 8.11), suggesting that growing rust resistant wheat varieties was profitable.

8.3.6 Gross profit margin

Gross profit margin from wheat production is determined both by the level of operating costs incurred and by the level of revenue generated, which, in turn, are closely related to the adoption status of each farmer and to the market channel through which farmers sell their produce. Operating costs depend on the quantity of farm inputs used and on the level of costs incurred to acquire each input. Similarly, farm revenue depends on the total quantity of output produced and the output price. The presence of many sellers and buyers with adequate information on prices and supply makes agricultural output markets highly competitive. As a result, farmers are generally price takers and receive a similar price for undifferentiated products. The actual prices received by (and gross profit margin of) sample farmers in this study depended, as we have seen, on the market channel.

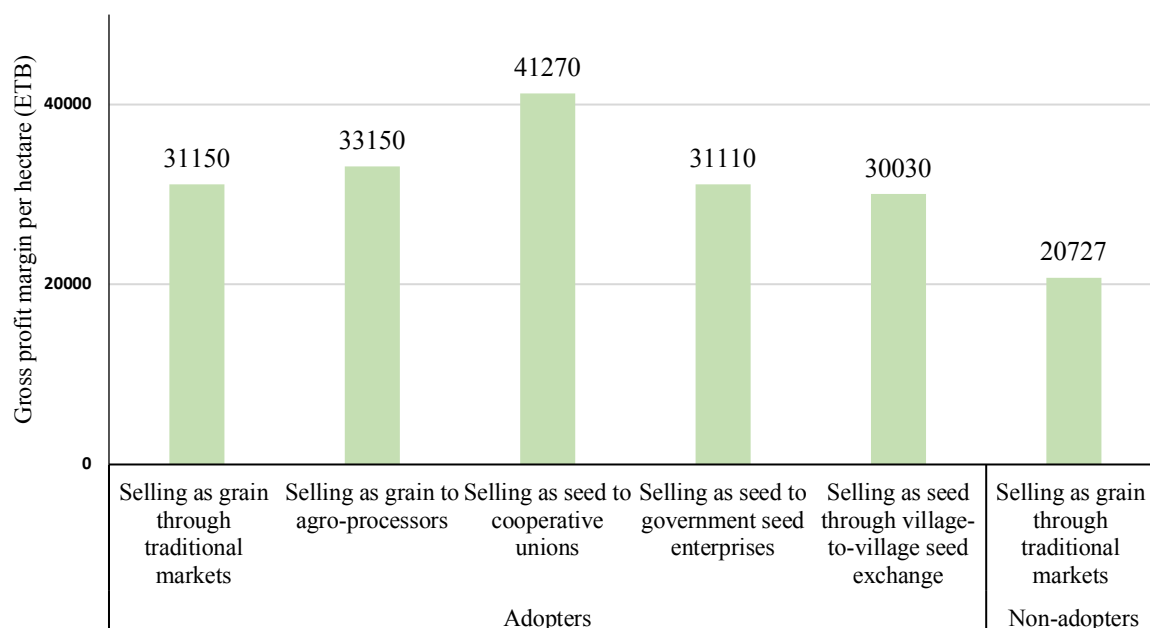


Figure 8.12. Gross profit margins from selling the harvest of rust resistant wheat varieties as grain or seed through different market channels, 2017-18.

The gross profit margin per hectare for grain of rust resistant wheat sold on traditional markets was ETB 31,150 (Fig. 8.12). The highest gross profit margin per hectare was obtained from selling wheat as seed to cooperatives (ETB 41,270 per hectare).

This margin was double (200% more than) that obtained by farmers who grew rust susceptible wheat varieties and sold the grain on traditional markets (ETB 20,727). The second most profitable market option was sales of durum wheat grain to agro-processors from which farmers earned ETB 33,150 on average.² Gross profit margins for selling rust resistant wheat grain on traditional markets (ETB 31,150) were 150% more than sales on those markets of grain of rust susceptible wheat varieties.

Our findings overall showed that seed and grain of rust resistant wheat varieties brought higher profits than products of rust susceptible varieties, meaning that the adoption of rust resistant wheat varieties was economically feasible.

8.3.7 Impact on household food security

Food security in this report is considered as the continuous availability of adequate food for family consumption. Food security is measured indirectly by considering the diversity of food consumed by family members. Both food security and nutrition security conclusions are based on the perceptions of farm household heads who were interviewed.

Wheat being a key component of agricultural livelihoods in the cereal based mixed farming systems of Ethiopia, improvement in its yield due to rust resistant and high-yielding wheat

² See Chapter 7 for details about durum wheat pricing and markets, but in general, attempts to link smallholder durum wheat farmers to domestic processing companies broke down and few farmers were able to sell their durum wheat grain this way.

varieties can have major household food and nutritional security impacts (Chilot et al., 2016), both in terms of food availability and accessibility. Higher wheat yields improve household food self-sufficiency and, thereby, household food availability. Household income from wheat sales can also be used to purchase additional and more diverse food.

Informal discussions with farmers interviewed during the sample survey reflected the positive food security impacts of wheat yield improvement. More formally, both sample beneficiary and sample non-beneficiary farmers were asked to rate their perceptions with regard to their household food security situation during the three-year intervention period of the Wheat Seed Scaling Project. The question was on the *continuous availability of adequate food* for the family. Among beneficiary farmers, 23% felt their household food security had improved significantly and 49% reported that food security in their households improved slightly.

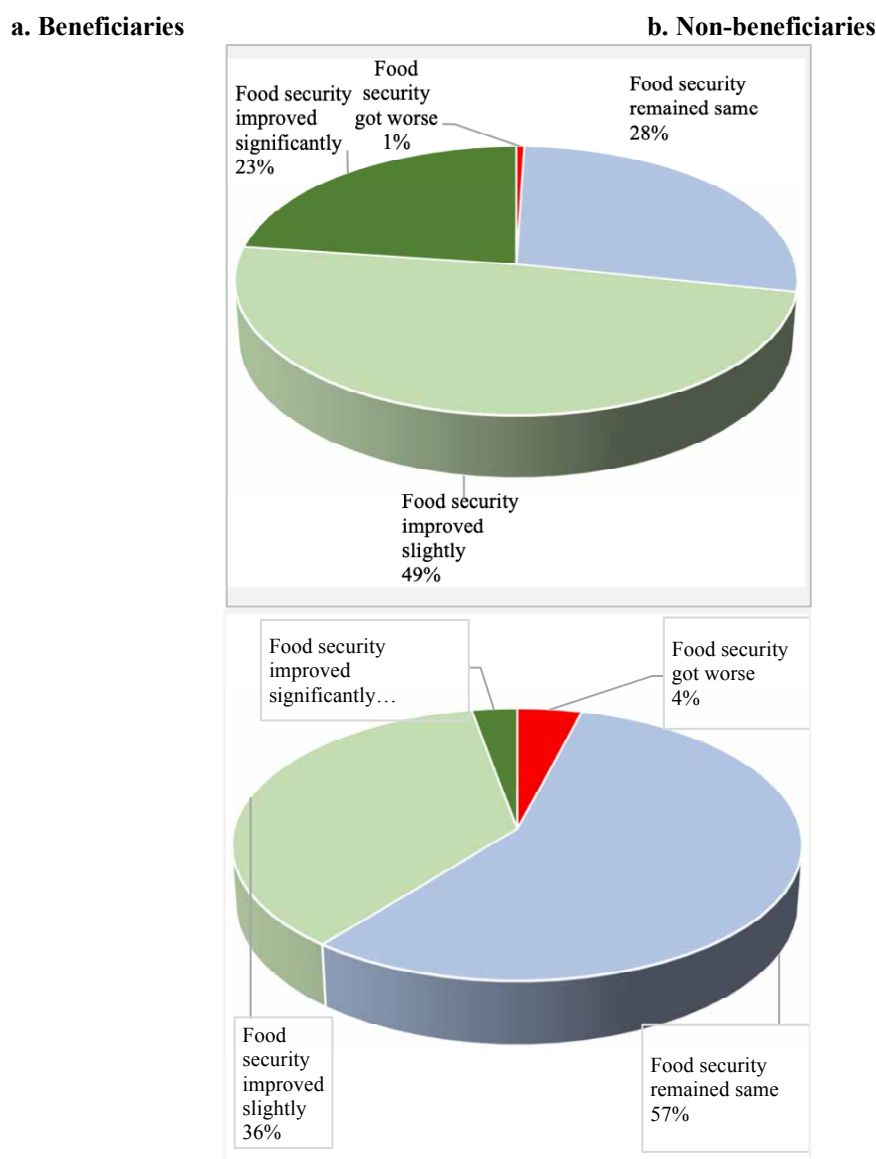


Figure 8.13. Perceptions of farmers regarding their household food security since 2015-16.

This means that 72% of the sample farmers who grew rust resistant wheat believed that the food security of their households improved over the three-year period (Fig. 8.13), whereas 39% of non-beneficiary farmers said their household food security had improved. Moreover, about 94% of farmers who grew rust resistant wheat varieties and who said their family food security had improved significantly attributed the improvement to the project (Fig. 8.14) and about 90% resistant wheat farmers who reported slight improvements in household food security said this was due to the project.

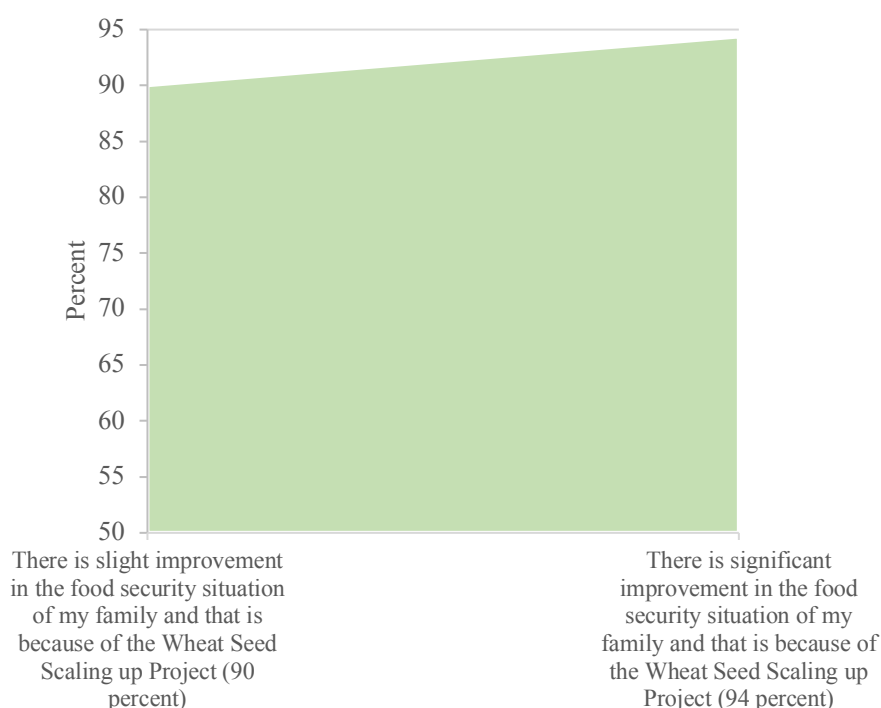


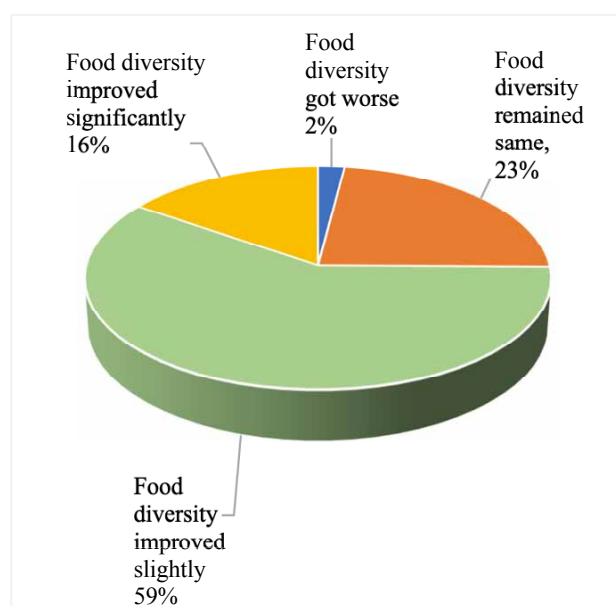
Figure 8.14. Proportion of farm households who attributed improvements in their food security to the Wheat Seed Scaling Project.

Additional opinions from woreda and kebele level agricultural experts confirmed the reported household food security improvements, mainly as a result of higher on-farm wheat yields and production. Accordingly, it can be concluded that the Wheat Seed Scaling Project improved food security for most farm households that grew rust resistant wheat varieties, which was the project's main goal.

8.3.8. Impact on household nutrition security

By raising income, wheat production increases can improve household nutritional security, allowing the purchase and consumption of more diverse food. Asked whether they perceived an improvement in the diversity of food consumed by their families during the project, 59% percent of the farmers who grew rust resistant wheat said there had been a slight improvement and 16% reported a significant improvement (Fig. 8.15). For non-beneficiary households, 2% of farmers said that food diversity had improved significantly and 34% said it had improved slightly.

a. Beneficiaries



b. Non-beneficiaries

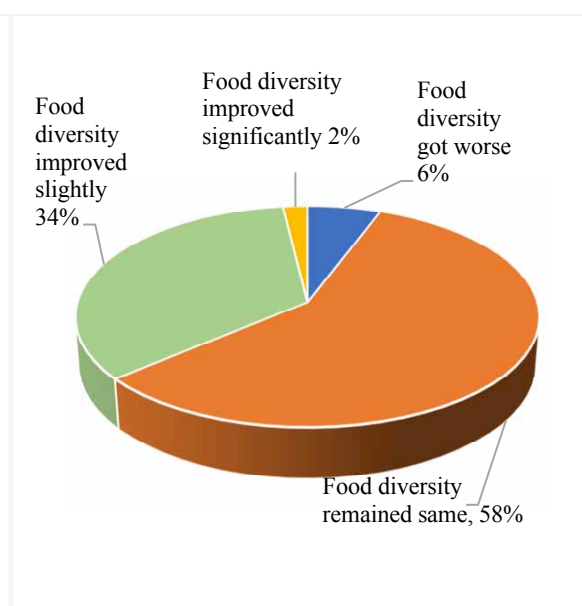


Figure 8.15. Perception of farmers concerning changes in their household food diversity since 2015-16.

About 72% of farmers who reported slight improvements in food diversity and about 95% those who cited significant improvements attributed the improvements to the Wheat Seed Scaling Project (Fig. 8.16). Accordingly, it can be concluded that the project contributed to improvements in household food diversity in most homesteads where rust resistant wheat was grown.

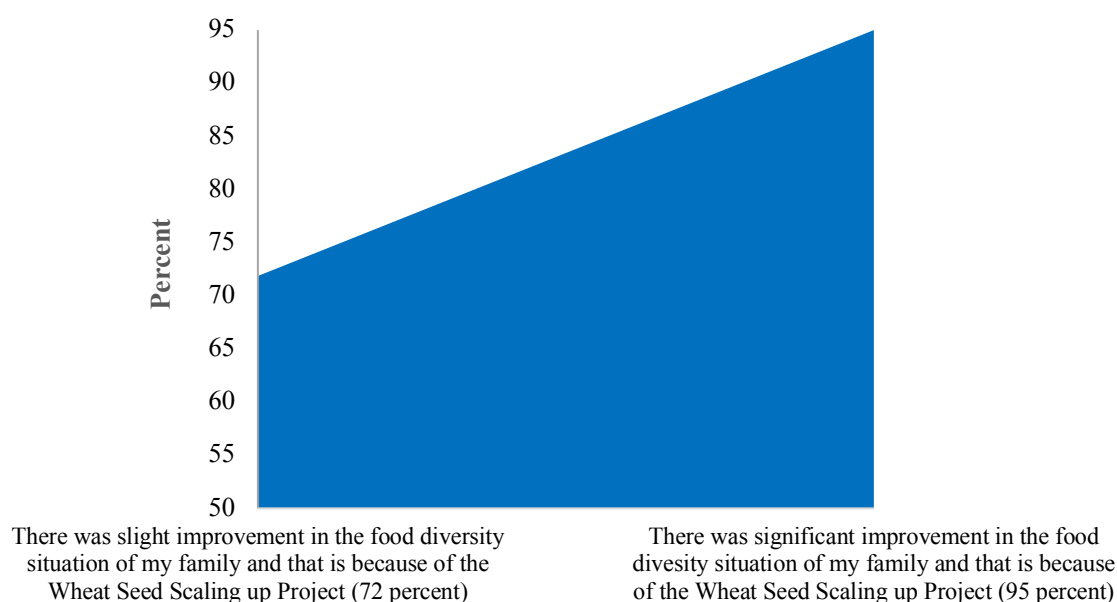


Figure 8.16. Farmers' perceptions regarding the possible contribution of the Wheat Seed Scaling Project to changes in food diversity in their households.

This analysis also explored the concern that, motivated by the benefits from improvements in their wheat yields through the project, smallholder farmers would begin to grow more wheat, potentially reducing the area on their homesteads sown to other, nutritionally important crops. In this regard, about 67% of the farmers who grew rust resistant wheat reported that they had indeed replaced other crops with wheat during the project period, but in most cases the crops replaced were other cereals, rather than nutritionally important alternatives such as pulses or vegetables (Fig. 8.17).

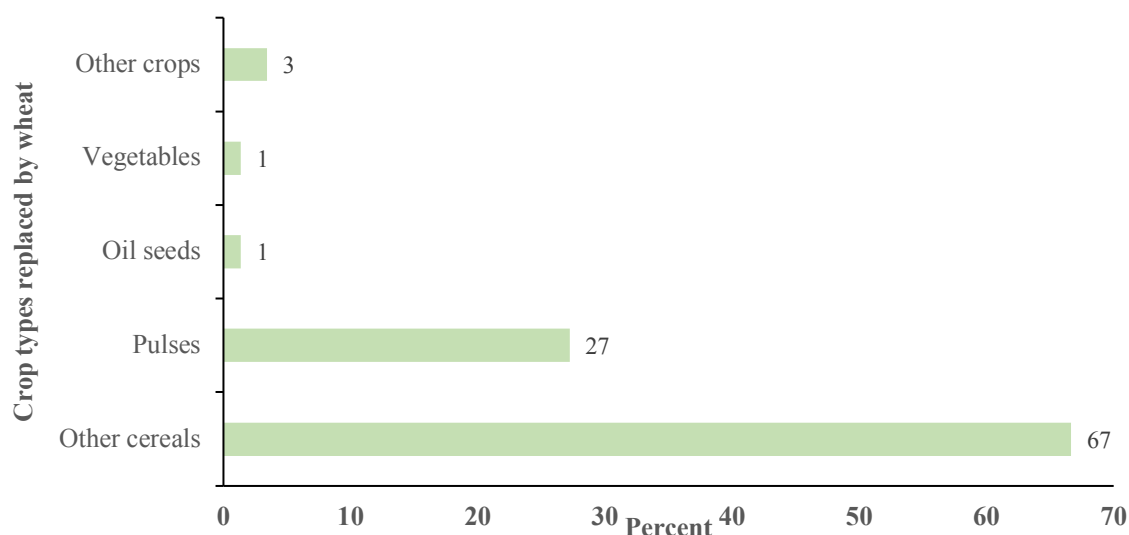


Figure 8.17. Proportion of rust resistant wheat farmers who had replaced other crops with wheat since the 2015-16 crop cycle.

8.4. Summary and conclusions

One of the major cereals grown by Ethiopian smallholders, wheat supports the livelihoods of 5 million farmers and their families, both as a household food crop and a source of income. Improving wheat productivity and production can generate significant income for farmers, as well as helping to reduce poverty and improve the country's food and nutrition security. However, wheat production in Ethiopia is continuously threatened by rust diseases that can have devastating yield impacts.

Implemented in Ethiopia by CIMMYT and EIAR during 2015-18, the Wheat Seed Scaling Project sought to improve the food security of wheat-growing households mainly improving farmers' access to durable rust resistant wheat varieties. To this end and with many partners, the project developed rust resistant wheat varieties, multiplied their seed, conducted field demonstrations, and generally scaled out the varieties by giving many more farmers access to the seed. The project fostered market linkages for small-scale wheat farmers in 54 woredas located in the major wheat growing regions (Amhara, Oromia, SNNPR, and Tigray) of Ethiopia.

An impact assessment for the project explored the resulting varietal adoption, wheat yield performance, farm income, and food and nutrition security, based on data collected through a survey and other means from 806 farmers in 26 project kebeles and 13 project districts, including project beneficiaries but also more than 400 non-beneficiaries as a control group, and comparing the outcomes to previously collected baseline data.

The results showed high rates of adoption of the rust resistant wheat varieties to which farmers gained access under the project and a reduction in the area sown to *Kakaba*, the most widely grown wheat variety, as well as gradual replacement of the popular varieties *Danda'a*, *Digalu*, and *Kubsa*, due to increased use of the new varieties, which include *Hidase*, *Ogolcho*, and *Mangudo* (the latter a durum wheat). Farmers who grew rust resistant wheat were also found to allocate most of their wheat area to the new varieties.

These outcomes underlined farmers' great interest in growing new, improved wheat varieties, mainly for their high yields and rust resistance. Wheat yields overall for rust resistant varieties grown by farmers during the project period averaged 4.09 t/ha, 21% percent higher than the average yield during the baseline (i.e. 3.39 t/ha) in 2014-15 crop cycle. The statistical significance and validity of this finding is supported with rigorous econometric analysis using Propensity Score Matching.

Accordingly, the Wheat Seed Scaling Project fairly achieved its target of raising by 25% the wheat yields of farmers who grow rust resistant wheat varieties.

The impact assessment also supported the financial feasibility of growing rust resistant wheat varieties, showing that their use was more profitable than growing susceptible wheat varieties, with gross profit margins of ETB 31,150 per hectare, compared to ETB 20,727 for farmers who did not benefit from the project, from selling wheat as seed in traditional markets. Profits were even higher (ETB 41,270) for farmers who grew seed of rust resistant varieties for sale to cooperative unions and for durum wheat farmers who sold grain to agro-processors under contract farming arrangements (ETB 33,150).

The Project also achieved its target of improving the food security and food diversity of wheat farmers, according to the survey results, which showed most farmers reporting this to be the case and attributing the improvement to the Project.

The positive yield impacts of rust resistant wheat varieties are widespread among farmers. During 2018-19 farmers have expressed great interest in continuing to grow them. The challenge that remains is uncertainty regarding the sustainable supply of quality seed. As is often the case in incipient seed markets, critical challenges include having reliable evidence of demand for seed producers and suppliers, whereas farmers cite problems with seed quality, delivery delays, high prices and, in some cases, lack of profitable output markets that compensate for higher production costs. Whatever the case, the lack of quality seed of certain rust resistant wheat varieties has led farmers to use up to third-generation saved seed, despite the associated reductions in yield and other traits. With the closing of the Wheat Seed Scaling Project and without concerted efforts by wheat value chain actors in Ethiopia, these issues may become critical, given potential gaps in the system for developing, procuring, and scaling rust resistant wheat varieties. The following recommendations are intended to address current and future challenges and sustainably improve farmers' benefits.

8.5 Recommendations

- **Sustain the current system and institutional set up established by the Wheat Seed Scaling Project for fast-track development, distribution, and scaling of rust resistant wheat varieties:** The fast-track rust resistant wheat variety development and scaling program underpinned by the Wheat Seed Scaling Project has created momentum to address wheat rust disease outbreaks. The project has brought together many actors and institutions, with CIMMYT and EIAR playing catalytic roles. The system and its institutional linkages should be sustained, so achievements and progress can be leveraged to detect and address new rust disease threats. This should continue at least until (i) a critical mass of new farmers adopt rust resistant wheat varieties, (ii) research and the extension system linkages to develop and distribute rust resistant wheat varieties are streamlined for effective scaling, (iii) and impacts are broadened and deepened. Accordingly, a new phase of the Wheat Seed Scaling Project is strongly recommended.
- **Improve seed certification, procurement, quality control, and delivery systems and practices:** There are suggestions that the variety *Hidasie* distributed in certain areas during 2017-18 carried mixed traits, such as both early- and late-maturing types, which likely indicates a seed quality problem. Similarly, the variety *Ogolcho* distributed in certain areas during the same period had shriveled, adulterated, broken, and undersized grains, in some places *Ogolcho* seed was sent back by farmers dismayed by its quality problems. Delays in seed deliveries were also commonly reported. All the above requires improvement, including mechanisms for working closely with farmers and creating awareness on how to procure seed, especially to make village-level seed exchanges and seed procurement from cooperative unions more reliable.
- **Continue research to develop wheat varieties with durable resistance to rust.** Instances have been reported of rust disease infections on rust resistant wheat varieties distributed to farmers. This shows the continued threat posed by new races of wheat rust and the need for continuous disease surveillance, capacity development, and research. These, in turn, call for an established and coordinated institutional presence, again justifying the recommendation for a new phase of the Wheat Seed Scaling Project.
- **Enhance the supply of certified rust resistant wheat seed to satisfy farmer demand:** The Wheat Seed Scaling Project provided basic seed of resistant wheat varieties to beneficiary farmers only once. Afterwards farmers used saved seed of C2 and C3 generations, seed from the seed loan system (which was saved seed), or seed from other farmers. The yield of varieties sown using farmer saved seed is expected to decline over successive crop cycles. This makes it crucial to improve the basic seed supply system so that farmers have access to new basic seed and the highest yields.
- **Strengthen private sector participation in basic seed multiplication and distribution:** In place of time-bound, externally funded projects to develop, multiply, and distribute pre-basic and basic seed of rust resistant wheat varieties, it is important to build the capacity of private seed producers, such as cooperative unions, to ensure the long-term maintenance and expansion of effective seed systems.
- **Continue attempts to promote farmer linkages to agro-processors and other markets:** Wheat agro-processors in Ethiopia depend on imported wheat because domestic supplies are inadequate, but farmers---and especially durum wheat growers---complain that they are poorly-linked to agro-processors and lack markets for their wheat.

Indeed, only 8% of farmers who grow rust resistant wheat market their grain to agro-processors. Special attention is thus needed to identify the constraints and better promote market linkages between farmers and agro-processors, as one more incentive for the adoption and use of rust resistant varieties.

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