Containing the Menace of Wheat Rusts

Institutionalized Interventions and Impacts

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Science for Better Livelihoods in Dry Areas

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THIS BOOK is the grandstand of the collaborative endeavours of diverse stakeholders in addressing the challenges of wheat production and wheat rusts in Ethiopia within the context of the international efforts across Africa and Asia. Wheat is one of the most important staple crops across the globe including Ethiopia. An emergence and quick spread of Ug99 coupled with a devastating outbreak of stripe rust in 2010 caused significant losses and economic hardship for Ethiopia's wheat farmers, and underlined the country's increasing vulnerability to the disease - a result of climate change and changing weather patterns. In response, the rapid development and deployment of high-yielding, rust-resistant wheat varieties which are helping Ethiopian farmers to raise their production and achieve higher incomes and greater food security was developed by a USAID funded initiative.

The book with its title "*Containing the Menace of Wheat Rusts: Institutionalized Interventions and Impacts*" provides a synthesis of the research for development and rich experience gained in quick deployment of rust resistant wheat varieties through this effective partnership including the Ethiopian Ministry of Agriculture and Natural Resources and Regional Bureaus of Agriculture, the National Agricultural Research System (NARS), the International Centre for Agricultural Research in the Dry Areas (ICARDA), formal and informal seed suppliers, NGOs and farmers.

Many of the contributors to this volume provide sound evidence in favour of diversified interventions with due focus on mechanisms for institutionalizing the research approaches to ensure sustainability in addressing the ever increasing challenges of wheat rusts. The experiences and knowledge gained are put in context aimed at decision-makers, not only in Ethiopia but in other developing countries for wider application and spill overs. The book provides useful insights to policy makers, researchers, students, development practitioners and donors involved in international development for generating and moving technologies out to the farmers' fields.

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Preface

In Ethiopia, wheat is an important cereal crop that significantly contributes to the livelihood of smallholder farmers and urban consumers. In 2014/15 cropping season, the country produced 4.23 million tons of wheat grain on about 1.7 million hectares of land representing 17.9 per cent of the cereal production and accounting 16.4 per cent of the cereal area. Over the decades, the country witnessed an impressive growth in wheat production due to both area expansion and productivity improvements. Wheat production grew from 2.3 million tons in 2007/8 to 4.2 million tons in 2014/15. Similarly, the area increased from 1.42 million ha in 2007/08 to 1.7 million ha with corresponding productivity increase from 16.3 tons ha^{-1} reaching 2.5 tons ha^{-1}. There is an increase of 20, 53 and 80% (an annual growth rate of 10%), respectively in terms of area, productivity and production.

The use of high yielding varieties and associated crop management practices has been the major drivers for the significant changes in wheat production and productivity. In 2010, improved wheat varieties were planted on 60% of the total wheat area (Chilot et.al, 2013). Wheat being a key source of livelihood in the cereal based mixed farming systems of the mid and high altitude areas of the country, a considerable increase in yield through the use of disease resistant and high yielding improved wheat varieties had a major impact on household food and nutritional security, income generation and overall welfare of smallholder farmers dependent on crop agriculture. In view of this, the generation and transfer of improved agricultural technologies in general and that of disease resistant, widely adaptable and high yielding wheat varieties in particular has been identified as one of the pillars in the National Food Security Strategy adopted by the Government of Ethiopia.

Nevertheless, wheat production and productivity are threatened by biotic and abiotic stresses. Among the biotic stress, diseases are the most important threats challenging the wheat sector. In this regard, wheat rust diseases have become frontline constraints. In response, there have been a number of efforts in the research and development arena. The possible options for wheat rust management are application of appropriate cultural practices, chemical application (fungicides) and/or use of resistant varieties. The wider application and adoption of these options crucially depend on economic feasibility. In addition, rust epidemic is influenced by abiotic factors mainly climate change and variability. Thus, promotion of integrated wheat rust management is highly recognized approach. In terms of sustainable wheat rust disease management, the development and use of resistant varieties along application of associated cultural practices is the best option.

This book documents ICARDA's experience in rapid deployment of rust-resistant wheat varieties through bilateral and multilateral projects in general and the ICARDA-EIAR project entitled *Deployment of rust-resistant varieties for ensuring food security in Ethiopia* in particular highlighting the framework of fast track variety testing and release and accelerated seed production to mitigate and/or control wheat rusts. Chapter 1 presents ICARDA's overall experience working with NARS in Egypt, Ethiopia and Pakistan. Chapters 2 to 7 considered the status of wheat rusts and the achievements and lessons learned in fast track variety release, accelerated seed multiplication, promotion of rust-resistant wheat varieties, awareness creation among stakeholders, training of farmers and development agents, and capacity building in terms of rust disease early warning system, and value chain development by enhancing linkage between smallholder farmers and agro-industries in Ethiopia. Chapter 2 highlights the historical and status of wheat rusts and the management options available to farmers. Chapter 3 presents, the development of rust-resistant wheat varieties and release including pre-release seed multiplication and variety maintenance at federal and regional agricultural research centers. Chapter 4 summarizes the early generation seed (breeder, pre-basic and basic) multiplication by NARS and large-scale certified seed production partnering with public seed enterprises and farmer seed producer's associations. Chapter 5 elaborates on demonstration, popularization, on-farm seed production and capacity strengthening of stakeholders. Chapter 6 elucidates the past attempts and the project efforts in linking smallholder farmers to the durum value chain. In Chapter 7 the impact of the project in terms of wheat productivity, production, household food security, and the institutional innovations in variety releases, seed multiplication and delivery systems are presented. Chapter 8 presents the achievements and lessons learned on critical research, development and policy implications both at global/regional and national levels.

The experiences documented in the book are expected to inform stakeholders including policy makers, researchers, farmers, the private and public commercial farms and development partners about the status, challenges, and opportunities in wheat rust management in Ethiopia and beyond paving the way for the development of more efficient intervention options for the future.

The editors of this book are thankful to the USAID and USDA for their financial support through bilateral and multilateral funding of the projects in the respective countries in combating the threat of wheat rusts in general and Ug99 in particular. Our special thanks to farmers who participated in the demonstration, popularization and on-farm seed production for quick dissemination of new improved rust-resistant wheat varieties. Finally, we would like to thank the NARS, public and private seed producers and suppliers and the agricultural extension services of Egypt, Ethiopia and Pakistan and their staff which were involved in implementing the project activities whose experience is documented here. The authors take the responsibility of any errors or omissions.

Editors
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Chapter I

Rapid Deployment of Rust-resistant Wheat Varieties: ICARDA's Experience and Lessons Learned

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1.1 Background

The emergence of Ug99 in Uganda (1999) and its variants elsewhere, its quick spread to neighboring countries in East Africa and the Middle East and anticipated potential spread further to South Asia and East Asia caused great alarm amongst the international community. About 85% of widely grown commercial wheat varieties from 18 African and Asian countries were found susceptible to Ug99. An estimated 52% of total wheat area of 74.6 million hectares planted with wheat in these countries which collectively represent 40% of global wheat production is planted with susceptible varieties. Ug99 (including its virulent races) considered a serious threat to global wheat production with potentially catastrophic consequences which could trigger a global food crisis. In the meantime the spread of strains of yellow rust virulent on varieties carrying the Yr27 gene in west and central Asia has exacerbated the anticipated food crisis in times of increasing cereal prices and market uncertainties (Shiferaw et al 2013).

In response to Ug99 crisis, CIMMYT and ICARDA in partnership with a number of National Agricultural Research Systems (NARS) have initiated the Borlaug Global Rust Initiative (ex GRI) under the leadership of the late Nobel Prize laureate Dr Norman Borlaug. Development and deployment of resistant varieties, adequate surveillance systems and effective plant protection strategies are important elements of an integrated wheat rust control strategy to replace widely grown susceptible varieties and ensure national, regional and global food security (Osborn and Bishaw 2009). Under the BGRI, CIMMYT, ICARDA and a number of NARS from developed and developing countries have tested thousands of accessions in Kenya and Ethiopia. A number of elite lines with adequate resistance against Ug99 and with up to 15% yield increase have been identified through such collaborative effort. Some of these materials were distributed as part of Elite Bread Wheat Yield Trials (EBWYT) and Stem Rust Resistance Screening Nurseries (SRRSN) by CIMMYT and ICARDA.

The most pressing challenge is not only developing rust resistance varieties, but finding innovative and flexible approaches to fast-track variety release and accelerate seed multiplication to ensure quick delivery to farmers for wider scale adoption and diffusion of these varieties both at national and regional levels. Availability of and access to wheat seed of resistant varieties is key to counter the threat of rusts and ensure food security. Osborn and Bishaw (2009) highlighted the key elements for ensuring rapid dissemination of wheat rust resistant varieties to farmers.

ICARDA in collaboration with CIMMYT and/or NARS has developed a number of multi-lateral and bilateral projects to counter the threat of stem rust and yellow rust. This paper summarizes ICARDA's experiences and lessons learned in implementing these projects.

1.2 Wheat projects and target countries

The first, CIMMYT-ICARDA joint project entitled 'Accelerated Seed Multiplication to Counter the Threat of Stem Rust in Wheat' covered six countries along the path of Ug99 in Africa and Asia: Afghanistan, Bangladesh, Egypt, Ethiopia, Nepal and Pakistan. ICARDA implemented the project in Egypt, Ethiopia and Pakistan whereas CIMMYT was responsible for Afghanistan, Bangladesh and Nepal. The second CIMMYT-ICARDA project was the 'Wheat Productivity Enhancement Program' in Pakistan and supported by USDA focusing on Ug99. The third was an ICARDA-EIAR bilateral project 'Rapid Deployment of High Yielding and Rust-resistant Wheat Varieties for Achieving Food

Security in Ethiopia' prompted by yellow rust epidemics in 2010 and supported by USAID.

The primary objectives of these projects were to ensure fast replacement of existing commercial varieties that are vulnerable to new races of stem rust and yellow rust by minimizing the time lag from the identification of potential resistant varieties to their availability in farmers' fields working with national stakeholders across the wheat value chain including policy makers, NARS, national seed programs, development practitioners and farmers.

The project target countries were selected for various reasons. First, wheat contributes substantially to daily caloric intake (up to 30%) and some countries have the highest per capita wheat consumption in the world (180-200 kg). Second, wheat occupies the highest percentage of cereal area and production (up to 80%) and is also the main staple crop of the country. Third, wheat area is extensively planted with Ug99 susceptible varieties and hence higher potential vulnerability to rust epidemics. Fourth, there is endemic domestic food insecurity where millions of tons are imported as food aid which could be exacerbated due to Ug99 epidemics. Fifth, the strength of the national seed sector is highly variable among the targeted countries operating under a wide range of policy, regulatory and institutional frameworks and technical constraints underpinned by poor socio-economic conditions of farmers. Such inherent weaknesses in the national seed industries hinder farmers' rapid access to new resistant wheat varieties in nearly all countries at risk of wheat rust.

1.3 Framework and Approaches

Development and deployment of resistant varieties is one of the key tools for wheat rust management. These could only be achieved by having effective contingency planning for organized fast-track release of new varieties and accelerated seed multiplication under pinned by flexible policies, and commitments by national and/or international community of stakeholders (Osborn and Bishaw, 2009).

A framework for fast track variety testing and release and accelerated seed multiplication was undertaken to address the objectives of the different projects as follows (see Figure 1.1):

- Identifying stem rust (Ug99) and yellow rust resistant wheat elite lines combined with better agronomic performance;
- Fast track testing and release of new rust-resistant wheat varieties through national dialogue with stakeholders;
- Popularizing and demonstrating newly released rust resistance wheat varieties in collaboration and partnership with extension services and development practitioners;
- Accelerating seed multiplication of promising lines (pre-release) or released varieties (post-release) to produce sufficient amount of early generation seed (breeder, pre-basic and basic seed);
- Accelerating large-scale certified seed production of released varieties by partnering with existing public and/or private seed sector;
- Distributing small seed-packs of released varieties to initiate on-farm seed production mobilizing farmers and assisting in informal varietal diffusion;
- Strengthening the infrastructure and human resources capacity of key stakeholders including farmers; and
- Monitoring and evaluation of project deliverables including adoption and impact studies

1.3.1 Screening rust resistance wheat

In order to safe-guard against the release of Ug99 susceptible varieties, the international collaboration was maintained where new elite germplasm from national and international breeding programs, potentially promising lines under national performance trials or newly released commercial varieties were continuously tested and monitored for resistance to Ug99 and its variants in hot spots in Kenya and Ethiopia. In addition, to Ug99, promising lines were also tested against yellow rust in Ethiopia and Syria.

The wheat research strategy against the threat of stem rust race Ug99 and other rusts anchored on the following activities:

- Screening national germplasm (old varieties, commercial varieties, promising lines, breeding materials) for resistance against Ug99 in hot spots;
- Identifying resistance genes that are effective against Ug99 and local races of stem rust, yellow rust and leaf rust that carries durable resistance using molecular tools; and
- Incorporating diverse resistance genes into adapted cultivars and evaluate them in hot spots to develop new high yielding varieties.

From the outset, several accessions have been screened in Kenya and shared globally with NARS through CIMMYT and ICARDA as part of EBWYT and SRRSN since 2005.

1.3.2 Fast-track variety testing and release

Variety release encompasses a broadly interrelated series of activities, from identifying promising lines for further testing to releasing a new variety and making available breeder seed for further multiplication (Bishaw and van Gastel 2010). NARS follow conventional plant breeding protocols using both performance (VCU = Value for Cultivation and Use) and registration (DUS = Distinctness, Uniformity and Stability) trials for official release of new varieties (for details see Turner and Bishaw, 2016). Egypt and Pakistan have partially independent compulsory variety testing and release system requiring both registration and performance trials. In Egypt, ARC conducts the VCU trials and the Central Administration for Seed Testing and Certification the DUS trials while the release is approved by the NVRC. In Pakistan, the National Wheat Coordinated Program affiliated with NARC and under the Pakistan Agricultural Research Council performs the VCU testing and FSCRD the DUS testing whereas the release is approved by the Provincial Seed Council. In Ethiopia, the release system is purely dependent on performance testing conducted by the NARS, evaluated by the technical committee and approved by a NVRC under the Animal and Plant Health Regulatory Directorate. In almost all three cases the recommendations comes from the technical committees established for the purpose and providing advice to the NVRC.

Although NARS are dependent on common germplasm pool introduced from IARCs, it is not always clear how many years of testing would be required before these lines are finally enter variety release trials based on their performance. The serious threat of wheat rust means that variety evaluation and release may need to be streamlined so that it is efficient and effective but at the same time to be carried out in as short a timeframe as possible. In Ethiopia, ‘adaptation’ testing program was initiated where introduced promising lines with Ug99 resistance were directly tested in one-year multi-location trials and released for commercial use. In Egypt, both DUS and VCU trials were conducted simultaneously where sometimes they are carried out in subsequent years. Moreover, promising lines were provisionally released for variety popularization and pre-release seed multiplication of later generations (up to registered seed). In Pakistan, promising lines with outstanding performance could be simultaneously entered into different stages of variety trials to expedite the release process for emergency situations. Moreover, the DUS testing can also be reduced to one year to confirm the description, if sufficient descriptive data of the candidate varieties is provided by the breeders.

Although the frequency of resistant lines against Ug99 from NARS was very low, these lines were considered as the first source of material for promotion, since they have been widely tested and seed was already available with NARS (Joshi et al 2011). In addition, a number of elite lines with adequate resistance against Ug99 and with yield advantage of up to 15% have been identified by CIMMYT and ICARDA and were distributed as part of Elite Bread Wheat Yield Trial and Stem Rust Resistance Screening Nursery since 2005 for further testing and release.

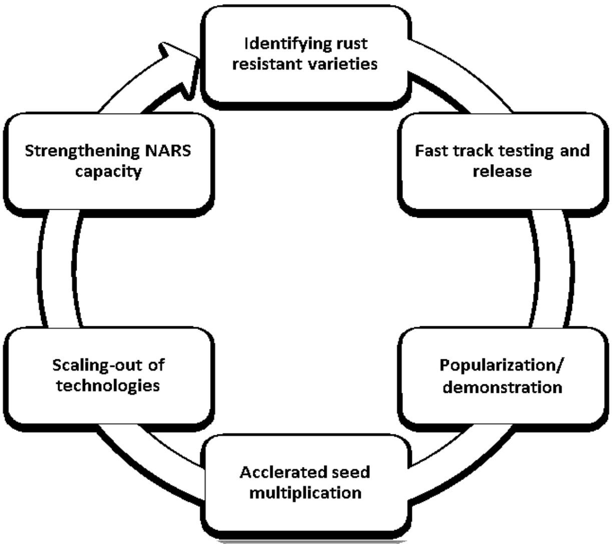


Figure 1.1. Approach in fast-track variety release and accelerated seed multiplication

1.3.3 Variety popularization and promotion

Weak extension services are often blamed for poor transfer of new agricultural technologies to farmers. In all three countries the sheer number of small-scale farmers engaged in wheat production would require doubled effort in number of demonstrations to reach reasonable number of farmers. A variety of approaches were used including regional travelling workshops, national wheat rust workshops, field visits and demonstration plots, field days and print media. NARS made an extraordinary effort in popularizing new rust-resistant wheat varieties to create farmers' awareness and demand for seed. NARS worked with agricultural extension and seed producers in conducting both on-station and on-farm demonstrations to create awareness among policy makers, researchers, seed producers, development agencies, extension services, NGOs and farmers.

1.3.4 Accelerated seed multiplication

There are two critical stages in seed multiplication along the pathway from variety release to getting the new varieties to farmers' fields: small-scale early generation seed multiplication (breeder seed to basic seed); and large-scale seed multiplication (basic seed to certified seed). Availability and access to basic seed of new varieties is often cited as major impediment for quicker seed delivery to farmers. Fast track variety testing and release system therefore should be linked with accelerated seed multiplication in moving rust-resistant wheat varieties from research plots to farmers' fields as quickly as possible.

A target for rapid seed multiplication should aim to cover at least 10% of the wheat production area. In most countries this was accomplished within three to four generations. Osborn and Bishaw (2009) outlined the systematic approach and planning for accelerated seed multiplication for quick replacement of rust susceptible varieties where national programs can follow the principles and procedures for wheat seed production described by van Gastel et al (2003).

a) Early generation seed multiplication

A flexible approach of 'pre-release' seed multiplication was initiated to overcome the legal and technical hurdles of early generation seed production. As a result multi-location variety trials, pre-release seed multiplication and variety popularization were carried out simultaneously (Figure 1.2). Seed multiplication was initiated much earlier to assure that at the time of release sufficient quantities of basic (foundation) seed are available for large-scale seed multiplication and eventual distribution to farmers. The project provided direct support for pre-release seed multiplication of breeder, pre-basic and basic seed in target countries. Moreover, NARS continue to carry out variety maintenance and early generation seed production once varieties were officially released for commercial production.

In Egypt and Ethiopia, pre-release seed multiplication was carried out strictly by NARS. In Pakistan, pre-release seed multiplication was carried out both by NARS and public and private seed companies under the umbrella of Foundation Seed Cell program. The basic (foundation) seed produced under pre- and post-release multiplication was made available to: (i) formal public and private seed sectors; and (ii) farmer/community-based seed initiatives for further multiplication under accelerated conditions both during main/off-season production.

b) Large-scale certified seed multiplication

The pre-and post-release accelerated seed multiplication by NARS was closely linked to large-scale certified seed production to replace rust susceptible varieties in high risk areas. In Egypt, the Central Administration of Seed Production (CASP) had early access to foundation seed to accelerate registered and certified seed multiplication. In Ethiopia, basic seed was provided to the Ethiopian Seed Enterprise, Regional Seed Enterprises (ASE, OSE and SSE), public state farms (Bale SF) and Private Estate Farms, development partners (AGRA) and NGOs engaged in farmer-based seed production. In Pakistan, accelerated seed multiplication was implemented with a number of seed companies from both the public (Punjab Seed Corporation), and the private sectors.

c) On-farm seed production

Apart from formal seed production through public and private sector, an alternative farmer based seed production was initiated in Ethiopia and Pakistan. In Ethiopia, a partnership was developed with district Bureau of Agriculture in districts with Agricultural Growth Program where farmers were identified, trained, fields clustered, and provided with seed of new rust-resistant varieties to produce and market the seed locally through formal or informal channels. A revolving seed scheme was established and implemented where farmers return the initial seed for further use by the project. In Pakistan, individual pioneer farmers or groups in rainfed areas of Punjab, Baluchistan and Khyber Pakhtunkhwa were identified and provided with seed of new rust-resistant varieties in areas where the formal sector operation is rather minimal. At least three networks of seed producer groups were initiated and linked with Barani Agricultural Research Institute, Cereal Crop Research Institute and National Institute of Food and Agriculture.

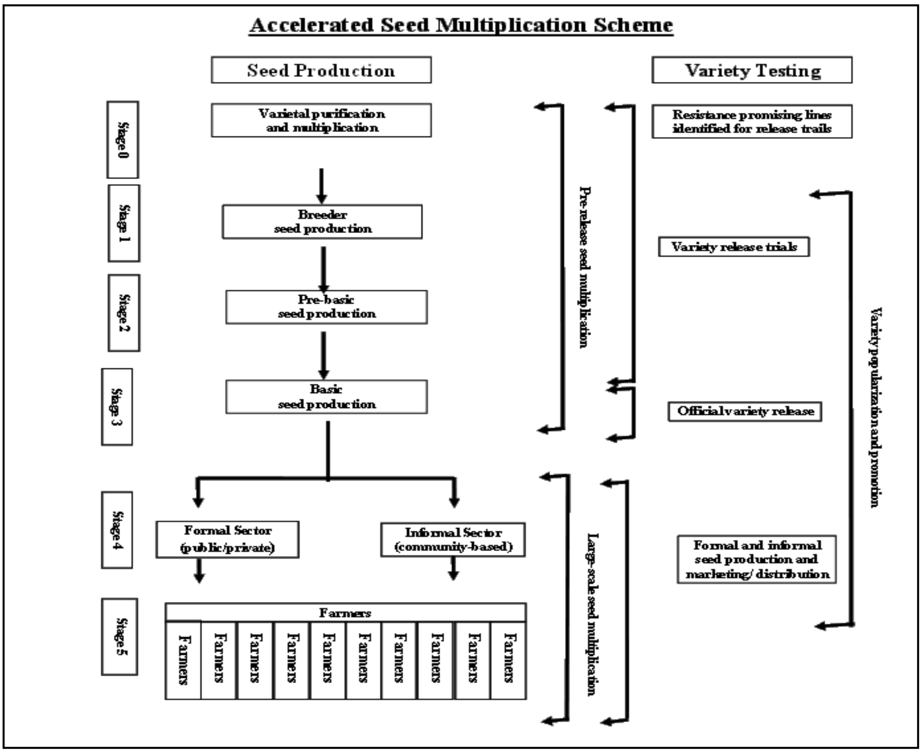


Figure 1.2. Accelerated seed multiplication scheme (Osborn and Bishaw, 2009)

d) Strengthening capacity for seed delivery

Rapid seed multiplication of large quantities of seed will require capacity building beyond the ongoing normal seed activities at country level or regional level. This emergency situation brings more work to an already limited infrastructure to undertake a huge task of both pre-release and large-scale seed multiplication where time is an essence of all operations. Apart from efficient use of existing resources and facilities additional investments may be necessary particularly for robust response to the crisis situation.

Strengthening infrastructure for NARS and stakeholders: In a well-functioning seed system, availability of basic (foundation) seed is a norm than an exception for immediate commercialization of the variety upon its release particularly in the private sector. In public NARS, because of least vested interest, there is disconnection between variety release and its commercialization. Lack of financial and physical resources such as land, equipment, and irrigation, risk avoidance (variety not released), lack of clear mandate, etc. are some of the constraints observed for the activity to remain ad-hoc instead of a regular feature of NARS program. It is important that a functional seed unit established and equipped with adequate physical, financial and human resources. It would be useful to institutionalize a sustainable early generation seed production for countries to adequately respond to any future emergency situations or normal operations.

Strengthening capacity of human resources: Seed production requires specific knowledge and practical experience to produce high quality seed of high standards of varietal purity and physical, physiological and health. From the outset, assistance in capacity development of NARS and national seed programs is a key to enhance their technical and managerial capacity. Short-term trainings were conducted in principles and techniques of variety maintenance, seed production, seed processing, and seed quality control for technical managers, technicians and farmers whereas workshops aimed at policy and decision makers and senior managers to create awareness of rust problems and contingency planning.

1.4 Partnership with key Stakeholders

A complete wheat variety replacement is an enormous task in terms of millions of hectares to be covered and the quantity of certified seed required for planting by small-scale farmers in developing countries. Large-scale varietal replacement can only be achieved with the full participation and partnership of the key stakeholders in the respective countries. A multi-stakeholders forum was initiated and partnerships established with the Ministries of Agriculture and its affiliated departments such as the agricultural research institutions, agricultural development and extension services, public and private seed companies, variety registration and seed certification agencies, NGOs and farmer associations to create awareness and define their roles, responsibilities and commitments (Figure 1.3). A high level national steering committee and technical committee were established for guiding the project planning and implementation. The project was implemented through a consultative process where each year work plans are prepared at the beginning of the season, activities implemented and monitored during the season, results reviewed at the end of the season and adequate planning made for the next season involving key stakeholders. This had helped in overcoming some policy and regulatory constraints that would hinder fast track variety release and accelerated seed multiplication to make available seed of new rust-resistant varieties to farmers. The key stakeholders and their roles are as described below:

CGIAR and NARS: It is important that new wheat varieties should combine rust resistance with better agronomic performance such as high yield and acceptable grain quality to induce farmers to adopt. ICARDA and CIMMYT developed the promising lines and distributed them as part of Elite Bread Wheat Yield Trials (EBWYT) and Stem Rust Resistance Screening Nurseries (SRRSN) as part of international nurseries network.

Federal (national) and/or regional agricultural research centers of respective countries undertook fast track testing and release of the new rust-resistant wheat varieties and earnestly engaged in pre-release and post-release seed multiplication to make available sufficient quantities of basic seed using both the main and off-seasons where feasible. This include Agricultural Research Center in Egypt, EIAR (federal) and RARIs (regional) in Ethiopia and federal (National Agricultural Research Center) and several provincial (Ayub ARI, Barani ARI, Cereal Crops RI, Regional ARI, etc.) agricultural research institutes in Pakistan.

Public and private seed producers: The public and private commercial seed suppliers embrace and multiply pre-basic and basic seed in pre-release seed multiplication working closely with NARS and later produced certified seed of new rust-resistant varieties for commercialization using their own resources. The Central Administration for Seed Production in Egypt; federal (ESE) and regional public seed enterprises (Bale Agricultural SE, Amhara SE, Oromia SE and Ethiopian SE) and private seed companies in Ethiopia; and provincial seed corporations (PSE) and several private companies in Pakistan

Regulatory and certification agencies: These agencies have facilitated the fast track testing and release of varieties and certification of early generation seed multiplied under pre-release seed multiplication. It includes the Central Administration for Seed Testing and Certification (Egypt), Animal and Plant Health Regulatory Directorate (Ethiopia) and Federal Seed Certification and Registration Department (Pakistan).

Agricultural development and extension services and NGOs: The agricultural development practitioners, extension services and NGOs partnered with NARS and the seed companies in demonstration and popularization of rust-resistant wheat varieties. They organized field days using all available means and including their resources. They also played key roles in on-farm seed production and dissemination, for example in Ethiopia. In Egypt, ARC worked with the Central Administration for Extension Services for variety demonstration and the Socio-Economic Research Institute to assess the economic benefits of the new varieties. In Ethiopia the district BoAs and some NGOs (SG2000) played a significant role in popularization and demonstration of new varieties and associated technologies. In Pakistan, NARS worked with the national agricultural extension services and/or directly with progressive farmers in variety demonstration and popularization.

Farmer groups and farmers: Farmer groups and farmers not only passive seed users or hosted demonstration, but also engaged in contractual seed production for the formal sector or local seed production and marketing through informal channels assisting the adoption and diffusion of new rust-resistant wheat varieties.

The main frontline actors however were thousands of farmers who participated in variety popularization and on-farm seed multiplication at various stages of project implementation in different countries.

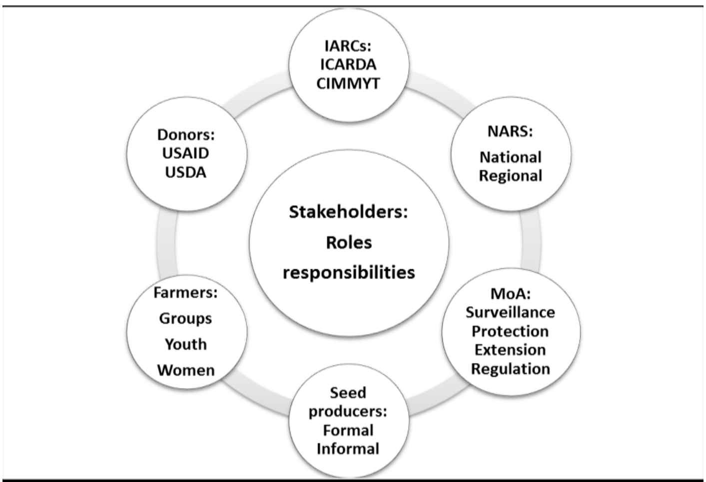


Figure 1.3. Key stakeholders in project implementation

1.5 Project Achievements

ICARDA implemented one regional project entitled 'Accelerated seed multiplication to counter the threat of stem rust in wheat' (Egypt, Ethiopia and Pakistan) completed in March 2012; and follow-up bilateral projects in Ethiopia (Rapid deployment of rust-resistant varieties supported by USAID) completed in December 2014 and in Pakistan (Wheat Productivity Enhancement Program supported by USDA) completed in September 2015, the experiences which are highlighted below.

1.5.1 Accelerated Seed Multiplication to Counter Threat of Stem Rust in Wheat

A geographically broader project jointly developed by ICARDA and CIMMYT and funded by USAID International Disaster and Famine Assistance was implemented from 2008/09 to March 2012. It aimed at fast track testing and release and accelerating seed multiplication to counter the threat of the Ug99 stem rust disease of wheat in countries that lie on the path of potential threat from Ug99. ICARDA implemented the project in Egypt, Ethiopia and Pakistan, and CIMMYT in Afghanistan, Bangladesh and Nepal.

a) Wheat variety releases

The project started with eight promising lines having Ug99 resistance and high yield of CIMMYT and ICARDA origin (Joshi et al 2011). A maximum of 50-100 kg seed each was distributed for further testing and release by NARS in 2008/09 crop season (Table 1.1). In addition promising lines already in the breeding program were also included in the project.

In Ethiopia adaptation testing program led to immediate release of three varieties in 2010 and 2011 from original five promising lines and followed with subsequent release of other five varieties with stem and/or yellow rust resistance over the years. In Egypt one variety each was released in 2009 and 2010 from among the varieties already identified from EBWYT. The variety registration and performance trials were conducted in parallel for the first time which was previously conducted in subsequent years, reducing the timeframe for quick release. In Pakistan, none among the three promising lines distributed were released because of changes in stem rust dynamics in the country. However, one line with Ug99 resistance identified from EBWYT was released along with other four varieties with confirmed resistance to local stem rust and other rusts. Later on, several wheat varieties resistant to stem (Ug99) and/or yellow rust were released during the project and follow-up projects over the subsequent years (Table 1.2).

Several rust-resistant (Yr, Lr and Sr specifically local strain or Ug99) and high yielding wheat varieties have been identified and released in all three countries from germplasm introduced from IARCs or locally developed by NARS starting from 2009/10 crop season. Two varieties in Egypt (*Misr1 and Misr2*), ten in Ethiopia (*Danda'a, Kakaba, Hoganna, Shorima, Hulluka, Gambo, Hidase, Ogolcho, Biqa and Honqolo*) and seven in Pakistan (*AARI2011, Aas2011, Dahrabi2011, Millat11, NARC2011, Punjab11, PAK2013*) have been released from 2010-2014 (Table 1.2). In, Ethiopia some of the newly released varieties have combined resistance to stem and yellow rusts and yield advantage of up to 21% over widely grown commercial varieties.

Table 1.1 Promising lines distributed (kg) for testing and release in target countries

Promising lines	Origin	Egypt	Ethiopia	Pakistan	Total
DANPHE #1	CIMMYT	-	100	-	100
CHONTE #1	CIMMYT	25	100	300	425
CHEWINK #1	CIMMYT	25	-	-	25
PICAFLOR #1	CIMMYT	-	100	-	100
QUAIU #1	CIMMYT	-	100	300	400
GRACKLE #1	CIMMYT	25	-	-	25
MUNAL #1	CIMMYT	-	100	300	400
Flag 3	ICARDA	-	100	-	100
Flag 5	ICARDA	-	100	-	100
Amir 2	ICARDA	-	100	-	100
Total		75	800	900	1775

Table 1.2. Wheat stem rust and/or yellow resistant varieties released in target countries from germplasm originated from CIMMYT, ICARDA and NARS

Country	Variety	Source	Year of release	Remarks
Egypt	Misr1	CIMMYT	2009	Ug99 resistant
	Misr2	CIMMYT	2010	Ug99 resistant
Ethiopia	Danda'a	CIMMYT	2010	Combined resistance to Ug99 and Yr
	Kakaba	CIMMYT	2010	Combined resistance to Ug99 and Yr
	Gambo	CIMMYT	2011	Combined resistance to Ug99 and Yr
	Hoggana	ICARDA	2011	Combined resistance to Ug99 and Yr
	Shorima	ICARDA	2011	Combined resistance to Ug99 and Yr
	Hulluka	ICARDA	2012	Combined resistance to Ug99 and Yr
	Hidase	CIMMYT	2012	Combined resistance to Ug99 and Yr
	Ogolcho	CIMMYT	2012	Combined resistance to Ug99 and Yr
	Biqa	CIMMYT	2014	Resistance to three rusts
	Honqolo	ICARDA	2014	Resistance to three rusts
Pakistan	AARI2011	Local cross	2011	Resistant to local Sr and Yr
	AAS2011	CIMMYT	2011	Resistant to local Sr
	Dharabi2011	CIMMYT	2011	Resistant to local Sr
	NARC2011	CIMMYT	2011	Ug99 resistant
	Millat2011	Local cross	2011	Resistant to local Sr
	Punjab2011	Local cross	2011	Resistant to local Sr
	Shahkar2013	CIMMYT	2013	Resistant to local Sr
	Pirsabak2013	CIMMYT	2013	Resistant to local Sr
	NIFA Lalma2013	CIMMYT	2013	Resistant to local Sr
	PAK2013	CIMMYT	2013	Ug99 resistant

NB: All newly released varieties were supported through pre-release seed multiplication

Regional variety release: CIMMYT and ICARDA developed set of stem rust resistant varieties and distributed to NARS as Elite Bread Wheat Yield Trials and Stem Rust Resistance Screening Nursery through a coordinated international nurseries network. Most NARS are evaluating similar breeding materials from the CGIAR across regions, with potential for both wide and specific adaptation, where opportunities must be explored for joint or regional release of varieties. From the list of potential promising lines distributed, one can observe 'common' promising lines released in some target countries (Table 1.1). For example, a promising line from 2nd EBWYT was released as *Misr1* in Egypt (2010), but also released as *Muqawim09* in Afghanistan (2009), and later as *NARC2011* in Pakistan (2011). This allowed Afghanistan to import about 151.5 tons of Misr1 seed from Egypt to head-start seed multiplication and distribution in the country. Similarly, Picaflor≠1 was released as *Kakaba* in Ethiopia (2010) and as *Baghlan09* in Afghanistan (2009). Quai≠1 was released as *Gambo* for irrigated areas in the lowlands of Ethiopia (2011) and Koshan09 in Afghanistan (2009). Danphae was released as *Danda'a* in Ethiopia (2010) and was submitted for release in Nepal (2012). Moreover, Francolin≠1 was released as *BARI Gom 27* in Bangladesh (2012) and as *NL1073* in Nepal

However, this may be a reminder of mega varieties and uniformity of varieties across regions once again raising the concern of vulnerability of wheat to rusts. It is important to maintain the varietal diversity and overcome varietal dominance by identifying and releasing those with comparable agronomic performance and preferred traits at national and/or regional levels. For example in Ethiopia, *Kakaba* was found relatively early maturing fitting to areas with short rainfall patterns whereas *Gambo* could fit well for irrigated lowlands, an area for potential wheat expansion. Attention should be given in diversifying the portfolio of varieties released across the countries to minimize regional vulnerability too.

b) Accelerated seed multiplication

The project played a catalytic role in supporting early generation seed production by NARS and linking that to large-scale seed production by existing public seed enterprise and/or private seed companies. In Ethiopia, both main season and off-season (irrigation for the first time) and low seed rates were used for pre/post-release accelerated seed multiplication of promising lines/varieties in early generation seed multiplication. In Pakistan, NARS and the private sector undertook pre-release and pre-basic seed multiplication under the Foundation Seed Cell program. This enabled to bulk-up sufficient amount of basic (foundation in Egypt) to enter large-scale certified seed production and marketing by the existing public and private sectors. The support by the project enabled for the new varieties to capture over 10% of wheat area envisaged at the end of the project period (Table 1.3).

Early generation seed production: The project initiated pre-release seed multiplication of rust-resistant promising lines identified through IARCs and NARS partnership in order to accelerate the availability of early generation seed while these lines were undergoing variety evaluation for release. A concerted effort was made by NARS and public/private sector to multiply seed of these newly identified promising lines in target countries (Table 1.4). Initially, 10 promising lines in Egypt, eight in

Ethiopia and six in Pakistan entered pre-release seed multiplication in 2008/09. In subsequent years 4 each in Egypt and Ethiopia and six in Pakistan were included in the pre-release seed multiplication. However, with the progress of the project fewer promising lines were included in the program where combined resistance against other rusts was also considered.

In Egypt, 42.23 tons of *Misr1* (22.83 tons) and *Misr2* (19.4 tons) were produced by ARC under pre-release seed multiplication during 2008/09 crop season. The seed produced was used for demonstration and further multiplication. CASP was provided with seed of both varieties and further multiplied producing 288 tons of *Misr1* and 52.5 tons of *Misr2* in 2009/10 crop season. The registered seed was further provided to private seed companies for further multiplication and sale to farmers. There was substantial quantity of seed was made available when Misr1 and Misr2 was released in 2010 and 2011, respectively.

In Ethiopia, both the main and off-seasons were used to shorten the time and maximize the availability of sufficient quantity of basic seed stock through pre-release seed multiplication. About 91 tons of *Danda'a* (29.35 tons), *Kakaba* (43.01 tons) and *Gambo* (19.55 tons) was available following the off-season seed multiplication upon the release of these varieties in 2010 and 2011 compared to the minimum requirement of 50 kg breeder seed for release. The seed of *Danda'a* and *Kakaba* produced during the off-season was used by KARC and provided to federal (ESE) and regional (ASE, OSE) public seed enterprises, public state (Bale) and private estate (Tinsae) farms and on-going projects (Alliance for a Green Revolution in Africa and Sasakawa Global 2000) for further multiplication and demonstration. About 478.53 tons of seed of the two varieties were produced during the next main season.

In Pakistan, three NARC selected promising lines from 2nd EBWYT already in NUYT and registration trials and another three lines from CIMMYT in different stages of variety testing were identified as potential for accelerated pre-release seed multiplication. However, while stem rust (Ug99) is a great concern it was emphasized that resistant to new local Sr race taken into account while evaluating the promising lines. All promising lines (23.584 tons) were dropped except one (0.2 tons and resistant to Ug99) and five more (three from NARS crosses and 2 from

CIMMYT) were included with known resistance to local Sr race and other major rusts. About 991.261 tons of seed was available in 2011 upon the release of *AAR11* (292.435 tons), *Millat11* (8.54 tons), *Punjab11* (580.586 tons), *Aas 2011*(106.2 tons) and *Dahrabi 2011* (0.5 tons). The seed was produced by NARS and public and private seed sector under the umbrella of Foundation Seed Cell program with the approval of FSCRD.

Although, large number of promising lines entered pre-release seed multiplication every year, limited number of varieties was released and the seed produced was advanced for further multiplication. NARS continued with regular early generation seed production of officially released varieties during the course of the project contributing to overall certified seed production (Table 1.4).

Table 1.3. Pre-release seed multiplication of promising lines in target countries in 2008/09-10/11 crop season

Country	No of lines multiplied[1]	No of lines added	Area planted (ha)	Seed produced (t)	No of varieties released[1]	Amount of seed available (t)	Remarks
Egypt	10 (3)	4	21.14	85.166	2	42.23	
Ethiopia	8 (5)	4	110.52	154.79	6 (3)	91.91	Main and off-season
Pakistan	6 (3)	6	330.3	991.26	6 (1)	991.26	
Total	24 (11)	14	389.7	885.766	13 (4)	738.91	

Note: [F]igures in parenthesis are promising lines initially distributed by CIMMYT or ICARDA whereas the rest were identified through regular breeding program from germplasm of NARS or IARCs.

Certified seed production: The basic (foundation) seed produced under pre-release seed multiplication by NARS or by the public and/or private sector directly entered large-scale certified seed production. The partnership enabled the seed suppliers' to get early access to seed of new varieties and accelerate large-scale certified seed production. The linkage and partnership of NARS and commercial seed suppliers enabled to bring seed of new varieties to farmers' fields in the shortest possible period of time.

In Egypt, an estimated 19,840 tons of certified seed of new rust-resistant varieties was produced by public and private sector and distributed during the three years of the project. This amount of seed had the potential to plant close to 11% of Egypt's wheat area, generating a substantial increase in wheat grain production in that country.

In Ethiopia, the production of over 33,423 tons seed of two new rust-resistant varieties by public sector enterprises was sufficient to plant over 12% of its total wheat area during the project period. There was substantial increase on the amount of certified seed of rust-resistant wheat varieties distributed during the project period and after increasing wheat production and productivity in the country.

In Pakistan, a total of 89,306 tons seed of five rust-resistant bread wheat varieties were multiplied by private and public sector entities in quantities sufficient to plant close to 10% of the wheat area. This substantial area covered by rust-resistant varieties improved wheat production and productivity and enhancing food security in target countries.

Table 1.4. Amount of certified seed of new rust-resistant wheat varieties produced in target countries

Country	New rust-resistant varieties (year released)	Amount of seed distributed (tons)		
		2010/11	2011/12	2012/13
Egypt	*Misr1* (2009) and *Misr2* (2010)	566	7,947	10,760
	Total certified seed wheat distributed (17 varieties)	39,622	51,365	53,376
	% certified seed of new varieties	1.4	16	20
Ethiopia	*Danda'a* and *Kakaba* (2010)	758	5,622	27,043
	Total certified seed wheat distributed (33-41 vars.)	27,086	38,736	71,078
	% certified seed of new varieties	2.81	15	38
Pakistan*	*AARI11, Millat11, Punjab11, NARC11* and *Dharabi11* (2011)	2287	42,750	44,269
	Total certified seed wheat distributed (16-20 vars.)	311,805	251,908	171,915
	% certified seed of new varieties	0.73	17	26

*Note: *In Pakistan, only NARC2011 is Ug99 resistance and NARS focus on local stem rust, yellow and leaf rust resistance; number of varieties (vars.) of certified seed varies from year to year*

Pakistan initiated VBSEs in rainfed areas where the formal seed system has limited penetration and farmers may not have access to newly released rust-resistant varieties because neither the public nor the private sector is interested in seed production of these varieties in rainfed areas. As a result, farmer-based seed multiplication was initiated in rainfed areas of Punjab and Khyber Pakhtunkhwa provinces. Preliminary analysis of on-farm seed production and marketing showed on average a net profit of \$348 ha^{-1} which shows better profitability in seed business than grain production.

c) Variety demonstration

New rust-resistant varieties were popularized along with recommended agronomic packages to demonstrate the economic potential. In Egypt, Wheat Research Department popularized *Misr1 and Misr2* working with CAAE (Central Administration for Agricultural Extension) and CASP in conducting both on-station (first year) and on-farm demonstrations (subsequent years) to create awareness among policy makers, researchers, extension services and farmers. In total 275 demonstration plots (2.1 ha) were planted in 24 governorates covering over 203 districts by ARC. In addition 64 field days were organized using seed production fields by CASP from 2009/10 to 2011/12. About 16,258 researchers, extension agents and farmers attended the field days.

In Ethiopia, variety demonstration (0.1 ha) was carried out by EIAR's Technology Demonstration and Scaling-up Program and other development projects like AGRA and SG2000. In 2010, 219 demonstrations were planted in Amhara (81), Oromia (58) and South (80) and Tigray regions by EIAR under the project and a total of 970 participants attended the field day (Asnake, 2012). The two varieties (*Danda'a* and *Kakaba*) were demonstrated on 144 farmers (0.25 ha each) by KARC and on 108 farmers by the AGRA project. Moreover, SG2000 reported that it planted demonstrations in 28 FTCs and with 1097 farmers where 680.79 tons of rust-resistant wheat varieties were produced and about 11,231 farmers were benefitted from informal farmer to farmer seed exchange (Gebretsadik, 2012).

In Pakistan, the popularization and demonstration was minimal until the set of new wheat varieties with stem rust resistance were confirmed by NARS. In 2010/11 about 15 demonstrations were carried for one variety, but nearly 81 demonstration plots were planted focusing on newly released varieties in 2011/12 crop season. In total about 3250 farmers attended the field days.

Farmers hosting the demonstrations were advised to save and use or share the seed with neighboring farmers to facilitate adoption and diffusion of the newly released varieties and serve as nodal diffusion points outside the formal sector. The demonstration has created awareness among farmers and a huge demand as witnessed by requests from farmers. The popularization and demonstration efforts enabled to bring seed of new rust-resistant wheat varieties to the farmers' fields even before varieties were officially released (e.g. *Misr2* in Egypt) and certified seed was produced through a regular program. This is a tremendous achievement and behavioral changes responding to emergency situations where existing laws, norms and procedures remain sacrosanct.

d) Assessing economic returns

In Egypt, the Agricultural Economics Research Institute investigated the economic returns of Misr1 and Misr2 varieties on farmers' fields with technological packages in demonstration plots (DP) and neighboring farmer's fields (NF) on grain yield, production costs, and net benefits in 2009/10 crop season Some governorates were selected in coordination with ARC to target DP and NF and a random sampling procedure was used to select farmers. Detailed data on management practices, production costs, inputs, yields and returns were collected and summarized below.

The study showed that average grain yield for Misr1 was 5.65 tons ha^{-1} in NF (n=35) and 7.05 tons ha^{-1} in DP (n=63), an increase of 24.9%. The total estimated return was about L.E 6929 and 5606 (@ L.E. 5.945 = UDS 1) in demonstration and non-demonstration fields, respectively with estimated net benefit of L.E. 3945 in demonstration fields, an increase of about 46% compared to non-demonstration fields (L.E 2702). The benefit/cost ratio was 2.32 for new variety (*Misr1*) in demonstration fields while it was 1.93 in non-demonstration fields.

Average grain yield for Misr2 was 5.52 tons ha^{-1} in NF (n=31) and 6.7 tons ha^{-1} in DP (n=52) showing an increase of 21.3%. The total estimated return was about LE 6597 and 5576 in DP and NF, respectively. The estimated net benefit was LE 3643 in DP, an increase of about 39.2% compared to NF (LE 2617). The benefit/cost ratio was 2.23 for *Misr2* in demonstration fields while it was 1.91 in non-demonstration fields. The recommended package for Misr1 and Misr2 in demonstration fields appeared to be productive and profitable and could be adopted by the farmers.

e) Strengthening infrastructure of key stakeholders

Early generation seed production require specialized field equipment such as plot planters, plot harvesters, small seed cleaners/treaters for timely operations and appropriate facilities like irrigation, and cold storage for main or off-season seed production. In order to strengthen such activities modest equipment (tractors, laser levelers, threshers) and vehicles were purchased and provided to NARS on case by case basis. In Pakistan farm machinery (4 tractors, seed drills, rotavators and threshers each and two levelers) were provided to AARI, BARI, NARC and RARI and three mobile seed cleaners were provided to support the network of farmer-based seed producers linked to NARS (BARI, CCRI and NIFA). Moreover, three vehicles were also provided to NARS for project implementation, one each for Egypt, Ethiopia and Pakistan.

f) Strengthening capacity of human resources

Seed production requires specific knowledge and practical experience to produce high quality seed of high standards of varietal purity and physical, physiological and health. From the outset, assistance in capacity development of NARS and national seed programs is a key to enhance their technical and managerial capacity. Short-term trainings were conducted in principles and techniques of variety maintenance, seed production, seed processing, and seed quality control for technical managers, technicians and farmers whereas workshops aimed at policy and decision makers and senior managers.

Regional workshop: In September 2011, a regional workshop on Variety Identification and Maintenance was organized by ICARDA, ESE and EIAR in Ethiopia. The workshop served as a forum for the three target countries to:

- Share experiences on innovative procedures for fast track variety release and accelerated seed multiplication and dissemination of new rust-resistant varieties;
- Provide technical knowledge on variety release processes (performance and registration trials);
- Variety maintenance and early generation seed production; and
- Establish partnerships for continuous collaboration on rapid release and dissemination of varieties.

- Twenty five scientists and technical staff from the three countries, Ethiopia (15), Egypt (5), and Pakistan (5), attended the workshop.

Regional travelling workshop: In April 2010, a two-day regional workshop was organized by ICARDA, FAO and ARC in Egypt as part of contingency planning to counter the threat of Ug99 for participants from seven countries: Egypt, Ethiopia, Iraq, Saudi Arabia, Sudan, Syria and Yemen. Thirty five participants visited ARC research stations, CASC variety registration trials and CASP seed multiplication fields to familiarize themselves with activities related to Ug99.

National workshop on wheat rusts: In Egypt, annually a one-day national wheat workshop was organized and accompanied by national travelling workshop for staff from agricultural research, department of agriculture, extension services, seed producers and farmers to keep abreast with new developments and progress of the project. About 364 participants attended the workshops from various stakeholder institutions covering several themes by ICARDA and NARS partners during the project period.

In-country courses: Several in-country hands-on practical training courses were organized for agricultural research, seed sector and extension staff focusing on wheat rust diseases, seed science and technology, and wheat production. About 444 staff has received such short courses during the project implementation phase in 2010 and 2011.

Rust surveillance and contingency planning: ICARDA also contributed and shared the experience to national and regional rust surveillance and contingency planning workshops conducted for North Africa, Central and West Asia under the FAO umbrella.

International conferences: Three senior researchers each from Egypt and Pakistan attended an international yellow rust conference in 2010 at ICARDA, Aleppo Syria. In another development 19 senior seed program managers from the public and private sector staff from Egypt, Ethiopia and Pakistan attended a regional seed conference in 2009 and 2010 in Turkey.

g) Variety release and seed marketing

ICARDA initiated a case study on variety release mechanism in Egypt, Ethiopia and Pakistan. The main purpose is to analyze the issues that arise in variety release and to make recommendations for 'good practice' that may be useful to those who manage the variety release system. The synthesis covered the full range of activities that occur from the identification of promising lines by the breeder until early-generation seed is available for multiplication and providing recommendations for good practices. In Pakistan, ICARDA organized in 2012 a national consultation meeting on the draft report and broader issues on seed production systems that highlighted the need to strengthen public-private partnership in research, create new and more effective seed legislation, and improve the capacity of all partners in the country's seed sector. Moreover, case studies on wheat seed marketing were also initiated and final reports were prepared in Ethiopia and Pakistan.

2.5.2 Rapid Deployment of Yellow Rust-resistant Varieties in Ethiopia

In 2011, a new ICARDA-EIAR joint project supported by USAID was launched (2011-2014) in response to 2010 yellow rust epidemics in the country. The project, built on the experiences of USAID Famine Fund, was to rapidly deploy high-yielding and yellow rust-resistant wheat varieties. The project broadened its scope including both stem and yellow rust-resistant varieties and focused on four thematic areas with focus on strengthening the national wheat breeding program's capacity to develop rust-resistant varieties and fast-track their testing and release; popularization and demonstration of rust-resistant varieties and associated technologies; accelerated seed multiplication (pre-release, post-release and certified seed production) during the main and off-seasons by existing public and private sector; on-farm seed production and marketing directly working with farmers in target districts of Agricultural Growth Program; and strengthening the infrastructure and human resources capacity of stakeholders.

The project has established a functional platform of broad range of partners and stakeholders which include federal (EIAR) and regional (AARI, OARI, TARI) agricultural research institutes; federal (ESE) and regional (ASE, OSE, SSE) public seed enterprises and private seed companies; public and private state farms involved in seed production; federal (MoA) and regional extension and input directorates; farmer seed producers associations and Farmers' Cooperatives Union; and farmers/seed users.

a) Wheat varietal releases

The project provided substantial support to the National Wheat Research Program, at KARC in fast-track testing and releasing of new rust-resistant varieties. The main activities include introduction and evaluating international nurseries, crossing and evaluating segregating population from national breeding program and conducting variety yield trials and verification trials of candidate varieties for release. In 2014, four candidate varieties were presented by KARC, among which *Honqolo* (for high rainfall areas) and *Biqa* (for dry areas) were released by the NVRC. The seed of these two new varieties was multiplied during the off-season and the main season and become available to public/private seed producers for large-scale multiplication by 2015/16 crop season.

The procedure was also adopted by other on-going wheat projects in Ethiopia such as SARD-SC and EAAPP where additional varieties were released and their seed multiplication was accelerated.

b) Early generation seed production

The project linked NARS with commercial seed producers and supported the accelerated seed multiplication of recently released and existing rust-resistant varieties during the main and off-season and 7,013 tons basic seed produced and provided to public seed enterprises and private sector (private seed companies, cooperatives and farmer seed producer associations) from 2011/12 to 2014/15 crop season to produce certified seed for distribution to farmers. Eight farmer seed associations, one federal and three regional public seed enterprises and public and private seed producing farms and new emerging private sector were provided with seed.

c) Large-scale certified seed production

Availability and access to basic seed regularly has enabled large-scale certified seed production. A significant achievement has been made where certified seed of rust-resistant wheat varieties were produced and distributed through partnerships of the public and private sector. For example, about 31,078 tons (32% new and 14% old varieties) certified seed of rust resistant wheat varieties from a total wheat seed supply of

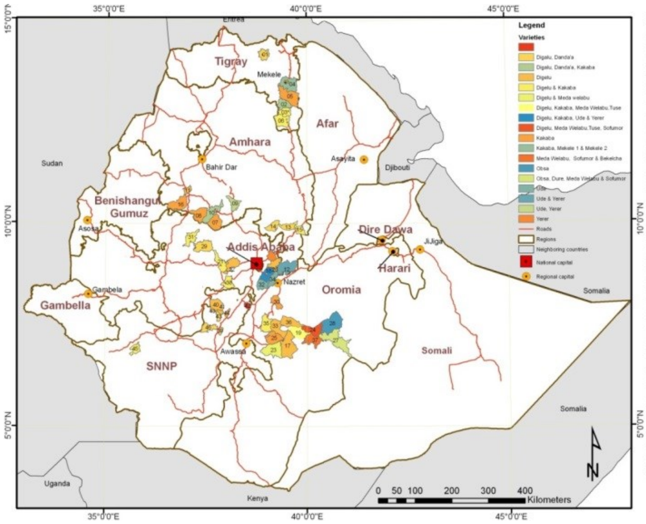
59,810 tons in 2013/14 crop season. Similarly, about 55,071 tons (60% new and 18% old varieties) certified seed of rust resistant wheat varieties were distributed from a total wheat seed supply of 70,738 tons in 2014/15. The certified seed of new and existing rust resistant varieties is sufficient to plant an estimated bread wheat area of 207,187 ha and 398,733 ha during the 2013/14 and 2014/15 crop seasons, respectively. This enabled quick and rapid deployment of new rust resistant varieties in farmers' fields. This is sufficient to plant an estimated bread wheat area of 207,187 ha and 398,733 ha during the two seasons. This enabled quick and rapid deployment of new rust-resistant varieties on farmers' fields.

d) On-farm seed production

Apart from direct support to formal sector operations of NARS and partnership with public or private seed enterprises, the project aimed to bring seed directly to target districts under Agricultural Growth Program working with farmers and district agricultural office (Figure 1.4). A group of 100 farmers were identified in selected *kebele* administration in each target district, clustered in adjoining fields, provided with seed of rust-resistant varieties sufficient to plant 0.25 ha. Farmers, and development and extension agents were trained on technical aspects of seed production and linked to regional seed inspection services to ensure seed quality.

Three approaches were used with the seed produced after participating farmers return in kind the amount of seed provided by the project and retain the 10% of the seed produced for own use; farmer's groups collect, process and market the seed under their own management; farmers are linked to FCU's which purchase seed from farmers and market the seed to their members and non-members; or farmers directly linked to PSEs (ASE, OSE and SSE) which purchase the seed and market it in respective and neighboring *woredas*.

Farmers returned the seed as a revolving fund, kept some for own use and sold excess seed to other farmers through informal channels or formally through cooperatives or PSEs. The revolving seed fund was used to reach more farmers through similar approach by the Office of Agriculture.



Code	Wereda
01	Adw a
02	Ambalage
03	Endamehone
04	Enderta
05	Hintalo Wajirat
06	Ofla
07	Baso Liben
08	Debere Elias
09	Enemay
10	Gozamin
11	Guagusa Shekudad
12	Minjar Shenkora
13	Mojana Wedera
14	Moretna Juru
15	Tarma Ber
16	Wenberma
17	Adaba
18	Adea
19	Agarfa
20	Aleitu
21	Ambo
22	Dendi
23	Dodola
24	Gasera
25	Gedeb Asasa
26	Gimbichu
27	GINIR
28	GOLOLCHA
29	GUDRU
30	Hitosa
31	Horo
32	Liben
33	Limuna Bilbilo
34	Lomme
35	Munesa
36	Shirka
37	Sinana
38	Weliso
39	Anigacha
40	ENEMOR ENER
41	Enidguagn
42	Mareqo
43	Misha
44	Misirak Azerenet Berb
45	Shay Bench
46	Soro

Figure 1.4. Target district for on-farm seed multiplication and dissemination

In four seasons the project distributed 894 tons of seeds through, which covered 7,095 ha producing 26,615 tons of seed/grain sufficient to plant 177, 433 ha. The project reached 19,631 farmers (out of which 12% were female) benefiting 100,751 household members in four major wheat production regions (Figure 1.5 and Table 1.5). In some target districts 80% of wheat area is planted with yellow rust resistant varieties. The multiplier effect will be considerably higher as part of the produce was used as seed for planting purpose in subsequent years. This would lead to substantial area coverage with Ug99 and yellow rust-resistant varieties.

Guagsa Wonberima District, West Gojam Zone, Amhara region

Dendi District, West Shewa Zone, Oromia region

Figure 1.5 Farmer seed producers

Average yields over four seasons were 3.8 tons with the highest of 7.8 tons on farmer's fields. The average estimated net income from rust-resistant varieties is varying from $50 to $200 depending on area planted by wheat. Given that the estimated total land area covered with new stripe rust-resistant wheat varieties at around 400,000 ha, the net returns from these improved varieties will be in the range of $20-80 million.

e) Scaling out of wheat technologies

The project also provided support to regular technology scaling out activities of EIAR in some target districts following the same modalities of on-farm seed production. The project directly distributed 261 tons seed through scaling out which was planted on 2,182 ha producing 7,758 tons of seed/grain potentially sufficient to plant 51,720 ha. The project directly reached 12,500 farmers (out of which 8% were female) benefiting and estimated 65,610 household members in four major wheat production regions (Figure 1.5 and Table 1.5).

f) Emergency seed relief

Emergency seed relief was provided to farmers affected by yellow rust in 2010 in Arsi and West Shewa zones and by the new stem rust strain in 2014 in Bale zones. A total of 120 tons were distributed and 813 ha was planted producing 2317 tons of seed/grain sufficient to plant 15,525 ha (Table 19). About 3799 farmers have direct access to seed benefitting 22,794 household members. The same process of on-farm seed production was used except that farmers were not required to return the seed to the revolving fund.

g) Durum wheat value chain

In Ethiopia, bread wheat production dominated the landscape, but it is highly vulnerable to periodic epidemics of rust diseases. Durum wheat appeared to be less vulnerable to stem rust and yellow rust. The project aimed at reviving durum wheat production to tackle the rust problems and diversify wheat production and at the same time create the producer-market linkage with the agro-industry. A durum wheat value chain workshop was organized on 17 June 2014 and attended by participants drawn from relevant wheat value chain actors including representatives of flour mills and pasta and macaroni factories.

Eight pilot districts were identified to initiate both seed and grain production of two durum wheat varieties. Member farmers of primary cooperatives were identified, organized and trained as durum wheat seed producers or grain producers. About 19.93 tons of seed was distributed for seed production to 208 farmers (18 female farmers) and planted on 170 ha. An estimated 547.2 tons was produced for distribution to durum wheat grain producers; and the amount is sufficient to plant 3,648 ha in 2015/16 crop season. The seed produced will be collected and marketed collectively or through farmer cooperative unions to their members for grain production in 2015/16 crop season.

Another 51.75 tons seed was distributed to 712 farmers (65 female farmers) and planted on 407.2 ha for durum wheat grain production. An estimated 1592.2 tons of durum wheat grain will be produced in 2014/15 crop season. Farmers produce durum grain as per the requirements of the industry which will be aggregated and sold through unions to the different factories based on contractual agreement. The grain will be aggregated (minimum 40 tons), sampled and tested at least for protein quality, gluten content, moisture content and hectoliter weight to determine the price based on the quality. The contractual agreement between the unions and factories will be signed and the samples will be collected and tested following harvest time. It is envisaged to expand the activities in the coming years including more farmers' cooperatives and unions across the country.

Table 1.5. On-farm seed production with farmer groups

Items	On-farm seed production	Scaling-out	Emergency seed	Value chain	Total
Seed distributed (t)	894	261	120	72	1347
Area planted (ha)	7095	2,182	813	577	10667
Estimated production (t)	26615	7,758	2317	2139	38829
Total farmers reached	19631	12500	3799	920	36850
% female farmers	12	8	2	9	8
Beneficiary HHs	100,751	65,610	22,794	5,520	194,675

h) Demonstration

The project also supported EIAR's pre-extension demonstration in major wheat production regions. Field days were organized at district level using Farmer Training Centers, demonstration plots and on-farm seed multiplication fields to create awareness and demand for seed of new rust-resistant varieties released over the project years. In these events farmers from participating and neighboring districts, development agents, extension workers, researchers and regional, zonal and district level administrators and policy makers participated. Annually the project supported one field day each in four regions. In 2011/12, in addition to *Danda'a and Kekeba* two new bread wheat varieties, namely; *Shorima* and *Hulluka* were demonstrated in 41 districts where four farmers per district were provided with seed of the two varieties i.e. 164 demonstrations. The project sponsored four field days in Oromia (Horro), Amhara (Wonberima), SNNP, and Tigray where over 700 farmers, development agents (DAs), extension workers and farmers participated in the farmers' field days. In 2012/13, four field days were sponsored in four districts in Amhara (Guagusa Shikudad and Tarmaber), Oromia (Agarfa) and SNNP (Mareko) where 1180 (5.8% female) farmers participated. In 2013/14 crop season, three new bread (*Hidase, Hoggana* and *Ogolcho*) and two new durum (*Mangudo* and *Mukiye*) wheat varieties were demonstrated at FTCs in 41 districts. Four field days were supported where 3,895 participants attended of which nearly 10.1% were female participants. In 2014/15, the activity is extended to 51 districts reaching more farmers in irrigated lowland areas. In addition to recent releases four new bread (*Biqa, Honqolo, Mandoyu*, *Sanate*) and one durum (*Mukiye*) wheat varieties were demonstrated at FTCs. About 400 demonstration fields were planted with newly released rust-resistant varieties both by the support of the project and national program.

i) Strengthening infrastructure and capacity

Substantial investment was made to strengthen the facilities and infrastructure and human resources capacity of NARS and key stakeholders during the project period.

Infrastructure: In order to upgrade the infrastructure, two heavy duty tractors, levelers, planters, ridgers each with spare parts were purchased and distributed to key NARS. A seed storage facility at KARC, and seed quality laboratory (KARC and DZARC) was supported and 14 sewing machines and 150,000 polybags of different size was purchased and used for branding EIAR basic seed production. Moreover, given the scale of field operations at federal and regional levels, one station wagon, five pick-ups, one minivan and two automobiles were provided to NARS.

The project provided three mobile seed cleaners, one each for seed producers in Oromia (Haqo Sado Farmer's Seed Producers' Cooperatives in Dodolla); Amhara (Dil Betigil Farmers Seed Producers Cooperatives in Womberma) and Tigray (Ayiba Birhan Farmer's Seed Producers' Cooperatives in Embalaje) Regions. The seed producer cooperatives were trained in the operation and maintenance of the machine and will be monitored for its effective use and their performance in seed production.

Human resources: The project created awareness of wheat rusts both at managerial and technical levels. Policy makers and senior managers participated both at international and national workshops whereas the technical staff attended regional and in-country courses.

***Workshops and conferences**:* The project inception workshop was attended by 72 participants from federal and regional NARS, public seed enterprises and Bureau of Agriculture; private seed companies in May 2011. A first round of national consultation meeting was carried out with heads of districts offices of agriculture and extension agents from 30 September-1 October 2011 where 46 participants attended the meeting to clarify the purpose and objectives of the EIAR-ICARDA Seed Project. A second round of two-day consultation meeting was organized on 29-30 February 2012 at Adama for Oromia and Southern regions and on 6 March for Amhara and Tigray regions (26 districts) and was attended by *Woreda* Agriculture, Extension offices and Administration. Each *woreda* reported on area planted, seed produced, number of farmers (male and female) participated in seed production, number of field days conducted and farmers participated, performance of rust-resistant varieties and farmer's perception, challenges during work plan implementation. The primary task of the meeting was to discuss the modalities for seed procurement (PSEs, FCUs or informal diffusion) and based on lessons learned plan activities for next main season. A workshop was organized and attended by 80 participants drawn from relevant wheat value chain actors including representatives of flour mills and pasta and macaroni factories.

***Training courses*:** Both regional and in-country courses were organized for key stakeholders in quality seed production. Accordingly, six participants from TARI and SARI and agricultural input experts from Amhara, Oromia and SNNP (6 participants) attended the seed production and marketing training given in Egypt (2012) and three seed experts each from RC participated in variety maintenance and quality seed production and seed certification courses in 2012 and 2013 in Egypt.

Each year farm managers and seed production experts from federal and regional research centers were trained in seed production technology to ensure quality breeder and pre-basic seeds production to be distributed to basic seed producers (Table 1.6). In addition training of trainers were organized in four regions for subject matter specialists (SMS), agricultural experts and development agents (DAs) of district BoA prior the planting time to assist the on-farm seed production. Training of DAs and model farmers were also undertaken in some districts who can demonstrate the technologies in their respective

Table 1.6. Number of participants in-country courses

Target groups	Number of trained personnel				Total
	2011/12	2012/13	2013/14	2014/15	
SMS and DAs*	270 (35)	410 (45)	370 (75)	440 (67)	1490 (222)
Farm Managers	50	45	35	40	157
Others		24	36	27	87
Total	320	479	441	507	1734

Note: Numbers in parenthesis are female participants

Project communication: The project leaders from NARS attended and presented the achievements to the annual FARA meeting (Ghana) international rust conference (Turkey). A short video on describing the activities undertaken and farm level impacts on the livelihoods of farmers were produced and circulated to all stakeholders in Ethiopia, USAID and CGIAR community.

1.5.3 Wheat Productivity Enhancement Program in Pakistan

The Wheat Productivity Enhancement Program (WPEP) project aimed to enhance and protect the productivity of wheat in Pakistan by supporting research that leads to the identification, adoption, and optimal agronomic management of new, high yielding and disease-resistant wheat varieties. Accelerated seed multiplication is one of the components of the project.

In Pakistan the wheat seed system appears diversified with involvement of both the public and private sector in the Punjab except in other provinces and dryland areas. However, availability of early generation seed remains a constraint in commercialization of new varieties in the country. Within the WPEP project which focuses on developing Ug99 resistant varieties, a modest budget was allocated for accelerated seed multiplication. A greater effort was made in accelerated seed multiplication of early generation seed (pre- and post-release) and linked to large-scale certified seed production by formal (public and private) and informal sectors in disseminating Ug99 resistant varieties.

The following were achieved during the two years of implementation (2011/12-12/13)

- 436 tons seed of promising lines were produced under pre-release seed multiplication (44 tons of exclusively 20 Ug99 resistant promisingly lines); one variety was released in 2013 and seed become available both to public and private sector;
- 2170 tons seed of early generation produced by NARS, public and private sector for further multiplication and distribution (104.4 tons exclusively Ug99 resistant varieties); and
- 494 tons seed produced from demonstration, popularization and on-farm seed production of new rust-resistant (164.8 tons exclusively Ug99 resistant varieties). From yield data, the estimated net return of \$227 ha^{-1} was achieved when seed of new varieties is sold as seed instead of grain.
- In dryland areas most of the varieties released were not multiplied by the formal sector due to weaker demand and expected low yields. Neither the public nor the private sector was interested in producing and marketing the seed in the dryland areas. The project initiated on-farm seed production with farmers through a support provided by NARS partners. About 284 tons seed of new and existing commercial varieties was produced with farmers in dryland areas of Punjab and KPK with average net returns from seed sales of \$337/ha.

After 2013/14-14/15, under the ICARDA-CIMMYT agreement, efforts were made in promoting and multiplying Ug99 resistant bread wheat varieties i.e. NARC 2011 and PAK 2013.

- 67.063 tons seed of promising lines in NUWYT's were produced under pre-release seed multiplication by 8-10 NARS partners from federal and provincial agricultural research institutes;

- 1020 tons seed of early generation produced by NARS (47.68 tons exclusively of Ug99 resistant varieties) and provided to public and private sector (40 seed companies) for further multiplication and distribution;
- Source seed of NARC 2011 and PAK 2013 was distributed to various federal and provincial agricultural research institutes (11 research institutes sufficient to plant 12.55 ha), public and private sector companies (40 companies on 31.97 ha) and farmers (102 farmers on 41.28 ha) in 2014/15 crop season to expand the seed production and distribution of Ug99 resistant wheat varieties;
- The project partnered with local NGO National Rural Support Program with membership of 400,000 farmers for diffusing Ug99 resistant varieties;
- The project initiated regular variety maintenance program at NARC for early generation seed production;
- The project provided emergency seed for internally displaced people in tribal areas due to flooding in 2014;
- Training in seed production technology and quality assurance was provided to 60 technical staff drawn from relevant seed sector stakeholders and 150 famers involved in local seed production

The project was able to partner with NARS and formal seed sector to quickly multiply and disseminate seed of not only of Ug99 resistant varieties but also to local stem rusts (Table 1.7). This enabled producing early generation seed production by NARS in partnership with FSCRD which was exclusively the activity of the public seed corporations.

Table 1.7 Amount of early generation seed produced during 2011/12-2014/15 crop seasons

Institutes	2011-12	2012-13	2013-14	2014-15
NARS	222.7	382.8	358.4	184.9
Public seed sector	677.3	876.9	1153.9	421.6
Total	900.0	1259.7	1512.3	606.5

Some of the key issues emerged from the project activities include the following:

- Pre-release seed multiplication of promising lines and post-release early generation of released varieties become institutionalized by NARS by engaging FSCRD in seed quality assurance. Pre-basic and basic seed production was exclusively used to be handled by public seed sector;
- Despite the diversity of wheat seed sector in the country, the performance of the formal sector in delivering seed of farmer preferred varieties still remain

problematic in dry areas and other provinces with exception to Punjab. A concerted effort is required to strengthen alternative strategies to reach farmers in drylands and remote areas; and

- The development and promotion of Ug99 resistance varieties must be combined with comparative yield advantage over the existing commercial varieties. An attempt to disseminate NARC2011 and PAK 2013 across all provinces showed mixed results both from seed producers and farmers. A diversified portfolio of rust-resistant varieties needs to be developed and disseminated to meet farmer's demand and to avoid vulnerability to rusts.

1.6. Project Coordination and Implementation

1.6.1 Guiding principles

Several guiding principles underpin the project implementation to guarantee the goals and objectives are achieved. These principles are based on shared values and trust of stakeholders. The project's guiding principles can be summarized as follows:

- The project strengthened local resources (human, institutional, physical, etc.) for the benefit of partner institutions;
- The project preserved and strengthened local knowledge and technologies in its work with plant genetic resources and farming practices;
- The project was mindful of multiple dimensions of sustainability i.e., genetic diversity in farmers' fields to ensure long-term environmental sustainability; and
- Project planning, research, and technology development and dissemination occur in the context of partnership networks, taking advantage of the comparative advantages and skills of different institutions working in the agricultural sector of target countries

1.6.2 Project coordination

For project coordination establishment of innovation platforms facilitated by the high level Project Steering Committees and Project Technical Committees are used across projects with some variations in respective countries. In Ethiopia, multi-stakeholders platforms were established at federal and regional levels (Amhara, Oromia, South and Tigray Regional States). These include federal and regional NARS; public and private seed enterprises; bureaus of agriculture, agriculture inputs and extensions, Farmer's Cooperative Unions and farmers.

ICARDA provide leadership and coordination of the project while EIAR was an implementing partner of the project. The steering committee consisted of five representatives from ICARDA, EIAR, and USAID was established to provide guidance in project implementation. In addition, an overall coordinator and thematic area coordinators were identified and assigned to implement the project

The project identified three major thematic areas including generation of new varieties through fast track testing and release, accelerated seed multiplication, and popularization and scaling up/out of rust-resistant wheat varieties. An overall project coordinator and three project thematic area coordinators were identified and were assigned by EIAR to play coordinating and facilitating roles in all project activities. At a regional level, a focal person was identified from Extension/Input Department of Bureau of Agriculture who coordinates the activities in respective regions. In addition, to oversee the logistics in technology distribution and multiplication a focal person in each district (woreda) was assigned facilitating project implementation.

Functionally, the platform operates at strategic and operational level bringing together different federal and regional research, seed sector and development stakeholders along the value chain. At strategic level the project has Project Steering Committee (composed of ICARDA, EIAR and USAID senior management) and Project Technical Committee (project coordinators and technical staff from ICARDA and EIAR). These was supported by regional and district level forums operated by focal persons of respective institutions.

1.7 Lessons Learnt

From the outset the project focused on key thematic areas in its implementation process. However, no two wheat seed systems are exactly the same regardless of any apparent similarities. The configuration of institutions involved in research, seed delivery, extension services, reflects unique characteristics of each country. However, there are recurring patterns of moving varieties from agricultural research stations to farmers' fields where different laws and polices need to be navigated in each country during the process of project implementation. The project is also unique in addressing an emergency situation where each country went through its own experience in responding to these challenges.

The following are some of the lessons learned during project implementation process:

- Availability of a mechanism for international collaborative variety testing established under the BGRI umbrella where both IARCs and NARS participate to evaluate their materials against Ug99 and its variants in Kenya and Ethiopia;
- Fast track variety release achieved through a 'crash' program in which elite germplasm from IARCs were selected for accelerated release following a single year of adaptation testing at multi-locations by NARS notably in Ethiopia;
- Popularization and demonstration of newly released varieties and/or promising lines to create awareness among farmers and key stakeholders to facilitate their adoption and diffusion;
- Accelerated pre-release seed multiplication of promising lines to produce sufficient amount of basic (foundation) seed before release of varieties. Pre-release seed multiplication occurred during the off-season notably in Ethiopia and in Pakistan involved the private sector under the Foundation Seed Cell program;
- During the fast track testing and accelerated seed multiplication, some varieties have been released in different countries. This may lead to predominance of mega varieties and uniformity of varieties across regions once again raising the concern of vulnerability of wheat to rusts. It is critical to maintain the varietal diversity and overcome varietal dominance by identifying and releasing those with comparable agronomic performance and preferred traits at national and/or regional levels;
- Partnerships engaging multiple stakeholders brought on board policy makers and regulatory agencies to facilitate flexible approaches to fast-tracking variety release and accelerated pre-release seed multiplication to achieve more timely response to rust threats;
- Availability of funds sufficient to support national and international efforts to address the global threat of stem rust both in developing new rust-resistant varieties and their rapid seed multiplication;
- A global network of variety testing and sharing data among advanced research institutes, IARCs and NARS accelerated the release and delivery of improved varieties in the region, for example seed of *Misr1* was shipped from Egypt to Afghanistan;

- Partnerships with private seed companies proved to be the quickest and most cost effective strategy for multiplying and delivering seed of rust-resistant varieties in some countries; and
- Senior leaders oversaw the planning and coordination for rapid seed multiplication with an effective partnership among stakeholders

1.9 Concluding Remarks

Wheat rusts remain a major challenge where the durability and longevity of resistance is short lived threating food security nationally, regionally and globally. The emergence of new races of rust and its potential for long distance spread with devastating consequences remain a big challenge and with no room for complacency. This situation would be exacerbated with emerging issues and the consequences of climate change. There is a need for state of preparedness and contingency planning at country level with broader participation of key stakeholders defining their clear roles and responsibilities. There is a need for policy makers to be aware for an immediate action and make available the necessary resources required for the effective management of rusts. This may embrace from establishing adequate surveillance and monitoring of rusts to development and deployment of diverse set of varieties through an effective and efficient seed delivery system to counter the threat of wheat rusts.

The project has made significant contribution in creating awareness of wheat rust threats and in establishing a functional platform bringing together the key stakeholders along the wheat seed value chain involving policy makers, development practitioners, and farmers. Several rust-resistant wheat varieties have been developed and deployed to farmers' fields within the shortest period of time using a variety of formal and informal approaches and partnerships at national and international levels. It enhanced wheat production and productivity and ensured food security averting the looming crisis of food security in target countries.

However, the development and deployment of rust-resistant wheat varieties cannot be a one-off or short-term effort. International and national breeding programs must develop a diverse set of rust-resistant wheat varieties over time, as any single form of resistance is expected to be short-lived. Durable resistance depends not in a single variety given the expected short longevity of rust resistance in wheat but in maintaining the diversity in the resistant varieties deployed to farmers.

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Chapter II

Incidence and Challenges of Rust Diseases in Wheat Production

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2.1 Introduction

The importance of rust diseases increased with the expansion commercially grown semi-dwarf wheat varieties in the 1980s (Hulluka *et al.*, 1991). Since 1977, recurrent yellow and stem rust epidemics noted in major wheat growing areas. Severe amounts of rust can halt plant growth or even kill the plant by reducing the photosynthetic area and causing losses of nutrients and water. With stem rust, lodging and stem breakage are common with early disease onset (prior to heading). The potential yield loss caused by these diseases depends on the rust type, host susceptibility and weather conditions, but the loss also is influenced by the timing and severity of diseases outbreak relative to crop growth stage. The greatest yield loss occurs when one or more of these diseases occur before the heading stage of development. Yield losses could be 50-100% depending on the rust type, amount of inoculums, the susceptibility of a cultivars and environmental conditions (Badebo *et al.*, 2008).

Since the inception of wheat improvement in Ethiopia, close to 100 bread wheat varieties have been released for commercial production; however, the majority were abandoned mainly due to susceptibility to new races of yellow and/or stem rusts. New races often evolve when a previously resistant wheat variety with R-gene is deployed in a wider area. For example, recently a new stem rust race (TKTTF) evolved and devastated the yield of mega variety, *Digalu in* Arsi and Bale zones. New races could also be carried across countries and continents *via* wind currents. The incursion of yellow rust races in 1988 (virulent to *Yr9)* another race in 1998 (virulent to *Yr27*) and stem rust race Ug99 (TTKSK) in 2003 indicated the importance of migration in the epidemiology of wheat rust diseases in the region.

2.2 Wheat Rust Diseases

Yellow rust also called stripe rust is caused by the fungus *Puccinia striiformis* f.sp. *tritici*. Unlike to leaf and stem rusts, the disease is quite common in cool highlands (above 2400 m). It could also be important in mid altitudes depending on the weather conditions. For example, the humid, foggy, and cool weather conditions prevailed in 2010 favored the development of yellow rust even in the lower altitudes. Free moisture on the leaves and an optimal temperature (10-15°C) are required for yellow rust infection. Pustules erupt within 10-14 days after infection. Damage from yellow rust depends on the susceptibility of the wheat variety, the onset of epidemic, the amount of yellow rust that develops and low temperature during grain filling. Losses can be severe (60%) due to shriveled grain and damaged tillers and in extreme situations, it can incur 100% losses, especially when the spikes re infected at higher altitudes (Badebo *et al*., 2008).

Stem rust also called black rust is caused by *Puccinia graminis* f. sp. *tritici*. The fungus is pathogenic on barley as well. It requires free moisture and warmer temperatures (18-30°C) to infect the plant and pustules can be seen after 10-20 days of infection. In Ethiopia, it is quite important at low and mid altitudes (< 2400 m). Stem rust could be important at higher altitudes on late sown and/or late maturing wheat varieties, especially grown on *vertisols*. The pathogen has ability to cause total loss on susceptible varieties, if it occurs early in the wheat growth stage.

Leaf rust is caused by the fungus *Puccinia triticina* (synonym, *P. recondite* f. sp. *tritici*). The leaf rust spores require 15 to 20ºC temperature and free moisture on the leaves to successfully infect wheat. The disease is quite common in altitudes between 2000 and 2400 m and the local cultivars (durum wheat) also suffer more to this disease. Most of the improved bread wheat cultivars grown in Ethiopia have sufficient protection to leaf rust. The disease could incur up to 50% yield loss if it occurs early in the wheat growth stage.

2.3 Recurrent Rust Epidemics

Recurrent rust epidemics occurred in the last three decades in Ethiopia (Table 2.1). The first rust epidemics occurred in 1977 when a semi dwarf wheat variety *Laketch*, succumbed to yellow rust in state farms in Arsi and Bale (Hulluka *et al.*, 1991). In 1988, another stripe rust epidemic noted on the then popular wheat variety, *Dashen* in Arsi and Bale zones (Badebo *et al.*, 1990). *Dashe*n carried *Yr9* gene originated from IB/1R translocation.

The yield loss incurred by yellow rust on *Dashen* reached 58% in the highlands of Arsi (Badebo *et al.*, 2008). Other derivatives of *Yr9* became susceptible to new race and subsequently, farmers tended to replace these varieties with old Kenyan originated variety, *Enkoy* with *Sr36*. In 1998, new yellow rust races virulent on *Wabe* and *Kubsa* were detected (Badebo *et al*., 2008).

Table 2.1 Recurrent rust epidemics in major wheat producing areas

Year	Variety	Disease	R - gene	Yield loss (%)	Location
1988	Dashen	Yellow rust	*Yr9*	58	Arsi
1994	Enkoy	Stem rust	*Sr36*	67-100	Arsi-Bale
2010	Kubsa	Stripe rust	*Yr27+*	Up to 50	SEE, CE, NWE
2010	Galema	Stripe rust	*Yr27+*	Up to 100	SEE, CE, NWE
2013/14	Digalu	Stem rust	*SrTmp*+	100	Arsi-Bale
2014/15	Digalu	Stem rust	*SrTmp*+	100	Arsi-Bale

Source: Badebo et al., 2014

Wabe was abandoned soon because of complete susceptibility (100S) to yellow rust whereas *Kubsa* and *Galema* sustained partial resistance to some extent and their cultivation expanded to other parts of the country (Figure 2.1). In 2010, country wide yellow rust epidemics debilitated the yields of these two *mega* wheat varieties and the country has experienced one of the devastating yellow rust epidemics in history. About 600,000 ha of wheat was affected and an estimated 60 million Birr were spent on fungicides (Table 2.2). The yield loss on susceptible varieties such as *Galema* reached 100% in the highlands.

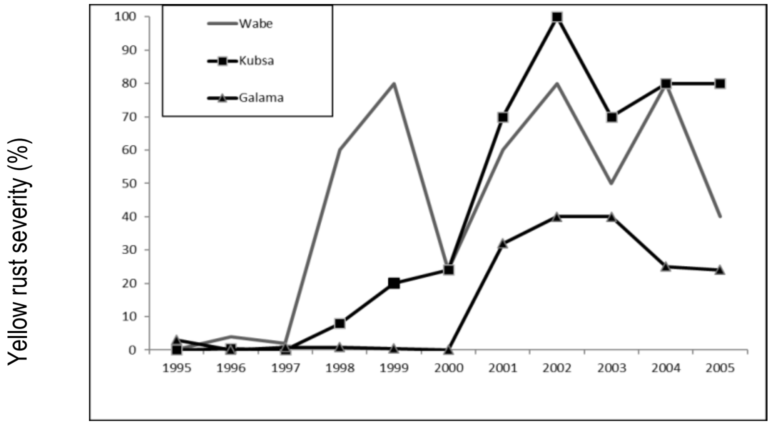

Figure 2.1. The reaction of three bread wheat varieties to yellow rust (severity trends) across seasons (Badebo *et al*., 2014)

Table 2.2. Area affected by yellow rust and % fungicide applied on farmers' field across different regions in 2010.

Region	Zone	District	Area affected (ha)	Area sprayed (ha)	% sprayed
Oromia	13	118	292,866	123,357	42.1
Amhara	8	77	161,348	26,579	16.5
SNNP	15	94	137,376	32,089	23.4
Total	36	289	591,590	182,025	30.8

Source: MoA, unpublished data 2010

Stem rust has been one of the devastating diseases of wheat in Ethiopia. In 1993//94, *Enkoy* was severely affected by stem rust and the yield loss incurred ranged from 67-100% in Arsi and Bale (Shank, 1994). *Enkoy* was replaced by *Kubsa* and *Galema,* which were released in 1994 and 1995, respectively. After the 2010 yellow rust epidemics, farmers tended to replace the two mega varieties with D*igalu*, a late maturing rust-resistant variety released in 2005 and newly released varieties like *Danda'a*, *Kakaba, etc*. *Digalu* started to cover wide area in Arsi and Bale but it was also succumbed to a new stem rust race (TKTTF) different from Ug99 (TKTTSK) in Bale in 2013/14. The first detection was at Gassara District early in October and increased its coverage in mid-November to other districts with yield loss of over 90% in worst affected areas (Table 2.3). An estimated area of 20,000 to 40,000 ha was seriously damaged by the rust epidemics.

Table 2.3. Yield loss due to stem rust epidemics on bread wheat variety *Digelu* in Bale zone, 2013/14

District	Kebele	No of fields	Yield loss (%)		
			Lowest	highest	Mean
Gassera	Koloba Sarara	9	54.5	82.6	74.7
	Koloba sa'ada	13	52.4	92.3	83.0
	Denmbel	7	40	91.4	64.1
Agarfa	Ambentu	7	50	77.3	59.5
	Ali	3	0	33.3	15.9
	Sheneka	6	0	71.7	45.1
	Elani	9	20	50	34.3
Sinana	Ilu Sanbitu	12	0	68.8	40.9
	Koloba Suleman	9	25	47.5	43.2

Source: Bekele Hundie, 2014

In 2014/15, the incursion of race TKTTF has increased in major wheat growing areas resulted in 100% yield loss on *Digalu* in Arsi and Bale. The epidemics were due to wide cultivation of the susceptible cultivars including *Digalu.* Moreover, the epidemics were aggravated due to favorable weather condition and late planting. *Digalu* race (TKTTF) is now completely dominant across major wheat producing areas (Woldeab and Hailu, 2015). Huge inoculum load is expected in 2015/16 as well (Hodson, 2015).

2.3.1 Causes of recurrent rust epidemics

All the recent epidemics have identifiable causes (classic disease triangle) and were largely predictable where the presence of susceptible host, virulent pathogen and conducive environment lead to rust epidemic. Vast areas planted to genetically uniform cultivars, for example, *Kubsa* and *Galema* resulted in the 2010 yellow rust epidemics. Similarly, the expansion of *Digalu* to wide areas of land exposed the variety to the new stem rust race in 2013/14. Growing susceptible cultivars will result to more rust epidemics. In addition to susceptible host, the very conducive environment – above average and prolonged rains favored the incursion of yellow rust in 2010. Favorable environmental condition and late planting has contributed for stem rust epidemics in 2013/14 and 2014/15 in Arsi and Bale.

2.3.2 Virulent races

New rust races either evolved locally or migrated from the neighboring countries. The yellow and stem rust races detected in Ethiopia are one of the most virulent ones (Tables 1.4 and 1.5). Of the 18 yellow rust resistance genes (differential lines) used for race analysis at GRRC, Denmark only three (*Yr5, Yr15, Yr32* and *YrSP*) are effective to the prevailing Ethiopian yellow rust races (Table 2.4).

Similarly, the stem rust races in Ethiopia attack most of the known resistance genes (Table 5). Out of the 20 stem rust differential lines used for race analysis in North America, only one (*Sr24)* is effective in Ethiopia. Stem rust races that overcome the resistance of *Sr24* have already been detected in Kenya.

Table 2.4. Yellow rust races in major wheat growing areas in Ethiopia

Year	*Yr* genes/yellow rust differential lines																		frq
	1	2	3	4	5	6	7	8	9	10	15	17	24	25	27	32	SP	Avs	
2010/11	-	(2)	-	-	-	6	7	8	9	-	-	-	-	25	27	-	-	Avs	3*
	1	2	-	(4)	-	6	7	-	9	-	-	-	-		27	-	-	-	17
	-	2	-	-	-	6	7	8	9	10	-	-	-	25	27	-	-	Avs	2*
2011/12	-	-	-	-	-	-	(7)	-	-	-	-	-	-	-	27	-	-	-	1
	1	2	-	-	-	6	7	8	-	-	-	-	-	25	-	-	-	Avs	1
	1	2	-	-	-	6	7	-	-	-	-	-	-	25	-	-	-	Avs	1
2012/13	-	-	-	-	-	-	(7)	-	-	-	-	-	-	-	27	-	-	-	1
	1	2	-	-	-	6	7	-	-	-	-	-	-	25	-	-	-	Avs	1
	1	2	-	-	-	6	7	-	-	-	-	17	-	25	-	-	-	Avs	1
	1	2	-	-	-	6	7	-	9	-	-	17	-	25	27	-	-	Avs	2
2014/15	-	-	-	-	-	6	7	8	-	10	-	-	-	-	-	-	-	-	1
	-	2	-	-	-	6	7	8	9	-	-	-	-	25	27	-	-	Avs	2
	-	2	3	-	-	6	7	8	-	-	-	-	-	25	27	-	-	Avs	1
	-	2	3	-	-	6	7	8	-	10	-	-	24	25	27	-	-	Avs	1
	-	2	3	-	-	6	7	8	9	-	-	-	24	25	27	-	-	Avs	1
	1	2	-	-	-	6	7	-	9	-	-	-	-	-	27	-	-	Avs	5
	1	2	-	-	-	6	7	-	9	-	-	17	-	-	27	-	-	Avs	1

Source: Hovmøller, 2014 and 2015

Table 2.5. Stem rust races

Stem rust races	*Sr* genes/ differential lines																		
	5	21	9e	7b	11	6	8a	9g	36	9b	30	13+17	9a	9d	10	Temp	24	31	38	MCN
TTKSK	5	21	9e	7b	11	6	8a	9g	-	9b	30	13+17	9a	9d	10	-	-	31	38	MCN
TTTSK	5	21	9e	7b	11	6	8a	9g	36	9b	30	13+17	9a	9d	10	-	-	31	38	MCN
RRTTF	5	21	-	7b	11	6	-	9g	36	9b	30	13+17	9a	9d	10	Temp	-	-	38	MCN
TRTTF	5	21	9e	7b	11	6	-	9g	36	9b	30	13+17	9a	9d	10	Temp	-	-	38	MCN
TKTTF	5	21	9e	7b	-	6	8a	9g	36	9b	30	13+17	9a	9d	10	Temp	-	-	38	MCN
JRCQC	-	21	9e	-	11	6	-	9g	-	-	-	13+17	9a	9d	-	-	-	-	-	MCN

Source: Olivera et al., 2012; Woldeab and Hailu, 2015

2.4 Management Options

There are several rust management options (resistance, fungicides and cultural), but the critical decision depends on profitability and safety to health and environment. It is possible to manage rust diseases through cultural practices such as sanitation, early planting and early maturing varieties—for stem rust; gene deployment, monitoring and early warning. However, rust diseases are best managed through the use of multiple options, both proactive, i.e., early planting-stem rust, resistant varieties, diversification; and reactive, i.e., application of foliar fungicides.

2.4.1 Cultural practices

Early planting and use of early maturing varieties (in case of stem rust) could help to reduce the damage of rust diseases. Farmers could plant early in areas with vertisols using proper drainage systems. Wheat rust diseases are also challenging in areas where farmers practice mono-cropping in Arsi and Bale regions. Farmers often tend to grow one or two mega varieties. Advises should be given to farmers to deploy different varieties at farm level and beyond. Monitoring of wheat rusts regularly could help to take anticipatory measures. In general, wheat rust management through cultural practices helps to minimize the damage level, but could be effective if integrated with other management practices.

2.4.2 Resistant varieties

The use of resistant cultivars is the most economic method of rust control. Resistant cultivars reduce additional costs for fungicide application and it is safe for health and environment; however, resistance does not last long. Varieties resistant to one rust or race may be susceptible to another. If we plant a single resistant variety in wider areas for long period, new race (s) of the pathogen may develop and overcome the resistance of a new variety. For example, the two popular bread wheat varieties, *Dashen* and *Kubsa* succumbed to yellow rust in 1988 and 2010, respectively. The two bread wheat varieties have been grown extensively in major wheat production regions of the country, and subsequently new races of yellow rust appeared that overcome the resistance of these varieties.

2.4.3 Fungicide application

Fungicides could be applied in case of emergency. They are risk to the environment and human beings, if not administered judiciously and safely.

Several fungicides are registered for the control of wheat rust (Table 2.6). Fungicides can add considerably to the variable costs of production and the feasibilities need to be determined by evaluating yield potential, varietal susceptibility and environmental conditions.

Table 2.6. Registered systemic fungicides against wheat rusts in Ethiopia

Common name	Trade name	Rate/ha
Propiconazole	Tilt 250EC	0.5-1 l
Propiconazole	Bumper	0.5 l
Propiconazole	Progress 250EC	0.5 l
Propiconazole	Topzole 250EC	0.6 l
Triadimefon	Bayleton	0.5-1 kg
Triadimefon	Prevent 20%EC	0.65 l
Tebuconazole	Orius 250EW	1l
Tebuconazole	Natura 250EW	0.65 l
Epoxiconazole	Soprano	0.75 l
Epoxiconazole + *Thiophanatemetyle*	RexDuo	0.5 l

2.5 Conclusion

In general, wheat farmers in Ethiopia are challenged by periodic epidemics of yellow and stem rusts. The Ethiopian highlands favor both the host and the rust pathogen. In addition to the favorable environmental conditions, different planting dates, deployment of few mega cultivars with major genes, evolution and migration of new virulent and aggressive races are amongst the challenges imposed by wheat rusts. To curtail losses and improve the livelihood of wheat farmers it is recommended to diversify varieties by including durum wheat or developing varieties with multiple minor genes or combinations of major and minor genes should be given due priority.

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Chapter III

Fast-track Variety Testing and Release of Rust-resistant Wheat Varieties

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3.1 Introduction

Wheat rusts remain one of the most important production challenges for wheat in the highlands and the country suffered from periodic rust epidemics as recently as 2010 (yellow rust) and 2014 and 2015 (stem rust) as shown in the previous chapters. The development and deployment of resistant varieties has been the major strategy to control rusts of wheat worldwide. While resistance conditioned by major genes has been most widely used breeding strategy pyramiding of several genes into a single cultivar is an attractive breeding strategy since it reduces stepwise accumulation of virulence by the pathogen against each gene. The alternative is the development and deployment of cultivars carrying durable or slow rusting resistance based on quantitatively inherited, multiple genes referred to as adult plant resistance.

In Ethiopia, as stated earlier, ICARDA in partnership with CIMMYT and EIAR formulated and implemented two successive projects with focus on stem and yellow rust, which complimented and reinforced each other in order to avert the risks and losses associated with the cultivation of susceptible bread wheat cultivars. The paper presents the achievement made in fast-track variety testing and release of rust-resistant varieties under national wheat research program to ensure the availability of new high yielding resistant varieties for replacement of existing susceptible commercial varieties.

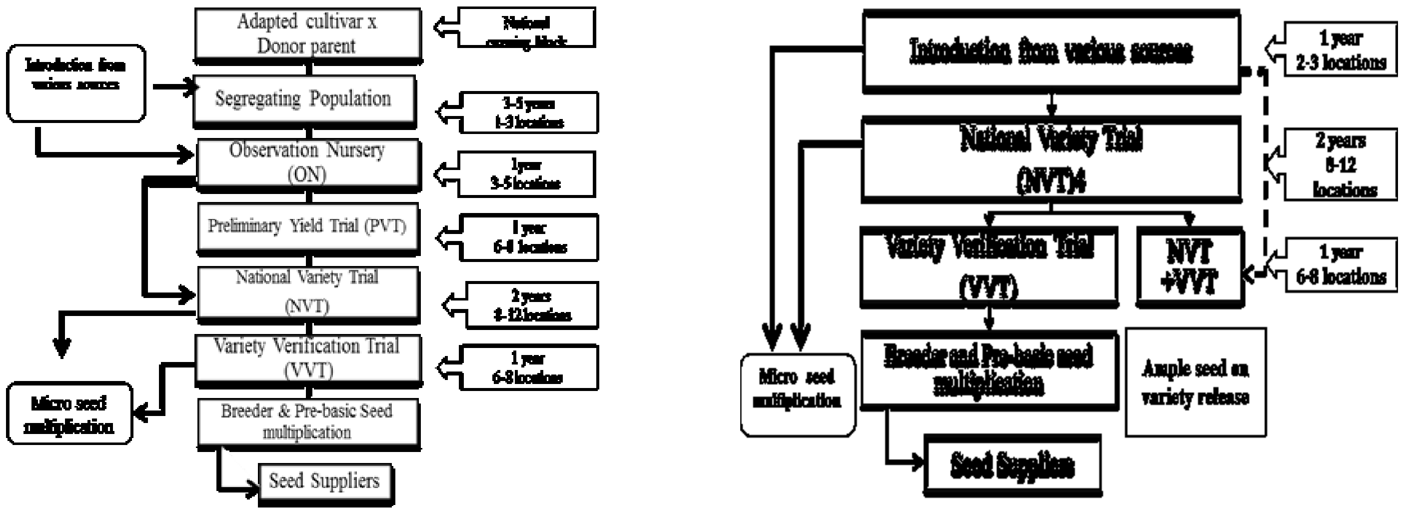
3.2 Variety Development, Evaluation and Release

The procedure for variety development, testing and release in Ethiopia is presented in Figure 3.1. Accordingly, two approaches are used where adaptation testing for fast tracking release in response to emergency situation or regular testing for release as per the national requirements stipulated in Seed Proclamation.

Adaptation testing is the approach for fast track testing and release where introduced germplasm with desired traits were directly tested for one-year multi-location trials across major agro-ecologies and released based on performance. In regular program, advanced lines from international and national sources go through multi-year and multi-location trials before they are released for commercial cultivation.

The research strategy against the threat of wheat rusts anchored on:

- introducing, testing and releasing of rust-resistant varieties from different sources including CG centers and NARS;
- screening national germplasm (old varieties, commercial varieties, promising lines, breeding materials) for resistance against rusts in hot spots;
- identifying resistance genes that are effective against rusts that carries durable resistance through molecular tools; and
- incorporating diverse resistance genes into adapted cultivars and evaluating them in hot spots to develop new high yielding varieties.



a) Conventional approach

b) Fast track approach

Figure 2.1. Variety development, evaluation and release in Ethiopia

3.2.1 Fast-track variety testing and release

Ethiopia is known for frequent outbreak of rust epidemics specially stem and yellow rusts in recent years. In recent years, the emergence and quick spread of Ug99 and its variants of stem rust coupled with the yellow rust epidemics in 2010 in Africa and Asia including Ethiopia posed serious threats to food and nutritional security at global, regional and country levels. In parallel with conventional breeding program (Figure 3.1a), fast-track variety testing and release was followed to quickly release resistant varieties within shortest possible period of time. Under this scheme, wheat germplasm with known resistance to rusts through hot spot testing and high yield potential through key location testing were identified and introduced for in-country adaptation trials for shortest possible period of time. The germplasm introduced can go through different trials for release. It either enters one year adaptation trial and advanced to the National Variety Trial (NVT) through regular procedure or directly enter Variety Verification Trial(VVT), where the two trials (NVT and VVT) can run in parallel (Figure 3.1b). The process may reduce the time required for release to one year combining the NVT and VVT

From the outset, to counter the threat of Ug99, several accessions have been screened in stem rust hotspot in Kenya and shared globally with NARS through CIMMYT and ICARDA as part of Elite Bread Wheat Yield Trials (EBWYT) and Stem Rust Resistance Screening Nurseries (SRRSN). Under this initiative on stem rust a regional project was launched in 2008/09 where germplasm of resistant varieties with higher grain yields were distributed and evaluated across Africa and Asia. In Ethiopia, five promising lines (Chonte #1, Danphae #1, Picaflor #1, Quaiu#1 and Munal) from CIMMYT and three promising lines (Flag 3, Flag5 and Amir 2) from ICARDA were introduced and tested during the off-season (stem rust hot spot in Debre Zeit) and for adaptation across the country during the 2009/10 main season (Table 3.1). The ‘adaptation’ testing led to the immediate release of four varieties in 2010 and 2011 from original eight promising lines and followed with subsequent release of other varieties with combined resistance to stem and/or yellow rust over the years (Table 3.2).

3.2.2 Regular variety testing and release

Under the regular program nurseries from national crossing blocks or international sources go through several stages of screening and evaluation before submission for release. These include observation nurseries, preliminary yield trials, national yield trials and verification trials. The process requires at least four to five years (Figure 3.1a).

a) Evaluation of international nurseries

The use of wheat germplasm with diverse genetic background is critical to develop high yielding and disease resistant varieties. Cognizant of this fact large number of wheat germplasm with diverse genetic background were introduced from ICARDA and CIMMYT and evaluated under the regular breeding program from 2011/12 to 2014/15 (Table 3.1). Apart from grain yield, resistance to stem and yellow rusts were the two main traits given due emphasis in the evaluation program.

Table 3.1. Number of bread wheat nurseries evaluated from 2011/12 - 2014/15 crop season

Year	# nurseries evaluated	Germplasm source	# entries evaluated	#. entries retained for further testing	% of lines selected
2011/12	16	ICARDA, CIMMYT	1983	698	35.2
2012/13	28	ICARDA, CIMMYT	3403	441	13.0
2013/14	24	ICARDA, CIMMYT	3505	874	24.9
2014/15	14	ICARDA, CIMMYT	1722	472	27.4
Total			10613	2485	23.4

A total of 10,613 genotypes were evaluated at Kulumsa and Debreziet Agricultural Research Centers both during the main and off seasons. Disease resistance is the first prioritized breeding trait to select and advance genotypes during the first year screening of all international nurseries, for. About 2485 genotypes (23.4%) were advanced to different level of variety trials (Table 3.2). Access to large number of germplasm provided opportunities to select genotypes having high yield and combined resistance and adapted to major wheat producing regions of the country within shortest period of time.

b) Variety testing and release

Advanced genotypes from national and/or international nurseries go through series of observation nursery, preliminary and national yield trials before submission for final release. Promising lines with outstanding performance could be proposed for variety verification trial. A variety verification trial will be conducted by NARS and evaluated by the technical committee with the recommendation to the National Variety Release Committee for final approval. Sufficient descriptive morphological information of the candidate varieties is provided by the breeders. The release system is dependent on performance testing conducted by the agricultural research and approved by variety release committee.

Increasing the number of genotypes in different yield trials was also taken as a strategy to increase the probability of genetic gain (Table 2). Moreover, for yield performance and yield stability, genotypes were evaluated in more location across the country than previous scenario to augment fast track variety testing and release.

Table 3.2. National wheat yield trials conducted from 2011 – 2014 crop seasons

Trials	2011/12		2012/13		2013/14		2014/15	
	# Set	# Entry	# Set	# Entry	# Set	# Entry	# Set	# Entry
ON	3	384	5	584	5	638	4	441
PVT	4	112	14	328	6	185	4	120
NVT	8	114	9	185	9	221	4	125
VVT	1	2	-	-	2	5	1	1
Total	16	612	28	1098	22	1049	13	687

Note: ON= Observation Nursery, PVT=Preliminary Variety Trials, NVT=National Variety Trials and VVT=Variety Verification Trials

Several wheat varieties have been identified and released from the Federal and Regional Agricultural Research Institutes (Table 3.3). However, due to low yield and susceptibility to rust and other disease very few of them are now under production. Hence, genotypes under different yield trials were evaluated strongly for multiple disease resistance in key disease screening nursery in hot spot areas.

Table 3.3 Bread wheat varieties released through fast track and regular program

Variety	Source	Year released	Remarks
Danda'a	CIMMYT	2010	Combined resistance to Ug99 and Yr
Kakaba	CIMMYT	2010	Combined resistance to Ug99 and Yr
Gambo	CIMMYT	2011	Combined resistance to Ug99 and Yr
Hoggana	ICARDA	2011	Combined resistance to Ug99 and Yr
Shorima	ICARDA	2011	Combined resistance to Ug99 and Yr
Hulluka	ICARDA	2012	Combined resistance to Ug99 and Yr
Hidase	CIMMYT	2012	Combined resistance to Ug99 and Yr
Ogolcho	CIMMYT	2012	Combined resistance to Ug99 and Yr
Adel-6	ICARDA	2013	Irrigated and heat tolerant
Lucy	ICARDA	2014	Irrigated and heat tolerant
Mandoyu	ICARDA	2014	Rust-resistant
Senate	ICARDA	2014	Rust-resistant
Biqa	ICARDA	2014	Rust-resistant
Honqollo	ICARDA	2014	Rust-resistant
Obora	ICARDA	2015	Rust-resistant
Dambal	ICARDA	2015	Rust-resistant

Variety development and seed production strategies followed a decentralized approach that comprises of federal and regional agricultural research institutes and federal and regional public seed producers.

3.3 Accelerated pre-release seed multiplication and maintenance

3.3.1 Pre-release seed multiplication

Availability of early generation seed remains a critical issue in seed multiplication of new rust-resistant varieties. The project initiated pre-release seed multiplication of rust-resistant promising lines identified during the NVT or candidate varieties during the adaptation testing or VVT in order to accelerate the availability of early generation seed while these lines were undergoing variety trials for release. The NWRP multiply candidate promising lines both during the main and off-season at Kulumsa and Werer ARC to shorten the time and maximize the availability of basic seed stock (Table 3.4). These enabled immediate accelerated large-scale seed production by the time the varieties are officially released. In addition, low seed rate to increase the multiplication of initial seed source were applied. The seeds of newly released varieties multiplied at pre-release stages were also grown at Kulumsa for further multiplication and enough seeds were produced for off-season seed multiplication.

Table 3.4. Pre-release seed multiplication of promising lines from 2009/10-2013/14 crop season

Lines (Varieties)		Amount of seed produced (t)					
Lines	Seed Source	2009	2010/11	2011/12	2012/13	2013/14	Total
Chonte #1	CIMMYT	2.8	25.9				28.7
Danda'a (Danphe #1)	CIMMYT	4	29.35				33.35
Munal #1	CIMMYT	5	15.502				20.502
Kakaba (Picaflor #1)	CIMMYT	3.7	43.01				46.71
Gambo (Quaiu #2)	CIMMYT	4.5	19.55				24.05
Shorima (ETBW5483)	ICARDA	0.135					0.135
Hulluka (ETBW5496)	ICARDA	0.2					0.2
Hoggana (ETBW5780)	ICARDA	1.95			1.5		3.45
Ogolcho (ETBW5520)	CIMMYT				1.5		1.5
Hidasse (ETBW5795)	CIMMYT						0
Honqollo (ETBW5879)	ICARDA					1.75	1.75
Biqa (ETBW 6095)	ICARDA					1	1
Others (3/7/2)*	ICARDA	2	0.781			1.93	4.711
Total		24.285	134.093	0	3	4.68	166.058

Note: In addition, King Bird bread wheat variety resistance to stem rust was introduced from Kenya and 90 t of seed was produced through CIMMYT support

3.3.2 Micro increase of breeding lines

The project supported micro-seed increase of promising lines to accelerate variety evaluation and release which otherwise would be delayed due to shortage of sufficient seed to conduct national multi-location variety trials and verification trials. In 2012/13, micro increase of 169 breeding lines (10 m x 0.8 m) was undertaken and about 3 kg each was produced (489 kg). Similarly, in 2013/14, micro-seed increase of 57 advanced breeding lines was undertaken and 456 kg seed was obtained for trials. In 2014/15, a total of 50 promising lines were selected for micro seed multiplication.

3.3.3 Variety maintenance of released varieties

The National Wheat Improvement Program at KARC is responsible to provide seed request coming from users both for nationally and regionally released varieties. The project supported variety maintenance of released varieties to ensure varietal purity and identity of early generation seed. From 2011/12 to 2014/15 a considerable number of wheat varieties were maintained and breeder seed was produced (Table 3.5).

Table 3.5. Variety maintenance of rust-resistant bread wheat varieties at Kulumsa (2011/12-2014/15

Year	Number of varieties	Amount produced (t)
2011/12	44	3
2012/13	16	2.8
2013/14	10	0.51
2014/15	46	2.3

3.4 Lessons learned

Introduction and adaptation testing for fast tracking variety release: Advanced breeding lines or released varieties with proven resistance of rusts were introduced and entered directly into multi-location variety trials and released within one year. Some of the released varieties have combined resistance to both stem and yellow rust and proved useful in replacing mega varieties found susceptible to rusts in the country.

Targeted breeding to address rust problems: In all breeding programs, grain yield is virtually a priority trait for release of varieties. While grain yield was a major objective of the breeding program, equal emphasis was given on resistance to rusts for release of new varieties.

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Pre-release multiplication of candidate varieties: To make available sufficient amount of seed for further multiplication the project employed preleased seed multiplication during the main and off-seasons.

Raising awareness of rusts: NARS in collaboration with the Ministry of Agriculture raised the awareness of wheat rusts in the farming sector. Farmers are being encouraged to replace and diversify the wheat varieties they grow. The awareness led to dramatic shift in resistant cultivars use by the farmers and coupled with good surveillance and preparedness of rust epidemics and availability of chemicals for control.

3.5 Conclusion

In the late 1990s the average age of varieties being used in farmers' fields was greater than 14 years. However, after the strategies developed for fast-track variety development and seed multiplication, susceptible wheat varieties were replaced in shortest possible time. This project strengthened the national wheat breeding program and assisted in the development, testing, and release of rust-resistant varieties. It adopts novel approaches of fast-track variety development and pre-release seed multiplication strategy that significantly shortens the time lag between variety release and availability of quality seeds directly in the hands of farmers to combat the rapidly evolving stripe rust.

Generally, fast-track variety development and pre-release seed multiplication of rust-resistant varieties in Ethiopia was successfully tackling Ethiopia's wheat stripe rust epidemic - a highly destructive crop disease that threatens national wheat production and is spreading more rapidly due to climate change. As a result, it protecting Ethiopian farmers from crop losses and helping them to raise their production, achieve high incomes, and strengthen national food security.

The project worked closely with other wheat projects including EAAPP, DRRW/CIMMYT and SARD-SC (ICARDA) where the germplasm were valuated. The wheat team received the National Science, Technology and Innovation certificate for outstanding recognition and achievement for the problem solving research. The Gene Stewardship Award in 2014 by BGRI in recognition for the effort/success to combat rusts shows the success for Ethiopia, the East Africa region and the world at large.

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Chapter IV

Accelerated Seed Multiplication for Deployment of Rust-resistant Wheat Varieties

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4.1 Introduction

In Ethiopia, the number of public seed enterprises and private seed companies has increased recently and are being involved in wheat seed production. The public seed enterprises include Ethiopian Seed Enterprise (ESE), Bale Agricultural Development Enterprise (BADE), Oromia Seed Enterprise (OSE), Amhara Seed Enterprise (ASE), South Seed Enterprise (SSE) and Somali Seed and Forage Enterprise (SSFE). The private seed producers include Tinsae Agro PLC, Alemayehu Seed Producer PLC, Anno and Gadisa Seed Producer PLC., Ethio-vage and Z-Endeta private farms. Besides, several business-oriented seed cooperatives, for example, Edget Union, input marketing cooperatives are also engaged in wheat seed production through farmer groups mainly supported by development partners. The cooperatives are linked with both farmer groups and formal sector.

During the last four decades NARS has developed and released more than 67 bread and 33 durum high yielding and disease resistant wheat varieties (MoA, 2014). Since 1960's the national wheat average yield increased four-fold from 0.6 to 2.54 tons ha^{-1}. However, recurrent rust epidemics and short longevity of rust resistance of bread varieties posed a major challenge to wheat production in the country. In recent years the emergence of new strain and variants of Ug99 and the yellow rust epidemics in 2010, posed a serious risk to millions of small-scale wheat producers. This chapter presents the approaches, achievements and lessons learned in accelerated seed multiplication of early generation seed (breeder, pre-basic and basic) and large-scale certified seed production by NARS and public and private sector including farmer seed producer groups during 2010/11-14/15 crop seasons as part of ICARDA-EIAR project.

4.2 Framework for Accelerated Seed Multiplication

Taking into account the framework described in earlier chapter, and using stakeholders' platforms at federal and regional levels, the accelerated seed multiplication component of the project implemented the following key activities:

- Identification and prioritization of rust affected target districts in each region aligned with AGP intervention areas;
- Identification of suitable wheat varieties for target districts;
- Estimation of potential seed demand and ensuring the availability of EGS;
- Ensuring accelerated seed multiplication through partnership involving NARS, public seed enterprises, private seed companies and farmer seed producers.

4.2.1 Identification and prioritization of target districts

The project aimed at addressing the agricultural growth program (AGP) districts as per government priority and donor interest where the stakeholders had identified and prioritized target districts based on severity of rust damage and potential wheat area coverage of each district (Table 4.1). In addition eleven non-AGP major wheat growing districts were included based on the recommendations of the regional bureaus of agriculture.

Table 4.1. AGP and non-AGP districts selected for scaling out seed technologies

Oromia		Amhara	SNNP	Tigray
Ada	Gololcha	Basoliben	Enemor Ener	Emba Alaje
Adaba	Guduru	Debre Eliyas	Endegagn	Endamehoni
Agarfa	Hitosa	Enemay	Mareko	Enderta
Aleltu	Horo	Guagusa Shikudad	Misrak Azernet	Hintalo Wajirat
Ambo	Limu-Bilbilo	Minjar	Shey Bench	Ofla
Bale	Lume	Moret	Soro	
Dendi	Munesa	Tarmaber		
Dodola	Shirka	Wenberima		
GedebAsasa	Sinana			
Gimbichu	Weliso			
Ginir	Ziquala			
Gololcha				
Total	**23**	**8**	**6**	**5**

4.2.2 Identification of suitable rust-resistant varieties for target districts

Deployment of yellow rust resistant wheat varieties were the primary focus and objective of the project. The project team from ICARDA and EIAR together with experts of the regional BoA selected available technologies including new and existing commercial wheat varieties with combined resistance to yellow and/or stem rust and associated agronomic practices suitable for each target district (Table 4.2).

Table4.2. List of rust-resistant wheat varieties distributed by the project and seed source

Variety	Source	Variety	Source
Digelu	ESE, ASE	Pavon-76	OSE
Danda'a	BADE, ESE, ASE	M/Welabu	Sinana RC
Kakaba	ASE, ESE, BADE	Bakalcha	Sinana
Tay	Adet, ASE	Illani	Sinana
Gasay	Adet, ASE	Tate	Sinana
Mekele-1	TARI	Toltu	Sinana
Mekele-2	TARI	Obsa	Sinana
Tuse	KARC	Ude	DZARC, Seed Asso
		Yerer	DZARC, Seed Asso

4.2.3 Ensuring availability of technologies

Once the technologies were identified, the project team and stakeholders had to ensure the availability of the required varieties. From the outset, an attempt was made to ensure that the available technologies were sourced from federal and regional research centers, public seed enterprises (mainly Ethiopian Seed Enterprise) and Bale Agricultural Development Enterprise (BADE), and farmers' cooperatives. Accordingly, about 22 new and existing commercial wheat varieties with combined resistance to yellow and/or stem rust resistance (including *Kakaba* and *Danda'a*) were selected for rapid seed multiplication and dissemination.

4.3 Accelerated Seed Multiplication

To achieve its primary objective the project played a catalytic role in supporting early generation seed multiplication by NARS and linking that to large-scale certified seed production by the existing public seed enterprise and/or private seed companies as well as farmer seed producer's associations through the support of district BoA.

NARS made relentless effort mitigating the shortage of seeds through provisions of appropriate technological interventions. To avail enough amounts of early generation seeds (EGS) to seed producers, the following basic approaches of accelerated seed multiplication schemes were used as intervention:

- Pre-release seed multiplication: The project supported micro-increase and pre-release seed multiplication of promising lines and candidate varieties to accelerate variety release which otherwise be delayed due to shortage of sufficient seed to conduct national multi-location variety trials (see Chapter 3) and to get sufficient amount of basic seed upon variety release.
- Two crop cycles per year: Accelerated seed multiplication particularly of early generation was conducted both during the main season and off-season under irrigation by NARS (Kulumsa, Werer, Adet, Mekelle) and by seed enterprises (Koga and Upper-Awash);
- Using low seed rate to increase multiplication factor (MF): Lower seed rates and intensive crop management have been used for providing multiplicative advantage for rapid seed increase. For example an MF 250 was achieved on a small plot where a seed rate of 8 kg was used and a yield of 2 tons ha^{-1} was produced at Kulumsa ARC; and
- Strengthening capacity of seed producers: NARS were provided with facilities to strengthen the EGS production through provision of farm

machinery, irrigation, equipment for seed quality laboratory, seed packaging and seed storage.

4.3.1 Early generation seed multiplication

Availability of and access to EGS is critical for quick deployment of new crop varieties to farmers. However, past experience have shown that the small amount of source seed from NARS remain a major bottleneck for quick dissemination and adoption of new crop varieties.

Ten federal and regional agricultural research centers were involved in accelerated seed multiplication. The newly released varieties such as *Danda'a, Kakaba, Gambo, Shorima, Hoggana, Hulluka, Hidase* and *Ogolcho* among bread wheat varieties and *Werer* and *Mangudo* among durum wheat varieties from federal system *Mekelle 01, Mekelle 02,* and *Tay* were multiplied to replace the susceptible varieties. These activities considerably improved the EGS supply and provide formal and informal seed producers with sufficient seed for further multiplication and dissemination. Since 2010/11 about 7,587 MT EGS was multiplied by federal and regional research institutes and public seed enterprises (Table 4.3).

Table 4.3. Early generation seed multiplication of rust-resistant wheat varieties

Season	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	Total
Main season	667	3,419	367	1,015	974.7	500.5	6,943.2
Off-season	365	105	82.7	48.2	20.0	22.6	643.5
Total	1,032	3,524	449.7	1,063.2	994.7	523.1	7,586.7

Apart from NARS, EGS was multiplied by public and private seed producers where sufficient quantity of seed was supplied from the accelerated seed multiplication scheme organized by the project. Different classes of EGS were provided to public seed enterprises and small-scale seed companies and farmer's seed producers associations. About 1553.4 tons of pre-basic and 22,215.4 tons of basic seed was produced by public seed enterprises at federal (ESE) and regional (OSE) levels (Tables 4.4, 4.5 and 4.6). A considerable effort in EGS multiplication by NARS and public seed enterprises with the express purpose of replacing rust susceptible varieties made significant contribution in dissemination of new resistant varieties.

Table 4.4 Early generation seed multiplication of rust-resistant wheat varieties by NARS from 2010/11 to 2015/16

Year	Season	Bread wheat			Durum wheat			Total
		New	Existing	sub-total	New	Existing	Subtotal	
2010/11	Main season	668.3	0	668.3	*0*	0	0	668.31
	Off-season	379.6	0	379.6	*0*	0	0	379.6
2011/12	Main season	3263.8	305.9	3569.7	*1.36*	25.04	26.4	3596.12
	Off-season	379.6	0	379.6	*0*	0	0	379.6
2012/13	Main season	224.3	113	337.3	*4.7*	24.9	29.6	366.9
	Off-season	181.4	23.2	204.6	*0*	0	0	204.6
2013/14	Main season	469.62	144.18	613.8	*15.62*	15.07	30.69	644.493
	Off-season	29.8	0	29.8	*4.2*	9.55	13.75	43.554
2014/15	Main season	418.29	224.33	642.62	*62.33*	166.09	228.42	871.04
	Off-season	20	0	20	*0*	0	0	20
Total	Main season	4376.01	787.41	5163.42	*84.01*	231.1	315.11	5478.53
	Off-season	610.8	23.2	634	*4.2*	9.55	13.75	647.75

[1]Seed produced by KARC, ESE, ASE, OSE, BADE and Tinsae PLC; [2] Koga irrigation (ESE+ASE) included; [3] KARC, HARC, DZARC, SARC, MARC, SIARC, AARC; [4] Werer and Mekelle

Table 4.5 Pre-basic seed multiplication by public seed enterprises

Variety	2010/11			2011/12		2012/13		2013/14	2014/15	Total
	ESE	OSE	ASE	ESE	OSE	ESE	OSE	ESE	OSE	
Kakaba	-	150	150	1,254	15	893	120	476	762	3,820
Danda'a				764	13	728	120	322	338	2,285
Hulluka				4	40	78		66	134	322
Shorima	764			4		74		54	41	936
Hidase					75	29		131	700	935
Hoggana					15	13		44	72	144
Ogolcho					75	20		54	67	216
Digalu	1,254			202	53	332	100	53	35	2,029
Pavon-76				334		172		-	-	506
Hawi	334			305		70		-	-	709
Mekele-1	4									4
Mekele-2	4									4
Madda Walabu	202					-		-	-	202
Simba	305			120		15			-	440
Kubsa	328			2,007		-		-	-	2,335
Galema	120			328		-		-	-	448
Ude	7			7		7		-	-	21
Total	15,354	150	150	5,329	285	2,431	340	1,199	2,149	15,354

Table 4.6. Basic seed multiplication by public seed enterprises

Variety	2010/11	2011/12		2012/13			2013/14			2014/15		Total
	ESE	ESE	OSE	ESE	OSE	SSE	ESE	OSE	SSE	ESE	OSE	
Kakaba		1,458		16,506	245	2,297	23,380		3,245	23,380	3,784	74,295
Danda'a				3,702	968	1,062	2,776	2,430	1,500	2,776	2,012	17,225
Hulluka					20		232			232	1,003	1,487
Shorima					80		583			583	2,027	3,273
Hidase							665			665	4,638	5,968
Hoggana							72			72	131	275
Ogolcho							238	60		238	5,282	5,818
Digalu	1,458	1,676		2,909	1,865	3,101	1,053	1,519	5,112	1,053	237	19,982
Pavon	287	4,713		1,629	450	68			78		1,757	8,981
Hawi	4,713	2,447		15,510	26							22,696
Simba	2,447	1,973				511			722			5,653
Kubsa	2,630	46,410		1,092	304							50,437
Galema	1,973	2,630		1,381	81							6,065
Total	13,509	61,308	-	42,728	4,038	7,039	28,998	4,008	10,656	28,998	20,871	222,154

4.3.2 Large-scale certified seed production

Currently, the public seed enterprises (PSEs) are the major players in the formal wheat seed supply while the role of private seed enterprises is still remain insignificant. The PSEs and seed producers associations were provided with large quantities of EGS of new/old rust-resistant wheat varieties for further multiplication and distribution. The project made strategic partnership with federal and regional PSEs and farmer seed producers associations to produce and market certified seed on a larger scale across the country. The project linked its activities to the Ethiopian Seed Enterprises (ESE), Amhara Seed Enterprise (ASE), Oromia Seed Enterprise (OSE), South Seed Enterprise (SSE), private seed producers, farmers unions and seed associations that are involved in seed production.

The linkage of PSEs with farmer-based seed multiplication schemes promoted by the project provided wider option for procuring and distributing seed through contractual agreement with farmers or associations.

a) Partnering with farmer's seed producers associations

To alleviate the seed shortage the project worked with semi-informal farmers' seed producers associations. The associations, usually established with about 25 members, were encouraged to gradually transform to formal seed producers depending on their capability. The associations were assisted through the provision of basic seed of rust-resistant improved varieties and technical backstopping. These associations include Biftu, Chala, Giche Garababo, Hundaf Hatau, Megertu Denkaka, Memhir Ager, Ude and Utuba Jirena. A total of 61.7 tons of source seed of rust-resistant wheat varieties among them Kakaba were provided during the project where it was further multiplied and distributed through formal and informal channels (Table 4.7). The associations serve as source of seed for farmers at local level and PSEs.

Table 4.7. Amount of wheat seed provided and seed produced by farmer seed producers associations

	2012/13	2013/14	2014/15	Total
Seed supplied (t)	9.7	15.7	36.3	61.7
Area planted (ha)	64.7	104.7	242	411.4
Seed produced (t)	226.5	366.3	847	1439.8
Area covered (ha)	1510	2442.2	5647	9599.2

b) Partnering with public and private seed companies

Rapid replacement of millions of ha of wheat with rust-resistant varieties requires multiple partners for massive seed production. The federal and regional public seed enterprises played a key role in this endeavor where seed of new and existing commercial rust-resistant varieties from federal and regional NARS were multiplied on their own farms or on clustered farmers' fields to produce sufficient quantity and quality seed for large-scale distribution to farmers (Table 4.8).

The project builds on successive wheat projects where ICARDA supported fast track testing and accelerated seed multiplication within the BGRI (ex GRI) initiative first to tackle Ug99 and subsequently the deployment of yellow rust resistant varieties. The availability of new wheat varieties such as *Danda'a* and *Kakaba* with combined resistance to Ug99 and yellow rust helped in rapid multiplication both of EGS and certified seed. During the four years of the project 226,135 tons of rust-resistant varieties were multiplied and, capturing a significant proportion of certified seed supply together with existing commercial varieties.

Table 4.8. Certified seed production of rust-resistant wheat varieties

Variety	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	Total
Newly released bread wheat varieties (≥2010)							
Kakaba	205	3,370	14,654	14,967	28,515	23,692	85,404
Danda'a	553	2,252	12,363	7,344	13,428	14,150	50,090
Shorima	0	-	24	10	22	99	155
Hulluka	0	-	2	254	268	268	792
Ogolcho	0	-	-	14	44	647	705
Hoggana	0	-	-	2		2	4
Hidase	0	-	-	8	28	1,188	1,224
Gambo	0	-	-	-		-	-
Tsehay	0	-	-	-		-	-
Mekelle 1	0	22	17	3	2	1	45

Mekelle 2	0	86	10	-	0	-	96
Jeferson	0	-	292	-	-	-	292
Global	0	-	22	-	-	-	22
Sub-total	758	5,730	27,384	22,602	42,307	40,047	138,829
Existing commercial bread wheat varieties (<2010)							
Hawi	456	1,860	3,422	3	98	13	5,852
Tuse	986	1,214	832	421	68	-	3,521
Mada Walabu	164	20	900	515		28	1,627
Simba	604	2,191	1,084	-	271	158	4,308
Shina		134	61	1,100	15	-	1,310
Sofumar		195	183	-	225	110	713
Digalu	3833	9,173	11,740	4,306	9,426	5,657	44,134
Meraro		-	-	-	-	-	-
Millenium	144	-	-	-	-	-	144
Pavon-76	5011	4,416	7,034	2,124	2,539	3,997	25,120
ET 13	0	58	-	-	-	-	58
Menze	0	-	85	-	20	-	105
Enseno-1	0	-	51	-	-	50	101
Tay	0	-	-	-		27	27
Sub-total	11197	19,260	25,392	8,469	12,662	10,040	87,020
Durum wheat varieties							
Buhe	4.6						
Kilinto	0.6						
Mangudo	0	-	-	-		16.0	16.0
Tate	0	-	50.0	-	-	-	50.0
Ude		-	6.0	7.0	102.0	73.0	188.0
Yerer		-	27.0	-	-	-	27.0
Sub-total	5	-	83.0	7.0	102.0	89.0	286.2
All certified seed (resistant)	11,960	24,990	52,859	31,078	55,071	50,176	226,135
All certified seed (wheat)	27,086	38,736	71,078	59,810	70,738	60,430	327,878

4.4 Achievements of the Project

During the last couple of years, there is a continuous and substantial increase in certified seed demand and supply. In recent years, there is massive scaling out activities by the government programs and different projects where awareness and demand for new varieties and seeds increased dramatically.

When we compare the certified seed of wheat produced by the formal sector, the amount doubled from around 27,000 tons in 201/11 to over 60,000 tons in 2015/16 season. Since 2009, the projects to accelerate seed multiplication of resistant varieties funded by USAID, EAAPP, etc have greatly contributed to the replacement of the widely grown and highly susceptible varieties such as *Kubsa* and *Galema*. The two bread wheat varieties covered about 57% of the wheat seed supply (Figure 4.1). After project intervention the susceptible varieties were replaced by the newly rust-resistant varieties (Figure 4.2). In 2015/16, the wheat seed production was mainly dominated by the newly released and rust-resistant varieties such as *Kakaba* (40%) followed by *Danda'a* (24%) from a total of 60,430 tons. The amount of rust-resistant wheat seed of lately released varieties like *Hidase, Ogolcho, Hulluka* and *Shorima* is increasing and replacing *Digalu*, which is now susceptible to stem rust. This is one of the fastest turnaround in terms of deploying rust-resistant varieties.

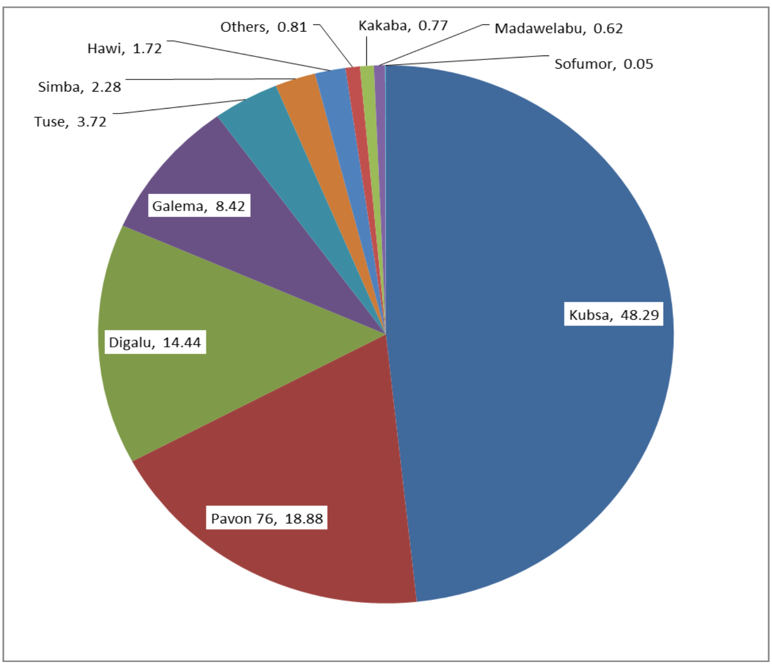

Figure 4.1 Varietal composition of certified seed production in 2010/11 crop season

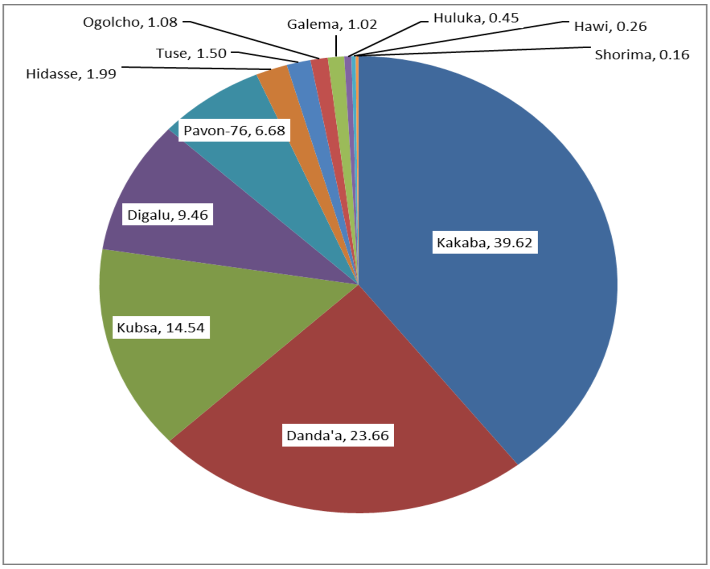

Figure 4.1 Varietal composition of certified seed production in 2015/16 crop season

During the project period the price of certified seed increased from 565 ETB in 2010/11 to 1008 ETB in 2012/13 and to 1,450 ETB in 2016/17 crop seasons, an increase of three fold. However, despite continuous price rise there is an increasing demand for certified seed showing farmers appreciation for quality seed.

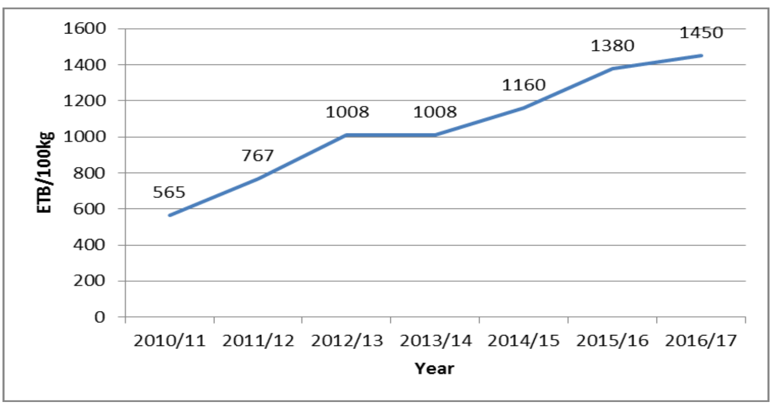

Figure 4.3. Wheat certified seed price (ETB) during 2010-16

4.5 Conclusion and Lessons Learned

The project was very successful in supporting and strengthening the accelerated seed multiplication for replacement of susceptible wheat varieties in the shortest possible period of time (about three to four years). However, most of the released yellow rust resistant varieties are now become susceptible to new strain of stem rust (Digalu race). Therefore continuous effort would be required in developing and releasing durable rust-resistant varieties by the NARS. In addition, most of the newly released varieties are not quickly multiplied by formal seed producers as expected. There is a need to create awareness about wheat rust with the public and private sector and farmers' groups and popularization of resistant varieties. In order to enhance the capacity of NARS, there is a need for continued collaboration with ICARDA and CIMMYT and other international wheat research centers; and donor assistance to deepen the achievements and mitigate emerging stem rust threat through capacity development.

The following are some of the lessons learned during project implementation period:

- The project demonstrated effective interventions with long-term impact to ensure sustainability. The project investment was enabled sustainable source (basic) seed supply by NARS.
- There is need to design long-term strategy on mitigating wheat rusts as evident from the recent outbreak of new strain of stem rust through diversification of cropping systems by incorporating legumes mainly chickpea and rape seed to break wheat mono-cropping in the highlands and promoting durum wheat (less rust pressure) along with bread wheat production;
- The need for linkages with seed sector actors and the need to promote decentralized seed production to reach different agro-ecologies and farmers;
- Considerations for expanding irrigated wheat for both bread and durum to boost production; and
- Strong and effective partnership among NARS and seed sector stakeholders and IARCs (ICARDA) and strong donor support (USAID)

Chapter V

Promoting Rust-resistant Wheat Varieties and Technologies

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5.1 Introduction

In Ethiopia the agricultural extension service went through several radical policy shifts during the last 50 years (Kassa, 2009). However, its core objective remained to be the improvement of agricultural production and productivity based largely on application of science, technology, and information provided through the national agricultural research and development system and various extension advisory services. Within this context, the success of agricultural development projects and programs has been shown to depend largely on direct stakeholder involvement in planning, implementation and evaluation. Within this context, the USAID supported ICARDA-EIAR project on 'Deployment of Rust-resistant Wheat Varieties implemented an innovative technology promotion and dissemination approach that comprises multiple processes and involve several stakeholders.

As one of the components of the project planned technology promotion through demonstration, popularization and on-farm seed production was implemented. This chapter documents the approaches, activities, achievements and lessons learned in promoting new rust-resistant varieties and associated technologies.

5.2 Approaches in Technology Promotion

Demonstration and popularization of new rust-resistant varieties was undertaken at farmer training centers (FTCs) and at the fields of selected model farmers in the target districts selected for the project implementation.

In parallel with demonstration and popularization activities on-farm seed production was implemented in collaboration with Office of Agriculture at district level in the target areas. On-farm seed production considered small seed pack distribution and organizing, clustering and training farmer groups to ensure the availability and access to seed of rust-resistant varieties for rapid adoption and dissemination. Farmers and development agents were trained on varietal options and quality seed production. Access to source seed through small seed pack was implemented through revolving seed scheme. Field days were organized by involving all relevant stakeholders to create awareness of wheat rust problems, improved varieties and demand for seed.

The key features of the approach followed include:

Use of technology as a package: Instead of promoting variety alone, as a piecemeal approach, the variety is used as a driving force and promoted along with integrated crop management packages including agronomy, use of inputs, etc

Integration of demonstration, popularization and seed multiplication: The integration of the three activities enhanced awareness creation and availability of technologies shortening the time lag of adoption compared to the conventional sequential technology generation followed by demonstration, popularization and seed production. The demonstrations were conducted on plots of at least a quarter of a hectare compared to conventional demonstration of 100 m^2. The popularization activities were linked to on-farm seed production and small seed pack distribution. This considered the involvement of both formal and informal seed actors.

Farmer seed production may also help non participant farmers to get access to seed at their farm gate with less transaction costs. It also facilitates seed exchange among farmers, share experiences and helps to incubate seed business.

Clustering of farmers' fields: To ensure group action and ensure community mobilization, clustering of farmers' fields was promoted on voluntary basis that consider interest in seed production and business and proximity to potential seed users. In each *kebele* (lowest administrative unit) about 100 farmers each with a minimum of quarter of hectare were organized as a group. Farmers clustered their fields to maintain the varietal purity and quality of seed produced.

Coordinated multi-stakeholders partnership: An all-inclusive and participatory collaborative partnership was established among all stakeholders involved in agriculture and rural development in the target areas. The stakeholders include multi-disciplinary team of the following members:

- Federal and regional agricultural research centers;
- Zonal and district bureau of agricultural development;
- Development agents in target *kebele* administration;
- District administration office;
- Farmers' primary cooperatives and cooperative unions;
- Farmers' representatives;
- Public and private seed producers;
- Agro-processors; and
- Non-governmental organizations.

All stakeholders are involved right from the planning stage through to the implementation of planned extension activities. The new partnership has a broad range of stakeholders with shared and clearly defined roles and responsibilities which proved highly effective in rapid dissemination and adoption of the improved technologies. The coordination of partnerships and regular follow-ups and supervision of the planned activities are vested upon the BoA and the project coordinators from respective research centers.

Revolving seed loan: Participating farmers were given source seeds for planting as seed loans to be paid back in equivalent amounts in kind after harvest. The approach is important particularly in addressing the wider distribution in subsequent years where the revolving seed was distributed to other communities in target areas.

Regular training of SMS, DAs and farmers: In addition to coordination and technical backstopping, the project provided training of trainers to SMS and DAs which in turn trains participant farmers and development agents of the target districts and other relevant stakeholders. The training includes awareness about wheat rusts, wheat varieties and associated technologies and seed production and marketing.

Provision of inputs and marketing options: In addition to seed of new rust-resistant wheat varieties provided by the project, the farmers' cooperatives and their unions played a vital role in the provision of required inputs (mainly fertilizers and pesticides) and market information, purchase of seed/grain from the participating farmers.

Field days and exchange visits: Field days have been organized by inviting all stakeholders including policy makers, researchers, extensionists, development practitioners and farmers to create awareness of available technologies and their performance and to discuss and address emerging policy and development issues. The event provides opportunities to share ideas and information and facilitates the awareness of relevant technologies among farmers, researchers and extensionists. It also empower farmers and thereby increasing their influence over other stakeholders. In addition exchange visits were organized for farmers for experience sharing and learning visiting each other's farms where good practices are demonstrated. This has enhanced peer influence among farmers.

Monitoring and evaluation: The M&E involves regular follow-up and supervision through field visits, workshops and reports. Field visits were made to provide technical backstopping at field level along with addressing emerging issues. Regular reporting was made through quarterly and annual progress reports using pre-designed format that show the performance against the plan. In addition, workshops were organized targeting different stakeholders to address emerging research, development and extension issues for enhanced promotion of wheat rust related technologies and information.

Regular follow-up and supervision of the on-farm performances and activities was performed by a team of researchers from the project in cooperation with the district BoA experts, focal persons and development agents. This has been crucial to the success for technology promotion.

5.3 Achievements of Technology Promotion

5.3.1 Demonstration and Popularization

Variety demonstration and popularization was a critical component of the project to create awareness of improved technologies and create demand. Rust-resistant wheat varieties were used as a driving force where all other integrated agronomic management practices were included as a package to demonstrate the superiority of improved technologies. Linked with demonstration activities seed of preferred and rust-resistant wheat varieties were further distributed as part of popularization (scaling up).

Demonstrations: Farmers Training Centers (FTCs) and farmers' fields were used to demonstrate high yielding rust-resistant wheat varieties. Demonstrations were conducted across 45 target districts. Each variety was demonstrated on plot sizes of 400 m^2 (20 m x 20 m) where four farmers per *woreda* were provided with seed of rust-resistant varieties. During the four years newly released rust-resistant bread wheat (*Kakaba, Danda'a, Gambo, Shorima, Hulluka, Hidase, Hoggana, Ogolcho, Biqa, Honqolo, Mandoyou and Sanate*) and durum (*Mangudo* and *Mukiye*) wheat varieties were demonstrated at FTCs in 51 districts and farmers' fields including irrigated areas in the lowlands.

Popularization: Linked with demonstration activities, the project has supported the popularization (pre-scaling out) of rust wheat technologies in four major regions. About 261 tons of seed was directly supplied to 12,500 farmers (8.2% women) and produced 7758 tons seed/grain sufficient to plant an estimated 67,238 ha (Table 5.1). About 65,610 household members benefitted.

Table 5.1 Demonstration and popularization of rust-resistant wheat varieties

Year	Seed distributed (t)	Area planted (ha)	Seed produced (t)	Area planted with seed available (ha)	No of farmers	No of HH members benefitted
2012/13	43.0	312.2	936.6	6,244	1,179	7,074
2013/14	72.4	482.6	1,689.3	11,262	1,931	11,586
2014/15	145.8	1,387.0	5,131.9	49,732	9,390	46,950
Total	261.2	2,181.8	7,757.8	67,238	12,500	65,610

Emergency seed supply: In 2010, with the outbreak of yellow rust epidemics, four non AGP districts (Ambo, Dendi, GedebAsasa and Hitosa) were considered for emergency seed relief because of severe rust epidemic occurrence and crop loss. About 5 tons seed of rust-resistant wheat varieties was distributed to the emergency districts. During the two project years, a total of 3452 farmers (306 female) farmers benefitted i.e. 1639 male and 37 female farmers in Ambo district and 1507 male and 269 female farmers in Gedeb Asasa directly participated in rust-resistant wheat seed production. A total of 8,404 and 17,469 household members have been benefited from the project in Ambo and Gedeb Asasa districts, respectively.

In 2014, an outbreak of new strain of stem rust caused serious damage in wheat growing areas of southeastern Ethiopia. A bread wheat variety *Digalu* was severely damaged by the stem rust attack with substantial yield loss. The project availed seed of rust-resistant varieties for farmers who lost most of their produce. A total of 19.5 tons of seed was distributed and 328 farmers (1968 HH members) benefitted from the intervention. The seed is sufficient to plant 135 ha and produce 405 tons of seed.

Field days: During the project life several field days were organized in target districts using FTCs and on-farm seed production fields. Annually, the project supported one mega field day in each region (four in total) attended by key stakeholders from farmers including those from neighboring districts to technical staff and policy makers from district, zonal, regional, and federal offices. In these events over 35,000 (2500 female) farmers, experts, and development agents from BoA, community seed producers, public and private seed enterprises, zonal and *woreda* administrators and other stakeholders were participated.

Apart from the field days organized by the project, every year each target district organized field days under the umbrella of BoA. The field days are aimed at promoting rust-resistant varieties and in creating awareness of good practice in agricultural production. This has created tremendous interest and surge in demand for quality seed. In most of the events there was good interaction among participant and non-participant farmers, development agents, researchers and policy makers. The project presented varietal choices but a home take message for the research system is to come up with diverse set of varieties not only with durable resistance but also comparable high yield to replace popular varieties like *Kubsa*.

5.4.2 On-farm seed production

The Ethiopian national seed policy recognizes farmers' role in local seed production and distribution with view of complimenting the formal sector. The project used small seed-pack distribution-cum-on-farm seed production as one of the strategy for quick dissemination of rust-resistant varieties to reach substantial number of farmers. In each target district an agreement was reached with BoA where select group of interested farmers are identified, organized into groups, provided with training and with seed to engage in local seed production of rust-resistant wheat varieties. The seed is provided on revolving seed scheme where farmers return the equivalent in kind at the harvest time.

In each district a group of farmers clustered their fields and provided each with 25 kg seed to plant a quarter of ha. Clustering was meant to minimize contamination to ensure quality seed production and ease of management of seed production fields. Apart from the practical training imparted to farmers, the development agents provide the regular technical support required during planting, crop growth and harvesting to ensure quality seed production. The seed produced either purchased by public seed enterprises if it went through formal certification by the regional quality control offices or through informal farmer to farmer sales and exchanges.

On-farm seed production was supported with regular train-the trainers (ToTs) where development agents who received the training in turn train farmers involved in project activities in their respective localities. The courses include about available wheat technologies, integrated wheat crop management practices, rust pathology and quality seed production. Besides, brochures were distributed and field days were organized to acquaint more farmers on the available wheat technologies to create awareness and demand for quality seed. Every year joint planning took place with the staff and experts from relevant stakeholders especially the regional, zonal and district BoA.

Source seed for on-farm seed multiplication scheme was supplied by the project on a revolving-seed basis where EIAR was responsible for seed purchase and distribution to the project districts and the district BoA were responsible for distributing the seed to the selected farmers; follow up the activities, collecting the revolved seed and recording all relevant data of the activities. Every year data on the seed distributed, area coverage, total production, revolved seed recovered, seed reused or recycled (including farmer to farmer exchange), number of *kebeles*, households (by gender) and total heads were recorded and summarized (Tables 5.2 to 5.5).

Farmers from 47 districts of the four regional states were participated during 2011/12-14/15 cropping seasons of which farmers from 19 districts participated throughout the project period (4 years) while the rest joined during the subsequent years. About 15 bread and 7 durum wheat varieties were distributed during the project period (Table 5.2) though the uptake varied by varieties. On-farm seed multiplication was started with a good number of improved wheat varieties (10 bread and 6 durum) and has continually declined in the subsequent years ending up with 7 varieties (5 bread and 2 durum) in the final year (2014/15). Since deploying few varieties has a risk of increased vulnerability to rust disease outbreak, diversifying and maintaining a good number of varieties in wheat production have to be accentuated. Two new and one existing bread wheat variety (*Danda'a*-21.6% and *Kakaba*-33.8% and *Digalu*-30.8%,) dominated the distribution constituting about 86.1% of the total seed made available for on-farm seed production. The proportion of the dominant varieties within the four project years was variable where the most dominant variety, *Digalu*, in the first year was declined while *Danda'a* and *Kakaba* were increased.

The dominance of the three bread wheat varieties (*Digalu, Danda'a* and *Kakaba*) might have resulted from limited varietal options of new released varieties, the inherent nature of the alternative varieties like low yield potential, susceptibility to rust diseases, and narrow adaptability. To stabilize the wheat production of the country and avoid crop failures in case of rust disease outbreak, deployment of more varieties is vital. There is some uncertainty in future too as the two dominant bread wheat varieties (*Digalu* and *Kakaba*) promoted by the project were already under severe stem rust threat particularly in Arsi, West Arsi and Bale zones during 2014/15 cropping season.

The relevance of the informal sector in providing seed of specifically adapted varieties so long as they are well promoted and their niches are well identified is immense. Moreover, the lag in generating widely adapted new varieties to cope with the recurring new rust strains in short intervals is obvious. Therefore, generation/adaptation of new and efficient use of the less utilized available varieties requires a concerted effort of the research and other stakeholders' to stabilize and boost the country's wheat production, thereby to realize the intended food self-sufficiency.

The diffusion of durum wheat varieties was unsatisfactory mainly due to problems associated with marketing rather than rust disease incidences. However, some efforts were initiated at the final year of the project where all relevant stakeholders in durum wheat value chain involved to improve its production and marketing as reported elsewhere in the document.

Table 5.2. Amount of seed distributed (t) for on-farm seed multiplication

Variety	Amount of see distributed (t)					
	2011/12	2012/13	2013/14	2014/15	Total	Proportion (%)
Bread wheat						
Galema	2.00	2.00	.	.	4.00	0.45
Tusie	0.80	3.00	.	.	3.80	0.43
Madaa Walabu	4.10	2.00	.	.	6.10	0.68
Sofumar	4.20	.	.	.	4.20	0.47
Dure	0.30	.	.	.	0.30	0.03
Digalu	56.88	67.70	66.45	84.05	275.08	30.78
Danda'a	5.98	42.70	65.80	78.20	192.68	21.56

Kakaba	54.27	59.60	65.60	122.43	301.90	33.78
Mekele-1	0.50	.	.	.	0.50	0.06
Mekele-2	0.50	.	.	.	0.50	0.06
Pavon 76	.	7.50	1.20	.	8.70	0.97
Shorima	.	0.05	2.00	.	2.05	0.23
Hulluka	.	0.58	1.60	.	2.18	0.24
Hidase	.	.	1.00	5.50	6.50	0.73
Ogolcho	.	.	.	0.04	0.04	0.004
Sub-total	129.52	185.13	203.65	290.21	808.52	90.46
Durum wheat						
Ude	6.75	34.00	4.50	0.30	45.55	5.10
Yerer	3.68	6.10	1.60	.	11.38	1.27
Ellani	1.20	3.50	.	.	4.70	0.53
Obsa	8.80	.	3.00	.	11.80	1.32
Tate	1.00	1.90	2.50	.	5.40	0.60
Toltu	1.40	3.00	.	.	4.40	0.49
Mangudo	.	.	.	2.00	2.00	0.22
Sub-total	22.83	48.50	11.60	2.30	85.23	9.54
Total	152.35	233.63	215.25	292.51	893.74	100

The amount of seed distributed each year for an informal on-farm seed multiplication ranged from 152.35 tons to 292.51 tons of which 68.4% to 99.2% were recovered as a revolving-seed, the average being 83.5% (Table 5.3). Of the total seed produced with the source seeds provided by the project, about 50.3% to 67.7% (on average 59.2%) was reused as seed through farmer-to-farmer seed exchange either by cash or other means for planting the next season crop each year (Table 5.3). About 3097 to 6588 households were directly participated in on-farm seed multiplication with source seed provided by the project of which female households ranged from 10.2% to 13.5% (on average 11.6%). The total number of individuals directly benefited ranged from 15,962 to 33,777.

The effect of the informal on-farm seed production scheme had a multiplicative effect where the area coverage with the improved varieties and the number of participant farmers has substantially increased considering the first round of revolving seed fund and farmer to farmer seed exchange in the subsequent years (Table 5.4). Though not tracked by the project, there were also some second round of revolved and reused seeds (Table 5.4) and the second cycle reused seed from the total produce through farmer-to-farmer seed exchange which ranged from 10.1 to 18.7% (an average 12.7%) each year.

From the first project year onwards, three categories of seeds (newly distributed source seed, revolved seed and farmer to farmer exchanged seed) originating from the project were tracked each year. The seed supply which has been started with 152.4 tons in the first year has reached 3695.9 tons; including revolved and farmer to farmer exchanged seed and covered about 30,291.3 ha by involving 86,533 households (HHs) in 2014/2015 cropping season (Table 5.5). Moreover, for planting the 2015/16 cropping season 7,642.8 tons of wheat seeds (1^{st} cycle revolved and farmer to farmer exchanged seeds) were retained and planted on about 51,564 ha and that gave 185,130 tons of produce accounting for 3.2% of the nation's annual wheat area and 4.6% of the total wheat production by involving 98,411 farmers and benefiting 502,672 HH members.

Table 5.3. Amount of seed distributed and area planted to rust-resistant wheat varieties in target districts of four regions

Year	Region	Number of districts	Number of PAs	Number of varieties	Amount of seed distributed (t)	Area planted (ha)	Total seed produced (t)	Used as seed (t)	Recovered as revolving seed (t)	Participating farmers (HHs)		No of direct beneficiaries	Productivity (t/ha)		
										Male	Female		Lower	Higher	Mean
2011/12	Amhara	5	22	3	38.36	255.74	937.25	913.7	15.8	713	46	3795	1.8	5	3.66
	Oromia	16	131	13	69.96	489.54	1573.14	904.06	61.61	1266	96	7345	0.9	5.4	3.21
	SNNP	4	19	4	25.03	166.86	793.14	297.05	8	486	173	3336	2.5	6	4.75
	Tigray	3	16	4	19.01	125.95	480.9	195.9	18.72	295	22	1486	2	5.2	3.82
	Total	28	188	16	152.35	1038.09	3784.43	2310.71	104.13	2760	337	15962	0.9	6	3.65
2012/13	Amhara	8	49	6	51.5	346.69	1321	499.37	37.26	1679	179	8968	0.95	6	3.81
	Oromia	22	268	13	123.83	852.26	2851.56	1814.73	107.46	2192	250	13708	0.7	8.7	3.35
	SNNP	6	46	6	32.1	214.5	870.7	458.7	27	652	84	4508	0.5	5.8	4.06
	Tigray	6	25	3	26.2	184.65	642.05	141.5	18.5	505	95	2547	2	5.2	3.48
	Total	42	388	14	233.63	1598.1	5685.3	2914.3	190.27	5028	608	29731	0.5	8.7	3.56
2013/14	Amhara	10	86	6	81.45	681.53	2523.69	1059.55	66	1692	170	8863	0.4	6	3.7
	Oromia	19	292	7	94.8	670.92	2625.59	1429.74	66.85	1455	165	8254	1	7.5	3.91
	SNNP	3	22	5	19.5	144.94	581.7	500.8	14.6	324	75	1936	2	5.5	4.01
	Tigray	6	24	3	19.5	135.1	550.6	251.4	14.4	383	46	2228	2	6	4.08
	Total	38	424	11	215.25	1632.49	6281.58	3241.49	161.85	3854	456	21281	0.4	7.5	3.85
2014/15	Amhara	10	69	4	67.01	650.92	2483.7	1762.6	66.95	1358	162	6892	2	6.6	3.82
	Oromia	19	229	5	112	1103	3697.2	2395.2	112	2763	208	15824	2	6.2	3.35
	SNNP	7	61	3	82.5	803	3662.5	2454.3	82.5	1089	347	8103	2	6.8	4.56
	Tigray	8	54	4	31	269.63	1020.5	735.15	28.74	486	175	2958	2	7	3.78
	Total	44	413	7	292.51	2826.55	10863.9	7347.25	290.19	5696	892	33777	2	7	3.84
	G. total	47*	1413	22**	893.74	7095.23	26615.21	15813.74	746.39	17338	2293	100751	0.40	8.70	3.75

**Some districts were added/dropped each year; **Similar varieties are usually grown in different regions*

Table 5.4. Amount of revolved seed and reused seed and area planted in districts of four regions through 2012/13-15/16 cropping seasons

Year	Region	No of varieties	Revolved seed (t)	Reused or exchanged seed (t)	Area planted (ha)	Total seed production (t)	Amount reused for 2nd cycle as seed (t)	Recovered as revolving seed for 2nd cycle (t)	Participating farmers (HHs)		No of beneficiaries	Productivity t/ha		
									Male	Female		Lower	Higher	Mean
2012/13	Amhara	3	15.80	913.70	6197.00	23305.10	1817.85	10.5	5129	442	27855	2.80	5.00	3.76
	Oromia	13	61.62	904.06	6426.32	22819.93	6677.90	37.70	22852	1397	130060	1.50	7.00	3.55
	SNNP	4	8.00	297.05	2032.50	9288.35	979.58	-	6950	636	45380	2.40	7.80	4.57
	Tigray	4	18.72	195.90	1445.00	4497.90	352.70	-	2167	242	12045	1.70	4.10	3.11
	Total	16	104.13	2310.71	16100.82	59911.28	9828.03	48.20	37098	2717	215340	1.50	7.80	3.72
2013/14	Amhara	6	37.26	414.07	3786.56	15951.78	4402.50	13.80	13031	745	68160	1.70	5.50	4.21
	Oromia	13	107.46	1815.48	13302.12	44911.90	7026.90	42.28	31601	2182	152914	0.80	6.50	3.38
	SNNP	5	27.00	458.70	3236.60	14405.40	2798.70	12.00	12183	1404	82321	2.00	7.80	4.45
	Tigray	3	18.50	170.40	1301.65	5178.90	803.40	11.4	1074	256	6310	2.00	5.44	3.98
	Total	14	190.22	2858.65	21626.93	80447.98	15031.50	79.48	57889	4587	309705	0.80	7.80	3.72
2014/15	Amhara	4	66.00	1059.55	9271.30	38729.40	4022.70	-	31299	958	153231	2.20	5.70	4.18
	Oromia	7	66.85	1429.74	11837.10	49278.80	4919.00	-	26500	1824	139681	1.70	6.50	4.16
	SNNP	5	14.60	500.80	4584.70	18397.30	1839.60	-	10673	1594	60829	3.00	5.50	4.01
	Tigray	3	14.40	251.40	1771.60	7906.50	793.50	-	6782	315	32629	2.50	6.00	4.46
	Total	8	161.85	3241.49	27464.70	114312.00	11574.80	-	75254	4691	386370	1.70	6.50	4.16
2015/16	Amhara	4	66.95	1762.60	12154.00	44486.10	6278.00	-	19415	1911	98958	2.20	5.20	3.66
	Oromia	5	112.00	2395.20	16673.00	54038.80	4440.00	-	25238	4179	151842	1.70	5.00	3.24
	SNNP	3	82.50	2454.30	16888.00	65635.50	6555.00	-	28208	3466	183371	2.00	5.30	3.89
	Tigray	4	28.74	740.55	5849.00	20969.50	1978.40	-	14272	1722	68501	2.20	5.20	3.59
	Total	7	290.19	7352.65	51564.00	185129.90	19251.40	-	87133	11278	502672	1.70	5.30	3.59
	Grand total	22	746.39	15763.49	116756.45	439801.16	55685.73	127.68	257374	23273	1414087	0.80	7.80	3.77

Table 5.5. Amount of seed distributed, recovered, farmer-to-farmer exchanged and area covered in target districts of four regions,

		Cropping season				
		2011/12	2012/13	2013/14	2014/15	2015/16
	Issued/distributed	152.35	233.63	215.25	292.51	
Seed (t)	Recovered *		104.13	190.22	161.85	290.19
	Farmer to farmer exchanged**		2310.71	2858.65	3241.49	7352.65
	Total	152.35	2648.47	3264.12	3695.85	7642.84
	Issued/distributed	1038.09	1598.1	1632.49	2826.55	
Area (ha)	Recovered		694.28	1349.31	1306.12	1957.83
	Farmer to farmer exchanged		15406.54	20277.62	26158.58	49606.17
	Total	1038.09	17698.92	23259.42	30291.25	51564
	Issued/distributed	3784.43	5685.3	6281.58	10863.9	
Production (t)	Recovered		2583.42	5019.17	5436.26	7029.18
	Farmer to farmer exchanged		57327.86	75428.81	108875.74	178100.72
	Total	3784.43	65596.58	86729.56	125175.9	185129.9
Participants	Issued/distributed	3097	5636	4470	6588	
(HHs)	Recovered		1717	3898	3802	3737
	Farmer to farmer exchanged		38098	58578	76143	94674
	Total	3097	45451	66946	86533	98411

*Note: *About 68.35%, 81.42%, 75.19% and 99.21% of the seed issued were recovered from the each year the average being 83.51%; **From the total seed produced by farmers from the issued seed every year, 61.1%, 50.3%, 51.6% and 67.7% were reused as seed the average being 59.2%*

5.4.3 Capacity development

Strengthening the human resources capacity and infrastructure of key stakeholders facilitated project implementation particularly for formal and on-farm seed production.

a) Strengthening capacity of human resources through trainings and workshops

The project designed the training of trainers' courses where technical staff receive basic knowledge and in turn organize hands-on practical training for farmers and development agents. To this effect, both in-country and international courses of different levels were given for stakeholders. Regular training of trainers of research technicians and agricultural experts at various levels including development agents played an important role in the success of the innovation process. The training was given every year in order to create awareness and understanding and to share experiences.

Accordingly, 1490 subject matter specialists and development agents, 87 research technicians, 75 researchers, 157 farm managers from agricultural research centers; and 106 experts from farmers' cooperative unions and other stakeholders from target districts, zones and regions were given training on wheat production technology from 2011 to 2015 (Table 5.6). The trainers in turn trained farmers and development agents in the target districts.

About three staff (one female) from NARS participated in a regional seed course organized by ICARDA on variety identification, maintenance, quality seed production and certification held in Cairo, Egypt. Moreover, six staff from inputs departments of regional bureaus of agriculture attended a regional course on seed enterprise development and management and seed marketing held in Cairo, Egypt.

Apart from training courses, two national workshops were organized to create awareness of wheat rusts and 137 participants attended including project staff, partners and stakeholders. Project staff also attended an international yellow rust conference to share the experiences and successes of the project with international community (international wheat rust conference in 2014).

Table 5.6. Training of trainers' courses organized and staff trained during 2011/12- 2014/15 cropping season

Trainees	Number of personnel trained				Total
	2011/12	2012/13	2013/14	2014/15	
Subject matter specialists and development agents	270 (35 F)	410 (45 F)	370 (75 F)	440 (67 F)	1490 (222 F)
Farm managers	50	45	35	40	157
Research Technicians		24	36	27	87
Researchers	25	15	10	25	75
Seed producers and cooperatives		30	36	40	106
Total	320 (35 F)	509 (45 F)	477 (75 F)	547 (67 F)	1911 (222 F)

Note: Figures in parenthesis are female participants

b) Strengthening capacity of stakeholders through provision of facilities

NARS and farmer seed producers are the major beneficiaries in provision of machineries and facilities. To strengthen the early generation seed production EIAR was provided with farm machinery, vehicles, laboratory equipment and storage facilities. The project provided one each station wagon and mini bus, five pick-ups, two automobiles, two heavy duty 180 HP tractors with necessary implements (levelers (2), ridgers (2), planters (2) and spare parts) to EIAR to facilitate project implementation and strengthen its early generation seed multiplication. Moreover, irrigation facilities, equipment for seed laboratory, seed storage and sewing machines and polypropylene bags were provided to EIAR.

In addition, one mobile seed cleaner each was provided to famer seed producer associations in Amhara, Oromia and Tigray regions. This includes Dil Betigil, Haqo Sado and Birhan Ayiba farmer seed producers associations from Amhara, Oromia and Tigray region, respectively. Members of the cooperatives and technical staff from regional bureaus of agricultural received the training during the assembling and commissioning of the mobile seed cleaners.

5.4 Lessons Learnt

Empowering female farmers: In Ethiopia, more than fifty percent of the farm related works are accomplished by the womenfolk. Unfortunately, their role in agricultural and horticultural crops and livestock production, post- harvest handling, etc., has not been recognized in the right perspective and as a result much effort has not been made in improving their positions in these areas. Moreover, experiences indicate that extension programs are increasingly proving to be gender biased unduly in favor of male section of the society. In cognizant of the above facts the project in collaboration with district BoA mobilized women farmers to form seed producers group at Endegagn district (Gurage Zone), believing that group approach is the cornerstone for the empowerment of women farmers. The 22 women members cultivate a four hectares land allotted to them by the *woreda* BoA and engaged in seed production by the project. The project provided source seed for 4 hectares. In 2012/13 they produced about 20 tons of seed and sold all to the Southern Seed Enterprise with a 15% premium price. During the off-season they mostly grow vegetables like onion and cabbages by harnessing the river adjacent to their farm land.

Women groups become self-reliant after starting the entrepreneurial activities. They learned to read and write and start savings. The group, by mobilizing their own physical and intellectual resources, has increased their family income, ensured their food security and able to pay for their children's education. The members of the group become stronger by day as the group dynamics got strengthened and the group bond get cemented and learned the benefits of group action and realized the importance of group strength. This is the first step towards independence.

Empowerment of farmers: telling adults what to do provokes reaction, but showing them triggers imagination, involving them improves understanding, and empowering those leads to commitment and action.

Community organization: Extension workers need to learn the principles of community organizing, skills in conflict resolution, negotiation and persuasive communication.

Capacity building: combine technical capacity with management capacity

Problem solving and education: help farmers identify problems and seek solutions by combining indigenous knowledge with improved knowledge and using their resources properly (learning by doing).

Knowledge of DAs: Most DAs have the basic technical expertise, but are deficient in specific skills which farmers demand. Hence DAs require training in key areas such as intensification and diversification of farming, agricultural marketing and communication skills.

5.5 Conclusion and Way Forward

The GoE seeks to double agricultural production during the Growth Transformation Plan (GTP) period by scaling up best bet technologies. The USAID supported ICARDA-EIAR project implemented an innovative technology promotion approach for deployment of rust-resistant varieties that comprises multiple processes where several key stakeholders with relevant expertise contributed towards its successful implementation. The forum includes a wide range of stakeholders including researchers, seed suppliers and policy makers from federal and regional offices as well as administrators and development agents and farmers from target districts.

The overall management and orientation of the promotion of best practices is driven by the farmers' expressed needs and priorities. A farmer- driven orientation ensures that the extension system is serving farmers in their areas of highest need and allows for flexibility at regional, national and district and even at kebele levels. An important factor to be considered in extension priorities is the role of women in increasing farm household income. In most cultures, including Ethiopia, rural women are primarily responsible for almost all agricultural activities carried out.

Historically the main thrust of extension has been to increase agricultural production. A shift in emphasis is needed to link farmers to markets in response to the current priorities and emerging realities. This new thrust requires additional knowledge or expertise in processing, market information and marketing. Extension needs to shift some of its focus from food security to increasing farm income and rural employment.

Indeed, knowledge and information systems had to come to be recognized as a fourth pillar alongside those of land, labor and capital.

The number of Development Agents (DAs) has expanded rapidly in recent years. However, at least as important as the number of DAs, their capabilities and their mind-sets are critical which determine their behavior at work. As observed over the four years of the project life, the vast majority of the extension workers (DAs) have the basic technical expertise and theoretical knowledge. But farmers were demanding specific skills. They need training and technical backstopping as they rapidly move into the production of high value crops and livestock enterprises as well as climate change. Some farmers noted that DAs lack the necessary practical experience and business skills and expertise to help farmers. There are serious constraints in the capabilities and mind-sets of DAs. Technical skills are rather limited, and business skills and entrepreneurial mind-sets are lacking. Furthermore, a technology–push mind-set dominates while knowledge of participatory methods and approaches are lacking as well. The supply driven approach could be appropriate to start with in a subsistence farming system, but to have a sustainable rural transformation demand side constraints should be addressed. Moreover, DAs are attempting to carry out the extension program from their own particular perspectives while farmers are seeking to diversify their farming system within specific agro-ecological areas. Due to their age, lack of on-farm experience, and their narrow subject matter focus, most DAs lack the practical, hands on skills and knowledge needed to gain the confidence of farmers. To improve the above mentioned constraints DAs need training in key areas such as intensifying or diversifying farming systems, agricultural marketing and other communication and soft skills and how to organize producer groups.

In a nut shell a collaborative arrangement that brings together several organizations working towards technical and social change or organizations that are involved in the generating, diffusing and adapting new knowledge in agriculture is a way out to improve and build the capacity of the conventional extension system. In Extension "no one size fits all. It is tailor made."

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Chapter VI

Linking Smallholder Farmers to the Durum Value Chain: A Retrospective Analysis of Experience in Ethiopia

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6.1 Introduction

Promoting enhanced linkage between smallholder durum wheat producers and domestic agro-industries was part of the different interventions in mitigating the challenges of wheat rust. The need for improving these linkages emanate from the fact that better adoption of rust-resistant wheat varieties is highly associated with better access to markets. Ensuring access to markets was made though contractual arrangements that set the quantity, quality, time of delivery and premium price system as well as provision of required production technologies, training of farmers and development agents. It also considered the engagement of service producers including aggregation by cooperative unions, extension service, and regulatory organs for contract enforcement.

The agro-processing industry is the largest subsector of the food and beverage industry in Ethiopia, which is becoming the main market for durum wheat. Based on information from Ethiopian Chamber of Commerce, there are about 455 medium and large scale agro-processing manufacturing industries in Ethiopia while the number of medium and large scale beverage industries is limited to 36. The pasta manufacturing industries are among the major agro-processing industries producing different pasta products mainly for local markets. Currently, there has been an increasing trend in the number of pasta manufacturing industries in Ethiopia, for instance in 2011, estimated at a total of 20 factories. The pasta manufacturing industry contributes 3% of the total employment and production each in the food and beverage industry. In 2010/11, it was estimated that a total of 50 thousand metric tons of pasta were produced in Ethiopia. Recognizing, these fundamental assets, enhancing the market linkage of smallholder durum wheat producers focused in contractual arrangement of marketing to agro-industries.

This chapter presents the overview of experiences from contract arrangements facilitated by research and development partners as mechanisms of enhancing the adoption of rust-resistant wheat varieties through enhancing market linkages with local agro-industries.

6.2 Research-Facilitated Market Linkage

The first initiative implemented by research represented by Debre Zeit Agricultural Research Center (DZARC) targeted the promotion of rust-resistant wheat varieties and other improved wheat varieties through market linkage of producers with agro-industries. This was implemented through contractual arrangement between Kaliti Food Share Company and Kesem primary cooperative and Lume-Adama and Yerer cooperative unions. The offices of agriculture and Woreda administrations of Ada, Akaki, Liben, Lume, Mareko, Minjar-Shenkora, Sodo and Ziquala were also involved in the process.

The main argument for wheat import by local pasta manufacturing industries is the perception associated with the lack of quality durum wheat in the local markets. Therefore, the first step of the initiative was to identify improved durum wheat varieties with preferred quality traits that meet industrial quality standards. In this case, Kaliti Food Share Company tested selected durum wheat varieties for industrial quality standards using its quality laboratory[1]. Consequently, nine durum wheat varieties were found to have the quality standards set by the pasta manufacturing industry and selected for further promotion and production purposes (Table 6.1).

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[1] Agro-industrial quality standards include grain color, vitreousity (hard/soft), hectoliter weight (kg/hl), wet gluten % and protein %.

Table 6.1. DZARC-released durum wheat varieties and industrial quality standards

Varieties	Physical and chemical 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, DZARC

After identifying the durum wheat varieties, a memorandum of understanding (MoU) was signed among DZARC, Kaliti Food Share Company (KFSC), and *Woreda* Bureaus of Agriculture (BoA) from Ada, Lume and Akaki for the promotion and production of quality durum wheat varieties for agro-processing purposes. A contractual agreement was signed for the durum wheat harvest in 2001/02 cropping season. In the contractual agreement, farmers were not signatory rather they were approached through Farmers' Research Group (FRG) which was established by DZARC for the promotion of improved durum wheat technologies. Instead, the interest and concerns of the farmers were implicitly well taken care of by DZARC. The participating farmers were selected based on their goodwill and ability in adopting improved technologies.

The contractual agreement stipulated that DZARC provides source seed and technical support to farmers. Accordingly, each farmer was provided with 87.5 kg of seed on a revolving scheme. The improved varieties consisting of *Kilinto, Foka, Quamy, Tob* 66, and *Boohai* were distributed to participating farmers. It was also agreed that KFSC would pay a premium of 40 ETB quintal^{-1} over the prevailing local market price at the time of harvest provided that the durum produced meet the required industrial quality standards. Moreover, it was agreed that transport would be managed by the factory starting at the farm gate. Routine field supervision and monitoring was managed by BoA.

According to the initial plan, it was expected that 50 tons of quality durum wheat would be supplied to the pasta factory in the first year of the initiative. However, the factory had managed to buy only 7.5 tons at a price of 160 Birr/quintal. The lengthy quality testing and procurement procedures of the factory were found to be the major factors leading to the limited volume of durum purchased from famers. It was noted that the factory was procuring the durum wheat supply in April which was too late for farmers who want to settle their input credit and other obligations on time. As a result, most of the durum wheat produced was destined to the local grain markets.

Despite all the hurdles in the first year, the premium price paid by the factory had encouraged more farmers to engage in durum wheat production. Consequently, the number of participating farmers increased in the second year. It was estimated that about 150 tons of quality durum wheat was delivered to the pasta factory. The setting of premium price of durum wheat was based on the market survey conducted by the marketing committee involving the KFSC, DZARC and BoA. However, the factory had breached its agreement to procure the durum wheat supply arguing that the actual supply is too small and not economic for its business operation. Consequently, the market linkage initiative had failed to achieve its ultimate objective and farmers were switched to the production of bread wheat.

In general, the following major limitations were be identified from this initial market linkage initiative

- It was primarily a research driven initiative where participating farmers were approached through farmers' research group (FRGs) instead of involving farmers' economic organizations such as cooperatives and unions; consequently, there was no farmers' representative signing the contractual agreement;
- The scale of intervention was very limited to generate a viable bulking size for processing purpose;
- Lack of clear commitment and mutual business interest among the major actors especially the agro-processor and farmers; and
- Lengthy quality testing procedure and subsequent payment delays by the agro-processor.

After two years, DZARC had once again tried to re-initiate and revitalize the durum wheat market linkage initiative in 2005/2006 cropping season by establishing durum wheat stakeholders platform based on the lessons learned from the initial intervention. In this case, a multi-stakeholder platform was established involving research (DZARC), agro-processor (Kaliti Food Share Company), farmers, unions/cooperatives (Kesem, Lume-Adama and Yerer), office of agriculture and *Woreda* administration of eight districts (Ada, Akaki, Liben, Lume, Mareko, Minjar-Shenkora, Sodo and Ziquala). The platform was expected to have not only the role of creating a market linkage but also enhancing durum wheat technology promotion. The platform had launched the market linkage initiative between farmers and agro-processing industry by developing a structured MoU, which was fully accepted and endorsed by all stakeholders. It was also agreed that the platform would establish its technical committee that would have a regular monthly meeting to monitor and evaluate the performance of planned activities. The MoU clearly stipulated the roles and responsibilities of each stakeholder as outlined below:

DZARC

- Technical support in site selection;
- Training of participating farmers and development agents;
- Technical backstopping from land preparation to harvesting;
- Provision of improved seeds in collaboration with farmers' unions and agricultural offices;
- Facilitate market linkage in consultation with the relevant stakeholders;
- Scaling up of preferred durum varieties in suitable agro-ecologies; and
- Coordination and facilitation of the platform.

Woreda Agricultural Offices

- Facilitate site selection and identification of participating farmers;
- Supervision and monitoring of all field operations;
- Facilitate and assist the agro-processor (KFSC) in sample collection for quality test in collaboration with Unions;
- Ensure the continuity of durum wheat production by organizing farmers;
- Facilitate the revolving seed scheme;
- Facilitate the delivery of quality durum wheat to Unions;
- Scaling up of improved durum wheat technology in their respective *woredas*; and

- Integration of durum wheat technology scaling up activities in the regular action plan.

Farmers' cooperatives unions

- Promote durum wheat production by assisting participating farmers;
- Facilitate the procurement of quality durum supply from farmers and storage in the respective warehouses, and delivery to the agro-processor;
- Participate in a market survey as a member of the marketing committee; and
- Agreed that having completed the quality test and market survey, the unions would procure the durum wheat supply from farmers within 7 days and then deliver the same to the factory within 7 days after procurement.

Kaliti Food Share Company

- Pay a premium of 15-20% over the local market price;
- Lead and assist the establishment of market survey committee involving research, agricultural office, union, and participating farmers to establish the base price
- Provide training on postharvest and quality management to farmers and development agents; and
- Provide packaging and logistic services in collaboration with Unions.

Participating farmers

- Produce quality durum wheat based on the recommended management;
- Timely delivery of revolving seeds to DZARC;
- Timely delivery of durum wheat supply to unions;
- Delivery of at least 75% of the total durum wheat production; and
- Actively participate in all trainings.

Woreda administration

- Provide a leadership role in facilitating the technology scaling up activities at all levels.

On the basis of the MoU, the market linkage initiative was first implemented in Ada *Woreda* in the 2005/2006 cropping season with the participation of 85 smallholder durum producers. A total of 236 tons of durum wheat was produced and KFSC had managed to purchase only 25% of the total durum production (Table 6.2).

With the persistent leadership of DZARC, the market linkage initiative expanded further to a total of 712 farmers from two *woredas* in the subsequent cropping season (2006/2007). In this case, the total durum wheat production reached 1,384 tons, which was more than a five-fold increment from the preceding cropping season. With this significant achievement in production, the factory, however, had managed to purchase only 21% of the total durum production.

It was observed that there had been a growing gap between the actual durum purchase by the factory and the volume of durum supply by farmers. This was indeed a major challenge straining the sustainability of the market linkage between farmers and the pasta factory. This scenario was further pronounced in the third year (2007/08 cropping season) where production had raised to a higher level, i.e. 4,768 tons produced by 1238 farmers in four adjacent woredas in East Shewa Zone while the factory had managed to buy only 1.25%, the worst performance of the market initiative. Despite all the efforts by DZARC and some stakeholders, finally the performance of the market linkage initiative turned out to be very poor and could not take off. Since then, there has not been any durum wheat market linkage activity at DZARC.

DZARC, as a coordinator of the national durum wheat research program, however has been actively continue to be engaged in durum wheat technology scaling up activities in major durum growing areas of the country. For example, a total of 1,350.4 tons of durum wheat was produced by involving 1317 farmers from nine *woredas* through the technology scaling up program (Table 6.3).

Table 6.2. Contract durum wheat production in selected pilot *woredas* during 2005-2008

Cropping Season	Woreda	Number 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: *Research Extension, DZARC*

Table 6.3. Durum wheat technology scaling up during 2008-2012

Cropping Season	Wereda	Number 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: *Research Extension, DZARC*

The following were major limitations observed during the course of the last market linkage initiative by DZARC:

- Farmers/unions were observed to have breached their agreement for short-term incentives, i.e. side selling to other traders for minor price increase over their contract;
- There was delay in the delivery of durum output by farmers to the warehouses of their respective unions due to opportunistic behavior associated with high price expectation;
- Delays on quality test and subsequent late payment for durum grain delivered to the factory;
- Lack of business interest to work with smallholder farmers so that there were no embedded services delivered by the factory except the logistic service to move the durum supply from the farm gate to the factory;
- Lack of trust between farmers and the pasta factory; and
- Failure to deliver their commitments by most stakeholders except DZARC, showing that the market linkage initiative seemed to be more research driven rather than business driven.

6.3 Experience from Development Partner-Facilitated Market Linkage

This initiative implemented in Bale zone jointly by Oromia Bureau of Finance and Economic Development (BoFED) and Ethio-Italian Development Cooperation represented by the Overseas Agronomic Institute (IAO), which targeted promotion of market linkage of durum wheat producers with agro-industries. The initiative targeted to reach half-million quintals quality durum wheat in five years' time starting from 2011/2012 cropping season, which is equivalent to the current industrial demand for durum wheat. In due course, it was expected that farmers' livelihood would be improved through viable market linkage with the private sector (agro-processing). The major stakeholders, which were involved in the initiative, include four unions and fifteen agricultural cooperatives, Sinanna Agricultural Research Center (SARC), and other local institutions in five *woredas* namely Agarfa, Ginir, Goro, Gololcha, and Sinanna of Bale zone. Some 10,000 smallholder farmers were expected to be direct beneficiaries of the project.

The Bale durum wheat value chain project has often been cited as the most successful intervention in linking smallholder farmers with agro-processing industries and developing innovative business models. The project has shared some of its success stories and associated best practices with different stakeholders in the durum wheat subsector by holding two successive workshops including the latest project conclusion workshop which was held on October 27, 2015 at Oromia Agricultural Research Institute (OARI), in Addis Ababa.

The salient features of some of its success stories could be summarized as follows:

- Rapidly increasing quality durum wheat supply to local pasta manufacturing industries. For instance, the total durum wheat supply to local processing industries increased from 500 tons in its first year (2011/2012 cropping season) to 4,500 tons in its third year (2013/14 cropping season). In the first year, SARC supplied 46 tons of basic seeds of two improved durum wheat varieties, namely; *Bakalcha* and *Ejersa*;
- Introduction of innovative agribusiness models such as the grain supply contracts between unions and local agro-processing industries. For instance, some 2,000 tons of quality durum wheat supply was sold to Dire Dawa Food Complex and Kaliti Food Share Company in 2013 based on a contractual agreement with seven farmers' cooperatives in Bale Zone;
- Awareness created on output quality and market linkage: continuous awareness creation events were organized with cooperatives and processing industries to establish viable market linkage;
- Establishment of quality based price incentive mechanisms: a premium price of 10 Birr for each increment of protein content by 0.1% was established over a fixed range of protein content with minimum of 10.5% and maximum of 12.5%. The base price was fixed at the prevailing local market price for bread wheat at harvesting time in the zone. The most protein-rich batches of durum wheat were sold at a premium price of 30% over the standard wheat;
- Enabling unions to engage in aggregation and bulking of durum wheat deliveries from farmers to reduce unit costs and unnecessary transaction

costs. In this case, the minimum marketable unit was fixed at 40 ton which is equivalent to a full loaded track with logistic costs covered by the agro-processing industry;

- Enforcement of quality control on grain and seed production to meet the required quality standards set by the pasta manufacturing industry; and
- Enhanced seed value chain development parallel to the rapidly growing demand for quality durum wheat production. Unions were responsible for collection and redistribution of quality seeds required for each cropping season

To achieve the success, the project has designed and implemented different strategies which are briefly outlined as follows:

- Focused intervention in major wheat production potential areas using two widely adapted improved durum wheat varieties released by SARC, i.e. *Ejersa* (2005) and *Bakalcha* (2005);
- Joint promotion of new seed multiplication schemes for achieving both larger volume and high quality of durum wheat supply;
- Enhance the sustainability of quality durum wheat supply based on the guiding principles of high protein content, large bulks, homogeneous and consistent supply over time;
- Engaging more farmers' cooperatives in project target areas;
- Providing support services to cooperatives in terms of supply of high quality seed and training and technical assistance
- Capacity building for cooperatives and unions, i.e. investment in warehouse facilities: 18 warehouse facilities (15 cooperatives and 3 unions) with a storage capacity of 800 to 1000 tons were constructed, and three seed cleaning machines were provided for three unions, i.e. Agarfa, Ginir, and Gololcha
- Capacity building of local institutions; i.e., establishment of quality laboratory to SARC for monitoring seed and grain quality: SARC was expected to perform the role of third party in durum supply contracts through efficient seed and grain quality analysis; field vehicles for SARC; and motorbikes to the respective woreda agricultural offices and SARC.
- Continuous lobbying and awareness creation for getting the interest of local pasta industries.

Despite the tremendous efforts and subsequent major achievements by the project, some key issues have still remained a challenge to the durum wheat value chain development

- The lack of trust between farmers and agro-processors due to apparent opportunistic behavior on both sides. Consequently, the sustainability of major achievements in the current market linkage still remains fluid as both parties are often less willing to engage in contractual agreement;
- Farmers' high price expectation poses competitiveness challenge in the durum value chain;
- The private sector did not show the business interest to the development of the durum value chain by providing embedded services such as finance, inputs and other necessary technical support;
- Lack of well-structured durum wheat marketing system with grades and standards; as a result hindering the use of quality and premium prices; and
- Limited capacity of farmers' cooperatives to discharge their economic role.

6.4 Scaling up Successes in Arsi and East Shewa Zones

Recognizing the experiences of the above initiatives, the research has reinitiated promotion of better adoption of rust-resistant wheat varieties through enhanced market linkage in 2014/15 production season by involving relevant stakeholders. The initiative is more of scaling up of the success from Bale based intervention implemented jointly by BoFED and Ethio-Italian Development Cooperation. The targets for scaling up were eight districts in Arsi and East Shewa Zones of Oromia.

About 19.93 tons of seed was distributed for seed production to 208 farmers (18 female farmers) and planted on 170 ha. An estimated 547.2 tons was produced for distribution to durum wheat grain producers; and the amount is sufficient to plant 3,648 ha in 2015/16 crop season. The seed produced will be collected and marketed collectively or through farmer cooperative unions to their members for grain production in 2015/16 crop season.

Another 51.75 tons seed was distributed to 712 farmers (65 female farmers) and planted on 407.2 ha for durum wheat grain production. An estimated 1592.2 tons of durum wheat grain was produced in 2014/15 crop season. Farmers produce durum grain as per the requirements of the industry which will be aggregated and sold through unions to the different factories based on contractual agreement. The grain was aggregated (minimum 40 tons), sampled and tested at least for protein quality, gluten content, moisture content and hectoliter weight to determine the price based on the quality. The contractual agreement between the unions and factories was signed and the samples were collected and tested following harvest time. In total, this scaling up activities benefited 177,306 smallholder durum wheat producers in one year.

6.5 Key Lessons

The key lessons from this scaling up of the approach in linking smallholder farmers with agro-industries indicate:

- The approached followed is found to be applicable to wider areas of durum wheat producing areas all over the country;
- The need to involve relevant actors including research, seed producers, cooperatives, offices of agriculture, and agro-industries from the inception up to implementation;
- Implementation of incentive based contract enforcement mechanisms; and
- The need of an organization that facilitates the linkage, which has been done through ad-hoc, bases either by the research or development partners voluntarily. This implies institutionalizing the approach for wider application;

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Chapter VII

Adoption and Impact of Rust-resistant Wheat Varieties on Productivity and Household Food Security in Ethiopia

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7.1 Introduction

Wheat being a key source of livelihood in the cereal based mixed farming systems of the mid and high altitude areas of the country, a considerable increase in yield through the use of disease resistant and high yielding improved wheat varieties will have a major impact on household food and nutritional security, income generation and overall welfare of smallholder farmers dependent on crop agriculture. In view of this, the generation and transfer of improved agricultural technologies in general and that of disease resistant, widely adaptable and high yielding wheat varieties is one of the pillars in the national food security strategy adopted by the Government of Ethiopia.

As indicated in previous chapters, in mitigating the challenges of wheat rust multiple activities with interrelated objectives that include the following were implemented

- fast-tracking testing and release of rust-resistant bread wheat varieties and accelerating their seed production;
- demonstration and popularization of the rust resistance bread wheat varieties to create demand;

- promotion of large-scale certified seed multiplication for the selected rust-resistant bread wheat varieties;
- supporting emergency seed distribution;
- promotion of revolving seed fund small-pack seed distribution-cum-on-farm seed production; and
- development of early warning system for yellow and stem rust in the country through building the capacity building of NARS both in terms of enhancing skills of human resources and providing key equipment and facilities.

This article presents the adoption and diffusion of rust resistance varieties in terms of area with simultaneous reduction in the number of farmers and area under rust susceptible wheat varieties. Furthermore, factors influencing the adoption of disease resistant wheat varieties are examined, and the impacts of these technologies on wheat productivity, production, and household food security are shown. In addition, the study examined the mix and effectiveness of institutional innovations promoted in terms of variety releases, seed multiplication and delivery system.

7.2 Methodology

The impact of the initiative is assessed considering the role of the project in promoting the adoption of the rust-resistant bread wheat varieties; assessing the impact due to adoption of the rust-resistant bread wheat varieties; and the impact of the project in institutional innovation, which is key in creating a responsive system in cases of rust epidemics in the future. These three dimensions of project impact are assessed employing various approaches and methodology that are discussed below.

7.2.1 Sampling Procedure and survey implementation

Multiple data collection techniques including secondary data collection and analysis, review of project reports, focus discussions with key stakeholders and quantitative household survey were employed to assemble critical data required for assessing the effectiveness of project interventions in terms of meeting stated project objectives.

The household survey was based on a stratified multistage sampling scheme. First, two wheat growing regions, namely Amhara and Oromia regional sates were identified purposively to represent the diverse socio-economic and biophysical wheat growing environments of the country. Second, in consultation with the biophysical scientists involved in the design and implementation of the project, a total of seven districts, three from Amhara and four from Oromia, believed to be representative of the respective wheat growing environments in the two regions were selected. Then the kebeles within each of the identified district were classified into two strata namely intervention (direct beneficiary), and control (non-beneficiary) kebeles based on targeting. An intervention kebele is one which directly benefits from the project by hosting project activities such as on-farm trials, demonstrations and scaling up activities including on-farm seed production organized and implemented by the project. In contrast, a control kebele was identified as one where none of the planned project activities are deliberately promoted by the project. Despite the fact that most of the control kebeles are situated far from the intervention kebeles, households are likely to receive information through the regular government extension system and non-governmental organizations actively working in agricultural related activities. Finally, given a selected KA (Kebele Administration), using a household list solicited from each KA, 453 households were randomly selected and included in the household survey (Table 7.1).

A structured household questionnaire is used to collect relevant data. A total of 13 people involving 11 enumerators and 2 supervisors were recruited for conducting the survey. The enumerators were recruited by EIAR and had previous experience in household surveys. Three days of intensive training was given to the selected enumerators and supervisors. The training included briefings of the study objectives, a thorough review of the questionnaire, interviewing techniques, direction as to how to fill the structured questionnaire, and how to ensure quality data collection.

Field data collection was carried out by two teams. Besides the two survey teams, one person from the respective district agricultural office and two development agents stationed in the respective *kebeles* assisted the survey teams in locating households identified for the interview. Data collection took place from October to November 20I4.

Table 7.1 Distribution of sample households interviewed

Region	Zone	District	Sample households (No)
Amhara	West Gojam	Wenberema	72
	East Gojam	Debre Elias	69
	East Gojam	Gozamen	72
Oromia	East Shewa	Adea	60
	Arsi	Etossa	60
	Arsi	Gedeb Assasa	60
	Bale	Sinana	60
Total			453

7.2.2 Analytical models: household level adoption and impact

Ample literature exist explaining technology adoption decision behavior of smallholder farmers with respect to the adoption of high yielding crop varieties. In Ethiopia or elsewhere, several studies examined the determinants of technology adoption under smallholder contexts employing econometric techniques (Feder et al., 1985; Shiferaw and Holden, 1998; Bekele and Drake, 2003; Gebremedhin and Swinton, 2003; Yirga and Hassan, 2008). While assessment of determinants of adoption of a binary dependent variable such as the use of improved wheat varieties is straight forward, some complexities arise in assessing the impact of technology adoption on welfare employing observational studies like ours. Consequently, studies assessing the impact of adoption of agricultural technologies on productivity and welfare of farm households are infrequent.

Several impact assessment tools are available in the literature that would allow the proper measurement and quantification of program interventions on participants. The choice of any one tool, however, depends on the availability of a baseline data and information for estimating a counterfactual outcome. A counterfactual entails knowing what would have happed to an individual's welfare indicator or outcome of interest had the program not been in place. In a situation where a randomized experimental design is possible, the impact of a program can be estimated by a simple mean difference between treatment and control outcomes. In our case, the promotion efforts of disease resistant improved wheat varieties neither used such a design nor is a baseline data available. Hence, in this study, first, an adoption decision model assessing the factors affecting the adoption decision of rust-resistant wheat varieties is estimated. Then, using impact models, we estimated the influences of adoption decisions on farm productivity, production and household food security. The effectiveness of the institutional innovations was assessed by reviewing project documents and drawing on group discussions involving various stakeholders of the project. Results can assist producers in making adoption decisions and research and extension to devise better mechanisms for augmenting the spread of superior and disease resistant wheat varieties in place of the old and rust susceptible varieties.

a) Adoption decision model

In this study an adopter is defined as household using rust-resistant improved wheat varieties during the study year. Household could be considered as an adopter even if he/she cultivated rust susceptible improved varieties on some portion of his/her wheat field. Given the binary nature of the dependent variable represented by a dummy variable 1 if a household cultivated disease resistant wheat variety and zero otherwise, a probit model would appropriately capture the adoption decision behavior of farm households. Following Green (2008), the probit model could be specified as follows:

$$Y_i^* = \beta X + \mu_i \qquad (1)$$

Where,

Y*= an underlying latent variable that indexes farmers use of rust-resistant wheat variety

i = 1, 2, 3… n (observations)

β_i =regression coefficients to be estimated

u_i = a disturbance term, and

X = covariates.

The coefficients generated from these regression models through maximum likelihood estimates are not straight forward. Hence, marginal effects, the effect of a small change in the explanatory variables on the probability of a particular outcome (adoption of rust-resistant wheat varieties), are commonly presented. Marginal effects are used to interpret the magnitude by which a one unit change in an independent variable will change the probability of the outcomes.

Variables often considered in modeling the adoption decision of farmers included household and farm characteristics, attributes of the technology and institutional factors such as land tenure, access to markets, information and credit (Feder et al., 1985; Shiferaw and Holden, 1998; Gebremedhin and Swinton, 2003; Bekele and Drake, 2003; Yirga and Hassan, 2008). In this study, based on review of the relevant literature a range of household, farm and plot characteristics, institutional factors and locational dummies are hypothesized to influence adoption of improved wheat varieties used by smallholder farmers in mixed crop-livestock based farming systems of the highlands of Ethiopia (Table 7.2).

Among household demographic characteristic age, education level of the household head, family size and wealth (livestock ownership and type of house) are believed to have differential impacts on the adoption decision behaviour of smallholder farmers. Farm characteristics hypothesized to influence adoption of disease resistant wheat varieties are distance of input markets and social capital. Institutional factors often considered to have differential impacts on technology adoption by smallholder farmers are access to information, institutional credit and off-farm employment (Table 7.2).

Table 7.2: Definition of variables hypothesized to condition adoption of rust-resistant improved wheat varieties by smallholder farmers in wheat based farming systems

Variable	Description	Values
HH characteristics		
Age	Age of the head of the farm HH	Years
Education	Illiterate, do not read and write	1= yes, 0=no
	Read and write/religious education	1= yes, 0=no
	Elementary (2-6 grades)	1= yes, 0=no
	Secondary (>6 grades)	1= yes, 0=no
Model farmer	If household head is designated as a model farmer	1= yes, 0=no
Livestock	Number of livestock owned by a HH	TLU
House type	Whether a HH owned corrugated iron roofed house or not	1= yes, 0=no
Family size	Number of family members of a HH	Number
Perception on incidence of rust	Whether a HH has faced rust incidence during the 2010 rust epidemics	1= yes, 0=no
Farm and plot characteristics		
Farm size	Total land owned in ha (crop, fallow, grazing)	Number in ha
Institutional factors		
Training	If HH has received training on improved wheat production technologies	1= yes, 0=no
Extension	Frequency of extension contact	Number of contacts in a year
Field days	Have not attended any field day during the year	1=yes, 0=no
	Attended at most two field days	1=yes, 0=no
	Attended three or more fielded	1=yes, 0=no
Credit	If a HH had access to institutional credit for the purchase of improved seeds	1=yes, 0=no
Off-farm	If a HH member participate in off-farm income generating activities	1=yes, 0=no
Plot operated	Number of plots cultivated	Number
Location (Zonal Dummies)	East Gojam, Amhara	1=yes, 0=no
	West Gojam, Amhara	1=yes, 0=no
	Arsi, Oromia	1=yes, 0=no
	Bale, Oromia	1=yes, 0=no
	East Shewa, Oromia	Comparison Group

b) Impact model

We used the propensity score matching (PSM) technique which is based on identifying assumption of un-confoundedness, or selection on observables for tracing and estimating causal treatment effects when program participants (adopters) and non-program participants (non-adopters) differ in characteristics that affect the outcome of interest (productivity of wheat) (Rosenbaum and Rubin, 1983). Assuming observable characteristics may account for all outcomes of relevant differences, matching techniques could be used. Once the distributions of observable characteristics are reweighed and are made identical between treatment and control, all other differences are assumed irrelevant for the outcome and a straight comparison of means is possible. Since we are interested in the productivity, production and food security effects of adopting rust-resistant improved wheat varieties, the average treatment effect (ATT) measuring the mean gain from adopting rust-resistant improved wheat for those who actually adopted was the main parameter.

The PSM is based on four critical steps including estimation of the propensity scores, choosing a matching algorithm, checking on common support condition and testing the matching quality (Caliendo and Kopeinig, 2005). The first step in the estimation of the PSM model is the construction of the propensity scores. This requires the selection of the observable variables or covariates that allow the estimation of the propensity score. It is worth noting that the covariates should not be affected by the treatment or intervention, but at the same time they need to influence simultaneously the participation decision and the outcome variable. In this study a host of covariates, including age, gender, education, family size, farm size, access to extension, livestock ownership including oxen and location dummies are used. The second step involved estimating the probability of getting the treatment as a function of observable characteristics. As is the case, we used the probit model. The third step is the use of the predicted values from the estimation to generate propensity score P(X) for all adopter and non-adopter group members. The fourth step involves the matching of treated unit with a sample of controls with similar P(X) based on several matching algorithms including the nearest neighbor, the kernel and caliper. Finally, ATT is estimated and test for the balancing of the most relevant variables conducted.

Outcome variables: The survey allows evaluating the impact of rust-resistant wheat variety use on four outcome variables wheat productivity, wheat production, income from wheat sales and household food security. While wheat productivity is basically yield per unit area measured in kilograms per hectare, wheat production pertains to total wheat harvest from all wheat plots operated by a household during the study year. Similarly income from wheat sales is measured as the amount of money the household earned from the sale of wheat grain and seeds from own production during the study year. Food security in our survey was a self-assessment captured as 1 if the household faces food shortages throughout the year, 2 if the households faces food shortages some months in a year, 3 if the household is self-sufficient (breakeven) and 4 if the households produces surplus. From this variable two food security dummy variables are generated for the impact analysis. The first food security dummy variable (fsecure 1) divides the households into two sub-groups, households facing food shortages with a value label of zero and households in the breakeven and surplus in the other sub-group with a vale label of 1. The second food security dummy variable (fsecure 2) as in the first one divides the sample into two with households producing surplus in one group with a value label of 1 and zero otherwise.

c) Contribution of the project for better adoption

The project started without a baseline survey that would have been used to compare the adoption and use patterns of improved rust-resistant bread wheat varieties in the target areas. Lack of baseline data paused serious difficulty to exactly document the contribution of the project in meeting project objectives. Nevertheless, we used data from a household survey conducted at a national level for measuring wheat technology adoption levels just before the launch of the program. Therefore, the impact of the project in enhancing the adoption rate of rust-resistant bread wheat varieties is assessed by comparing the varietal adoption levels of the present survey (see the detail in part 3.2) and the 2011 survey made at national level (Chilot et.al., 2013). The 2011 survey covered a sample of 2096 household from 125 *kebeles* from 60 wheat growing districts in Amhara, Oromia, Southern Nations, Nationalities and Peoples and Tigray Regions

d) Impact on institutional innovation

In addition to the direct impacts of the project through enhanced adoption of rust-resistant varieties and benefits gained due to use of rust-resistant varieties, several institutional innovations has played key role in addressing future wheat rust epidemics are identified. These are related with

- a new approach of fast-tracking variety testing and release;
- procedures of adequate seed multiplication for pre-released candidate varieties that would ensure adequate multiplication of basic and certified seed production;
- intensive demonstration and field days to popularize rust-resistant varieties to create awareness among farmers, stakeholders and policy makers;
- small-pack seed distribution-cum-on-farm seed production reaching 46 target districts;
- alignment of the various seed system actors (research, seed enterprises, commercial farms etc.) to timely respond in cases of rust epidemics; and developed rust epidemics early warning system linked with enhanced capacity in terms of human resources and physical capacities.

The impact of these institutional innovations of the project were assessed through narration of information generated through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) with relevant stakeholders (farmers, expert of MoA, researchers) and with project implementers (EIAR, ICARDA). Various reports of the project mainly progress reports were used to augment the information generated from KIIs and FGDs.

7.3 Results and Discussion

7.3.1 Household level adoption of rust-resistant wheat varieties and its determinants

a) Farmers' awareness of rust-resistant wheat varieties

Farmers' awareness about the different types of rust resistance wheat varieties plays a key role in the adoption of the varieties. The mean levels of awareness for each of the improved wheat varieties in the sample are provided in Table 7.3. Awareness of disease resistant improved wheat varieties was higher among households in the intervention villages than in non-intervention villages. Among the disease resistant varieties promoted by the project three varieties namely, *Kakaba, Danda* and *Digelu* are widely known by farmers among sample farmers in the study areas but more so in intervention villages than non-intervention villages. For *Kakaba*, the level of awareness was about 94% in intervention villages and 75% in non-intervention villages. Mean awareness across all the disease resistant varieties, however, was low.

Table 7.3 Levels of awareness for improved wheat varieties by sample households in the sample

Variety	Member of intervention community (N=259)	Non-Member of intervention community (N=194)	All sample HHs (N=453)
Kakaba	93.8	75.3	72.4
Danda'a	58.8	26.8	36.6
Digalu (HAR 3116)	33.0	19.1	22.3
Kubsa (HAR 1685)	28.9	14.9	18.8
Galema (HAR 604)	4.6	7.2	5.1
Mada Walabu (HAR 1480)	3.6	8.2	5.1
Tusie (HAR 1407)	4.6	4.6	4.0
Simba (HAR 2536)	7.2	0.5	3.3
Shorima	4.6	3.1	3.3
Hulluka	1.0	6.7	3.3
Ogolcho	2.6	5.2	3.3
Sof-Oumar (HAR 1889)	5.2	2.1	3.1
Wetera (HAR 1920)	6.7	0.0	2.9
Hidase	4.6	1.5	2.6
Ude (CD 95294-2Y)	5.2	0.0	2.2
Other bread wheat varieties	1.5	3.1	2.0
Ejersa (CD 98206)	2.6	2.1	2.0
Werer (Mamouri I)	3.6	0.0	1.5
Shina (HAR 1868)	1.0	2.1	1.3
Hawii (HAR 2501)	1.0	1.5	1.1
Yerer (CD 94026-4Y)	2.1	0.0	0.9
Pavon 76	1.0	0.0	0.4
Abola (HAR 1522)	1.0	0.0	0.4
Dinknesh (HAR 3919)	0.0	0.5	0.2
Tossa (HAR 3123)	0.0	0.5	0.2
Other durum wheat varieties	0.0	0.5	0.2
Foka	0.5	0.0	0.2
Obsa (Altar 84)	0.5	0.0	0.2

Source: Own survey, 2014

b) Adoption of disease resistant wheat varieties

In this study, a farmer is considered as an adopter if he/she used disease resistant improved wheat variety on any one of her/his plots during the study year. Proportion of households growing rust-resistant wheat varieties disaggregated by intervention village is given in Table 7.4. Of the rust-resistant improved wheat varieties promoted by the project only three varieties namely *Kakaba, Digalu* and *Danda'a* have been found to be grown during the study year. Among the three rust-resistant varieties *Kakaba* appear to be the most widely grown by 49% of households followed by *Digalu* and *Danda'a* grown by 14% and 5% of households, respectively. Adoption levels, measured by proportion of households growing the varieties, however, did not differ significantly between intervention villages and non- intervention villages which may be due the intensive farmer to farmer seed and information exchange. Discussions with key informants and community leaders revealed that despite the fact that non-intervention villages were not directly targeted by the project, most community members in non-intervention villages benefited from farm to farm exchange of information and seeds of rust-resistant varieties. The distinction between intervention and non-intervention villages, therefore, is somewhat murky as information received by community members quickly diffuse to non-intervention villages. Hence, in subsequent sections, discussions on adoption levels of rust-resistant varieties and adoption decision behaviour of farm households are presented by district.

Table 7.4: Proportion of households using improved wheat by target group as of 2014

Type of variety	Variety	Target				Sample (N=453)	
		Intervention villages (N=259)		Non-intervention villages (N=194)			
		No	%	No	%	No	%
Rust-resistant	Kakaba	127	49.0	95	49.0	222	49.0
	Digalu	33	12.7	32	16.5	65	14.3
	Danda'a	14	5.4	9	4.6	23	5.1
Rust susceptible	Kubsa	105	40.5	70	36.1	175	38.6
	Sofumar	10	3.9	2	1.0	12	2.6
	Wetera	8	3.1	0	0.0	8	1.8
	Mada-Walabu	4	1.5	4	2.1	8	1.8
	Pavon	1	0.4	0	0.0	1	0.2
	Hidase	1	0.4	0	0.0	1	0.2
	Ude	1	0.4	0	0.0	1	0.2
	Hulluka	1	0.4	0	0.0	1	0.2
	ET-13	0	0.0	2	1.0	2	0.4
	Millennium	0	0.0	1	0.5	1	0.2
	Simba	0	0.0	1	0.5	1	0.2
	Hawii	0	0.0	1	0.5	1	0.2
	Other improved	3	1.2	1	0.5	4	0.9
	Other local	0	0.0	0	0.0	0	0.0

Source: Own survey, 2014

Table 7.5 presents, adoption rate estimates of rust-resistant wheat varieties aggregated by district. On the whole, the proportion of wheat farmers adopted rust-resistant varieties is fairly high estimated at about 69%. Adoption rates, however, differed considerably from one district to another. Within the project intervention districts, adoption of rust-resistant wheat varieties is highest in Wonebera district of the Amhara Region while adoption rates are the lowest in Ada'a district with only 3% of households growing. However, it should be noted that Ada'a is not a hot spot for yellow rust. At a region level, the proportion of households using rust-resistant varieties is much better in Amhara with 85% of sample farmers growing rust-resistant varieties on 91% of the wheat area compared to Oromia Region grown by about 43% of households on 54.6% of the wheat area. In terms of area, about 67% of the wheat area is under rust-resistant varieties, the bulk of which is covered by the variety *Kakaba*. Among the non-resistant wheat varieties, *Kubsa* appears to be dominating covering about 30% of the wheat area given the fact that is was one of the mega-variety grown across the country before 2010 yellow rust epidemics.

Table 7.5: Adoption rates of rust-resistant wheat varieties, 2014

Region	District	Sample size (N)	HH adopting (%)	Wheat area under rust-resistant varieties (%)
Amhara	Debre Eleni	69	84.9	97.1
	Gozamen	73	20.0	53.8
	Wonberema	72	100.0	100.0
Oromia	Etossa	60	45.0	53.9
	Gedeb Asassa	60	38.3	36.9
	Sinanna	60	85.0	89.3
	Ada'a	60	3.33	3.5
Whole sample		453	62.7	68.8

Source: Own survey, 2014

Table 7.6 shows effect of individual variables on adoption of rust-resistant wheat varieties comparing mean values of adopters and non-adopters. Among others household resource endowments (livestock), human capital (education level), access to information, participation in field days, access to credit for purchasing improved seeds have a significant effect on adoption of rust-resistant wheat varieties. Location representing a household's propensity to have access not only to improved seeds but also information is found to have a significant effect on varietal adoption. On the other hand demographic factors such as age and gender represented by the sex of the household head did not have a significant effect on rust-resistant varietal adoption.

Table 7.6 Socio-economic characteristics of sample households by adoption status

	Pooled data (N=453)	Adopters (N=283)	Non-Adopters (N=169)
Sex of the HH			
Male	91.8	94.4	87.6
Female	8.2	5.6	12.4
Age of the HH (Years)	44.2	44.7	43.4
Education (% households)			
dmy_educ1	32.45	24.65	45.56
dmy_educ2	22.08	26.41	14.79
dmy_educ3	30.46	33.45	25.44
dmy_educ4	15.01	15.49	14.20
Extension (number of contacts)			
dmy_ext1	7.95	3.87	14.79
dmy_ext2	34.22	36.27	30.77
dmy_ext3	57.84	59.86	54.44
Participation in field days (number)			
flday_dmy1	52.76	40.49	73.37
flday_dmy2	32.67	39.44	21.30
flday_dmy3	14.57	20.07	5.33
Credit Access	35.32	38.73	29.59
Social capital	10.98	11.93	9.40
Ownership of corrugated house (%)	85.21	89.79	77.51
Off-farm job (% households)	26.93	24.30	31.36
Family size (no)	6.18	6.24	6.07
Number of plots	5.59	6.02	4.86
Land per person (ha)	0.43	0.46	0.40
Livestock (TLU)	7.80	8.77	6.16
Distance to seed market (Km)	3.53	3.32	3.90
Distance to district d market (Km)	10.36	10.30	10.45
Perception on wheat rust (%)	64.59	62.19	68.67
Zone (% households)			
East Gojam, Amhara (Comparison)	29.14	26.06	34.32
West Gojam, Amhara	31.13	38.38	18.93
Arsi, Oromia	26.49	17.61	41.42
Bale, Oromia	13.25	17.96	5.33

Source: Own survey, 2014

c) Determinants of adoption of disease resistant varieties

The dependent variable for the probit model is binary representing 1 if the household adopted rust-resistant wheat varieties, zero otherwise. Table 7.7 presents both estimated coefficients and the marginal effects along with the level of significance. The likelihood ratio statistics as indicated by the χ^2 statistics is highly significant ($P<0.0000$) suggesting strong explanatory power of the model.

Among the hypothesized variables education level of the household head, extension contact, participation in field days, access to credit for the purchase of improved seeds and livestock ownership positively and significantly impacted the probability of using rust-resistant wheat varieties. Other hypothesized variables such as sex, age of the household head, social capital, participation in off-farm activities and past experience with rust incidence, however, are found to have no effects on likelihood of using rust-resistant wheat varietal adoption.

Of the considered household characteristics, education level of the head of the household is found to have a positive impact on the chances of using rust-resistant wheat varieties. The chances of using rust-resistant wheat varieties would be higher by 18 % for a household with elementary level of education compared to a household with no formal education. Similarly, the likelihood of using rust-resistant wheat varieties would be higher by about 20% for a household with secondary level of education. Hence, public interventions aimed at improving farmers' access to formal education are likely to improve the likelihood of using rust-resistant varieties among smallholder farmers in the study area.

The institutional variables considered in the study were access to extension services, participation in field days and access to institutional credit for the purchase of improved seeds. As expected, access to extension services was positively and significantly associated with the use of rust-resistant wheat varieties. Other things being equal, the chance of using rust-resistant varieties would be higher by 24% and 22% for households having less frequent and more frequent extension contacts compared to a household who do not have any extension contacts. These results suggest that extension messages emphasizing the importance of switching to newly released disease resistant varieties supported by field days had a higher chance of success. These results, therefore, suggest an important role of increased institutional support to promote knowledge regarding tackling rust epidemics through the use of resistant varieties.

Access to institutional credit for the purchase of seeds of improved varieties has a positive and significant impact on the likelihood of using rust-resistant wheat varieties. A possible explanation is that households who have access to credit for the purchase of seeds and complementary inputs are more likely to invest on improved seeds and allocate a higher proportion of their the land to rust-resistant varieties while households who do not have access to institutional credit depend on own saved seeds from previous harvest and use recycled seed. A recent adoption and seed system studies in Ethiopia indicated that seed recycling is a common practice in wheat growing areas of Ethiopia (Chilot et.al. 2013; Bishaw et al. 2010; Dawit and Bishaw 2015). The adoption study indicated that about 84% of the wheat growers depend on recycled seeds and the majority recycles wheat seeds at least for 6 years. This and other studies have shown the importance of improving smallholder farmers' access to credit in enhancing the adoption of improved seeds and complementary inputs such as inorganic fertilizers.

Number of livestock owned, measured in TLU showed a positive and significant influence on the use of rust-resistant wheat varieties. Livestock is a source of traction, manure, cash and cushion against crop failures and other misfortunes. Households who own livestock are thus more likely to adopt rust-resistant varieties as these households could purchase seeds of newly released rust-resistant varieties from income generated from livestock products. The greater likelihood of using rust-resistant varieties, therefore, could be due to the fact that respondents owning livestock are relatively better off, have got the resources and management skills, and are able to take the production and marketing risks associated with using new wheat varieties.

It is widely believed that individual perceptions of incidence of rust epidemics and past knowledge of site specific conditions influence the adoption decision of smallholder farmers in the study area. Contrary to expectations, however, experience of rust epidemics in 2010 did not have a significant influence on the adoption decision behaviour of wheat growers. Focus group discussion with wheat growers revealed that most farmers perceive rust incidence as a random event associated mainly with climatic variability. Consequently, farmers tend to keep high yielding and popular wheat varieties susceptible to rust for a longer period than necessary believing that such varieties are likely to do better in subsequent years.

Another interesting result worth noting is the differential effect of location on the adoption decision of rust-resistant wheat varieties. All else being the same, the chances of adopting rust-resistant wheat varieties in the West Gojam Zone of the Amhara Region and Bale Zone Zones of Oromia would be higher by about 17% and 35%, respectively compared to a typical households in the East Shewa Zone of the Oromia zone, the comparison group. Most of the research and development organizations are actively engaged in the promotion of agricultural technologies in Arsi and East Shewa Zones of the country for a long time. As a result, farm households in these zones are weary of the information provided by external agents. In the other less addressed zones of Bale and West Gojam zones, however, new information and knowledge on farming are eagerly accepted. Moreover, on-farm wheat varietal trials, demonstrations and scaling up efforts besides providing new knowledge and experience required for adopting rust-resistant varieties, provided the initial seeds critical for farmer testing of rust-resistant wheat varieties.

d) Contribution in enhancing adoption of rust-resistant wheat varieties

The project has contributed to the adoption of the different rust-resistant bread wheat varieties (Table 7.8). As indicated in the methodology part, due to lack of baseline survey for the project, the contribution in enhancing adoption of rust-resistant bread wheat varieties is assessed by comparing the national adoption level estimates of wheat varieties for 2010/11 production season with the 2013/14 production season estimates. Accordingly, there is a considerable difference in the level of adoption of the rust-resistant varieties, especially for the popular rust-resistant varieties (*Kakaba* and *Digalu*), where higher adoption rates are reported compared to the estimates in 2010/11 production season. Somewhat perplexing result is the high adoption level reported for *Kubsa* variety, which is susceptible to rust where the adoption level was estimated to be about 24% in 2010/11 and it was 39% in 2013/14 production season. It is worth noting that in some agro-ecologies such as the semi-arid mid highlands, tepid to cool (SA2) and moist lowlands, hot to warm (M1), the level of use for *Kubsa* in 2010/11 was 55% and 43%, respectively. Furthermore, the earlier survey was conducted right the year after the rust epidemic where farmers immediately dropped *Kubsa*, but later on readopt the variety in the absence of rust disease in subsequent years. Though, low level of adoption, older rust-resistant varieties was reported under use in the 2013/14 production season (Table 7.8).

Table 7.7: Parameter estimates of the determinants of rust-resistant wheat variety use: probit model estimates

Variable	Coefficient	SE	Z-value	P>|Z|	Marginal Effect
Sex of the HH	0.0953	0.2689	0.3500	0.7230	0.0348
Age of the HH (Years)	0.0025	0.0061	0.4000	0.6860	0.0009
Education of the HH					
dmy_educ2 (elementary)	0.5450	0.2042	2.6700	0.0080	0.1786
dmy_educ3 (Junior secondary)	0.5816	0.1942	3.0000	0.0030	0.1948
dmy_educ4 (Senior secondary)	0.2898	0.2627	1.1000	0.2700	0.0983
Extension (number of contacts)					
dmy_ext2	0.7272	0.3085	2.3600	0.0180	0.2420
dmy_ext3	0.6011	0.3017	1.9900	0.0460	0.2175
Participation in field days					
flday_dmy2	0.4210	0.1683	2.5000	0.0120	0.1447
flday_dmy3	0.8533	0.2552	3.3400	0.0010	0.2509
Credit Access	0.3689	0.1561	2.3600	0.0180	0.1282
Social capital	0.0100	0.0064	1.5700	0.1170	0.0036
Ownership of corrugated house	0.1827	0.2179	0.8400	0.4020	0.0672
Off-farm job	-0.2641	0.1655	-1.6000	0.1110	-0.0969
Family size	-0.0859	0.0421	-2.0400	0.0410	-0.0308
Number of plots	0.0543	0.0410	1.3200	0.1850	0.0195
Land per person	-0.7814	0.3746	-2.0900	0.0370	-0.2800
Livestock (TLU)	0.0807	0.0186	4.3500	0.0000	0.0289
Distance to seed market (km)	0.0050	0.0241	0.2100	0.8360	0.0018
Distance to district d market (km)	-0.0368	0.0138	-2.6600	0.0080	-0.0132
Perception on wheat rust	0.0757	0.1554	0.4900	0.6260	0.0273
Zone (dummies)					
West Gojam, Amhara	0.4930	0.2084	2.3700	0.0180	0.1674
Arsi, Oromia	-0.1468	0.2504	-0.5900	0.5580	-0.0534
Bale, Oromia	1.4812	0.3071	4.8200	0.0000	0.3540
Number	449				
LR chi2	150.98				
Prob > Chi2	0.00				
Log-Likelihood	-264.88				
Pseudo R-Square	0.2552				

Table 7.8. Adoption levels of wheat varieties

Rust resistance	Variety	2010/11 production season[1]	2013/14 production season[2]
Resistant varieties	Kakaba	-	49.0
	Digalu	2.2	14.3
	Danda'a	-	5.1
	Mada Walabu	5.1	1.8
	Pavon 76	4.7	0.2
	Hidase	-	0.2
	Ude	-	0.2
	Hulluka	-	0.2
	Tusie	3.7	-
Susceptible varieties	Kubsa	23.9	38.6
	Galema	10.3	-
	Dashen	8.2	-
	ET-13	3.3	0.4
	Enkoy	2.0	-
	Simba	1.5	0.2
	Hawii	-	0.2
	Sofumar	-	2.6
	Wetera	-	1.8
	Millennium	-	0.2

Source: [1] Chilot et al. (2013) and [2]own survey, 2014

7.3.2 Impact of adoption rust-resistant wheat varieties on productivity, production and household food security

a) Assessing the matching quality

As noted in the methodology section we estimated the probability of participating in adopting rust-resistant wheat varieties using a *probit* model to evaluate the impact of adopting rust-resistant wheat varieties on selected outcomes. We used three matching techniques namely Single Nearest Neighbor Matching, Kernel based matching with band width 0.25, and Caliper matching of 0.01.

Several tests are often used that would allow to gauge the matching quality (Sianesi, 2004). The first and basic method used to gauge quality of the match is covariate balancing tests before and after matching. This method basically compares the regression results before and after matching to identify whether there still are differences between both groups. As expected, the regression results revealed that statistical differences observed before matching disappeared after matching suggesting the matching strategy has worked. The second parameter used to assess matching quality is to compare the pseudo-R^2 after matching with the one obtained with all the observations (before matching). After matching there should be no systematic differences in the distribution of covariates between adopting and non-adopting households and for this reason the pseudo-R2 should be low. As shown in Table 7.9, the pseudo-R^2 for all the three matching algorithms used are significantly reduced from an average of about 8.6% before matching to about 1.5 % after matching. The third parameter considered in the assessment of matching quality is the comparison of bias before and after matching. Generally, the literature suggests that a mean bias less than 5% after matching is considered acceptable. In our case, of the three matching algorithms considered in the analysis, the Single Nearest Neighbor Matching and Kernel provided the best match with about 3.9% and 4.5 % mean bias after matching, respectively (Table 7.9). Overall, the low pseudo-R^2, low mean standardized bias, high total bias reduction, and the insignificant p-values of the likelihood ratio test after matching suggest that the proposed matching strategy has worked in terms of balancing the distribution of covariates between adopting and non-adopting households. Reported results, therefore, are based on the Single Nearest Matching and Kernel Matching algorithms that provided the best fit including only adopting and non-adopting households in the common support distribution.

b) Impact of using rust-resistant wheat varieties on wheat productivity and production

Table 7.10 provides the mean wheat productivity and production of adopters and non-adopters as well as the average treatment effect on the treated for Single NNM and Kernel matching algorithms that provided the best match. On average, adopters not only enjoyed higher productivity but also produced more wheat than non-adopters. The mean difference between adopters of rust-resistant varieties and non-adopters (used conventional varieties) ranges from 351 to 455 kg/ha and are statistically significant, suggesting the use of rust-resistant wheat varieties significantly improved wheat productivity and production. The results therefore unequivocally suggest that adoption of rust-resistant wheat varieties has a significant and positive effect on wheat productivity.

Table 7.9: Key statistics for assessing quality of the propensity score matching, impact of adopting rust-resistant wheat varieties on wheat productivity, production and food security

Outcome variable	Matching method	Ps R2 before matching	Ps R2 after matching	LR chi2 before matching (P-value)	LR chi2 after matching (P-value)	Mean bias before matching	Mean bias after matching	Total % (bias) reduction
Yield (kg/ha)	Single nearest neighbor matching	0.0887	0.008	52.45 (0.000)	3.7 (0.999)	21.3	3.8	82.159
	Kernel bwidth (0.25)	0.0851	0.017	50.37 (0.000)	13.09 (0.596)	30.9	4.4	85.760
	Caliper	0.0851	0.018	50.37 (0.000)	13.47 (0.566)	31.3	5.2	83.386
Production (kg/ha)	Single Nearest Neighbor Matching	0.0884	0.010	52.32 (0.000)	4.58 (0.995)	23.4	3.9	83.333
	Kernel bwidth (0.25)	0.0852	0.018	50.38 (0.000)	13.41 (0.571)	31.2	4.7	84.935
	Caliper	0.0852	0.018	50.38 (0.000)	13.12 (0.593)	30.9	6.2	79.935
Income from sale wheat seed and grain (Birr)	Single nearest neighbor matching	0.0887	0.010	52.45 (0.000)	4.83 (0.993)	24.1	4.1	82.987
	Kernel bwidth (0.25)	0.0851	0.018	50.37 (0.000)	13.56 (0.559)	31.4	4.6	85.350
	Caliper	0.0851	0.018	50.37 (0.000)	13.47 (0.566)	31.3	5.2	83.386
Binary food security (HH produce surplus)	Single nearest neighbor matching	0.0887	0.010	52.45 (0.000)	4.83 (0.993)	24.1	4.1	82.987
	Kernel bwidth (0.25)	0.0851	0.018	50.37 (0.000)	13.56 (0.559)	31.4	4.6	85.350
	Caliper	0.0851	0.018	50.37 (0.000)	13.47 (0.566)	31.3	5.2	83.386

Table 7.10 Mean treatment effect of adopting rust-resistant wheat varieties on wheat productivity and production

Outcome variable	Matching algorithms	Adopters	Non-adopters	ATT	t-stat
Wheat yield (kg/ha)	Single NNM	2975	2624	351	2.72
	Kernel band width (0.25)	3071	2650	421	3.47
	Caliper (0.01)	3066	2611	455	2.80
Wheat production (kg/ha)	Single NNM	3396	2811	585	1.52
	Kernel band width (0.25)	3761	2926	836	2.02
	Caliper (0.01)	3765	2359	1406	3.19

c) Impact of using rust-resistant wheat varieties on cash earnings

Smallholder farmers in the wheat- based farming systems of Ethiopia are generally cash constrained. Several studies indicated that lack of cash for the purchase of critical agricultural inputs such as improved seeds and fertilizer are identified among the major impediments to widespread adoption of improved technologies including improved wheat varieties (Feder et al, 1985). Hence, in this analysis, we assessed the impact of adopting rust-resistant wheat varieties on cash earnings using income from wheat and crop sales as a second set of outcome variables.

Our results show that the use of rust-resistant varieties has a positive impact on cash earnings of adopting households. This impact is reflected in an increase of the cash earnings from sales of wheat grain and seeds. The impact of adopting rust-resistant wheat varieties on crop income, however, although positive is not statistically significant (Table 7.11).

Table 7.11 Mean treatment effect of adopting rust-resistant wheat varieties on income form wheat and crop sales,

Outcome variable	Matching algorithms	Adopters	Non-adopters	ATT	t-stat
Income from wheat seed and grain sales (Birr)	Single NNM	9795	8391	1404	1.10
	Kernel band width (0.25)	11994	9292	2702	1.79
Income from crop sales (Birr)	Single NNM	13708	12459	1249	0.65
	Kernel band width (0.25)	16963	13967	2995	1.38

d) Impact of using rust-resistant wheat varieties on household food security

Table 7.12 presents the mean treatment effect of adopting rust-resistant varieties on self-reported household level food security obtained using the propensity matching. Two outcome variables based on self-assessment of households are constructed to capture food security at household level. The first food security dummy variable (fsecure 1) divides the households into two sub-groups, households facing food shortages with a value label of zero and households in the breakeven and surplus in the other sub-group with a vale label of 1. The second food security dummy variable (fsecure 2) as in the first one divides the sample into two with households producing surplus in one group with a value label of 1 and zero otherwise. As noted on Table 7.12, adoption of rust-resistant wheat varieties significantly increased the likelihood of food security as measured by fsecure 2. The impact of adopting rust-resistant varieties on perceived household food security measured by fsecure1, although, positive is not statistically significant. The results, therefore, suggest that the use of rust-resistant varieties have improved the wellbeing of smallholder farmers. Interventions amid at promoting the adoption and diffusion of rust-resistant varieties should be intensified to further consolidate the gains achieved thus far.

Table 7.12 Mean treatment effect of adopting rust-resistant wheat varieties on wheat productivity, production and food security based on several matching techniques

Outcome variable	Matching algorithms	Adopters	Non-adopters	ATT	t-stat
Binary food security = fsecure2 (1 if HH produces surplus)	Sngle NNM	0.199	0.120	0.078	0.040
	Kernel bwidth (0.25)	0.214	0.159	0.055	0.038
Binary food security = fsecure2 (1 if HH produces surplus)	Sngle NNM	0.765	0.747	0.018	0.047
	Kernel bwidth (0.25)	0.804	0.804	0.000	0.045

e) Impact on institutional innovation to address rust related epidemics

Results of the KII and FRG discussions revealed that the project have created institutional innovation in areas of fast-tracking variety testing and release, accelerated seed multiplication especially for pre-released candidate varieties, alignment of the various seed sector actors to ensure the seed demand from farmers' is fulfilled, and development of rust epidemics early warning system (Table 7.13).

Fast-track variety testing and release (FTVR): **Among the institutional innovations of the project is the introduction of fast track variety testing and release (FTVR) approach. This FTVR approach is a system where international and national research system actors collaborate to release varieties that are resistant to rust disease challenges. Through the project a partnership among ICARDA, CIMMYT and EIAR has been established to fast track variety testing and releases. Accordingly, 40 sets of 6523 wheat entries from ICARDA and CIMMYT international nurseries and 41 sets of 3504 wheat entries/lines from NARS were evaluated and five rust-resistant wheat promising lines were identified for verification and release in 2014 (Abebe, et al., 2014). This approach also gave priority for adaption of resistant varieties for abroad for quick release and also seed multiplication of candidate varieties for release (Table 7.13). A total of 10 stem rust and/or yellow rust resistant varieties were released through accelerated and/or regular approaches associated with the two projects from 2010 to 2014.**

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Table 7.13 Impact on institutional innovation to address wheat rust epidemics

Innovation	Conventional approach (before the project)	Project innovation (after the project)
Fast track variety testing and release	• Variety testing took formal and protracted procedure • Pre-release seed multiplication was not allowed	• Facilitated a 'crash' program for fast tracking variety testing and release for emergency situation • Created a system for pre-release seed multiplication procedure for selected candidate varieties • Aligning variety release with popularization and demonstration to create awareness and demand for seed
Accelerated seed multiplication of source seeds	• Early generation seed multiplication was made once a year • Early generation seed multiplication conducted only at research centers located in mid and highland environments	• Institutionalized a system to multiply early generation seed twice a year • Created a system where early generation seed multiplication is done in all potential areas including lowland irrigated environments • Alignment to fulfill demand was made by linking early generation seed production with certified seed production by public and private sector including public and private farms • Aligning of formal and informal seed systems using on-farm seed production with farmers through revolving seed system;
Alignment of the actors of wheat seed system	• Early generation seed was multiplied only considering multiplication capacity • Limited linkage between the formal and informal seed system	• Full engagement of regional, zonal and district BoA including the administration, extension experts, development agents, seed regulatory agencies in seed production and popularization • Full engagement of public and private seed sector as well as private and public commercial farms to ensure the multiplication of all seed classes (early generation and certified), • Work modalities of alignment became institutional culture in organizations involved
Early warning system of rust epidemics	• Ad hoc assessment of epidemics	• Institutionalized early warning system at MoA (Plant Health and Regulatory Directorate) in collaboration with NARS

Accelerated seed multiplication (ASM): Lack of seeds in sufficient quantities has been a major hurdle in promoting newly released improved varieties including rust-resistant varieties in Ethiopia. As a result the time lag between variety release, seed multiplication and farmer adoption of released varieties has been very high (Chilot et al. 2013). Unlike the conventional approach which takes several years to produce sufficient quantities of newly released wheat varieties, the project designed and implemented an accelerated source seed multiplication (ASM) approach.

The ASM approach involves both planning and implementation of enhanced micro-seed increase and maintenance breeding; accelerated pre-release and post-release seed multiplication of breeder, pre-basic and basic seed during the main and off-seasons using irrigation; and large-scale certified seed multiplication through both formal and informal. These activities were conducted through engaging relevant federal and regional research centers, and building their capacity in multiplication of source seed both during the main and off-season mainly through investments in irrigation facilities at research centers involved in wheat research.

Micro-seed increase and maintenance breeding in wheat seem to have been institutionalized at all wheat research centers including Kulumsa, Holetta, and Debre Zeit Research Centers of EIAR, Sinanna Research Center of OARI, Mekelle Research Center of TARI, Sirinka Research Center of ARARI, and Areka Research Center of SARI. Similarly, under the ASM approach, considerable amount of certified seed of rust-resistant bread wheat varieties were multiplied and supplied through the formal and informal channels.

The project purchased and provided farm machineries for research centers and mobile seed cleaning equipment for seed producers which proved to be critical for seed multiplication. Such capacities built by the project would allow actors to provide required service in a sustainable manner at least in the years to come.

Alignment of the actors of wheat seed system: The other critical institutional innovation introduced by the project is alignment of stakeholders for greater synergy. As a first step in the alignment process, institutions that have a stake along the seed value chain from the development of new wheat varieties to seed production, marketing and promotion activities were identified. Accordingly various actors in the seed system including research, seed producers, quality regulators, marketing agents specially cooperatives and BoA are identified as critical for moving seeds of newly released varieties form research centers to the final clients, smallholder farmers. The identified institutions were then brought together for clarifying mandates, expectations and roles. The discussions culminated in alignment of the various operations essential to fulfill the revealed demand by farmers and/or to create demand for new technologies.

Linked with strengthening the variety testing and release, source and certified seed multiplication, creation of a mechanism to align the different actors in the wheat seed system has been one of the impacts of the project. The project ensured the alignment through a mechanism where actors of the research system (EIAR and RARIs), seed producers (public seed enterprises and seed growers), extension system (MoA and BoA), and farmers themselves managed to work together. The project has created a system where seed multiplication was made not only in the mid and highland environments but also in lowland environments for which the country is well endowed with. This alignment is normally reflected in the multiplication of required type and amount of source seed (breeder, pre-basic and basic seed) for the production of the demanded type and quantity of certified seed. The linkage created between the formal and informal wheat seed system especially in the form of revolving wheat seed system, which run by local offices of agriculture, has contributed to process of fulfilling revealed demand. In addition, this alignment has helped timely distribution of the produced certified seed to farmers.

Developing rust early warning systems: Early warning systems for adverse effects play important role to reduce the impact of the events like drought, flood or disease epidemics. Early warning is about providing timely notice to elicit appropriate responses that will reduce or eliminate the impact of the adverse event (Davies, et al., 1991).

The wheat rust incidence in 2010 has affected considerable area in the major growing areas of Amhara, Oromia and SNNP Regional States covering an estimated total area of 591,590 ha in 289 districts. Consequently, fungicides were the only viable option at hand to control the rust epidemics. And yet, in the same year only 30% of the total affected wheat area was treated with fungicides costing the county about USD 3,273,810, which is about ETB 55 million. Experience from elsewhere in the world indicated that such costs could be reduced substantially or even avoided totally had the country instituted an early warning system capable of early detection of the epidemics. Accordingly, the project invested in building the capacity to predict rust epidemics through human capacity building, availing required facilities, and adequate sensitization of relevant stakeholders for early warning and establishment of working modalities.

The human capacity building included provision of practical training for model farmers, frontline extension workers, and SMS about identification of wheat rust incidence, reporting system, management options etc. The physical facilities provided to relevant stakeholders were provision of vehicles to enhance mobility in wheat production areas for surveillance. The created system is linked with the joint surveillance visits of researchers, experts of MoA and BoA, and fungicide reserve system in case of serious outbreak of wheat rust.

Plant health and regulatory directorate is responsible for the early warning system in close collaboration with regional BoA and the National Agricultural Research System.

7.4 Conclusion

The contribution of the project in enhancing the adoption of rust-resistant wheat varieties was very high especially for the recently released varieties like *Kakaba, Digelu,* and *Danda'a* varieties. The results indicate that there is clear evidence that the project has had a significant impact on wheat productivity, production, cash earnings and household food security. These results suggest that future project interventions aimed at promoting rust-resistant wheat varieties should focus in wheat growing areas that have not been addressed by the regular extension system. Furthermore, future programs should not only be limited to information provision but also consider credit provision that do not exclude the poorest farmers of the agricultural sector. Further research on this topic would require additional data and evaluation of impacts in other dimensions (e.g. environmental effects or costs of production).

In addition to the direct impacts of the project through enhanced adoption of rust resistance varieties and benefits gained due to use of those varieties, the project has contributed in putting in place institutional innovations indispensable for addressing current and future wheat rust epidemics. Among others, the institutional innovations established a fast-track variety testing and release approach; designed and implemented new procedure of adequate seed multiplication for pre-released varieties that can ensure adequate multiplication of basic and certified seed production; created a mechanism for alignment of the various seed system actors (research, seed enterprises, commercial farms etc.) to timely respond in cases of rust epidemics; and developed rust epidemics early warning system linked with built capacity in terms of human resources and physical capacities.

Wheat rusts remain major threats for wheat production in Ethiopia. Despite the impact of adoption of rust-resistant varieties on farmers' livelihoods, there is serious lack of varieties with stable and durable resistance where their longevity is very short lived. It is evident that recent experiences demonstrated that the conventional approach of development and deployment of rust-resistant varieties alone will not address the impeding risk of wheat production in the country. It is time to take stoke and make a concerted effort to develop an integrated strategy to tackle the rust threats. Developing a capacity for rust surveillance, use of chemical control and diversification of wheat-based production system are some of the measures need to be taken in addition to rust-resistant varieties. More importantly bringing together the wheat value chain actors particularly of durum wheat varieties by linking producers with markets is critical in the diversification efforts and to tackle the rust problems.

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Chapter VIII

Policy and Development Implications and Way Forward

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8.1 Introduction

Wheat rusts remain a challenge for wheat production at national, regional and global levels. Empirical evidence shows the emergence of new races and their quick spread across countries and continents with devastating consequences. The recent examples are the emergence of yellow and stem rusts in East Africa and their quick spread which has triggered an alarm amongst the international community. Apart from the emergence of Ug99; for example the spread of strains of yellow rust virulent on varieties carrying the Yr27 gene in west and central Asia has exacerbated the anticipated food crisis in times of increasing cereal prices and market uncertainties (Shiferaw. et al 2013).

In response to Ug99 crisis, CIMMYT and ICARDA in partnership with a number of National Agricultural Research Systems (NARS) have initiated the Borlaug Global Rust Initiative (ex GRI) under the leadership of the late Nobel Prize laureate Dr Norman Borlaug. Development and deployment of resistant varieties, adequate surveillance systems and effective plant protection strategies are important elements of an integrated wheat rust control strategy to replace widely grown susceptible varieties and ensure national, regional and global food security (Osborn and Bishaw 2009). Accordingly the achievements and lessons learned in this book present critical research, development and policy implications both at global/regional and national levels.

8.2 Global Implication

The emergence of new rust races and their potential long distance and rapid spread remain major challenge threatening food security nationally, regionally and globally. An extensive use of mega varieties like *Sakha 63* in Egypt, *Kubsa* in Ethiopia and *Sehar2006* in Pakistan which found dominating wheat production landscape are testimony to how such rust susceptible varieties posed high potential vulnerability and risk to food production in these countries and beyond. International and national breeding programs have managed at developing and releasing a wide range of varieties with diverse genetic background to wheat rust resistance to reduce vulnerability and risk of disease epidemics. However, the development and deployment of these varieties would require very careful consideration. The present practice of releasing similar varieties carrying similar resistance genes under the guise of fast tracking release and accelerated seed multiplication need to be avoided if one has to learn from past experiences and such similar crises to be averted in the future.

Wheat rusts remain a major challenge where the durability and longevity of resistance is short lived threating future wheat production. The search for durable rust resistance appears elusive and the achievements are modest as new varieties become susceptible with no time once enter commercial production. Such rapid varietal turn over due to rust diseases appears incompatible with rate of varietal replacement rates in farmers' fields in many developing countries. Such short cyclic rust epidemics are difficult to manage where seed production of resistant varieties takes time putting the wheat seed delivery under huge pressure. Therefore, it is important to develop a robust and effective strategy of wheat rust management combining varietal resistance, chemical control and cultural practices. In this context effective surveillance and monitoring coupled with plays an important role to manage wheat rusts in the future.

8.3 National Implications

In Ethiopia, wheat is one of the major cereal crops with continued area expansion and increased production in the country. Although Ethiopia continues to be a major wheat producer in Africa, there is still significant deficit in production to meet national demand. Within Ethiopian context the following issues require careful consideration:

To date the wheat research is rather preoccupied with many competing agenda and defining its roles and responsibilities at national, regional or global levels is desirable. It is high time to develop a wheat research strategy with clear vision and mission focusing on national priorities to address the key challenges.

Wheat rusts remain a major challenge for wheat production threating national food security. In recent years, we have witnessed three major events: emergence of Ug99 (2002), outbreak of yellow rust (2010) and new race of stem rust (2013). In order to tackle this critical problem diversification of crops to include durum wheat and expansion of production to irrigated lowlands should be a priority agenda for wheat sector in the country.

To date despite the release of large number of wheat varieties their resistance to rusts remains short-lived putting the national wheat and seed sector under tremendous pressure. A national wheat rust management strategy should be devised where an effective rust surveillance should be in place for early warning coupled with adequate preparedness for chemical control as a priority in case of rust out breaks.

The bread wheat monoculture in the highlands posed serious problems not only with pests (rusts, weeds) but also affecting soil fertility questioning the long-term sustainability of the wheat based farming systems in the highlands. A clear strategy need to be developed for introduction and integration of legumes in the wheat farming system to tackle both the disease and farming systems issues.

A regular basic seed supply is a key for sustainable seed sector. The project provided the basic facilities and infrastructure but the future lies how the research and the seed suppliers are willing to work together. Providing incentives and adopting procedures for royalty collection (in the absence of PVP) would strengthen the program. The Foundation Seed Cell program in Pakistan and the royalty collection system in Egypt are some of the key steps in the right direction to make early generation seed production on a sustainable footing in the future.

8.4 Recommendations

The dynamic nature of wheat rust diseases implies that in addition to emergence of new rust races either evolving locally or migrating from elsewhere, there is often a breakdown in the genetic resistance of newly developed varieties. This calls for continuous research on biology and management of the rust disease as well as the development of new resistant varieties.

The lesson learnt from the interventions that triggered the success in controlling the disease were mainly emanated from the systematic design and implementation of the project addressing key systemic constraints along the seed value chain. This implies the need for institutionalized approach to ensure sustainable and consistent management of the diseases. Practically, this justifies the need for institutionalization of fast track variety release, accelerated seed multiplication, popularization and promotion of rust-resistant wheat varieties to create awareness and demand for seed, rust disease early warning system, wheat value chain development and above all creating awareness among policy makers and farmers the impeding threat of rusts.

The short longevity of rust resistance and the periodic outbreak of rust epidemics pose serious threat of food security for over 4.5 million small-scale farmers engaged in wheat production in the highlands of Ethiopia. The situation is exacerbated with wheat monoculture having serious consequences not only from pests (rusts, weeds) but also from declining soil fertility and soil health questioning the long-term sustainability of the wheat based farming systems. Furthermore, farmers often tend to grow one or two mega varieties continuously increasing the genetic vulnerability of wheat crop from risks associated with emerging diseases and climate change. In order to curb these challenges, appropriate cultural practices linked with avoidance of wheat mono-cropping are crucial interventions. Thus, application of crop rotation and diversification interventions need to be in place and adequately and frequently monitored to tackle both the disease and farming systems issues.

Efficient wheat production is attainable when care is taken to integrate practices that reduce or control the development of diseases that reduces the yield potential. Among the wheat disease, wheat rusts remain a major challenge where the durability and longevity of resistance is short lived threating future wheat production. This obviously demands for putting in place integrated wheat rust management by combining varietal resistance, cultural practices and chemical control. Specifically, it will be important to integrate the following interventions

- The national wheat breeding program need to continue developing a diverse set of rust-resistant wheat varieties over time, as any single form of resistance is expected to be short-lived. Durable resistance depends not in a single variety given the expected short longevity of rust resistance in wheat but in maintaining the genetic diversity in the resistant varieties deployed to farmers;

- The national wheat breeding program need also to strengthen the global partnership especially with CGIAR and NARS from neighboring countries given the global nature of rust epidemics;

- The development of resistant varieties need to be coupled with adopting fast-track variety release and accelerated seed multiplication in partnership with various stakeholders along the seed value chain to ensure fast replacement;

- Adequate variety demonstration, popularization, and dissemination of resistant varieties to create awareness and demand for seed from farmers;

- Enhance the adoption of resistant varieties through improved market linkages and value chain development activities;

- Devising an effective rust surveillance system for early warning coupled with adequate preparedness for chemical control as a priority in case of rust out breaks;

- Introducing legumes and durum wheat to break the monoculture and ensure sustainable diversification and intensification of the framing systems; and

- Devising a strategy for expanding irrigated wheat production through development of varieties adapted to the lowlands

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